An Integrated GT–Kano–AHP–QFD–VIKOR Framework for the Sustainable Design of Chinese Reclaimed Ship Timber Furniture

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Old ship timber is a wood resource that combines reuse potential, cultural significance, and distinctive aesthetic characteristics. By extending the material life cycle and promoting resource circularity, it provides potential value for sustainable furniture design. However, wood furniture design remains limited by insufficient requirement identification, experience-driven decisions, and inadequate integration of cultural values with contemporary functional needs. To address these challenges, this study focused on Chinese old ship timber furniture and proposes a sustainable design decision-making framework integrating Grounded Theory (GT), Kano model, the Analytic Hierarchy Process (AHP), Quality Function Deployment (QFD), and VIKOR. Semi-structured interviews were conducted with 15 participants to capture users' perceptions, and GT identified five categories of user requirements—functional, visual, cultural, material, and market-related—comprising 15 elements. Kano classified these requirements, while AHP quantified their relative importance, identifying material expressiveness, ergonomic performance, and style compatibility as the highest-priority requirements. QFD translated these priorities into nine technical characteristics, and VIKOR evaluated four design schemes. Results indicate that Scheme 2, emphasizing the integration of reclaimed ship timber with contemporary living environments, achieved the highest overall evaluation score. The findings suggest that the framework supports requirement identification, technical translation, and alternative selection for sustainable furniture design.

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INTRODUCTION

Sustainability has become a central focus across multiple disciplines, encompassing environmental, cultural, economic, and social dimensions (Hariram *et al.* 2023). Among its key objectives, resource efficiency and circular utilization have become important priorities in sustainable development strategies (González-García *et al.* 2011). As an essential consumer product, furniture can enhance public awareness of sustainability through its widespread use in residential, workplace, and tourism settings (Li *et al.* 2022). Moreover, owing to the complexity of material processing and manufacturing, wooden furniture offers considerable potential for optimization throughout its production lifecycle (Lin and Huang 2016).

Wood is one of the most widely used materials in the global furniture manufacturing industry (Bumgardner *et al.* 2020). According to international trade statistics, the cumulative export value of wooden furniture—including bedroom, kitchen, office, and other furniture products—reached USD 345.3 billion between 2015 and 2021 (International Trade Centre. 2019). During the same period, China maintained a leading position in the global market, accounting for USD 93.8 billion in exports across these four product categories. Previous studies have consistently highlighted the importance of strengthening sustainability practices within the wooden furniture industry to reduce the approximately 10 million tonnes of waste furniture disposed of in landfills annually (Seyajah *et al.* 2016; Bosch *et al.* 2017; Vicente *et al.* 2017; Koszewska and Bielecki 2020). Consequently, sustainability has emerged as a key consideration in design decision-making throughout the wood processing and furniture manufacturing sectors (Bumgardner *et al.* 2020).

China has become one of the world's leading and most competitive furniture exporters (Li and Zhao 2023). In response, the Guidelines for the Sustainable Development of China's Cultural Furniture Industry emphasize the role of innovative design in environmental protection and advocate the integration of digital technologies and artificial intelligence (AI) to improve design efficiency and product quality (Fan and Yi 2024; Fu *et al.* 2025). As an important category of recycled materials in the furniture industry, old ship timber offers considerable potential to enhance the social, cultural, and environmental value of furniture products. Old ship timber refers to wood reclaimed from dismantled wooden vessels. Originally used in the construction of seagoing ships, it typically comprises high-quality hardwoods, such as elm, merbau, ironwood, and sandalwood, which are characterized by high density, exceptional hardness, and naturally occurring oils or waxes developed over decades of growth. Long-term exposure to the marine environment contributes to distinctive grain patterns and surface textures, while the physical properties of reclaimed ship timber may vary depending on species, service history, and preservation conditions. These characteristics make old ship timber a valuable recycled material with significant cultural heritage, strong resource-circulation potential, and substantial promise for furniture design. Previous studies have demonstrated the design potential of old ship timber furniture. Li *et al.* (2012) suggested that reclaimed ship timber has broad application prospects in furniture manufacturing and argued that innovative designs can be effectively developed by leveraging its intrinsic material properties in conjunction with fundamental design principles. Similarly, Luo *et al.* (2023) examined the value of old ship timber from artistic, cultural, and ecological perspectives and proposed design strategies based on form redesign, cultural empowerment, and consumer-oriented development.

Although the circular economy and the use of reclaimed wood have become prominent topics in furniture design research, existing studies have focused on material substitution and resource recovery. Limited attention has been given to the systematic integration of design principles into user requirement identification, the translation of user needs into design attributes, and design decision-making. Moreover, the design of old ship timber furniture continues to rely heavily on experience-based approaches, with insufficient exploration of user requirements and inadequate integration of cultural values with contemporary functional needs. Consequently, the potential of old ship timber has not been fully realized throughout the product development process. Developing a systematic design decision-making framework that simultaneously addresses user requirements, cultural heritage is therefore essential for advancing innovation in old ship timber furniture design. User-centered design has emerged as an effective paradigm for addressing these challenges.

Among the available approaches, Grounded Theory (GT), the Kano model, the Analytic Hierarchy Process (AHP), and Quality Function Deployment (QFD) are widely recognized as core methods for identifying, prioritizing, and translating user requirements into design solutions. Grounded Theory is particularly effective in eliciting both explicit and latent user needs from complex social contexts (Urquhart *et al.* 2010). The Kano model has been applied to identify and classify user requirements in product design (Xu *et al.* 2009). For example, Taifa and Desai (2016) and Kapuria *et al.* (2020) employed the Kano model to analyze students' needs, satisfaction, and requirement attributes for classroom furniture, subsequently proposing scientifically grounded redesign strategies. Despite its effectiveness in classifying and prioritizing user requirements, the Kano model is susceptible to ambiguity arising from variations in user perceptions. Consequently, a robust quantitative approach is required to evaluate these perceptual differences. As a decision-making method that integrates qualitative judgment with quantitative analysis, AHP effectively addresses inconsistencies associated with heterogeneous user perceptions (Chen *et al.* 2024). Xiao *et al.* (2024) integrated user requirement analysis with AHP to develop a sustainable evaluation framework for office furniture, providing valuable guidance for sustainable furniture design, management, and research. To enhance methodological integration and practical applicability, researchers have increasingly combined AHP with QFD to establish systematic requirement-to-function transformation models. Fan and Wang (2025) applied the Kano model to identify and classify consumer requirements for gift packaging, employed AHP to determine the relative importance of design criteria, and used QFD to translate these requirements into specific design parameters. The resulting sustainable packaging solutions not only satisfied users' functional and aesthetic expectations but also significantly enhanced environmental awareness. With the growing emphasis on sustainability in design research, multi-criteria decision-making (MCDM) methods have been increasingly adopted to evaluate and optimize design alternatives. This study incorporated the VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method, which effectively resolves conflicts and trade-offs among multiple evaluation criteria. As a multi-criteria optimization technique, VIKOR ranks design alternatives by jointly considering the group utility measure, the individual regret measure, and the compromise solution index (Wang *et al.* 2022). For example, Arıkan Kargı and Cesur (2024) applied VIKOR to support technology selection in hotel building production processes, providing stakeholders with a comprehensive multi-criteria decision-making framework for evaluating renewable energy technologies.

Building on the preceding discussion, this study proposes an integrated decision-making framework based on the GT-Kano-AHP-QFD-VIKOR methodology. By integrating qualitative inquiry with quantitative decision-making methods, the framework establishes a multi-level, multi-source approach for supporting sustainable furniture design. First, Grounded Theory (GT) was employed to analyze semi-structured interview data and develop a comprehensive framework of user requirements for old ship timber furniture. Second, a structured questionnaire based on the Kano model was designed to classify user requirements and evaluate their asymmetric effects on customer satisfaction. Third, the Analytic Hierarchy Process (AHP) was applied to determine the relative importance of user requirements through expert judgment, thereby quantifying their weights within the decision-making framework. Fourth, Quality Function Deployment (QFD) was used to translate the weighted user requirements into actionable design and sustainability attributes. Finally, the VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method was employed to conduct a multi-criteria compromise evaluation of alternative old ship timber furniture design schemes, identifying the optimal solution by balancing user experience, cultural heritage preservation, and design feasibility.

Although previous studies have explored reclaimed wood utilization, sustainable furniture design, and consumer-oriented product development, existing research has mainly focused on material characterization, environmental benefit analysis, or design case exploration. However, studies on how to integrate user requirement identification with systematic decision-making approaches and apply them to reclaimed wood furniture design and development remain relatively limited. This study focuses on transforming reclaimed ship timber into value-added furniture products through a user-driven and multi-criteria decision-making approach.

By integrating grounded theory (GT), the Kano model, analytic hierarchy process (AHP), quality function deployment (QFD), and the VIKOR method, this study establishes a systematic pathway from the extraction of user-perceived requirements to the optimization and selection of design concepts. Therefore, the novelty of this study does not solely lie in the application of individual evaluation methods, but rather in the development of an integrated design decision-making framework that connects cultural perception, functional requirements, sustainable value, and furniture design decision processes, providing a new research pathway for reclaimed wood furniture development.

EXPERIMENTAL

Experimental Processes

With the growing emphasis on sustainable development and increasing consumer expectations regarding the functional, emotional, cultural, and ecological attributes of furniture, traditional experience-based design approaches are no longer sufficient to address the multidimensional decision-making challenges associated with recycled-material furniture development. This limitation is particularly evident in the design of old ship timber furniture, which combines the environmental benefits of material reuse with rich historical and cultural significance and distinctive aesthetic value. To address these challenges, this study takes old ship timber furniture as the research object and proposes an integrated design framework based on the GT-Kano-AHP-QFD-VIKOR methodology to support systematic, user-centered, and sustainable furniture design decision-making.

