Integrating Kansei Engineering with Hesitant Fuzzy Quality Function Deployment for Rosewood Furniture Design

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To enhance the scientific rigor of design decisions and develop new rosewood furniture that aligns with user emotions, this study integrates the strengths of the Hesitant Fuzzy Analytic Hierarchy Process (HFAHP) and Hesitant Fuzzy Quality Function Deployment (HFQFD) within the framework of Kansei Engineering (KE). This method accurately translates Consumer Requirements (CRs) into Engineering Characteristics (ECs). First, the KJ Method was used to screen and categorize Kansei words, create product sample images, and deconstruct the form of rosewood furniture using morphological analysis. Second, after collecting valid questionnaires using a 7-point Likert scale, Factor Analysis (FA) was employed to extract three key Kansei factors. Third, HFAHP was utilized to calculate the weights of the Kansei words. Fourth, HFQFD was applied to construct a hesitant fuzzy correlation matrix between CRs and ECs, determining the priority of design elements for rosewood furniture. Finally, using a square table as an example in the design practice, the optimal Scheme No. 9, which highly meets consumer emotional needs and features harmonious form combinations, was selected. This study enhances the emotional value of rosewood furniture, optimizes the design decision-making process, and improves contemporary consumer satisfaction.

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INTRODUCTION

Rosewood furniture denotes traditional Chinese furniture crafted from high-quality hardwoods such as *Pterocarpus erinaceus* Poir. and *Cassia siamea* Lam.. Since the Ming and Qing dynasties, rosewood furniture has sustained popularity, constituting an integral facet of the contemporary Chinese solid wood furniture market. The raw material for rosewood furniture, identified as “Hongmu” in Mandarin, possesses commendable attributes encompassing hardness, color, and texture, thereby enhancing its economic, practical, and aesthetic worth. Nevertheless, in the contemporary context, the product development process of rosewood furniture encounters specific challenges.

Investigations elucidate that the widespread adoption of semi-automated workshops in recent years has engendered a high degree of maturity and advancement in the functionality, structure, and manufacturing processes of rosewood furniture. Discernible differences in performance, quality, and materials among furniture products from various manufacturers have notably diminished. Concurrently, within the prevailing era of the aesthetic economy, the aesthetic qualities of commodities exert influence on consumer perceptions during both the transactional and utilization phases (Böhme 2003). Consumers are increasingly concerned with the psychological impact of a product's appearance (Demirbilek and Sener 2003). The explicit design features of a product directly influence the user's first impression (Norman 2004). A good appearance is a key determinant of a product's success in the market (Bloch 1995). Consequently, today, designers should pay more attention to the aesthetic impact of products (Lu and Hsiao 2022). The home furnishings industry increasingly prioritizes sensory experience design (Huang *et al*. 2023). However, the imperative for expeditious profitability by numerous rosewood furniture enterprises has resulted in a design decision-making process marked by a dearth of systematicity and precision. The subjective creativity of designers makes it challenging to accurately align the furniture's form with the emotional preferences of modern consumers, leading to issues of mismatched supply and demand and wasted resources.

