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Unveiling the Core Design Elements of Bamboo Furniture

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ABSTRACT Bamboo furniture, as an emerging low-carbon industry, has become a significant component of the furniture sector's sustainable development. To identify the key design elements of bamboo furniture and evaluate their importance, this study employed a combination of the Knowledge Creation Model, text mining, the Analytic Hierarchy Process (AHP), and Quality Function Deployment (QFD). The SECI knowledge creation model was utilized to establish the process framework. BERTopic was applied to analyze online bamboo furniture reviews. Key user needs were extracted using AHP. A QFD matrix was constructed to transform these needs into design elements and technical attributes, determining the weights and rankings of the design factors. The findings revealed that safety, comfort, and ease of use are the most critical factors for users. Safety is a core element throughout the product lifecycle. Enhancing bamboo furniture engineering attributes, including improving connector performance, selecting durable materials, and incorporating ergonomic design, is key to enhancing product safety and extending its lifespan. This study provides valuable insights into design elements to prioritize in bamboo furniture product development. This contributes to improved design quality and promoting sustainable growth of the industry.

INDEX TERMS Bamboo furniture, text mining, BERTopic, Analytic Hierarchy Process, Quality Function Deployment, Design Elements.

I. INTRODUCTION

Furniture made of bamboo represents an emerging low-carbon industry composed of bamboo. China has abundant bamboo resources widely distributed [1]–[3]. It is a rapidly renewable biological resource that offers advantages such as rapid growth [4], short maturity periods, lightweight, ease of processing, and strong mechanical characteristics [5]. Compared to wood, bamboo exhibits superior strength and resilience, contributing to reduced deforestation, mitigation of climate change, and sustainable development goals, including job creation. It serves as an ideal alternative to solid wood for furniture production. As wood resources become increasingly scarce and the supply-demand imbalance appears, existing research [6]–[8], indicates that bamboo is becoming more and more popular as a supplementary resource for eco-friendly and green materials to meet various market demands and wide-ranging application opportunities, including construction, automotive, textiles, appliances, interior design, and furniture. In 2020, the bamboo industry in China had an significant impact on manufacturing, particularly in the furniture sector [9]–[10], with an industry output value exceeding 300 billion RMB. Chinese bamboo furniture trade value increased to 171 million USD [11]. Bamboo furniture has become a significant category in the furniture market, contributing positively to sustainable development.

Bamboo furniture is gaining attention in the furniture market, but it faces several challenges in various aspects. First, the bamboo furniture industry is generally characterized by small-scale operations, lack of standardization, and insufficient quality control [12]–[13]. These problems stem from the fact that most bamboo furniture enterprises evolved from traditional apprentice workshops, where production techniques remain labor-intensive and experience-driven. Second, in the design aspect, as consumer expectations for bamboo furniture continue to rise, there is a growing need to comprehensively consider user requirements and experiences in the design process. However, traditional design methods often rely on individual designers' personal experiences and design trends, which lack a systematic and scientific approach [14]. This leads to a disconnect between design elements and technical integration, affecting craftsmanship and product quality. Therefore, to bridge the gap between design concepts and user expectations, it is crucial to emphasize the precise evaluation of key needs in the design process. It is also crucial to promote the seamless integration of design and technical elements.

Current research on bamboo furniture focuses on materials science and environmental science. It emphasizes enhancing bamboo's physical, mechanical, and chemical properties [15]–[20]. In recent years, bamboo furniture design research has gained attention [21]–[22]. For instance, Wan *et al.* [23] employed eye-tracking experiments and subjective evaluation systems to explore how bamboo furniture surface characteristics affect human visual cognition. Similarly, Kang *et al* [24] utilized deep convolutional neural networks to train image recognition models of bamboo chairs, generating designs that meet users' emotional needs. Nevertheless, systematic research into bamboo furniture design elements remains relatively scarce.

This study integrates text mining, the Analytic Hierarchy Process (AHP), and Quality Function Deployment (QFD) to address key product design challenges, leveraging each approach's strengths. With the rapid growth of China's online furniture retail market [25], user reviews have become a major driver of product iteration and innovation [26]–[27]. Consumers often rely on online reviews when purchasing bamboo furniture. These reviews provide rich data, and text mining techniques efficiently extract and analyze critical information. This offers data-driven support for optimizing product design and overcoming traditional data collection inefficiencies. Compared to conventional techniques, text mining can quickly process large datasets and identify key user priorities, providing a distinct advantage in design.

The AHP method establishes design elements' prioritization through a clear hierarchy. Its straightforward calculation process allows for effective handling of hierarchical requirements and flexibility in different decision-making contexts. While methods like Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Fuzzy Analytic Hierarchy Process (Fuzzy AHP) can also analyze design elements, AHP is particularly effective at managing complex decisions. TOPSIS ranks alternatives based on proximity to the ideal solution, making it more suitable for simpler decisions, whereas Fuzzy AHP is better for uncertain environments. In this study, the AHP model processes bamboo furniture information, with results directly applied to the QFD matrix. This ensures logical consistency and interpretability.

QFD uses the "House of Quality" matrix to link user needs with engineering characteristics and design objectives, helping designers define technical requirements and optimize design solutions. Compared to Theory of Inventive Problem Solving (TRIZ), QFD emphasizes the accurate translation of user demands into design goals. In contrast, TRIZ focuses more on resolving technical conflicts and encouraging innovation. Additionally, QFD allows flexible priority adjustments based on regional user needs. By combining text mining efficiency, AHP's structured analysis, and QFD's systematic mapping, this approach enables cost-effective, impactful improvements in bamboo furniture design, making it ideal for small and medium-sized enterprises and fast-paced design environments.

AHP and QFD integration further enhances design efficiency and systematization. AHP quantifies the prioritization of user needs, providing weightings for the QFD matrix, whereas QFD systematically maps these needs into actionable design characteristics. For example, Li *et al.* [28] applied the AHP-QFD model to transform user requirements into functional requirements, mapping them to design parameters. Similarly, Li [29] *et al.* validated the effectiveness of the AHP-QFD model in managing user requirements (UR) and design requirements (DR). Yu *et al.* [30] proposed a method combining AHP with a grey prediction model to analyze potential online furniture buyers' purchasing behaviors. It also determined key factors influencing online furniture consumption. Mayyas [31] utilized the AHP-QFD model to identify optimal and alternative materials during the early design stages of automotive body-in-white, maximizing user satisfaction and minimizing production costs. Zhao *et al.* [32] developed an evaluation model combining the Kano model, AHP, and grey relational analysis to provide a design evaluation method for modular wooden storage furniture for children. Lyu *et al.* [33] employed QFD theory to quantify the weight of various factors by analyzing and ranking user group needs, thus reducing subjective bias and supporting the development phase of open-office wooden desks. Kürüm *et al.* [34] suggested modular adjustments and optimization of the AHP-QFD method to select superior design criteria, ultimately improving design quality.

In summary, this study aims to comprehensively extract user needs for bamboo furniture through text mining. It also aims to refine the systematic analysis of bamboo furniture based on the AHP-QFD model. It also seeks to identify design elements that significantly impact bamboo furniture under users' multidimensional needs.