Grounded Theory (GT) was employed to analyze the semi-structured interview data through open, axial, and selective coding. This process enabled the systematic abstraction and categorization of user perceptions, resulting in a comprehensive framework of user requirements for old ship timber furniture and improving the rigor and reliability of user need identification (Glaser and Strauss 1967). Subsequently, the Kano model was applied to classify the attributes of user requirements, determine their impact coefficients and priority levels, and identify the critical needs that should guide product design. This analysis provided clear design priorities and strategic direction for the development of old ship timber furniture while enhancing user satisfaction. The Analytic Hierarchy Process (AHP) was then employed to construct a hierarchical evaluation model. Domain experts conducted pairwise comparisons of the identified user requirements, and the relative weights of each criterion were calculated and validated through consistency testing to determine their importance in the overall design decision-making process (Saaty 2008). The prioritized user requirements were subsequently translated into specific technical characteristics using Quality Function Deployment (QFD), enabling abstract user expectations to be systematically converted into actionable design strategies. To resolve potential trade-offs among user satisfaction, sustainability performance, and design feasibility, the VIKOR method was employed to conduct a comprehensive multi-criteria evaluation of alternative old ship timber furniture design schemes. The research framework is presented in Fig. 1.

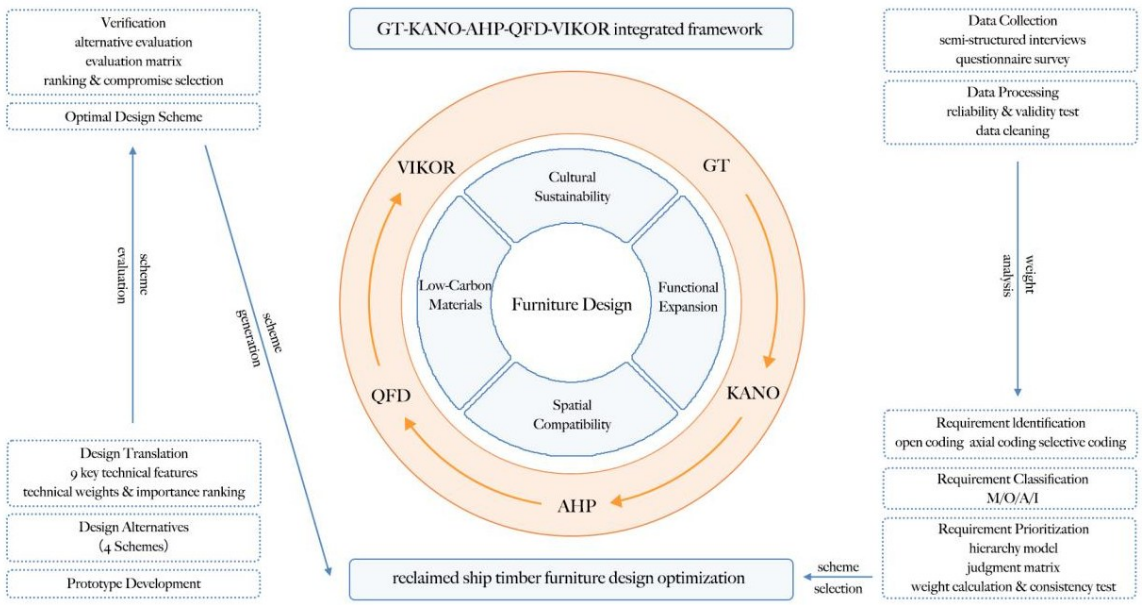

Fig. 1. Research framework

Data Collection

In qualitative research, sample adequacy is generally determined by research objectives, participant diversity, and theoretical saturation rather than a fixed numerical threshold. Accordingly, this study employed purposive sampling to recruit 15 participants from three key user groups: the traditional craftsmanship group (n=6), the modern usage scenario group (n=6), and the theoretical validation group (n=3). The participant selection was designed to ensure diversity of perspectives related to old ship timber furniture, including traditional craftsmanship, practical usage, material knowledge, and sustainable design considerations.

Semi-structured interviews, each lasting approximately 30 to 45 min, were conducted to explore participants' perceptions and understanding of old ship timber furniture and its cultural significance. An interview guide was developed to examine four key dimensions: functional requirements, appearance and spatial compatibility, cultural and historical perceptions, and material applications. The interview protocol is presented in Table 1. All interviews were conducted face-to-face in Chinese, and the collected data were transcribed and analyzed for subsequent Grounded Theory coding.

Table 1. Semi-Structured Interview Guide

No	Interview Questions
1	What is your first impression of old ship timber as a material?
2	In your opinion, what characteristics distinguish old ship timber from conventional wood?
3	How important is furniture durability when making a purchasing decision?
4	Based on your experience, what aspects of old ship timber furniture do you find comfortable or uncomfortable during use?
5	Beyond its basic functions, what additional features would you expect old ship timber furniture to provide?
6	To what extent do you think the color, form, and style of old ship timber furniture are compatible with contemporary interior spaces? Please explain your answer.
7	What are your views on furniture made from recycled materials? Would you accept old ship timber furniture if it incorporated modern materials? Why or why not?
8	Does old ship timber furniture evoke any historical or cultural associations for you? If so, how important are these associations in your evaluation of the furniture?
9	Have you ever developed an emotional attachment to furniture because of its design, material, or cultural significance? Would this influence your willingness to purchase or collect such furniture? Please explain.
10	What are your perceptions of the price of old ship timber furniture? To what extent does price influence your purchasing decision?

The traditional craftsmanship group consisted of four traditional woodworkers and two artisans specializing in wood decoration. These participants were selected because of their extensive knowledge of wood properties and the symbolic meanings embedded in traditional craftsmanship. The modern usage scenario group included three users from regions where old ship timber furniture is commonly found and three cultural tourism consumers. The former provided insights into practical issues encountered during everyday use, whereas the latter offered perspectives on contemporary aesthetic preferences and market expectations.

The theoretical validation group comprised one furniture design scholar, one materials science expert, and one sustainable design researcher. The furniture design scholar ensured the logical consistency of translating user requirements into design characteristics, the materials science researcher validated the interpretation of old ship timber properties and its potential applications, and the sustainable design researcher assessed the sustainability-related implications derived from the qualitative findings.

The selection criteria were established to ensure that participants possessed relevant knowledge and practical experience related to old ship timber furniture, traditional craftsmanship, furniture design, or material applications. Participants were required to have professional backgrounds or practical experience in related fields, including traditional woodworking, furniture design, material research, cultural studies related to traditional craftsmanship, or sustainable design. In addition, participants with direct experience in reclaimed timber processing, furniture use, or cultural tourism consumption were prioritized to ensure the richness and relevance of the collected qualitative data. The detailed demographic characteristics and professional backgrounds of all participants are summarized in Table 2.

Table 2. Participant Demographics and Professional Backgrounds

Group	Code	Participant Background	Characteristics
Traditional Craftsmanship Group	T1	Traditional wooden ship carpenter from a coastal shipbuilding workshop	Extensive experience in wooden ship construction, with expertise in hardwood selection and woodworking techniques
	T2	Traditional wooden ship restoration artisan (Intangible Cultural Heritage practitioner)	Experienced in the restoration and reuse of old wooden ships, with in-depth knowledge of old ship timber properties
	T3	Traditional furniture craftsman	Skilled in traditional furniture construction and handcrafted woodworking techniques
	T4	Owner of a small woodworking workshop	Experienced in both traditional craftsmanship and commercial furniture production
	T5	Wood decoration artist	Specializes in wood surface decoration and the creation of culturally inspired motifs
	T6	Cultural and creative product designer	Specializes in translating traditional cultural symbols into contemporary visual design
Modern Usage Scenario Group	U1	Resident of a coastal region	Long-term household user of old ship timber furniture
	U2	Small business owner	Uses old ship timber furniture in commercial interior environments
	U3	Furniture enthusiast	Interested in environmentally friendly and customized furniture
	U4	Cultural tourism consumer	Prefers products with strong cultural value
	U5	Cultural souvenir consumer	Values cultural symbolism and aesthetic design
	U6	Young urban consumer	Prefers modern furniture that integrates aesthetics and functionality
Theoretical Validation Group	E1	Furniture design scholar	Conducts research and teaching in furniture design
	E2	Materials science researcher	Specializes in wood material properties, recycling technologies, and the sustainable utilization of timber
	E3	Sustainable design researcher	Specializes in sustainable furniture design, circular material utilization, and environmental assessment approaches for product development

The interview transcripts from the 15 participants were analyzed line by line using the Grounded Theory coding procedure. The analysis comprised three sequential stages: open coding, axial coding, and selective coding. As shown in Table 3, open coding yielded 23 initial concepts. During axial coding, these concepts were organized into related categories, and their interrelationships were examined to establish the major categories. Building on the results of the open and axial coding stages, selective coding was subsequently conducted to integrate the overall structure of user requirements for old ship timber furniture, as presented in Table 4.

The results indicate that user requirements for old ship timber furniture extend beyond basic functional considerations and constitute a multidimensional system comprising five core categories: functional, visual, cultural, material, and market requirements. To assess the reliability of the coding process, ten transcripts were selected for initial coding, while five additional transcripts were reserved as validation samples. After the initial coding framework was established, the five reserved transcripts were re-examined using the same coding procedure. No additional concepts, categories, or relationships emerged during this validation, indicating that theoretical saturation had been achieved.