In recent years, Kansei Engineering (KE) has gained widespread application in design as a systematic approach utilizing engineering techniques to analyze the intricate relationship between human emotions and product features. Prominent companies, such as Mazda, Toyota, Canon, and Samsung, have effectively integrated KE into the early stages of new product development, resulting in notable success in the market. The fundamental aim of KE is to convert user emotional needs into discernible product engineering characteristics, thereby facilitating design and development teams in the creation of innovative products closely aligned with consumer emotions. Consequently, this study seeks to employ the KE framework to systematize the design decision-making process of rosewood furniture. A systematic review of prior research uncovers certain deficiencies in existing KE methodologies. On the one hand, the correlation between CRs and ECs is key to KE's ability to transition from the user side to the design side. Specifically, the amalgamation of Cluster Analysis (CA) and T-test for correlating Kansei words with product samples is noted (Yang *et al*. 2023c). However, this methodology yields only a generalized directional correlation, lacking the establishment of a one-to-one correspondence between user requirements and design features. The resultant analysis is susceptible to interference from irrelevant design elements within the system. While Quantitative Theory Type I (QTT-I) (Hsiao *et al*. 2010) has been applied for correlating sensory semantics with design elements, its affiliation with multivariate linear regression analysis poses limitations, given that human subconscious thinking does not consistently adhere to linear characteristics (Nagamachi *et al*. 2006). The application of QTT-I to predict subjective human emotions may introduce biases in experimental outcomes, with the associated complex and time-consuming calculation processes. In response to these challenges, the Backpropagation Neural Network (BPNN) (Woo *et al*. 2022; Chen and Bian 2024) has been employed to construct a nonlinear mapping model. However, this method heavily depends on sample data, rendering it vulnerable to local minima and lacking a unified network selection method, potentially compromising result predictability. Notably, Fuzzy Quality Function Deployment (FQFD) (Kang and Nagasawa 2023; Wang and Yang 2023) has been proposed in recent years for mapping models between consumer requirements (CRs) and engineering characteristics (ECs). Despite offering user-centered advantages by incorporating triangular fuzzy numbers to align with the inherent fuzziness and non-linear thinking in decision-makers' evaluation processes, FQFD falls short in capturing hesitations in decision-making processes involving multiple experts. In contrast, Hesitant Fuzzy Quality Function Deployment (HFQFD) (Onar *et al*. 2016), as the latest extension of traditional QFD (Chen and Sun 2023) and fuzzy QFD, integrates the theory of Hesitant Fuzzy Sets (HFSs). Torra (2010) proposed HFSs due to the difficulty in determining the membership of elements, a challenge that arises from decision-makers' hesitation in identifying the correct value among possible options. Noteworthy for its comprehensive and meticulous depiction of decision-makers' hesitations, HFQFD mitigates information loss and enhances correlation accuracy and design quality in comparison to other methods. Consequently, this study opts for HFQFD to construct a hesitant fuzzy correlation matrix.

On the other hand, for the acquisition of precise consumer demands, certain scholars (Yang *et al*. 2023a) have combined the Analytic Hierarchy Process (AHP) with Factor Analysis (FA) to discern pivotal Kansei requirements. Notably, decision-makers exhibit a heightened inclination towards utilizing interval numbers over exact values in the evaluative process (Öztaysi *et al*. 2015). Addressing this proclivity, the Hesitant Fuzzy Analytic Hierarchy Process (HFAHP) (Kosamia *et al*. 2023) proves instrumental in navigating decision-making amidst uncertainty by furnishing hesitant fuzzy linguistic terms (HFLTs). However, a lack of literature is evident regarding the application of HFAHP within the realm of product design for the determination of demand indicator weights. This study integrates the aforementioned method with HFQFD, assimilating critical requirements and their weights derived from FA and HFAHP into the House of Quality (HOQ), thereby constituting an associative model delineating the nexus between CRs and ECs.

In summary, situated within the framework of KE, this investigation introduces an innovative integrated method model encompassing HFAHP and HFQFD, thereby improving the systematicity and precision in the design of rosewood furniture forms. Primarily, FA and HFAHP are employed to capture key Kansei factors and consequential CRs. Lastly, HFQFD is implemented to more accurately articulate CRs into ECs. This methodology facilitates designers in ascertaining optimal design schemes that closely adhere to consumer needs, thereby curtailing trial-and-error expenses and fortifying market competitiveness.