This study is structured into five sections. Section 1, "Introduction," presents the research background, literature review, research questions, and the proposed approach to addressing these questions. Section 2, "Methods and Background," introduces the overall research framework, SECI knowledge creation model, text mining, the AHP-QFD methodology. Section 3 details the research process. Section 4, "Results and Discussion," discusses the findings based on the data analysis. Finally, Section 5, "Conclusions," summarizes the key findings, outlines the study's limitations, and provides recommendations for future research.

II. MATERIALS AND BACKGROUND

A. RESEARCH FRAMEWORK

This study adopts the SECI model of knowledge management innovation, proposed by Japanese scholars [35]. This model focuses on the dynamic transformation of knowledge in activities such as product development and improvement. The core of the SECI model lies in the interaction between tacit and explicit knowledge, achieved through four stages: Socialization, Externalization, Combination, and Internalization. These stages facilitate knowledge integration and application [36]. In this research, the SECI model provides theoretical support for the research process. Unstructured user data is gradually extracted and transformed through text mining, eventually forming engineering data suitable for QFD analysis. This process not only helps designers and engineers better understand user needs but also provides a solid foundation for identifying bamboo furniture design elements. The method proposed in this study is divided into three steps, each corresponding to a stage of the SECI model's transformation process:

1) Socialization:
Collecting the Voice of the User (VOC), which involves gathering online user review data through web scraping tools and consolidating scattered user feedback into foundational research data. At this stage, text mining techniques are used to uncover potential tacit knowledge within the review data, providing the basis for subsequent analysis.

2) Externalization:
By classifying and summarizing text mining results, tacit knowledge is converted into explicit knowledge. This stage creates an AHP user needs table, extract the key elements of bamboo furniture user needs. This table lays the groundwork for further design characteristics analysis.

3) Combination:
By integrating the user needs table and design characteristics analysis, bamboo furniture engineering characteristics are identified. A QFD matrix model is constructed. During this process, explicit knowledge is further internalized into actionable strategies and methods for the design team. This facilitates knowledge conversion into practice.

The overall process of the above method is illustrated in Figure 1, clearly demonstrating the specific pathway from user data collection to QFD analysis.

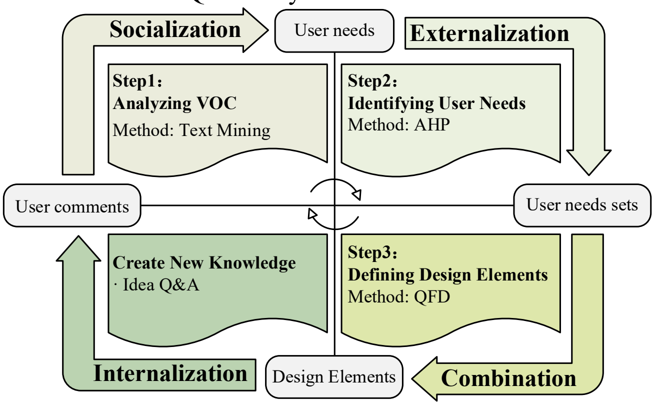

FIGURE 1. **Overall graphical framework. (adapted from [37])**

B. TEXT MINING

Text mining is a method of inductive analysis and quantitative research that objectively reveals hidden information behind data [38]. Mining online consumer reviews offers the advantages of large data volumes and multidimensional analysis, providing a basis for decision-making and driving product improvements [39]. However, traditional text mining methods, such as frequent word analysis or LDA models, typically focus on surface word frequency. They fail to capture contextual semantic relationships and latent themes between words. This limitation becomes particularly evident when dealing with complex, diverse, flexible, and semantically rich review data.

To address this problem, this study employs the Bidirectional Encoder Representations from Transformers Topic Model (BERtopic model) to more effectively extract latent themes and user needs from reviews. Based on the BERT pre-trained model [40], BERtopic leverages deep semantic embeddings and c-TF-IDF techniques to identify potential topics. It reveals contextual relationships between words, generates interpretable topic labels, and supports dynamic updates to adapt to data changes. This makes it especially suitable for analyzing diverse Chinese review data and identifying user needs at various levels. This guides the extraction of design elements.

The study uses the web scraping tool "Octoparse" to extract user review data. Since review text is natural language, it requires preprocessing before further analysis. To ensure objectivity in online review analysis, data from different products is cleaned uniformly. The cleaning process includes removing stopwords, stemming, and label replacement. Unlike English texts, where words are segmented by spaces, Chinese text segmentation requires statistical analysis based on a standard corpus [41].

BERtopic is widely used in text topic extraction, with studies applying it to identify research hotspots and their evolution in academic fields through structured literature [42]–[43]. The algorithm consists of three stages: constructing a document similarity matrix using a pre-trained transformer, reducing dimensions with Uniform Manifold Approximation and Projection (UMAP), and clustering documents with Hierarchical Density-Based Spatial Clustering of Applications with Noise (HDBSCAN) to generate topics. This method enables continuous topic modeling and reveals topic distributions through an interactive distance map, enhancing text analysis flexibility. Compared to traditional methods, BERtopic's semantic capture and model update features make it ideal for user review analysis.

Ultimately, these results will be integrated into the AHP hierarchy to build a multi-objective decision model, thereby improving the reliability and scientific nature of the decision-making process. As shown in Figure 2, this process clearly illustrates the pathway from text mining to AHP conversion.

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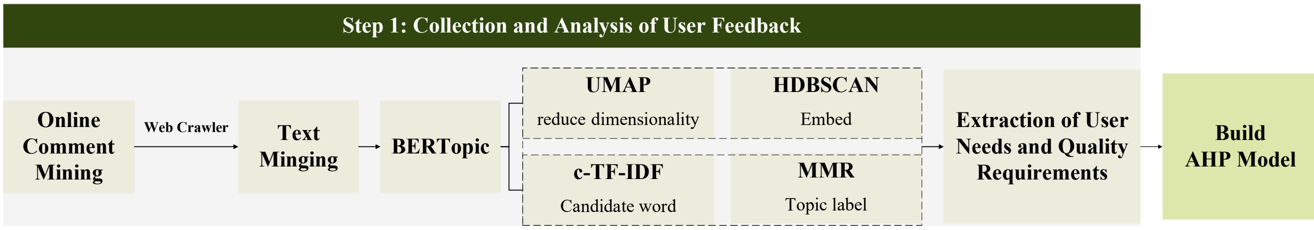

FIGURE 2. Text mining to AHP conversion flow.