Construct the Kano Model

Based on the results of the open coding stage of the Grounded Theory analysis, a Kano-based questionnaire was developed to systematically classify user requirements according to Kano categories (Jin *et al.* 2022). The questionnaire employed a two-dimensional evaluation approach, in which each user requirement attribute was assessed using both functional (positive) and dysfunctional (negative) questions. The functional question examined users' feelings when a given attribute was provided, whereas the dysfunctional question examined users' feelings when the attribute was absent.

Each question adopted the standard five-category Kano response format: "Dislike," "Can Tolerate," "Neutral," "Must Be," and "Like," as shown in Fig. 2. These paired responses were subsequently combined according to the Kano evaluation matrix to classify each requirement attribute into Attractive (A), One-dimensional (O), Must-be (M), Indifferent (I), Reverse (R), or Questionable (Q) categories. The Kano questionnaire was subsequently administered to evaluate the identified user requirements. Stratified sampling was adopted to ensure representative participation from four stakeholder groups: industry practitioners, tourists, local residents, and domain experts. A total of 381 questionnaires were collected, of which 360 were valid, resulting in a valid response rate of 94.5%. The 21 invalid responses were excluded due to incomplete answers or inconsistent response patterns, and the valid samples were used for Kano classification of the identified requirements.

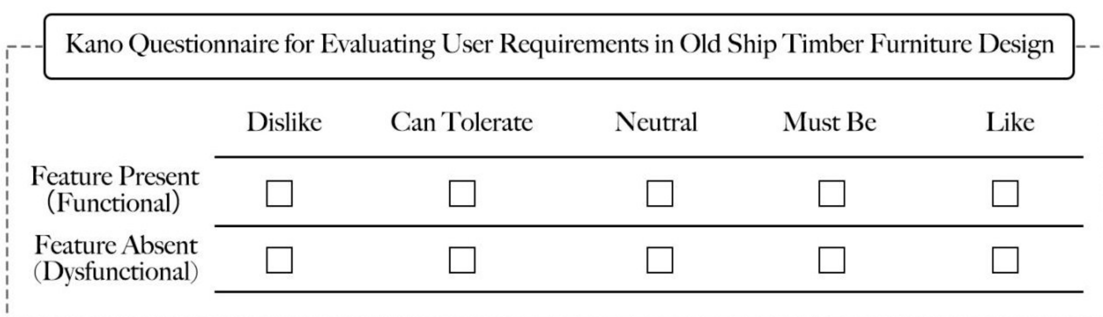

Fig. 2. Kano questionnaire structure for assessing user requirements in old ship timber furniture design

Table 3. Results of Open Coding

Representative Quotations from the Interview Data	Initial Concept
Wooden ships are typically constructed from high-quality hardwoods, such as elm, merbau, ironwood, and sandalwood.	A1: Use of high-quality hardwood materials
After prolonged exposure to the marine environment, old ship timber develops a distinctive grain pattern that conveys a strong sense of history and craftsmanship.	A2: Historical and cultural value
This type of furniture is highly durable and can remain in good condition for many years.	A3: Long-term durability
The color is relatively dark, and the design is somewhat rigid, making it difficult to integrate with contemporary interior styles.	A4: Color compatibility
	A5: Limited diversity of design forms
	A6: Difficulty integrating with modern interiors
The seat is too hard, causing back discomfort during prolonged use. A more ergonomic design would improve comfort. In addition, the surface feels cold in winter.	A7: Seating comfort issues
	A8: Cold tactile sensation in winter
Each piece of timber has a unique grain pattern, making every furniture item one of a kind.	A9: Uniqueness
I would like the furniture to provide additional functions, such as storage.	A10: Demand for multifunctionality
Some finely crafted pieces are valuable enough to be collected.	A11: Collectible value
Furniture that incorporates the cultural identity of locally sourced ship timber and reflects local cultural heritage would be more attractive to tourists.	A12: Appeal of cultural symbolism
	A13: Emotional value
Old ship timber is a recycled material with environmental benefits.	A14: Use of recycled materials
	A15: Environmental awareness
Old ship timber furniture is generally expensive. Combining it with modern materials could reduce production costs.	A16: High cost
	A17: Demand for hybrid material applications
The furniture is relatively heavy, making it difficult to transport and relocate.	A18: Heavy weight and limited mobility
The furniture is generally large and occupies considerable space, making it less suitable for small living environments.	A19: Large size and high space occupancy
This type of furniture requires regular maintenance and is less convenient to care for than conventional furniture. Poor maintenance may shorten its service life.	A20: Maintenance requirements
The edges and corners are relatively hard, which may pose safety risks for households with children or older adults. Protective design features would improve safety.	A21: Safety concerns
This type of furniture appeals to a relatively niche market. Many consumers are unfamiliar with old ship timber and are therefore hesitant to purchase it.	A22: Limited consumer acceptance
Some aspects of the craftsmanship require further refinement, particularly the finishing of joints and edges.	A23: Need for improved craftsmanship quality

Table 4. Results of Selective Coding

Category	Subcategory	Associated Initial Concepts
Functional Requirements	B1: Durability B2: Ergonomic performance B3: Environmental adaptability B4: Functional flexibility	A3: Long-term durability A20: Maintenance requirements A7: Seating comfort issues A21: Safety concerns A8: Cold tactile sensation in winter A10: Demand for multifunctionality A18: Heavy weight and limited mobility
Visual Requirements	B5: Style compatibility B6: Spatial compatibility B7: Material expressiveness	A4: Color compatibility; A5: Limited diversity of design forms A6: Difficulty integrating with contemporary interiors A19: Large size and high space occupancy A9: Uniqueness A23: Need for improved craftsmanship quality
Cultural Requirements	B8: Cultural value B9: Collectible value B10: Cultural symbolism B11: Emotional resonance	A2: Historical and cultural value A11: Collectible value A12: Appeal of cultural symbolism A13: Emotional value
Material Requirements	B12: Sustainability B13: Material selection strategy	A1: Use of high-quality hardwood materials; A14: Use of recycled materials A15: Environmental awareness A17: Demand for hybrid material applications
Market Requirements	B14: Economic feasibility B15: Market acceptance	A16: High cost A22: Limited consumer acceptance

Based on the questionnaire survey data, reliability and data suitability analyses were conducted using SPSS 27.0, and the results are summarized in Table 5. The consistency of the questionnaire responses was examined using Cronbach's α coefficient. The obtained Cronbach's α value of 0.782 exceeded the recommended threshold of 0.70, indicating acceptable consistency among the questionnaire responses. The suitability of the dataset for subsequent statistical analysis was subsequently examined using the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity.The questionnaire included 30 variables, consisting of functional and dysfunctional responses for the 15 requirement attributes, which corresponded to the degrees of freedom (df = 435) in Bartlett's test. The KMO value was 0.684, exceeding the acceptable threshold of 0.60, while Bartlett's test was statistically significant ($p<0.001$), indicating that the null hypothesis of no correlation among the variables could be rejected. These findings indicate that the dataset has acceptable sampling adequacy and sufficient correlations among variables, supporting its suitability for subsequent Kano classification and related analyses.

During the data processing stage, SPSS was used for data cleaning and cross-tabulation analysis. Based on the Kano evaluation matrix (Table 6), the paired responses to the functional and dysfunctional questions for each attribute were mapped to their corresponding Kano categories. The category with the highest frequency among the six Kano categories (A, O, M, I, R, and Q) was assigned as the final classification result for each requirement attribute. In cases where two categories showed the same highest frequency, the classification was determined by comparing the relative priority of functional requirements and the Kano evaluation logic. Reverse and Questionable responses were retained in the classification analysis and were reviewed during data screening to identify potential abnormal response patterns. This procedure generated the requirement classification matrix, and the resulting classification outcomes are presented in Table 7.

Table 5. Reliability and Data Suitability Test Results of Kano Questionnaire

Test Type	Index	Value
Cronbach Reliability Test	Cronbach's α Coefficient	0.782
	KMO Value	0.684
Bartlett's Sphericity Test	χ^2	8215.928
	df	435
	p-value	<0.001

Table 6. Kano Evaluation Matrix for User Requirement Classification

Requirement Attribute		Dysfunctional Response				
		Dislike (1)	Can Tolerate (2)	Neutral (3)	Must Be (4)	Like (5)
Functional Response	Dislike (1)	Q	R	R	R	R
	Can Tolerate (2)	M	I	I	I	R
	Neutral (3)	M	I	I	I	R
	Must Be (4)	M	I	I	I	R
	Like (5)	O	A	A	A	Q
Note: A = Attractive; O = One-dimensional; M = Must-be; I = Indifferent; R = Reverse; Q = Questionable.						

To further quantify the influence of each user requirement on customer satisfaction characteristics, the Better-Worse coefficients were calculated. The Better coefficient (*B*) measures the increase in customer satisfaction when a specific requirement is fulfilled, whereas the Worse coefficient (*W*) measures the increase in customer dissatisfaction when the requirement is not fulfilled. The calculation formulas for the Better and Worse coefficients are given in Eqs. 1 and 2, respectively,

$$B=(A+O)/(A+O+M+I) \tag{1}$$

$$W=-(M+O)/(A+O+M+I) \tag{2}$$

where A is the Attractive value, O is the One-dimensional value, M is the Must-be value, and I is the Indifferent value.

The Better coefficient (*B*) is typically positive, with higher values indicating a greater increase in customer satisfaction when a specific functional attribute is provided. In contrast, the Worse coefficient (*W*) is typically negative, with more negative values indicating a greater increase in customer dissatisfaction when the corresponding functional attribute is absent.

Based on the calculated Better-Worse coefficients, a four-quadrant priority matrix was constructed to visualize the relative priority of user requirements for old ship timber furniture. The horizontal and vertical boundaries of the matrix were determined using the average values of the Better and Worse coefficients, respectively. Requirements located in different quadrants were interpreted according to their influence on satisfaction and dissatisfaction: requirements with high Better and high Worse values were considered high-priority attributes requiring improvement, while requirements with lower influence were assigned relatively lower priority.