LITERATURE REVIEW

Rosewood Furniture

Rosewood furniture has enjoyed popularity in China since the mid to late Ming Dynasty, undergoing a gradual evolution into two predominant stylistic forms recognized as Ming-style and Qing-style. In the 21st century, New Chinese-style has emerged. Because of its many advantages in terms of appearance, structure, craftsmanship, materials, and cultural significance, rosewood furniture has sustained widespread favor among the Chinese populace over an extended duration. In the 20th century, a multitude of scholars engaged in research on rosewood furniture. However, the predominant focus was on theoretical analysis, with a deficiency in the incorporation of quantitative methodologies and outcomes reflecting innovative design. In the 1940s, German scholar Ecke (1991), through extensive data collection, conducted surveys and studies on the form, structure, and dimensions of traditional Chinese furniture. Kates *et al*. (1962) conducted a detailed analysis of over 100 pieces of traditional Chinese furniture. In the 1970s, Ellsworth (1971) studied numerous cases of high-quality hardwood furniture. By the 1980s, Wang (1989) initiated the first systematic study of Ming-style furniture in China, analyzing and appreciating the categories, shapes, and materials of many rosewood furniture pieces, sparking a domestic trend in researching traditional furniture. Pu (2012) conducted a systematic study on the history, categories, and artistic features of Chinese rosewood furniture, including furniture forms.

Kansei Engineering

Kansei Engineering (KE), initially introduced by Mitsuo Nagamachi (Nagamachi 1995) during the 1970s, integrates fundamental theories derived from the fields of psychology and engineering. It serves to capture and quantify user emotions, which are then translated into tangible design elements of products, ultimately enhancing consumer satisfaction (Nagamachi 2002). This theory found its early application within Japanese corporations, enabling them to optimize product development, minimize trial-and-error probabilities, and reduce costs. Furthermore, since the inception of Kansei Engineering, it has garnered significant attention from universities around the world, inspiring scholars to apply it in various domains such as transportation, everyday consumer goods, and creative cultural products. This includes innovative design endeavors in form, color, and material choices. For instance, Yang *et al*. (2023c) employed a combination of Factor Analysis, T-test, and Cluster Analysis to compare the perceptual attributes of fabrics dyed with tea leaves and tea stems.

In addition, certain scholars have engaged in discussions regarding the integration of KE with other theories or methodologies. For example, Liu *et al*. (2023) developed a crawler program to extract online product reviews and parameters. They computed the evaluation value of Kansei word pairs for various product samples and subsequently employed a BP Neural Network to train a mapping model, leading to an improvement in prediction accuracy. Shieh *et al*. (2016) introduced Rough Set Theory (RST) in the Kansei Engineering system to design the form and color of toothbrushes.

In recent years, some scholars have applied KE to the design of wooden furniture. For example, Lin *et al*. (2024) conducted perceptual semantic experiments on Ming and Qing dynasties, and modern Chinese furniture based on Kansei Engineering, and then used the single factor variance method to compare the perceptual images of the three styles of solid wood chairs and deconstruct the form elements of the furniture. QTT-I and multiple linear regression models were used to establish the relationship between morphological elements and perceptual semantics.

EXPERIMENTAL

Research Framework

The general arrangement of this research process is outlined in several phases, as illustrated in Fig. 1. Phase 1 involves preliminary preparations for the formal experiment. This includes collecting and filtering descriptive vocabulary related to the forms of rosewood furniture, gathering and selecting images of rosewood furniture, creating experimental samples, and constructing a deconstruction table for rosewood furniture forms. Phase 2 focuses on identifying key Kansei words. Factor analysis is performed on the questionnaire data to extract key Kansei factors. Phase 3 involves constructing a weight judgment matrix for the Kansei words. HFAHP is used to calculate the weights of each descriptive term. These terms and their weights are then imported into the left and right walls of the HOQ, respectively. Phase 4 involves constructing a mapping model between

CRs and ECs. The design features of rosewood furniture are incorporated into the ceiling of the HOQ. Linguistic terms are used in the correlation matrix to express the corresponding fuzzy numbers, determining the strength of the relationships. Finally, the importance and ranking of the form elements are imported into the floor of the HOQ, thus identifying the priority elements for development.