C. AHP-QFD MODEL

1) AHP MODEL

The Analytic Hierarchy Process (AHP), proposed by Saaty [44], is a well-established method for addressing complex problems, particularly those involving hierarchical and interrelated evaluation criteria that are difficult to quantify. AHP plays a significant role in modern scientific research [45]–[47]. The method decomposes decision elements into objectives, criteria, alternatives, and other levels for both qualitative and quantitative analysis, offering advantages of systematization, flexibility, and simplicity. The AHP process, shown in Step 2 of Figure 3, generally involves the following four steps:

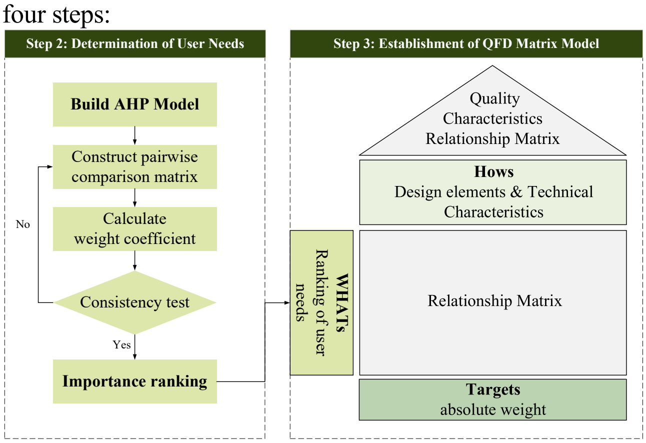

FIGURE 3. Framework for converting AHP model to QFD model.

1) Constructing a hierarchical analysis model for user needs [48]: Based on user needs extracted through text mining analysis, this study constructs a hierarchical analysis model. The top level represents the goal of selecting bamboo furniture that satisfies users, the second level includes key factors, whereas the bottom level encompasses specific design elements related to these factors.
2) Establishing judgement matrices for all levels: A judgement matrix is constructed for each level of the hierarchy, where matrix elements represent the relative importance derived from pairwise comparisons. A 1-9 scale and its reciprocal quantification method are used for comparisons (see Table 1). Pairwise comparison data for each element within a category are obtained from questionnaire data. Comparisons are made only within the criterion and sub-criterion layers, focusing on the relative importance of elements at the same level under the higher-level criteria.

TABLE I
FUNDAMENTAL SCALE OF AHP.

No.	Original Information
1	Elements i and j are equally important
3	Elements i is slightly more important than element j
5	Elements i is much more important than element j
7	Elements i is proved to be more important than element j
9	Elements i is absolutely more important than element j
2,4,6,8	Middle values
Reciprocal	If the importance ratio between factor i and factor j is a_{ij} , then the importance ratio between factor j and factor i is $a_{ij} = 1/a_{ij}$

Based on these instructions, criteria and rankings are converted into matrix A, as shown in (1). The construction of the judgment matrix is as follows:

$$A = (a_{ij})_{n\times n} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

3) Weight calculation after constructing the judgement matrix: The first step is to normalize each value in the matrix A:

$$b_{ij} = \frac{a_{ij}}{\sum_{i=a}^{n} a_{ij}} (i = 1, 2, \ldots, n) \quad (2)$$

After obtaining the matrix as in (2), sum each row of the resulting matrix, as shown in (3):

$$\overline{c_i} = \sum_{j=1}^{n} b_{ij} (i = 1, 2, \ldots, n) \quad (3)$$

Calculate the weights of each criterion to obtain the weight vector, where the subjective weight of each criterion is given by (4):

$$\omega_i^1 = \frac{\overline{c_i}}{\sum_{i=1}^{n} \overline{c_i}} (i = 1, 2, \ldots, n) \quad (4)$$

4) Consistency check: Since the AHP method relies on experts or decision-makers' judgments, which may inherently contain some inconsistency, a consistency check is required to ensure the rationality of the judgment matrix. The check is performed using the following formula:

$$CR = \frac{CI}{RI} < 0.1 \quad (5)$$

In the formula, Consistency Ratio (*CR)* is the consistency ratio of the judgment matrix; Consistency Index (*CI)* is the consistency index of the judgment matrix, $\lambda_{\max}$ is the maximum eigenvalue of the judgment matrix, and n is the order of the matrix. The *CI* is given by the following formula:

$$Consistency\ Index(CI) = \frac{\lambda_{\max} - n}{n - 1} \quad (6)$$

Random Consistency Index (*RI)* is the average random consistency index of the judgment matrix. The values of *RI* for judgment matrices of order 1 to 9 are shown in Table 2. The consistency ratio *CR* is the ratio between the consistency index *CI* and the random consistency index RI. This index is derived from extensive simulation experiments and varies based on the matrix order. If $CR < 0.1$ [48], the judgment matrix shows consistency, and the weights are valid. If $CR > 0.1$, the judgment matrix needs to be adjusted and recalculated until it meets the consistency condition.

TABLE II
RANDOM CONSISTENCY INDEX VALUES.

Matrix size	1	2	3	4	5	6	7	8	9	10
Random index	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49

AHP normalized weights are directly used as importance weights for user requirements in the "left wall" of the QFD. These weights represent the priority of each user requirement and serve as the basis for assigning weights to subsequent design characteristics.

2) QFD MODEL

The Quality Function Deployment (QFD) system originated in Japan in the late 1960s and early 1970s [49]. In QFD, user requirements are converted into technical specifications by using the "House of Quality" (HOQ) method, which demonstrates the relationship between user needs (referred to as "WHATs") and technical characteristics (referred to as "HOWs") [50]. The core concept of QFD is user-centered, utilizing the "House of Quality" (HOQ) matrix to consider user requirements (i.e., the "Voice of the User") and incorporate them into the engineering characteristics of a product or service [51]. This approach helps designers develop new products or optimize existing ones. The basic form of QFD, the HOQ, is shown in Step 3 of Figure 3.

The weight results obtained from AHP are integrated into the "WHATs" section of the QFD matrix, establishing a mapping relationship between user needs and bamboo furniture engineering characteristics. Based on the absolute and relative weights of the technical characteristics and design elements of bamboo furniture, the calculated values for the basement of the House of Quality (Target) serve as the objective of this study, as detailed in (7) – (8).

$$W_j = \sum_{i=1}^{n} d_i \times r_{ij} (i,\ j = 1, 2, \ldots, n) \quad (7)$$

In these equations, W_j denotes the weight of the j^{th} technical requirement, whereas *di* represents the importance of the i^{th} user requirement. The coefficient r^{ij} indicates the relationship between the i^{th} user requirement and the j^{th} technical requirement, which can be derived from the "relationship matrix" in the House of Quality (HOQ) diagram. The relative weight is then calculated using (8), The term Z_j refers to the relative weight (level of importance) of the j^{th} technical requirement."

$$Z_j = W_j / \sum_{k=1}^{m} W_k \quad (8)$$

By calculating the relative weights Z_j of all technical characteristics *j*, the technical characteristics can be ranked according to their importance, thereby providing a clear prioritization for product design.

III. RESEARCH PROCESS

A. STEP1: COLLECTION AND ANALYSIS OF USER FEEDBACK

Step 1 involves two stages: (1) collecting the Voice of the User (VOC) and processing the information, and (2) conducting preliminary analyses of the information. This step corresponds to the Socialization phase of the SECI model, wherein tacit knowledge is consolidated through information aggregation.

1) COLLECTION AND PROCESSING OF USER FEEDBACK INFORMATION

To ensure that the online reviews analyzed represent a diverse user group, we selected JD.com as the data source. As the second-largest e-commerce platform in China, JD.com covers a wide range of age, gender, regional, and consumer groups, particularly young and middle-aged users, with significant distribution across different cities and genders. Therefore, it provides diverse and highly representative bamboo furniture user review data.