Table 7. Kano Classification Results for User Requirements

Requirement Attribute	A	O	M	I	R	Q	Kano Category	Better	Worse
B1. Durability	21.11%	14.72%	55.28%	3.61%	3.89%	1.39%	M	37.83%	-73.90%
B2. Ergonomic Performance	21.39%	20.28%	53.33%	5.00%	0.00%	0.00%	M	41.67%	-73.61%
B3. Environmental Adaptability	5.00%	54.72%	21.94%	17.22%	0.00%	1.11%	O	60.39%	-77.53%
B4. Functional Flexibility	46.39%	25.00%	24.72%	3.61%	0.28%	0.00%	A	71.59%	-49.86%
B5. Style Compatibility	32.22%	40.83%	23.06%	3.06%	0.83%	0.00%	O	73.67%	-64.43%
B6. Usage Scenario Compatibility	49.17%	17.50%	28.33%	5.00%	0.00%	0.00%	A	66.67%	-45.83%
B7. Material Expressiveness	13.33%	51.67%	21.39%	12.50%	0.28%	0.83%	O	65.73%	-73.88%
B8. Cultural Value	42.22%	17.22%	35.28%	5.00%	0.00%	0.28%	A	59.61%	-52.65%
B9. Collectible Value	22.78%	10.00%	17.22%	50.00%	0.00%	0.00%	I	32.78%	-27.22%
B10. Cultural Symbolism	50.56%	15.56%	28.33%	5.00%	0.00%	0.56%	A	66.48%	-44.13%
B11. Emotional Resonance	24.17%	18.61%	18.61%	38.61%	0.00%	0.00%	I	42.78%	-37.22%
B12. Sustainability Value	48.06%	17.50%	27.22%	5.00%	0.00%	2.22%	A	67.05%	-45.74%
B13. Material Selection Strategy	21.67%	15.56%	18.89%	41.67%	0.00%	2.22%	I	38.07%	-35.23%
B14. Economic Feasibility	21.94%	17.22%	44.17%	15.56%	1.11%	0.00%	M	39.61%	-62.08%
B15. Market Acceptance	44.44%	16.11%	34.17%	4.72%	0.00%	0.56%	A	60.89%	-50.56%
Note: A = Attractive; O = One-dimensional; M = Must-be; I = Indifferent; R = Reverse; Q = Questionable.									

The position of each requirement within the matrix provides an intuitive representation of its Kano priority characteristics and supports the identification of design priorities. The Kano priority results were further considered during the subsequent AHP-based weighting process to support the determination of design requirements. The resulting four-quadrant priority matrix is presented in Fig. 3.

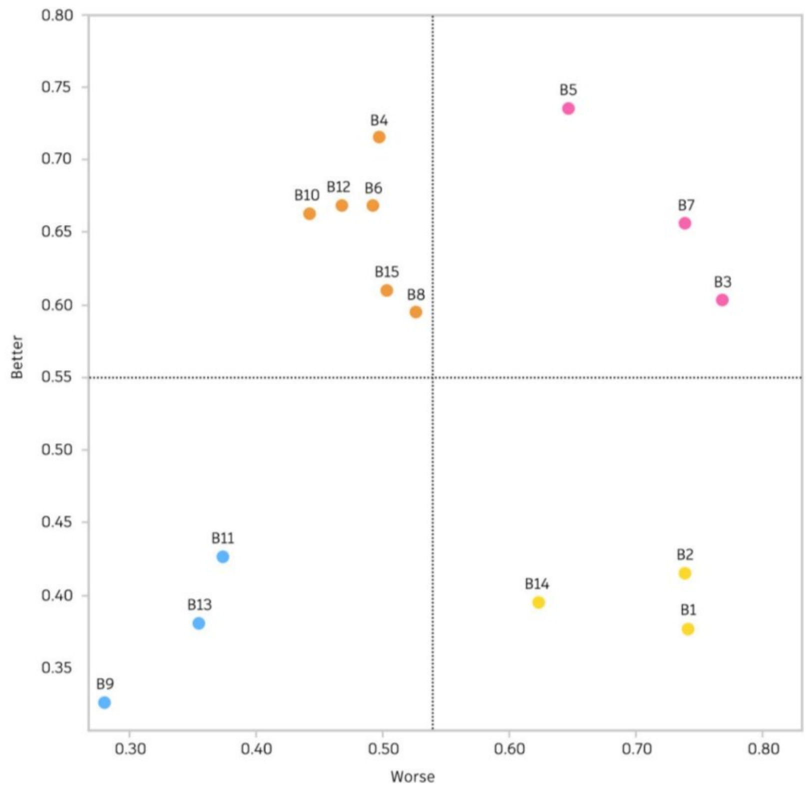

Fig. 3. Four-quadrant better-worse matrix of user requirements for old ship timber furniture

Construct the AHP Model

To convert the qualitative assessment of user requirement importance into a rigorous quantitative evaluation, the Analytic Hierarchy Process (AHP) was incorporated following the Kano model analysis. An AHP hierarchical structure was established, as shown in Table 8, to provide a systematic framework for subsequent design decision-making. The hierarchy comprises three levels. The goal level represents Old Ship Timber Furniture Design. Based on the Kano classification results, the criteria level consists of three requirement categories: Must-be (M), One-dimensional (O), and Attractive (A). These Kano categories were selected as the criteria level because they represent different levels of user-perceived value and satisfaction influence, providing a structured basis for prioritizing requirements in the design decision-making process. The indicator level comprises 11 specific user requirements, each assigned to its corresponding criterion. Indifferent (I) attributes were excluded because they showed limited influence on user satisfaction and design priorities. In this study, Kano satisfaction coefficients were not directly incorporated into the AHP weighting process; instead, the Kano classification results were used to establish the hierarchical structure, and the relative importance of each requirement was determined through AHP evaluation.

Table 8. AHP Hierarchical Structure of User Requirements

Goal Level	Criteria Level	Indicator Level
Sustainable Design of Chinese Old Ship Timber Furniture	Must-be Requirements (M)	M1: Durability
		M2: Ergonomic Performance
		M3: Economic Feasibility
	One-dimensional Requirements (O)	O1: Environmental Adaptability
		O2: Style Compatibility
		O3: Material Expressiveness
	Attractive Requirements (A)	A1: Functional Flexibility
		A2: Usage Scenario Compatibility
		A3: Cultural Value
		A4: Cultural Symbolism
		A5: Sustainability Value

After establishing the hierarchical structure, 13 experts with expertise in furniture design, materials science, and old ship timber culture were invited to perform pairwise comparisons of the hierarchical elements using Saaty's 1–9 scale (Harker and Vargas 1988; Saaty and Vargas 2012). These experts were selected based on their professional experience, familiarity with furniture design evaluation, reclaimed wood applications, or traditional wood craftsmanship. Each expert independently completed the pairwise comparison questionnaire according to the established AHP hierarchy. Based on their evaluations, the individual pairwise comparison matrices were aggregated using the geometric mean method to obtain the group judgment matrix, which preserves the reciprocal property of AHP comparisons. The aggregated pairwise comparison matrix is presented in Eq. 3.

$$A=\begin{bmatrix} a_{11} & a_{12} & \cdots & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & \cdots & a_{2n} \\ \cdots & \cdots & a_{ij} & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & \cdots & a_{nn} \end{bmatrix} \tag{3}$$

In the pairwise comparison matrix, a_{ij} denotes the relative importance of criterion A_i compared with criterion A_j. If A_i is judged to be more important than A_j, then $a_{ij} > 1$; if the two criteria are considered equally important, then $a_{ij}=1$. Based on the experts' pairwise comparisons of the criteria, the resulting judgment matrix is presented in Table 9.

Table 9. Pairwise Comparison Matrix and Criteria Weights with Respect to the Goal Level

	Must-be Requirements	One-dimensional Requirements	Attractive Requirements	Weight
Must-be Requirements	1.0000	0.3611	2.6667	0.2562
One-dimensional Requirements	2.7692	1.0000	5.3333	0.6367
Attractive Requirements	0.3750	0.1875	1.0000	0.1071

After determining the criteria-level weights with respect to the goal level, pairwise comparison matrices were constructed for the 11 indicator-level criteria, and their corresponding local weights were calculated, as presented in Tables 10 to 12. The global weight of each indicator was then obtained by multiplying its local weight by the weight of the corresponding criterion, followed by normalization. Finally, all indicators were ranked according to their global weights, as shown in Table 13.

Table 10. Pairwise Comparison Matrix and Local Weights of Indicator-Level Criteria under the Must-be Requirements Criterion

Must-be Requirements (M)	Durability (M1)	Ergonomic Performance (M2)	Economic Feasibility (M3)	Local Weight
Durability (M1)	1.0000	0.4444	3.3333	0.2990
Ergonomic Performance (M2)	2.2500	1.0000	5.3333	0.6005
Economic Feasibility (M3)	0.3000	0.1875	1.0000	0.1005

Table 11. Pairwise Comparison Matrix and Local Weights of Indicator-Level Criteria under the One-dimensional Requirements Criterion

One-dimensional Requirements (O)	Environmental Adaptability (O1)	Style Compatibility (O2)	Material Expressiveness (O3)	Local Weight
Environmental Adaptability (O1)	1.0000	0.3889	0.1698	0.0985
Style Compatibility (O2)	2.5714	1.0000	0.2611	0.2133
Material Expressiveness (O3)	5.8879	3.8298	1.0000	0.6882

Table 12. Pairwise Comparison Matrix and Local Weights of Indicator-Level Criteria under the Attractive Requirements Criterion

Attractive Requirements (A)	Functional Flexibility (A1)	Usage Scenario Compatibility (A2)	Cultural Value (A3)	Cultural Symbolism (A4)	Sustainability Value (A5)	Local Weight
Functional Flexibility (A1)	1.0000	6.6667	5.0000	4.0000	2.6667	0.4766
Usage Scenario Compatibility (A2)	0.1500	1.0000	0.3889	0.2611	0.1865	0.0457
Cultural Value (A3)	0.2000	2.5714	1.0000	0.5000	0.2611	0.0847
Cultural Symbolism (A4)	0.2500	3.8298	2.0000	1.0000	0.5000	0.1427
Sustainability Value (A5)	0.3750	5.3617	3.8298	2.0000	1.0000	0.2504

To ensure the reliability and validity of the calculated weights, consistency tests were performed on both the criteria-level and indicator-level judgment matrices. These tests evaluated the logical consistency of the experts' pairwise comparisons and verified the validity of the resulting weighting system.