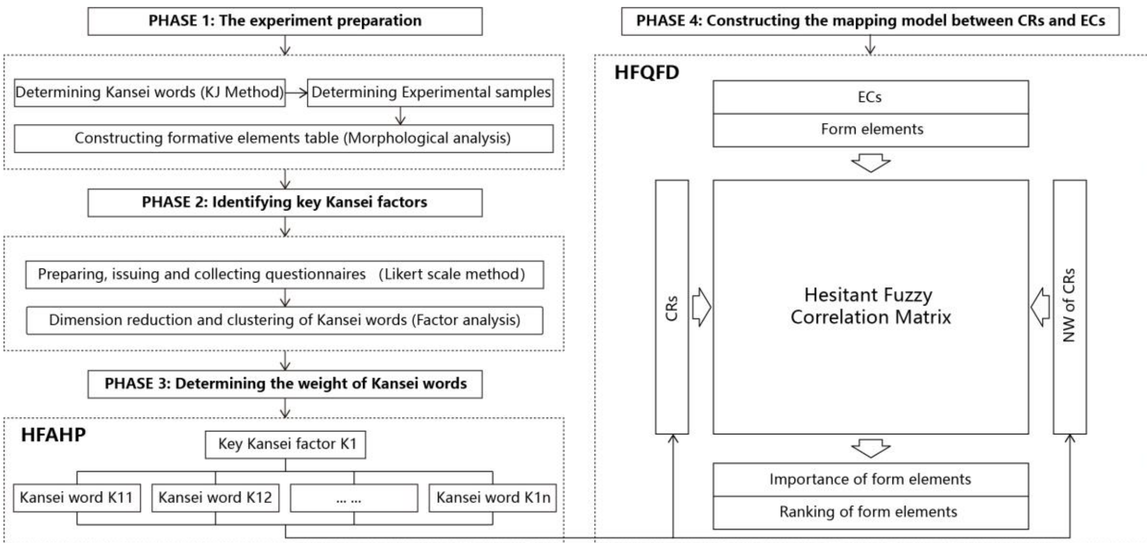


Fig. 1. The method framework for rosewood furniture design

Research Methods

Hesitant Fuzzy Analytic Hierarchy process

The HFAHP can organize diverse indicators within complex systems and construct hierarchical relationship models. Once the key Kansei factors and their corresponding internal Kansei words are identified, the weights and rankings of CRs under different dimensions are determined based on HFAHP. The specific steps of HFAHP can be roughly divided into 6 steps, which are discussed below.

Step 1: After constructing the hierarchical model, experienced experts in the field assess the weights between two indicators. They use the linguistic terms provided in Table 1 to represent the degree of importance of the first indicator compared to the second indicator.

Table 1. Triangular Fuzzy Numbers and Corresponding Linguistic Terms in HFAHP

Si	Linguistic Term	Abbrev.	Triangular Fuzzy Number
S10	Absolutely high importance	AHI	(7,9,9)
S9	Very high importance	VHI	(5,7,9)
S8	Essentially high importance	ESHI	(3,5,7)
S7	Weakly high importance	WHI	(1,3,5)
S6	Equally high importance	EHI	(1,1,3)
S5	Exactly equal	EE	(1,1,1)
S4	Equally low importance	ELI	(0.33,1,1)
S3	Weakly low importance	WLI	(0.2,0.33,1)
S2	Essentially low importance	ESLI	(0.14,0.2,0.33)
S1	Very low importance	VLI	(0.11,0.14,0.2)
S0	Absolutely low importance	ALI	(0.11,0.11,0.14)

Step 2: Buckley (1985) indicates that the consistency of $A=\left[a_{ij}\right]$ can be determined by examining the consistency of $A=\left[a_{ij}\right]$. Therefore, the first step involves converting fuzzy numbers to precise numbers using Eq. 1,

$$A=\frac{l+4m+u}{6} \tag{1}$$

where l is the left side of triangular fuzzy number, m is the middle side of triangular fuzzy number, and u is the right side of triangular fuzzy number.

Subsequently, the maximum eigenvalue $\lambda_{\max}$ is obtained through Eq. 2, and then Eq. 3 is applied to calculate the Consistency Ratio (CR). If CR < 0.1, the matrix is considered logically sound and classified as an effective matrix (Miao *et al*. 2024). The value of RI is determined based on the number of matrix indicators, as shown in Table 2.

$$\lambda_{\max}=\sum_{i=1}^{n}\frac{(BW)_i}{nw_i} \tag{2}$$

$$CI=(\lambda_{\max}-n)/(n-1)$$
$$CR=CI/RI \tag{3}$$

Table 2. RI Value

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Step 3: The Fuzzy Envelope Approach is employed to combine assessments from all experts (Liu and Rodríguez 2014). The linguistic terms in Table 1 are ranked from the lowest value (S_0) to the highest value (S_g). Assuming expert ratings fall between two linguistic terms, denoted as S_i and S_j, it holds that $S_0 \leq S_i < S_j \leq S_g$.