To ensure the objectivity and diversity of the data, this study employed a combined approach of manual collection and the web scraping software "Octoparse " for data acquisition, a web crawler program. To analyze the results, we selected 22 of the most popular products ranked by combined sales volume and number of reviews under the keyword "bamboo furniture."

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The product categories include beds, clothing racks, bookshelves, cabinets, desks, sofas, chairs, benches, and coffee tables, totaling nine categories. In total, 11,481 comments were collected on May 14, 2024.

For the sake of ensuring the accuracy of the research results and preventing meaningless data from influencing the findings, all comments collected were subjected to a rigorous screening process. Specifically, four categories of comments were targeted for exclusion or modification:

1) Removal of directly copied or duplicate comments.
2) Exclusion of system-generated default comments such as "This user did not provide any review."
3) Deletion of comments irrelevant to the product or lacking clear meaning, such as "just to fill in the word count."
4) Appropriate modifications, such as changing "good good" to "good" or converting traditional Chinese characters to simplified Chinese characters.

Following this screening process, 11,207 valid comments were retained for analysis.

2) TEXT MINING OF USER COMMENTS

This study employs the BERtopic topic model for text mining. BERtopic offers semantic clustering and topic visualization. The 11,207 textual data points collected using the Octoparse 8.0 tool were processed, with text embeddings generated using the Sentence Transformer model, all-MiniLM-L6-v2. As a lightweight multilingual model, it is suitable for topic modeling tasks. In BERtopic's topic modeling process, keywords for each topic were extracted from topic_model.get_topics, resulting in 20 user demand themes. These similar themes were then merged into 12 topics, retaining the top five c-TF-IDF keywords for each theme.

Based on the 12 user demand themes extracted from BERtopic and supplemented with literature analysis, certain terms were classified into the AHP criteria layer. During the analysis, common evaluation standards for the furniture industry were identified, such as quality, price, design and appearance, brand, and after-sales service. These standards are widely applicable across different furniture sectors and significantly influence user choices. By recognizing these common standards and considering the characteristics of the bamboo furniture industry, the focus areas for bamboo furniture were identified. These areas are shown in Table 3. This analysis not only helped refine the five key AHP criteria layers—Aesthetic, Usability, Comfort, Safety, and Economic—but also provided theoretical support for the subsequent development of sub-criteria layers.

TABLE III
CLASSIFICATION OF USER NEEDS INTO AHP CRITERIA USING BERTOPIC.

User Needs Topic	AHP Criteria Layer	Explanation
Topic6_Good Value_Attractive_Elegant	Aesthetic	Reflection of design and aesthetic needs
Topic7_Bamboo_Material Nan Bamboo		Related to the natural beauty and aesthetics of bamboo
Topic3_Item_Good_Received	Usability	Feedback related to satisfaction and ease of use
Topic4_Table_Chair_Shoes		Involves furniture functionality and use
Topic10_Height_Adjustable_High Quality		Functional needs involving adjustable features and high standards
Topic1_Solid Wood_Wood_No	Comfort	Suitable for bamboo furniture materials, compatible with other materials
Topic9_Space_Footprint_Convenient		Consideration of how the footprint affects user comfort
Topic0_Good_Quality_Suitable		Quality-related needs impacting user comfort
Topic2_Installation_Convenient_Good	Safety	Evaluation of installation-related functions
Topic8_Smooth_Surface_Patronage		Emphasizes smooth surface to ensure safe use
Topic5_Patience_User Service_Reassuring	Economic	Good brand platform service quality directly impacts purchase decisions
Topic11_Good_Quality_Fast		Price and service delivery speed affect economic needs

After extracting latent themes and trends from the bamboo furniture review data using the BERtopic topic clustering method, we visualized the top five feature words under each of the 12 themes. A bar chart was used to present the weight and contribution of keywords in each theme, as shown in Figure 4. These visual results provide insights into bamboo furniture's potential needs and concerns. The keywords with higher weights in each theme reflect the specific needs users focus on during bamboo furniture purchasing.

To effectively transform the user need themes and related keywords from the BERTopic model analysis of bamboo furniture into the sub-criterion layer of the AHP model, this study combines semantic clustering analysis, literature review, and expert consultation to ensure the scientific rigor and rationality of the process.

Based on the 12 user need themes and their keywords extracted from the BERTopic model, we initially screened and refined the core demand features, whereas eliminating irrelevant or duplicate keywords (such as "JD" for Jingdong). These keywords not only reflect users' explicit demands regarding bamboo furniture but also reveal latent needs. By integrating general evaluation standards from the furniture industry (such as quality, price, design style) with the specific characteristics of the bamboo furniture industry, we further categorized and mapped the keywords. For instance, the term "installation" has two meanings: first, "installation safety" is classified under "structural safety"; second, "easy installation" is classified under "ease of use." Additionally, keywords like "good quality and affordable" are categorized under "cost-effectiveness," reflecting the user's comprehensive consideration of both economic and usability factors. This categorization method comprehensively covers the semantic features of keywords whereas highlighting user needs.

To verify the accuracy and reliability of the classification, a panel of eight industry experts from the bamboo furniture design, user experience, marketing, quality management, and product engineering fields was invited. The expert group,

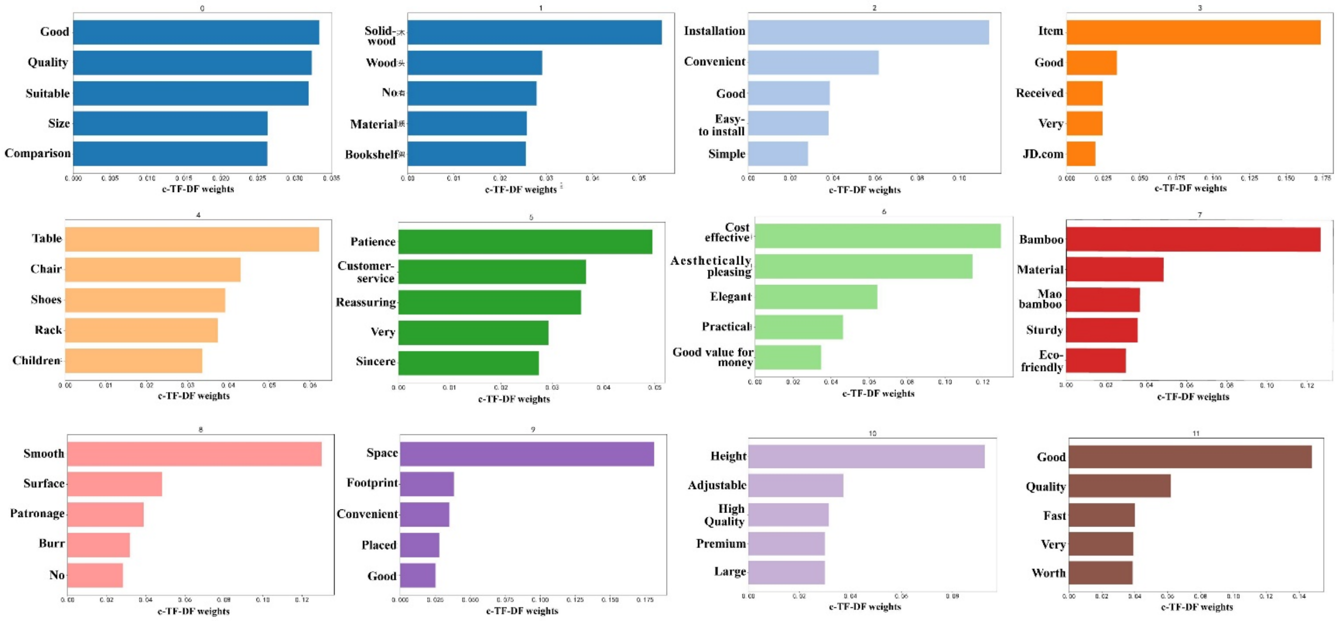

FIGURE 4. User demand themes and related demand keywords (Notes: All the words (vocabularies) in the figure are translated from Chinese).