Table 13. Overall Priority Ranking of User Requirements

Criteria Level	Criteria Weight	Indicator Level	Local Weight	Global Weight	Priority
Must-be Requirements	0.2562	Durability (M1)	0.2990	0.0766	4
		Ergonomic Performance (M2)	0.6005	0.1538	2
		Economic Feasibility (M3)	0.1005	0.0257	8
One-dimensional Requirements	0.6367	Environmental Adaptability (O1)	0.0985	0.0627	5
		Style Compatibility (O2)	0.2133	0.1358	3
		Material Expressiveness (O3)	0.6882	0.4382	1
Attractive Requirements	0.1071	Functional Flexibility (A1)	0.4766	0.0510	6
		Usage Scenario Compatibility (A2)	0.0457	0.0049	11
		Cultural Value (A3)	0.0847	0.0091	10
		Cultural Symbolism (A4)	0.1427	0.0153	9
		Sustainability Value (A5)	0.2504	0.0268	7

Using the eigenvector method, the maximum eigenvalue of the criteria-level judgment matrix was calculated as λ_{max}=3.017, as shown in Eq. 4,

$$\lambda_{max}=\frac{1}{n}\sum_{i=1}^{n}\frac{(Aw)_i}{w_i} \tag{4}$$

where n is the order of the judgment matrix, A is the judgment matrix, w_i is the weight of the i-th criterion, and λ_{max} is the maximum eigenvalue of A.

After calculating λ_{max}, a consistency test was conducted. The Consistency Index (CI) was calculated using Eq. 5.

$$CI=\frac{\lambda_{max}-n}{n-1} \tag{5}$$

The Consistency Ratio (CR) is calculated as the ratio of the Consistency Index (CI) to the Random Index (RI), as shown in Eq. 6.

$$CR=\frac{CI}{RI} \tag{6}$$

A CR value of less than 0.10 indicates acceptable consistency, demonstrating that the experts' pairwise comparisons are sufficiently consistent and that the derived weights are suitable for subsequent decision-making (Padilla-Garrido *et al.* 2014).

Using the above procedure, consistency tests were conducted for both the criteria-level and indicator-level judgment matrices. The results are presented in Table 14. All calculated Consistency Ratio (CR) values were below the acceptable threshold of 0.10, indicating that all judgment matrices satisfied the consistency requirement. These results demonstrate that the expert pairwise comparisons exhibited satisfactory logical consistency, thereby supporting the reliability of the derived weighting process and providing a quantitative basis for the subsequent Quality Function Deployment (QFD) analysis.

Table 14. Summary of Consistency Test Results

Index	P	M	O	A
λmax	3.0118	3.0129	3.0295	5.1259
CI	0.0059	0.0065	0.0147	0.0315
RI	0.52	0.52	0.52	1.12
CR	0.0113	0.0124	0.0283	0.0281

Construct the QFD Model

Following the prioritization of user requirements, Quality Function Deployment (QFD) was employed to translate user requirements into actionable technical characteristics, thereby establishing a systematic linkage between customer requirements and technical solutions. The primary objective of QFD is to ensure that customer requirements are systematically identified, translated into engineering characteristics, and effectively incorporated throughout the product design and development process, thereby enhancing the alignment between design solutions and customer expectations (Hu *et al.* 2024).

To ensure the methodological rigor of the QFD analysis, user requirements were ranked according to their AHP-derived global weights. The top 80% of the ranked requirements were selected as the core inputs for subsequent technical mapping, resulting in a total of nine high-priority requirements. This strategy not only follows the Pareto principle to maximize customer satisfaction but also reduces the structural complexity of the House of Quality (HOQ), thereby improving the clarity and interpretability of the evaluation process (Dunford *et al.* 2014). To establish an effective correspondence between user requirements and technical characteristics, the research team synthesized evidence from user interviews, expert workshops, and representative case studies to identify a preliminary set of technical characteristics for the sustainable design of old ship timber furniture.

Based on the preliminary set of technical characteristics, an independent panel of 12 experts from diverse disciplinary backgrounds was convened to evaluate the proposed mapping scheme through multiple rounds of relevance assessment. Following iterative evaluation and cross-validation, the research team identified and finalized nine key technical characteristics for the sustainable design of old ship timber furniture. The finalized technical characteristics are presented in Table 15.

Table 15. Translation of User Requirements into Technical Characteristics for the Sustainable Design of Old Ship Timber Furniture

Goal Level	Criteria Level	Indicator Level	Technical Characteristic
Sustainable Design of Old Ship Timber Furniture	Must-be Requirements (M)	Durability (M1)	D1. High-Stability Structural Design
		Ergonomic Performance (M2)	D2. Ergonomic Support Design
		Economic Feasibility (M3)	D3. Cost-Effective Composite Material Design
	One-dimensional Requirements (O)	Environmental Adaptability (O1)	D4. Adaptive Design for Multiple Usage Environments
		Style Compatibility (O2)	D5. Contemporary Interior Integration Design
		Material Expressiveness (O3)	D6. Natural Ship Timber Grain Preservation
	Attractive Requirements (A)	Functional Flexibility (A1)	D7. Modular Functional Design
		Cultural Symbolism (A4)	D8. Translation of Regional Cultural Elements
		Sustainability Value (A5)	D9. Circular Application of Recycled Materials

The House of Quality (HOQ), the core tool of Quality Function Deployment (QFD) (Das and Mukherjee 2008; Xu and Chen 2025), consists of three principal components: the customer requirements-technical characteristics matrix, the relationship matrix, and the technical correlation matrix. Together, these components evaluate the strength of the relationships between customer requirements and technical characteristics while assessing the interactions among technical characteristics. As a structured decision-support tool, the HOQ quantitatively determines the contribution of each technical characteristic to satisfying specific customer requirements and identifies the priorities and synergies among alternative technical solutions throughout the product design process.

Based on the nine selected requirements and the corresponding technical characteristics identified in the previous stage, a complete House of Quality (HOQ) model was constructed. To establish the relationship matrix, the eight frequent users were selected from participants with practical experience in using or interacting with old ship timber furniture. Together with the 12 experts described above, formed a 20-member QFD evaluation panel. Using a consensus-based rating approach, the panel evaluated the strength of the relationships between each user requirement and technical characteristic. Any differences in evaluations were discussed among panel members and resolved through consensus rather than direct averaging, resulting in the final HOQ relationship matrix. As shown in Fig. 4, the user requirements are positioned on the left wall of the HOQ, with their corresponding importance weights displayed on the right wall, while the technical characteristics are arranged along the roof, forming the engineering response structure. The roof matrix represents the correlations among technical characteristics, where "+" denotes a positive correlation and "−" denotes a negative correlation (Kürüm *et al.* 2021; Li *et al.* 2023). The central relationship matrix (*i.e.*, the body of the HOQ) characterizes the relationships between user requirements and the technical characteristics of old ship timber furniture. Relationship strengths were quantified using four levels: ▲ = strong (5), ◆ = moderate (3), ○ = weak (1), and a blank cell = no relationship (0) (Maisano *et al.* 2024). Based on the completed relationship matrix, the absolute importance and relative importance of each technical characteristic were subsequently calculated using Eqs. 7 through 9,

$$w_i^{'} = \frac{W_i}{\sum_{i=1}^{n} w_i^{'}} \tag{7}$$

$$w_j = \sum_{i=1}^{n} w_i^{'} R_{ij} \tag{8}$$

$$w_j^{'} = \frac{W_j}{\sum_{j=1}^{n} w_j} \tag{9}$$

where $w_i^{'}$ is the relative importance of the i-th user requirement, w_i is its importance weight, R_{ij} is the relationship coefficient between the i-th user requirement and the j-th technical characteristic, w_j is the importance weight of the j-th technical characteristic, and $w_j^{'}$ is its relative importance.

Based on the calculated importance values from the HOQ, the technical weights were normalized by dividing each technical characteristic importance value by the total importance value of all technical characteristics. The normalized QFD weights are presented in Table 16. These normalized weights were subsequently transferred to the VIKOR evaluation.