The parameters of the trapezoidal fuzzy membership functions $A=(a,b,c,d)$ are computed using Eqs. 4 through 7:

$$a = \min\left\{a_L^i, a_M^i, a_M^{i+1}, \ldots, a_M^i, a_R^j\right\} = a_L^i \quad (4)$$

$$d = \max\left\{a_L^i, a_M^i, a_M^{i+1}, \ldots, a_M^i, a_R^j\right\} = a_R^j \quad (5)$$

$$b = \begin{Bmatrix} a_M^i, if\ \ i+1=j \\ OWA_{w^2}(a_m^j, \ldots a_m^{(i+j)/2}), if\ \ i+j\ is\ even \\ OWA_{w^2}(a_m^j, \ldots a_m^{(i+j+1)/2}), if\ \ i+j\ is\ odd \end{Bmatrix} \quad (6)$$

$$c = \begin{Bmatrix} a_M^i, if\ \ i+1=j \\ OWA_{w^1}(a_m^j, a_m^{j-1} \ldots a_m^{(i+j)/2}), if\ \ i+j\ is\ even \\ OWA_{w^1}(a_m^j, a_m^{j-1} \ldots a_m^{(i+j+1)/2}), if\ \ i+j\ is\ odd \end{Bmatrix} \quad (7)$$

The operation of OWA requires a weight vector, where parameter '*a*' is defined as the first type of weights within the unit interval [0, 1] and the second type of weights (Filev and Yager 1998).

The first type of weights $W^1 = (w_1^1, w_2^1 \cdots w_n^1)$ is defined as:

$$w_1^1 = \alpha_2, w_2^1 = \alpha_2(1-\alpha_2), \ldots w_n^1 = \alpha_2(1-\alpha_2)^{n-2}$$

The second type of weights $W^2 = (w_1^2, w_2^2 \cdots w_n^2)$ is defined as:

$$w_1^2 = \alpha_1^{n-1}, w_2^2 = (1-\alpha_1)\alpha_1^{n-2}, \ldots w_n^2 = 1-\alpha_1$$

where $a_1 = \dfrac{g-(j-i)}{g-1}$ and $a_2 = \dfrac{(j-i)-1}{g-1}$.

where *g* is the number of linguistic terms, *j* is the highest value within the assessment range, and *i* is the lowest value within the assessment range.

Step 4: The hesitant fuzzy pairwise comparison judgment matrix was constructed, as illustrated in Eq. 8,

$$C = \begin{bmatrix} 1 & \tilde{c}_{12} & \ldots & \tilde{c}_{1n} \\ \tilde{c}_{21} & 1 & \ldots & \tilde{c}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{c}_{n1} & \tilde{c}_{n2} & \ldots & 1 \end{bmatrix} \quad (8)$$

where $\tilde{c}_{ij} = (c_{ij_l}, c_{ij_{m1}}, c_{ij_{m2}}, c_{ij_u})$.

Simultaneously, the reciprocal of $\tilde{c}_{ij}$ can be represented as follows:

$$\tilde{c}_{ji} = \left(\frac{1}{c_{ij_u}}, \frac{1}{c_{ij_{m2}}}, \frac{1}{c_{ij_{m1}}}, \frac{1}{c_{ij_l}}\right)$$

Step 5: Calculate the fuzzy geometric mean for each row of the matrix using Eq. 9,

$$r_i = (\tilde{c}_{i1} \otimes \tilde{c}_{i2} \ldots \otimes \tilde{c}_{in})^{1/n} \quad (9)$$

Step 6: Obtain the fuzzy weights w_i for each indicator based on Eq. 10. The values of $\tilde{r}_1 \oplus \tilde{r}_2 ... \oplus \tilde{r}_n$ are accepted as the maximum parameters for AHI in Table 1.

$$w_i = r_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 ... \oplus \tilde{r}_n)^{-1} \tag{10}$$

Step 7: Apply Eq. 11 to de-fuzzify the trapezoidal values of fuzzy weights, yielding de-fuzzification weights for each indicator:

$$DW = \frac{c_l + 2c_{m1} + 2c_{m2} + c_u}{6} \tag{11}$$

Step 8: Normalize the de-fuzzification weights using to obtain normalized weights, ensuring that the sum of all indicator weights within the same hierarchy equals 1.