drawing on practical experience and user behavior analysis, conducted in-depth discussions and revisions on the matching relationship between keywords and the AHP criteria and sub-criteria layers. For example, experts pointed out that keywords like "smooth," "surface," "shine," and "burr" emphasize the smoothness and tactile experience of the furniture surface, which should be classified under the "bamboo material treatment" sub-criterion layer, whereas "solid wood" and "wood" are more appropriately classified under the "material matching" sub-criterion layer. The introduction of expert feedback further improved the accuracy and applicability of classification results.

Ultimately, combining the outputs from the BERTopic model, literature research, and expert opinions, this study confirmed the AHP criteria layer (aesthetic, usability, comfort, safety, and economic) and its corresponding 13 sub-criteria layers, which include styling, functionality, material matching, space adaptability, structural safety, ease of use, and cost-effectiveness, among others. This classification process laid a solid foundation for subsequent AHP modeling and calculation. It provided scientific theoretical support and practical guidance for user-centered bamboo furniture design.

B. STEP2: DETERMINATION OF USER NEEDS

Step2 involves the detailed analysis of the data and information from Step 1. It also involves the creation of an AHP user requirements table to better inform bamboo furniture user needs. This process represents the transformation of tacit knowledge into explicit knowledge, known as the "externalization of user language."

1) EXTERNALIZATION OF USER NEEDS

To provide a clearer presentation of the AHP model's structure, we first integrated the criteria and sub-criteria layers derived from the BERTopic analysis into the AHP model. Hierarchical relationships were then visualized to facilitate understanding. Figure 5 illustrates the model structure, detailing the hierarchical division from the AHP criteria layer to the sub-criteria layer. This visualization aids in intuitively comprehending the prioritization of design elements and their interrelationships. The visual representation enhances the clarity of the model's logical framework and provides a convenient foundation for subsequent calculations.

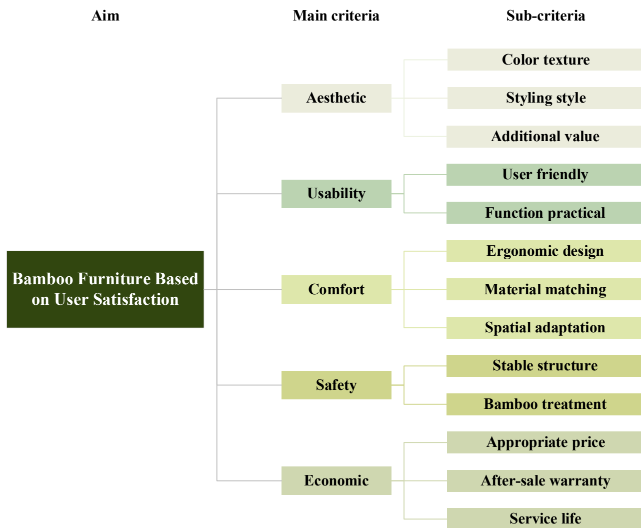

FIGURE 5. Target user satisfaction hierarchy analysis model.

2) DEVELOPMENT OF AHP USER NEEDS TABLE

After constructing the AHP model, the study progressed to the calculation phase. At this stage, judgment matrices were developed to quantify the relative importance between criteria layers and sub-criteria layers. A common approach involves using the eigenvalue method to determine the maximum

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eigenvalue of the judgment matrix and conducting a consistency check to ensure the matrix's validity. This process enabled the calculation of weights for each criterion and sub-criterion, followed by their ranking to establish the priority of various design elements. The results provide a theoretical foundation for bamboo furniture design, supporting design teams in making more targeted decisions during product development.

To establish a comprehensive performance evaluation index weighting survey for bamboo furniture at the main criteria and sub-criteria layers, a scoring scale ranging from 1 to 9 was utilized. To ensure the objectivity of the evaluation, 120 users who had purchased or used bamboo furniture were invited to participate in a questionnaire survey and provide ratings. A total of 108 valid responses were collected after screening. The survey data revealed a balanced gender distribution among participants, with ages ranging from 18 to over 50 years old. The average living space per person varied from less than 30㎡ to over 50㎡, demonstrating a relatively even distribution across gender, age, and living space. This diversity ensures bamboo furniture's broad applicability to real-world usage scenarios.

Using pairwise comparison, the relative importance of each evaluation criterion was assessed and quantified, providing a weight analysis to guide product design. Using SPSS software for data calculations, all values were found to be below 0.1, and the KMO coefficient of questionnaire validity analysis was 0.88, indicating that the consistency test requirements were met and validating the weights. The results (Table 4) also show the weights assigned to the third-level user requirements, as derived from the AHP and subsequent calculations. This table can serve as the left wall, or "WHATs" in the HOQ based on the AHP and subsequent calculations.

TABLE Ⅳ
WEIGHTS OF BAMBOO FURNITURE BASED ON USER SATISFACTION.

Main criteria	Global weights	Sub-criteria	Global weights	Sibling weights	Consistency test
B1 Aesthetic	0.0493	C1 Color texture	0.0095	0.19	3.0092
		C2 Styling style	0.0346	0.70	
		C3 Additional value	0.0052	0.11	
B2 Usability	0.1759	C4 User friendly	0.0879	0.50	0
		C5 Function practical	0.0879	0.50	
B3 Comfort	0.3472	C6 Ergonomic design	0.0868	0.25	0
		C7 Material matching	0.0868	0.25	
		C8 Spatial adaptation	0.1736	0.50	
B4 Safety	0.3472	C9 Stable structure	0.0868	0.25	0
		C10 Bamboo treatment	0.2604	0.75	
B5 Economic	0.0804	C11 Appropriate price	0.0201	0.25	0
		C12 After-sale warranty	0.0201	0.25	
		C13 Service life	0.0402	0.50	

C. STEP3: ESTABLISHMENT OF QFD MATRIX MODEL

Step 3 can be divided into two stages: First, using literature research and expert consultation, an engineering characteristics quality table for bamboo furniture is developed based on the user requirements list from Step 2. This table includes two core sections: design elements and technical characteristics, and it aims to provide the key quality attributes (i.e., "HOWs") for constructing the House of Quality (HOQ). Second, the information from Step 1 and Step 2 is integrated to construct the HOQ model. This model is used to systematically display and relate bamboo furniture quality characteristics. This process represents the Combination stage of the SECI model, where dispersed explicit knowledge elements are integrated into a coherent explicit knowledge system.