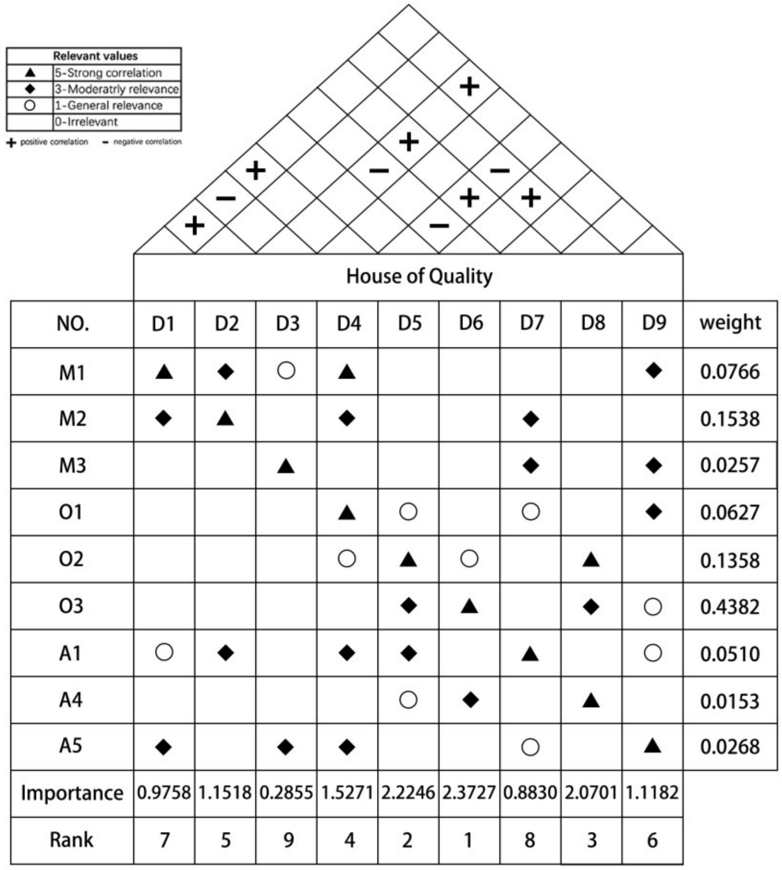

Fig. 4. House of Quality (HOQ) Model for the Sustainable Design of Old Ship Timber Furniture

Table 16. Normalized Weights of Technical Characteristics Derived from QFD

Technical characteristics	Importance	Normalized QFD weight	Rank
D1	0.9758	0.0775	7
D2	1.1518	0.0915	5
D3	0.2855	0.0227	9
D4	1.5271	0.1214	4
D5	2.2246	0.1768	2
D6	2.3727	0.1885	1
D7	0.8830	0.0701	8
D8	2.0701	0.1643	3
D9	1.1182	0.0889	6

To prioritize the technical characteristics for the sustainable design of old ship timber furniture, the importance values derived from the QFD analysis were used to establish a relative priority ranking of technical characteristics. The normalized QFD weights were further used to compare the relative contributions of different technical characteristics. Based on the ranking results, a prioritized hierarchy of technical characteristics was established to identify the key design directions for sustainable old ship timber furniture. As shown in Table 17, the resulting priority hierarchy was further used to support the subsequent design evaluation and functional deployment strategy.

Table 17. Priority Ranking of Technical Characteristics for the Sustainable Design of Old Ship Timber Furniture

Priority Level	Requirement Category	Technical Characteristic	Priority
Level I (First-tier Priority)	O	D6. Natural Ship Timber Grain Preservation	1
	O	D5. Contemporary Interior Integration Design	2
	A	D8. Translation of Regional Cultural Elements	3
Level II (Second-tier Priority)	O	D4. Adaptive Design for Multiple Usage Environments	4
	M	D2. Ergonomic Support Design	5
	A	D9. Circular Application of Recycled Materials	6
Level III (Third-tier Priority)	M	D1. High-Stability Structural Design	7
	A	D7. Modular Functional Design	8
	M	D3. Cost-Effective Composite Material Design	9

Level I functional analysis

Level I functions represent the First-tier priority group identified from the QFD-based ranking and define the core value of the sustainable design of old ship timber furniture through three key dimensions: the preservation of material characteristics, integration with contemporary living environments, and the expression of regional cultural heritage. D6: Natural Ship Timber Grain Preservation was identified as the highest-priority technical characteristic. By preserving the natural grain patterns and weathered textures developed through prolonged marine exposure, it reinforces the material identity of old ship timber while preserving its historical and cultural significance. D5: Contemporary Interior Integration Design focuses on enhancing the compatibility of old ship timber furniture with modern living environments. Through the application of contemporary design language and spatial adaptation strategies, it improves product versatility and market acceptance. D8: Translation of Regional Cultural Elements facilitates the reinterpretation of ship timber culture and regional cultural symbols in contemporary furniture design, thereby strengthening the product's cultural identity and emotional value. Collectively, these Level I functions establish the core framework for the sustainable design of old ship timber furniture, providing a foundation for balancing cultural heritage with contemporary market demands.

Level II functional analysis

Level II functions represent the Second-tier Priority group identified from the QFD-based ranking and focus on enhancing user experience and sustainability performance. D4: Adaptive Design for Multiple Usage Environments improves the adaptability of old ship timber furniture to diverse climatic conditions and usage scenarios, thereby enhancing environmental resilience and extending product service life. D2: Ergonomic Support Design enhances user comfort during prolonged use by optimizing structural dimensions and the ergonomic interface between the user and the furniture. D9: Circular Application of Recycled Materials embodies the principles of the circular economy and sustainable design by improving the utilization efficiency of recycled materials, thereby contributing to enhanced resource efficiency and potential environmental benefits. Collectively, these Level II functions complement the Level I functions by improving product performance and further reinforcing the sustainable design value of old ship timber furniture.

Level III functional analysis

Level III functions represent the Third-tier Priority group identified from the QFD-based ranking and primarily support product realization and market implementation. D1: High-Stability Structural Design enhances furniture safety and durability by optimizing structural connections and load-bearing systems, thereby ensuring long-term structural reliability. D7: Modular Functional Design improves functional flexibility and spatial adaptability, enabling the furniture to accommodate diverse user needs and usage contexts. D3: Cost-Effective Composite Material Design explores the potential application of composite materials and optimized production strategies to support manufacturing feasibility and market competitiveness while maintaining the functional requirements of old ship timber furniture.

Although these technical characteristics occupy relatively lower positions in the QFD ranking, they remain important for improving manufacturability, cost-effectiveness, and market implementation of old ship timber furniture.

RESULTS AND DISCUSSION

Design Scheme Generation

To translate user requirements into implementable design solutions, this study integrated a Large Language Model (LLM) with diffusion model-based image generation within the QFD framework to establish a hybrid design workflow. This workflow was designed to improve the semantic consistency, functional completeness, and conceptual expression of concepts generated during the early stages of product development (Chen *et al.* 2024).

Fig. 5. Hybrid AI-assisted design workflow and candidate prototype library for old ship timber furniture

The nine key technical characteristics identified during the QFD stage, together with their corresponding importance weights, were used as the core semantic inputs. These inputs were integrated with a three-dimensional semantic framework comprising functional attributes, usage scenarios, and sustainability considerations to generate design prompts. Based on these prompts, ChatGPT Image 2 and Nano Banana were employed as AI-assisted visualization tools to automatically generate a series of conceptual visualizations of old ship timber furniture, facilitating the exploration and refinement of preliminary design concepts. Through multiple rounds of iterative optimization, a set of candidate conceptual designs was generated, resulting in the establishment of a preliminary concept visualization library (Fig. 5).

During the generation process, the prompts were constructed based on the prioritized technical characteristics and design requirements obtained from the QFD analysis. Iterative refinement was conducted by adjusting semantic descriptions related to material characteristics, functional attributes, spatial scenarios, and cultural expression. No copyrighted or confidential third-party images were used as input references, and the generated concepts were derived from original textual descriptions based on the research findings.

Building on this workflow, the generated design concepts were comprehensively evaluated based on functional coverage, semantic consistency, and design completeness. An expert review panel comprising five specialists, including two furniture design researchers, one materials science expert, one old ship timber culture researcher, and one sustainable design researcher, assessed the candidate concepts. The candidate concepts were screened according to their alignment with the prioritized design requirements derived from the QFD analysis, including functional attributes, material expression, cultural representation, and sustainability-oriented design considerations. Based on the evaluation and screening results, four design concepts that best matched the prioritized design requirements were selected for further conceptual development. These concepts were subsequently refined and optimized from three design perspectives: the expression of material characteristics, integration with contemporary living environments, and cultural sustainability-oriented innovation, ultimately resulting in the final conceptual design outcomes of this study.

Scheme 1. This design scheme is centered on the preservation of ship timber cultural heritage, emphasizing the reinterpretation of the historical traces and maritime cultural memory embodied in old ship timber. As shown in Fig. 6, the design preserves the natural grain patterns, selected weathered cracks, and aging marks developed through prolonged marine exposure, while these surface characteristics are retained only after necessary material inspection, cleaning, stabilization, and safety evaluation. Traditional structural features, including ship hull components and planked hull construction, are reinterpreted using a contemporary design language. Cultural details, such as ship rivets and vessel identification numbers, are incorporated to reinforce the furniture's cultural identity and narrative character. The overall color palette retains the natural dark-brown tones of old ship timber together with the subtle chromatic variations produced by long-term oxidation, creating a restrained and historically evocative aesthetic. This scheme is intended primarily for cultural exhibition spaces, boutique homestays, high-end cultural tourism projects, and the collectible furniture market, emphasizing the integration of cultural value, emotional resonance, and collectibility.

Scheme 2. This design scheme focuses on integrating old ship timber with contemporary living environments, aiming to achieve a harmonious balance between the material characteristics of reclaimed ship timber and modern interior spaces. As shown in Fig. 7, the overall form adopts a clean, streamlined contemporary design language. Optimized proportions and structural configurations aim to reduce the visual heaviness traditionally associated with old ship timber furniture. Metal framing and upholstered elements are incorporated to create a visually lighter appearance and support potential user comfort, while preserving selected areas of the natural ship timber grain as distinctive visual features. This scheme is intended for modern residential, office, and commercial environments, targeting younger consumer groups and the contemporary furniture market, with particular emphasis on aesthetic compatibility and market acceptance.