Hesitant fuzzy quality function deployment

In the application of HFQFD, the initial procedural step entails the establishment of the House of Quality (HOQ). The CRs derived from the HFAHP are introduced on the left side, while the normalized weights associated with CRs are introduced on the right side. Concurrently, ECs are integrated into the upper side. The triangular fuzzy numbers within the HFQFD framework are stratified into seven distinct levels, as delineated in Table 3. Following the methodologies articulated in Eqs. 4 through 7, the aggregated trapezoidal fuzzy correlation is ascertained. Subsequently, this correlation is positioned within the HOQ matrix to signify the magnitude of correlation between CRs and ECs.

Table 3. Triangular Fuzzy Numbers and Corresponding Linguistic Terms in HFQFD

Linguistic Term	Abbrev.	Triangular Fuzzy Number
Absolutely low	AL	(1,2,3)
Very low	VL	(2,3,4)
Low	L	(3,4,5)
Medium	M	(4,5,6)
High	H	(5,6,7)
Very high	VH	(6,7,8)
Absolutely high	AH	(7,8,9)

The determination of the absolute importance (AI) for each EC is contingent upon the standardized weights assigned to CRs located on the left side of the HOQ and the correlation strength situated at the center of the HOQ. Utilizing the corresponding fuzzy numbers, AI is derived in accordance with Eq. 12. Subsequently, by employing the analogous procedures delineated in Eq. 11, the process of defuzzification is applied to AI, leading to the derivation of the defuzzification absolute importance (DAI). Ultimately, employing Eq. 13, the relative importance (RI) of ECs is ascertained, and subsequent ranking procedures are executed. The resulting data are then assimilated into the HOQ matrix, thereby acquiring significant ECs. Equations 12 and 13 are as follows,

$$AI_j = \sum_{i=1}^{n} NW_i \otimes C_{ij} \tag{12}$$

$$RI_j = \frac{DAI_j}{\sum_{j=1}^{m} DAI_j} \quad (13)$$

where NW_i represents the standardized weight of the ith CRs derived in HFAHP; C_{ij} signifies the degree of correlation between the ith CRs and the jth ECs, represented as a set of trapezoidal fuzzy numbers; AI_j denotes the fuzzy absolute importance of the jth ECs; DAI_j signifies the defuzzification absolute importance of the jth ECs; and RI_j denotes the relative importance of the jth ECs.

Preliminary Preparation of Experiment

Kansei words serve as manifestations of consumers' emotional requirements, and for grasping of the direction in subsequent product development, it is imperative to meticulously select representative Kansei words. Two channels were employed to extensively collect Kansei words related to rosewood furniture. The first involved a direct perusal of relevant books and academic journals, while the second encompassed researching product descriptions and consumer comments from auctions, online shopping platforms, and websites of furniture brand companies. Excluding negatively connotated or undesirable terms, a preliminary compilation of 53 Kansei words describing the form of rosewood furniture was obtained. An expert panel consisting of professionals engaged in research, design, or sales of rosewood furniture was invited to form a focus group. After discussions and exchange of opinions, the Initial word list was subjected to condensation and refinement using the KJ method. Redundant synonyms were eliminated, followed by the removal of terms less closely associated with the morphology of rosewood furniture and those with overly broad and general meanings. The outcome retained a set of 9 effective Kansei words, as illustrated in Table 4.