1) IDENTIFICATION AND CLARIFICATION OF ENGINEERING CHARACTERISTICS

This study conducted a comprehensive analysis of the design requirements and technical characteristics of bamboo furniture based on user needs and product features. To minimize subjective bias, a carefully selected panel of 17 experts was formed. Each expert evaluated independently to avoid mutual influence. The panel members were drawn from various key sectors within the bamboo furniture industry, bringing extensive professional experience and deep expertise. The experts' titles included scholars, lecturers, associate professors, and general managers. Specifically, five experts were from bamboo furniture enterprises, eight were scholars specializing in furniture and bamboo furniture research, and the remaining four were experts in panel furniture research. An overview of the expert classifications and their evaluation tasks can be found in Table 5.

TABLE Ⅴ
INFORMATION ON BAMBOO FURNITURE INDUSTRY EXPERTS.

Personnel classification	Brief introduction	Qty	Evaluation task
Bamboo furniture company staff	Corporate managers, production personnel, and after-sales staff with relevant professional background and skills.	5	C1-C13
Furniture researchers	Professionals specializing in furniture research, design, and manufacturing optimization.	4	C1-C9, C12, C13
Bamboo furniture researchers	Professionals specializing in bamboo material research, design, and manufacturing process optimization.	4	C1-C13
Panel Furniture Researchers	Professionals specializing in the evaluation of sheet material properties, furniture manufacturing, and engineering technology research.	4	C1, C2, C4-C10, C13

Following the steps described above, a quality characteristics table was created by systematically categorizing existing literature reviews, industry standards, and expert consultations. By translating user requirements into relevant design elements, technical specifications, and manufacturing requirements essential for the production process, QFD enables designers to better meet user expectations by designing to their needs [52]. Table 6 summarizes the quality characteristics derived from these inputs, which are further delineated in design elements and technical specifications. The quality characteristics table forms the ceiling of the House of Quality (HOQ), closely related to the requirements of the end users.

TABLE Ⅵ
EXPLANATION OF TECHNICAL CHARACTERISTICS AND DESIGN ELEMENTS OF BAMBOO FURNITURE.

Sub-criteria	Quality Characteristics	Design elements	Technical characteristics
C1	D1 Coloring matches Bamboo natural color	Natural bamboo color; Kansei engineering; CMF (Color, Material, Finish) design trends.	Meeting the aesthetic and surface physicochemical performance requirements of bamboo and engineered wood components.
C2	D2 Unified Bamboo material, joints and texture	Emotional design; point, line, surface, solid.	The design is based on the elements of points, lines, and surfaces, supplemented by textures for interpretation.
	D3 Well-processed of skeleton combination and surface layer	Detachable design; visual design.	Make sure the framework and surface layer are compatible in terms of their connection structure and support structure.
C3	D4 High cultural and ornamental value	Cultural attributes, imagery, historical and cultural elements of bamboo; modern design language.	Decorative techniques for bamboo furniture can include bamboo weaving, carving, and mortise-and-tenon joinery.
C4	D5 Easy to assemble and lightweight	Modular design; lightweight design.	Design of modular and interlocking bamboo furniture parts based on dynamic characteristics; optimization of adjustability such as telescopic and rotational features.
C5	D6 Easy to operate and practical	Modular design; detachable design; user-friendly design.	Simplify and optimize the structure.
C6	D7 Fit Ergonomic design	People-oriented design.	Design based on human physiology, psychology, and usage behavior; consider the form, dimensions, and functionality of bamboo furniture.
C7	D8 Material and process matching	Principle of contrast and balance; functional design.	The craftsmanship of bamboo furniture can be enhanced by incorporating other materials, such as wood, rattan, metal, or glass.
C8	D9 Size and space adaptation	Multifunctional design; integrated design; interior design.	Consider size versatility; optimize space utilization of bamboo furniture by incorporating foldable, shared, movable, and adjustable structures.
C9	D10 Bamboo components are structurally stable	Product system design; modular design.	Consider bamboo material selection, processing methods, structural design, and connection techniques; ensure that bamboo components are free of fractures and connections are secure.
	D11 Assemble structure of parts are solid	Integrated structural product design; product system design; collaborative design.	Consider the precise processing and assembly standards for metal parts, hardware, plastic components, and upholstered parts of bamboo furniture; conduct tests for shaking, pulling, pressing, opening and closing, and base stability.
C10	D12 Bamboo three-proof treatment meets standards	Safety design; furniture design and manufacturing processes; material design.	Maintaining cleanliness in the processing environment and improving storage conditions are essential for bamboo furniture. Various methods can be utilized, including physical and chemical modification, sol-gel, encapsulation, boiling, and drying.
	D13 Bamboo cracking prevention and material properties	Structural design.	Analyze the physical and mechanical properties of bamboo from different parts; methods such as localized injection molding can be used to enhance mechanical performance. Enhance bamboo stability and crack resistance through techniques like heat treatment, fine woodworking, laminated structures, and the application of varnish and UV-blocking coatings.
C11	D14 Bamboo furniture is cost-effective	Sustainable design; modular design; functional design.	Analyze functionality and costs using value engineering evaluation systems and lean cost management, maximizing the value of products, systems, and services on an economic and technical level.
C12	D15 Brand quality after-sales service	Service design; user experience design.	Adhere to relevant certifications and standards for bamboo furniture manufacturing; offer return and exchange services through platforms and

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			brands; provide repair and maintenance services; establish a rapid response mechanism.
C13	D16 Long service life of Bamboo furniture	Recyclable design; sustainable design; ecological design.	Prepare a comprehensive, systematic plan for the entire lifecycle of bamboo furniture during the initial design phase, taking into account the material, structural, production, and transportation requirements, as well as the needs of users and recyclers.

2) CONSTRUCTION OF THE HOUSE OF QUALITY MODEL

After completing the user needs table and the quality table for engineering characteristics, this study further integrates explicit knowledge into QFD. In this process, the user needs table ("WHATs," derived from the second step of analysis) is incorporated into the "left wall" of the House of Quality (HOQ) to identify user requirements for purchasing or utilizing bamboo furniture. The HOQ core matrix illustrates the relationships between user needs, technical characteristics, and design elements. These relationships are quantified using a symbol-based scoring system. Specifically, the "left wall" represents user needs, whereas the "ceiling" corresponds to engineering characteristics and design requirements. The degree of correlation between these elements is quantified using the American evaluation system [53]: '◎' denotes strong correlation (score of 9), '○' indicates moderate correlation (score of 3), '△' represents weak correlation (score of 1), and a blank denotes no correlation.

The scoring process was independently conducted by 17 experts specializing in bamboo furniture design, material research, and user experience. This ensured objectivity and scientific validity of the results. Figure 7 presents evaluation outcomes Within the HOQ model, 13 user needs items (from the "left wall") are ranked according to their importance weights. Additionally, the "basement" section provides relative and absolute weights, along with rankings of 16 engineering characteristics. These findings offer significant insights into bamboo furniture design practices, particularly innovation and design optimization.