Scheme 3. This design scheme focuses on spatial adaptability and functional flexibility, emphasizing modularity and adaptability to diverse usage scenarios. As shown in Fig. 8, the design adopts a modular architecture with standardized connection mechanisms, enabling the flexible combination and rapid reconfiguration of sofas, coffee tables, and storage units. Individual modules can be rearranged or expanded according to spatial requirements, aiming to improve space utilization and functional versatility. Ergonomic principles are integrated throughout the modular configurations to support user comfort across different usage modes. This scheme is intended for modern residences, apartments, shared workspaces, and creative cultural spaces, effectively addressing the growing demand for flexible spatial solutions and multifunctional furniture.

Scheme 4. This design scheme is founded on the principles of circular resource utilization and sustainable design, emphasizing potential for efficient reuse of reclaimed old ship timber through sustainable design strategies. As shown in Fig. 9, reclaimed old ship timber is used as the primary material and combined with recycled wood-based panels and recyclable metal components to form a composite structural system. This material strategy is intended to promote resource utilization while providing potential considerations for structural performance and durability. The design further aims to reduce material waste and potentially improve manufacturing efficiency, thereby exploring potential environmental and economic benefits. This scheme is intended for green residential environments, eco-hotels, and sustainable demonstration spaces, demonstrating the innovative potential of old ship timber furniture within the framework of the circular economy.

In summary, the four proposed design schemes represent distinct design pathways centered on ship timber cultural heritage preservation, integration with contemporary living environments, modular functional design, and sustainable design, demonstrating the proposed framework’s capacity to address diverse user requirements. All schemes were derived from the AI-generated prototype library and subsequently refined through semantic filtering, structural evaluation, and iterative optimization. This process ensured a high level of consistency among functional priorities, implementation feasibility, and sustainability objectives. The resulting generation-screening workflow highlights the complementary capabilities of Large Language Models (LLMs) and generative image models in user-centered furniture design, providing a novel methodological framework and technical pathway for AI-assisted furniture prototype development.

Fig. 6. Old ship timber furniture design concept (Scheme 1)

Fig. 7. Old ship timber furniture design concept (Scheme 2)

Fig. 8. Old ship timber furniture design concept (Scheme 3)

Fig. 9. Old ship timber furniture design concept (Scheme 4)

Design Scheme Evaluation Based on VIKOR

To identify the optimal compromise solution that balances user requirement priorities with multiple evaluation criteria, this study assembled an interdisciplinary expert panel comprising 23 professionals to conduct the multi-criteria evaluation. The panel included seven furniture designers, six materials science experts, five specialists in old ship timber culture, and five experts in sustainable design. The expert selection criteria were consistent with those used in the AHP weighting stage. Among the 23 experts, some participants overlapped with the previous AHP panel due to their relevant expertise, while additional experts from complementary disciplines were included to provide a broader evaluation perspective.

Prior to the formal evaluation, an anchored scoring protocol was established to minimize subjective variability in expert ratings. The experts were first provided with standardized definitions of the nine evaluation criteria together with explicit scoring guidelines. For example, under the criterion "Contemporary Interior Integration Design (D5)," scores of 9 to 10 were defined as "highly compatible with contemporary living environments," whereas scores of 1 to 2 indicated "an overly traditional and visually heavy furniture style."

Table 18. Initial Evaluation Matrix

Technical Characteristic	Scheme 1	Scheme 2	Scheme 3	Scheme 4
D1. High-Stability Structural Design	8.8	8.2	8.5	8.0
D2. Ergonomic Support Design	7.2	8.8	8.5	7.5
D3. Cost-Effective Composite Material Design	4.5	7.2	7.8	9.0
D4. Multi-Environment Adaptive Design	6.8	8.7	8.9	8.2
D5. Contemporary Interior Integration Design	5.2	9.5	8.2	7.5
D6. Ship Timber Grain Preservation	9.8	7.2	6.5	6.8
D7. Modular Functional Design	3.8	6.2	9.7	5.5
D8. Translation of Regional Cultural Elements	9.4	6.8	5.5	6.2
D9. Circular Application of Recycled Materials	6.5	7.2	7.5	9.8

The experts independently evaluated each design scheme. To minimize the influence of extreme ratings, the evaluation scores were aggregated using the geometric mean, yielding the initial evaluation matrix presented in Table 18. Combined with the normalized technical-importance weights obtained from the QFD analysis, this matrix was used as the input for the subsequent VIKOR multi-criteria decision analysis. These weights reflect the relative importance of the nine technical characteristics determined through the QFD relationship matrix between user requirements and design characteristics.

Based on the initial evaluation matrix, the VIKOR method was employed to perform a multi-criteria decision analysis of the four design schemes. The VIKOR approach proposed by Opricovic and Tzeng (2004) was adopted to identify the optimal compromise solution among multiple alternatives. In this study, all nine technical characteristics (D1 to D9) were considered benefit criteria, where higher scores indicated better performance. For each alternative, the normalized distance value d_{ij} between the performance value of alternative i and the ideal solution of criterion j was calculated. The best and worst values of each criterion were defined as f_j^* and f_j^- , respectively.

With the group utility parameter set to v=0.5, the group utility measure (S_i), individual regret measure (R_i), and compromise ranking index(Q_i)were calculated for each scheme using Eqs. (10)–(12). In these equations, S^* and S^- represent the best and worst values of S_i, while R^* and R^- represent the best and worst values of R_i, respectively. The results are presented in Table 19.

$$S_i=\sum_{j=1}^{n} w_j\, d_{ij} \tag{10}$$

$$R_i=*max_j(w_j d_{ij}) \tag{11}$$

$$Q_i=v\frac{S_i\text{-}S^*}{S^-\text{-}S^*}+(1\text{-}v)\frac{R_i\text{-}R^*}{R^-\text{-}R^*} \tag{12}$$

Table 19. VIKOR Analysis Results

Scheme	Comprehensive Utility Value S_i	Maximum Regret Value R_i	Comprehensive Evaluation Index Q_i	Rank
Scheme 1	0.5487	0.1768	0.5926	2
Scheme 2	0.4530	0.1485	0.0000	1
Scheme 3	0.5311	0.1885	0.6949	3
Scheme 4	0.6533	0.1714	0.7857	4

According to the VIKOR method, the alternatives were evaluated using three indices: the group utility measure (S_i), the individual regret measure (R_i), and the compromise ranking index (Q_i). A lower Q_i value indicates that an alternative is closer to the ideal solution and therefore exhibits superior overall performance. As shown in Table 19, the alternatives were ranked as follows: Scheme 2 > Scheme 1 > Scheme 3 > Scheme 4. According to the VIKOR methodology, the optimal compromise solution must satisfy both the acceptable advantage criterion and the decision stability criterion. In this study, the acceptable advantage condition was evaluated based on four alternatives (m=4), and Scheme 2 satisfied both criteria, confirming its selection as the optimal compromise solution. Furthermore, a sensitivity analysis was conducted by varying the group utility parameter (v) to examine the stability of the ranking results, and Scheme 2 remained the preferred solution under different v values.

Condition 1:Acceptable Advantage, as defined in Eq. 13.

$$Q_{(1)}-Q_{(2)} \geq \frac{1}{n-1} \tag{13}$$

Condition 2: Scheme 2 also ranks first in the sorting of S_i and R_i.

In summary, Scheme 2 satisfied both Condition 1 and Condition 2 and was therefore identified as the unique compromise solution. Accordingly, it was selected as the final recommended design.

Interpretation of the Optimal Design Scheme

The VIKOR evaluation identified Scheme 2 as the optimal compromise solution, demonstrating the best overall balance among the technical characteristics prioritized by the QFD analysis. The highest-weighted criteria, including Ship Timber Grain Preservation (D6), Contemporary Interior Integration Design (D5), and Translation of Regional Cultural Elements (D8), indicate that these technical characteristics were prioritized within the proposed evaluation framework, emphasizing the preservation of reclaimed ship timber characteristics and its adaptability to contemporary living environments.

Compared with other alternatives, Scheme 2 achieved a more balanced integration of material expression, aesthetic compatibility, and practical application. The scheme preserves selected natural ship timber grain and weathered textures while adopting a streamlined contemporary form to reduce the visual heaviness of traditional ship timber furniture. The combination of metal framing and upholstered elements further enhances visual lightness and user comfort, enabling reclaimed ship timber furniture to better fit modern residential, office, and commercial spaces.

Although Scheme 1 showed stronger cultural expression and Scheme 3 provided greater functional flexibility, Scheme 2 achieved a better balance between cultural value, contemporary aesthetics, and potential application requirements. In particular, the cultural elements in Scheme 2 are expressed through the integration of ship timber characteristics and contemporary design language rather than direct reproduction of historical symbols. Therefore, it was selected as the optimal design scheme for transforming reclaimed ship timber into modern furniture products with broader user appeal.

Theoretical Contributions of the Integrated Framework

From a methodological perspective, the contribution of this study extends beyond the development of an optimal design solution for reclaimed ship timber furniture. More importantly, it demonstrates the applicability of the integrated GT-Kano-AHP-QFD-VIKOR framework to the design of furniture made from culturally significant reclaimed materials. Grounded Theory (GT) ensured the contextual validity of user requirement identification; the Kano model revealed the nonlinear relationship between requirement attributes and user satisfaction; AHP transformed subjective judgments into a computable weighting system; QFD systematically translated user requirements into engineering characteristics; and VIKOR provided a quantitative basis for compromise decision-making among competing design alternatives. Collectively, these methods establish a systematic sequential decision-support framework that links qualitative insights with quantitative evaluation, user requirements with technical characteristics, and design concept generation with alternative selection. This integrated framework provides a systematic methodology for the sustainable design of reclaimed ship timber furniture and offers a meaningful methodological contribution to research on furniture design using culturally significant reclaimed materials.