IV. RESULTS AND DISCUSSION

A. RESULTS

Previous studies on bamboo furniture focused on the material and environmental sciences, with relatively small attention given to user and enterprise needs. This study employs the AHP-QFD model to clearly define the comprehensive weights and rankings of bamboo furniture design elements based on user satisfaction.

According to the calculation results of the AHP criteria layer (Table 5), the weight ranking for bamboo furniture design is as follows: Safety (B4) > Comfort (B3) > Usability (B2) > Economic (B5) > Aesthetic (B1). Safety, comfort, and usability are the most critical design criteria, receiving higher priority. In contrast, economic and aesthetic rank lower, indicating that users prioritize fundamental functionalities, such as safety and comfort, over aspects like aesthetic and cost-effectiveness.

According to Table 4, B4 Safety = B3 Comfort > B2 Usability > B5 Economic > B1 Aesthetic. This indicates that bamboo furniture prioritizes safety, comfort, and usability. The expanded and subdivided criteria reveal some changes in sub-criteria ranking (Fig. 5). Safety's bamboo treatment (C10) and comfort's spatial adaptation (C8) have the highest weights, with a total share of 43.4%. This is followed by usability's User friendly (C4) and Functional practical (C5).

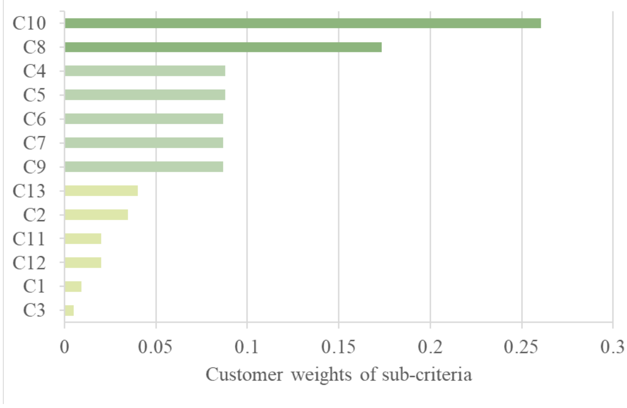

FIGURE 6. User weights of sub-criteria histogram.

Based on the weight ranking of the AHP sub-criteria layer (see Figure 6), the sub-criteria can be categorized into three groups:

- First group: Sub-criteria with weights greater than 0.15, accounting for 43.4% of the total weight. This includes "Bamboo treatment (C10)" from Safety and "Spatial adaptation (C8)" from Comfort.
- Second group: Sub-criteria with weights between 0.05 and 0.1, which include "User friendly (C4)" and "Function practical (C5)" from Usability, "Ergonomic design (C6)" and "Material matching (C7)" from Comfort, and "Stable structure (C9)" from Safety.
- Third group: Sub-criteria with weights between 0 and 0.05, which are related to Aesthetic and Economic factors, given lower priority.

The AHP analysis of the criteria and sub-criteria layers highlights that Safety, Comfort, and Usability are the most highly valued demands in bamboo furniture design, whereas Economy and Aesthetic hold lower priority.

Based on the comprehensive ranking analysis in Figure 8, all design elements are categorized into three groups:

Legend: ◎ Strong Relationship_9; ○ Moderate Relationship_3; ▲ Weak Relationship_1

Row	Customer Weights	Customer Requirements (a.k.a. "WHATs") / Engineering Metrice (a.k.a. "HOWs")	D1 Coloring matches Bamboo natural color	D2 Unified Bamboo material,joints and texture	D3 Well-processed of skeleton combination and surface layer	D4 High cultural and ornamental value	D5 Easy to assemble and lightweight	D6 Easy to operate and practical	D7 Fit Ergonomic design	D8 Material and process matching	D9 Size and space adaptation	D10 Bamboo components are structurallAy stable	D11 Assemble structure of parts are solid	D12 Bamboo three-proof treatment meets standards	D13 Bamboo cracking prevention and material properties	D14 Bamboo furniture is cost-effective	D15 Brand quality after-sales service	D16 Long service life of Bamboo furniture
1	0.0095	C1 Color texture	◎		▲									○	○			
2	0.0346	C2 Styling style	○	○			▲		○	○	○					○		
3	0.0052	C3 Additional value	▲	○	○					○						○		
4	0.0879	C4 User friendly			○								▲			○		○
5	0.0879	C5 Function practical																○
6	0.0868	C6 Ergonomic design			○		○			▲	▲							
7	0.0868	C7 Material matching			○		○	○				○			▲	○		○
8	0.1736	C8 Spatial adaptation			○			▲	○									
9	0.0868	C9 Stable structure			○				○	○						○		
10	0.2604	C10 Bamboo treatment		○										▲				
11	0.0201	C11 Appropriate price				○	○	○	○					○			○	▲
12	0.0201	C12 After-sale warranty										○				○		
13	0.0402	C13 Service life		○			○	○	▲	○								
Weight / Importance			3.3193	1.8879	4.2458	0.504	3.0997	3.7595	3.3489	3.7975	2.5441	5.3895	4.5465	1.6731	3.7828	4.6416	0.603	4.4754
Relative Weight (%)			6.4304	3.6574	8.2253	0.9764	6.005	7.2832	6.4878	7.3568	4.9286	10.441	8.8079	3.2413	7.3284	8.9921	1.1682	8.6701
Improtance ranking			10	13	5	16	11	8	9	6	12	1	3	14	7	2	15	4

FIGURE 7. Customer weights of sub-criteria histogram.

- First group (Weight: 0.10–0.12): This includes "Bamboo components are structurally stable" (D10) in Bamboo treatment, "Long service life of bamboo furniture" (D14) in Service life, "Assembled structure of parts is solid" (D11) in Stable structure, "Long service life of bamboo furniture" (D16), and "Well-processed skeleton combination and surface layer" (D3) in Styling style. These elements indicate that users place high importance on safety, durability, and cost-effectiveness.
- Second group (Weight: 0.04–0.08): This includes "Material and process matching" (D8), "Bamboo crack prevention and material properties" (D13), "Easy to operate and practical" (D6) in User friendly, "Fit ergonomic design" (D7) in Ergonomic design, "Coloring matches bamboo's natural color" (D1) in Color texture, "Easy to assemble and lightweight" (D5) in User friendly, and "Size and space adaptation" (D9) in Spatial adaptation. These factors, whereas slightly less important, still significantly enhance user experience and comfort.
- Third group (Weight: 0–0.04): This includes "Unified bamboo material, joints, and texture" (D2), "Bamboo three-proof treatment meets standards" (D12), "Brand quality after-sales service" (D15), and "High cultural and ornamental value" (D4). Although these factors have a lower weight, they still contribute to the overall competitiveness of the product.

The AHP-QFD comprehensive ranking analysis results suggest that safety is the core element in bamboo furniture design and holds the highest priority. This finding underscores that ensuring user safety is the primary task in bamboo furniture development. To further understand and optimize bamboo furniture safety performance, the subsequent sections will discuss design aspects and technical requirements related to safety. These sections will include innovations to improve stability, compressive strength, and long-term safety.