Implications for Sustainable Furniture Design

Sustainable design should not be viewed merely as the substitution of conventional materials with recycled alternatives. Rather, it should be conceptualized as a systematic design strategy encompassing resource circularity, product life extension, and user behavior change. Although reclaimed ship timber inherently possesses sustainable value through resource reuse, users' perceptions of its environmental value are shaped not only by the material itself but also by cultural identity and emotional engagement. The high rankings of Ship Timber Grain Preservation (D6) and Translation of Regional Cultural Elements (D8) suggest that extending the cultural life cycle of reclaimed materials may be as important as extending their physical service life.

The findings of this study demonstrate that sustainable design and cultural identity are not independent objectives but can instead generate synergistic benefits. In the context of reclaimed ship timber furniture, integrating reclaimed material utilization, cultural value expression, and product life extension not only promotes resource circularity and sustainable development, but also enhances the product's cultural value and market competitiveness. This integrated approach provides a systematic pathway for the design of furniture made from culturally significant reclaimed materials, effectively balancing environmental sustainability with cultural value creation.

Limitations and Future Research

Despite the contributions of this study, several limitations should be acknowledged. First, the sample size was relatively limited due to the specific cultural context of reclaimed ship timber furniture. Although purposive sampling and theoretical saturation were applied, future studies should include broader user groups to improve the generalizability of the findings.

Second, the proposed framework mainly relied on expert judgments and user perceptions. Although consistency analysis and sensitivity analysis were conducted to improve the reliability of the decision-making process, further validation using larger-scale surveys and empirical user evaluations is still needed.

Finally, the AI-assisted design concepts were evaluated through the proposed decision framework rather than actual market testing. Future studies should further examine consumer acceptance, manufacturing feasibility, and commercialization potential of AI-supported reclaimed timber furniture designs.

CONCLUSIONS

1. *A Sustainable Design Perspective for Reclaimed Ship Timber Furniture.* This study proposed an integrated GT-Kano-AHP-QFD-VIKOR framework for the sustainable design of Chinese reclaimed ship timber furniture. The findings indicate that users value not only functional performance, but also material expressiveness, cultural identity, and spatial compatibility. These results suggest that reclaimed ship timber furniture has evolved beyond a recycled-material product into a comprehensive design medium that integrates cultural, aesthetic, and sustainable values.
2. *A Synergistic Innovation Pathway Integrating Traditional Materials, Contemporary Spaces, and Regional Culture*. The findings indicate that Ship Timber Grain Preservation, Contemporary Interior Integration Design, and Translation of Regional

Cultural Elements are the three key dimensions underpinning the sustainable design of reclaimed ship timber furniture. Together, they establish a core design framework that integrates material expression, spatial adaptation, and cultural heritage preservation, thereby supporting the sustainable design of reclaimed ship timber furniture.

3. *A User-Centered Decision-Making Mechanism for Sustainable Design*. Through the integrated application of the Kano model, AHP, and QFD, this study established a quantitative mapping between user requirements and technical characteristics. The VIKOR evaluation further identified the optimal compromise solution based on the derived technical priorities and expert evaluations, resulting in a balanced design solution that integrates cultural expression, user experience, design feasibility, and sustainable performance. These findings indicate the potential applicability of a cultural identity-driven decision-making mechanism for sustainable design.
4. *A Transferable Research Framework for Furniture Design*. Overall, the integrated methodological framework developed in this study demonstrates that combining qualitative user requirement elicitation with quantitative decision-making methods is both feasible and effective for the design of furniture made from culturally significant reclaimed wood. In addition to advancing research on the sustainable design of reclaimed ship timber furniture, the proposed framework offers a replicable methodological paradigm and empirical foundation for the design of other reclaimed wood furniture, products incorporating regionally significant cultural materials, and sustainable furniture.

Conflicts of Interest

The authors declare that we have no known competing financial interests or personal relationships that could have influenced the work reported in this manuscript.

Use of Generative AI

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) solely for language editing and translation assistance of certain sections of the text. The AI tool was employed solely to improve the clarity, fluency, and academic tone of the English version of the manuscript, particularly for passages originally drafted in Chinese. All content generated or refined by AI was thoroughly reviewed, verified, and edited by the authors to ensure accuracy, consistency with the original research, and adherence to academic standards.

In addition to using ChatGPT Image 2 and Nano Banana to generate relevant design schemes during the scheme design validation phase—as described in the manuscript—no other AI tools were employed for data analysis, image/figure creation, or substantive content generation.

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APPENDIX

Kano Questionnaire for Evaluating User Requirements in Old Ship Timber Furniture Design

Dear Respondent,

This questionnaire aims to investigate users' perceptions of old ship timber furniture design requirements. A bidirectional questioning format based on the Kano model is adopted, including functional (attribute present) and dysfunctional (attribute absent) questions. Please answer according to your immediate feelings and perceptions. All responses will be used only for academic research purposes and will remain confidential. Thank you for your participation and support.

I. Instructions for Completion

Each item in this questionnaire consists of two questions: Functional (positive)question: How do you feel when this feature is present? Dysfunctional (negative)question: How do you feel when this feature is absent? For each question, please select the single option that best reflects your true feelings: □Dislike □Can Tolerate □Neutral □Must Be □Like

II. Basic Information (Optional)

1. Gender: □Male □Female □Other
2. Age:□18-25□26-35□36-45□46or above
3. Occupation: □Student □Design-related□ Culture/Education □Other:______
4. Have you previously been familiar with or exposed to old ship timber furniture ?
□Frequently □Occasionally □Heard of it □Never

III. KANO Bidirectional Requirement Evaluation Items

B1 Durability

(1) Feature Present(Functional): When old ship timber furniture has a stable structure, long service life, and low maintenance requirements, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

(2) Feature Absent(Dysfunctional):When old ship timber furniture is not durable and requires frequent maintenance, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

B2 Ergonomic Performance

(1) Feature Present(Functional):When old ship timber furniture meets ergonomic requirements in terms of seating comfort, support, and usage safety, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

(2) Feature Absent(Dysfunctional):When old ship timber furniture provides uncomfortable seating or presents certain safety risks, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

B3 Environmental Adaptability

(1) Feature Present(Functional):When old ship timber furniture provides a good user experience in different seasons (such as tactile comfort in winter and usability in summer), how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

(2) Feature Absent(Dysfunctional):When old ship timber furniture provides poor usability in certain seasons (such as being too cold in winter), how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

B4 Functional Flexibility

(1) Feature Present(Functional):When old ship timber furniture provides multiple functions (such as storage and modular combinations), how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

(2) Feature Absent(Dysfunctional):When old ship timber furniture has limited functions and lacks expandability, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

B5 Style Compatibility

(1) Feature Present(Functional):When the form and color of old ship timber furniture can be well integrated into modern interior styles, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

(2) Feature Absent(Dysfunctional):When old ship timber furniture has limited design forms or is difficult to integrate with modern spaces, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

B6 Usage Scenario Compatibility

(1) Feature Present(Functional):When old ship timber furniture has appropriate dimensions and can adapt to different spatial scenarios (such as small apartments or multifunctional spaces), how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

(2) Feature Absent(Dysfunctional):When old ship timber furniture is oversized, occupies considerable space, and is difficult to adapt to different usage scenarios, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

B7 Material Expressiveness

(1) Feature Present(Functional):When old ship timber furniture demonstrates high-quality material expression and craftsmanship details (such as clear textures and refined workmanship), how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

(2) Feature Absent(Dysfunctional):When old ship timber furniture has rough craftsmanship details or poor surface treatment, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

B8 Cultural Value

(1) Feature Present(Functional):When old ship timber furniture reflects its historical background and cultural connotations, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

(2) Feature Absent(Dysfunctional):When old ship timber furniture lacks cultural expression and exists only as ordinary furniture, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

B9 Collectible Value

(1) Feature Present(Functional):When old ship timber furniture has certain collectible value and long-term preservation significance, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

(2) Feature Absent(Dysfunctional):When old ship timber furniture lacks collectible value, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

B10 Cultural Symbolic Expression

(1) Feature Present(Functional):When old ship timber furniture incorporates regional

characteristics or culturally symbolic design elements, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

(2) Feature Absent(Dysfunctional):When old ship timber furniture lacks cultural symbols or recognizable characteristics, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

B11 Emotional Resonance

(1) Feature Present(Functional):When old ship timber furniture evokes emotional resonance (such as nostalgia or a sense of storytelling), how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

(2) Feature Absent(Dysfunctional):When old ship timber furniture cannot provide emotional experiences, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

B12 Sustainability Value

(1) Feature Present(Functional):When old ship timber furniture uses recycled materials and reflects environmental protection and sustainability concepts, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

(2) Feature Absent(Dysfunctional):When old ship timber furniture does not reflect environmental protection or sustainability characteristics, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

B13 Material Selection Strategy

(1)Feature Present(Functional):When old ship timber furniture improves performance and aesthetics through reasonable combinations with other materials (such as metal and upholstery), how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

(2)Feature Absent(Dysfunctional):When old ship timber furniture uses only a single material and lacks optimized material combinations, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

B14 Economic Feasibility

(1) Feature Present(Functional):When old ship timber furniture has a reasonable price and high cost-effectiveness, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

(2) Feature Absent(Dysfunctional):When old ship timber furniture is expensive and has relatively low cost-effectiveness, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

B15 Market Acceptance

(1) Feature Present(Functional):When old ship timber furniture has high market awareness and is widely accepted by consumers, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like

(2) Feature Absent(Dysfunctional):When old ship timber furniture has low awareness and limited market acceptance, how do you feel?

□Dislike □Can Tolerate □Neutral □Must Be □Like