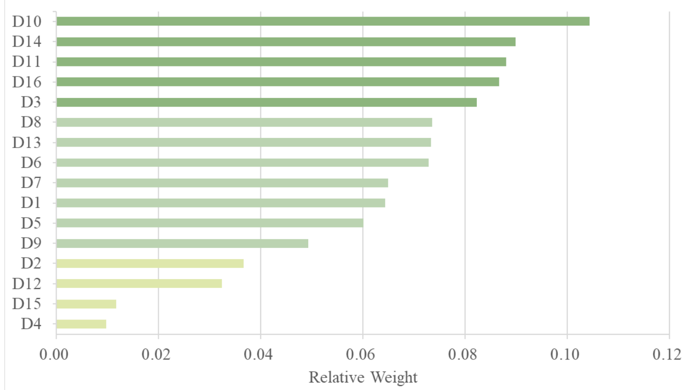

FIGURE 8. Relative weight histogram.

B. DISCUSSIONS

Safety is the cornerstone of bamboo furniture development, safeguarding consumer rights and contributing significantly to sustainable development. From structural, material, and design perspectives, bamboo furniture safety risks stemming from three primary problems: the connection between structures, chemical treatments, and design aspects. This process also represents the Internalization phase of the SECI model, where acquired explicit knowledge is internalized into tacit knowledge.

1) CONNECTION STRUCTURE OF BAMBOO FURNITURE

Bamboo furniture's structure is closely related to its external shape and safety, with bamboo's structure primarily influenced by bamboo jointing method. In response to this, this paper proposes recommendations for optimizing bamboo furniture jointing methods. On the one hand, the connection performance within the structural design can be improved, such as by designing laminated bamboo joints with enhanced ductility (Dauletbek and Li [54]) or by improving transverse connections to increase the load-bearing capacity of composite bamboo materials (Zhou *et al*. [55]). On the other hand, the use of connectors, load-bearing components, and wear-resistant parts made from other materials can enhance bamboo furniture's wear resistance and compressive strength. Due to the differences in structure and material properties between bamboo and wood, bamboo furniture joints can be structurally innovated to improve stability and functionality. For instance, He [56] proposed embedding metal fittings through injection molding in specific areas of bamboo furniture to enhance structural stability and introduce functional innovations.

Installation is a key aspect of the bamboo furniture connection structure, and there are two main installation methods: one involves factory-assembled units, which offer the advantages of speed and standardization, but may suffer from problems such as uneven hardware depth and loose components; the other involves user assembly, which allows for more detailed installation but may lead to assembly failures or even safety accidents due to lack of experience. Therefore, manufacturers must not only ensure that hardware quality meets the required standards but also simplify the installation process to enhance bamboo furniture safety. Bamboo furniture companies and platforms should respond promptly to user needs, strengthen user education, and establish a comprehensive installation service system. This will improve installation and acceptance quality.

2) CHEMICAL SAFETY OF BAMBOO FURNITURE

Currently, most bamboo furniture on the market contains various harmful substances, including formaldehyde, volatile organic compounds, heavy metals and their compounds, and preservatives. Raw materials directly determine the level of toxic substances. A major consumer complaint in recent years is furniture odors. The substance formaldehyde, in particular, is persistent and harmful. It is present in almost every stage of furniture production. It releases slowly and has a long duration, leading to high levels of emissions. According to Rybin *et al.* [57], harmful substances gradually decrease over time until they reach permissible levels. Manufacturers of furniture can take a number of measures to select materials for structural and auxiliary parts that meet the maximum permissible standards for releasing harmful substances into the air during the development stage.

3) DESIGN SAFETY OF BAMBOO FURNITURE

Bamboo furniture design aims to align the user and the furniture optimally. This alignment must not only meet the user's functional requirements but also achieve physiological and psychological harmony. This design philosophy aligns closely with user-centered design principles and safety considerations. Overall, safety design can be considered from ergonomics and information design.

Ergonomics is a critical factor influencing furniture design, significantly impacting user health [58]. Furniture design addresses ergonomic considerations at three levels: human dimensions, user movements, and sensory experience. First, human dimensions form the foundational basis for functional bamboo furniture design and can be categorized into static and dynamic dimensions. Static dimensions refer to body measurements, such as height, shoulder width, arm length, and leg length. Dynamic dimensions relate to user posture changes, such as movement range whereas standing, sitting, or lying down. Understanding these dimensions helps determine the best furniture sizes for users. Second, to meet bamboo furniture design sensory experience requirements, the focus should be on creating products that align with both the physiological and psychological functions of users. This remains a significant challenge in bamboo furniture design.

Additionally, information design plays a crucial role in bamboo furniture design, as it can both prevent potential hazards and influence user behavior. Considering the popularity of online platforms, labels and nameplates for bamboo furniture should clearly indicate the maximum load capacity. This is to minimize damage or accidents caused by overloading. During installation, clear instructions should be provided, such as warnings about sharp edges and recommendations for gloves. Instructions should be prominently displayed to prevent misuse. High-risk areas, such as those prone to impacts or involving moving parts, should be equipped with appropriate signage, impact-resistant stickers, and hole covers to reduce safety risks. Furthermore, it is essential to recognize that users' cognitive abilities may vary. Therefore, optimizing design elements such as color, graphics, text, form, and scale can enhance information comprehensibility.

V. CONCLUSIONS

As a vital part of the low-carbon industry and sustainable development, bamboo furniture faces challenges in accurately capturing user needs while avoiding homogenization with wooden furniture. Bamboo furniture design elements are crucial for market relevance and academic research. This study integrates text mining with the AHP-QFD method to extract key information from user reviews, using AHP to determine the weight of user needs and applying QFD to quantify these needs and convert them into design features. The resulting model aims to assign appropriate weights to various design elements, providing a scientific foundation for bamboo furniture innovation. This study contributes in three key areas:

1. It demonstrates that safety is central to bamboo furniture sustainability throughout its life cycle. Major safety risks arise from structural connections, chemicals, and design factors. By optimizing structural connections, selecting safe materials, and adhering to ergonomic and inclusive design principles, bamboo furniture's safety and user experience can be significantly improved.
2. The combination of text mining and the AHP-QFD model proves highly effective in capturing user needs and translating them into design elements. This approach is particularly beneficial for furniture design that prioritizes user experience and rapid iteration. As e-commerce platform competition intensifies, user reviews become a critical source of feedback. It is recommended that companies adopt this model early in the design phase to enhance R&D efficiency and market competitiveness.
3. Innovation in bamboo furniture design should focus not only on safety and comfort but also on sustainable materials and environmentally friendly production processes. Future research can explore how to integrate green design principles more effectively into the design process, improving bamboo furniture ecological sustainability.

Looking ahead, improvements in bamboo furniture's material properties and structural performance, such as enhanced pull-out and bending resistance, will further strengthen its safety. Additionally, bamboo furniture should ensure inclusivity, catering to diverse user groups, including the elderly, pregnant women, children, and people with disabilities. This will improve the overall user experience. Beyond safety, bamboo furniture's aesthetic appeal, leveraging its distinct texture and color, should also be emphasized to enhance its market competitiveness.

However, the methodology of this study has limitations, particularly regarding biases in online reviews. In addition, the subjectivity of expert input is assessed in the AHP and QFD methods. Future research could reduce subjectivity by incorporating primary user data, such as interviews, thereby improving the accuracy and applicability of the models.

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