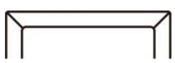
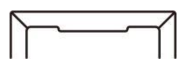
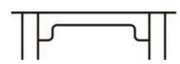
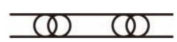
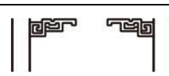
Table 4. The Reserved Kansei Words

Kansei Word		
Natural	Simple	Exquisite
Steady	Opulent	Well-proportioned
Elegant	Ethereal	Stately

In this study, square tables were chosen as the experimental subjects for investigating the form of rosewood furniture. Square tables represent a fundamental category within the realm of furniture and possess distinct representativeness due to their widespread market demand and versatile applicability in various scenarios in China. First, a comprehensive collection of images of rosewood square tables was gathered from sources such as websites and books. After an initial screening, highly similar images were eliminated, resulting in an initial pool of 60 samples. Subsequently, to reduce respondent burden and enhance the accuracy of research results, a focus group further examined the initial samples. Products with both distinctive morphology and significance were retained, while low-resolution images were discarded. Ultimately, 12 representative samples were obtained. Lastly, the representative sample images underwent uniform processing using the computer image editing software Adobe Photoshop. Standardized and properly sized experimental samples were created, eliminating background and shadow pixels from the 12 sample images except for the product itself. These images were then output as white background JPG files with dimensions of 500 mm x 500 mm and a resolution of 300 PPI. The product was centered within each image. Additionally, to prevent color elements from interfering with respondents' emotional perception, the saturation of the color images was reduced to -100 to convert them into grayscale form.

To establish an association matrix within the HOQ in subsequent steps, a Morphological Analysis method was employed to pre-construct a form element table for rosewood square tables. The design characteristics of the square table were decomposed, encompassing 7 components. Subsequently, this study analyzed the initial samples collected in the preliminary stage. After compiling all the form element types under each design characteristic, a selection was made of the most frequently occurring ones to construct a form element matrix. Unified specifications for morphological profiles were created using Adobe Illustrator, accompanied by encoding, as shown in Table 5.

Table 5. Design Characteristic Table

Design Characteristic	Form Element			
	Type 1	Type 2	Type 3	Type 4
Tabletop side (A)				
	A1	A2	A3	A4
Waist (B)	Nothing			
	B1	B2	B3	B4
Spandrel (C)				
	C1	C2	C3	C4
Decorative strut (D)	Nothing			
	D1	D2	D3	
Stretcher (E)				
	E1	E2	E3	E4
Corner spandrel (F)	Nothing			
	F1	F2	F3	
Table leg (G)				
	G1	G2	G3	G4

Using Likert Scale and FA to Determine the Key Kansei Factors

To begin, a 7-point Likert scale questionnaire was formulated based on the initial selection of 9 Kansei words and 12 experimental samples. A total of 95 participants were enlisted to partake in responding to the questionnaire. Once the data collection phase concluded, a meticulous examination of data quality was conducted. Subsequently, 15 questionnaires characterized by notably brief response durations and logically incongruous answers were excluded from consideration. Ultimately, a set of 80 validated datasets was retained, serving as an objective foundation for identifying key Kansei factors. Effective data matrix can be found in Table 6.

Subsequently, the effective data matrix was imported into the SPSS Statistics 27 software for the purpose of conducting a validity assessment. The suitability of the variables for factor analysis was determined through the KMO and Bartlett's Test of Sphericity within the context of factor analysis. The test outcomes are as follows: KMO = 0.823, Bartlett's Test of Sphericity < 0.001. This result proves that the data is suitable for factor analysis.

Table 6. Data Matrix

Sample	Natural	Simple	Exquisite	Steady	Opulent	Well-proportioned	Elegant	Ethereal	Stately
1	4.80	5.54	3.68	4.36	2.52	5.25	4.51	3.51	2.71
2	4.15	3.54	5.04	5.26	5.00	5.22	4.78	3.15	4.05
3	4.71	4.81	3.91	3.71	3.09	5.00	4.55	3.94	2.98
4	4.29	4.96	4.32	3.92	3.39	5.19	4.53	3.89	2.98
5	4.16	2.90	5.55	4.96	5.09	5.19	4.94	3.44	4.20
6	4.99	5.52	3.99	4.01	3.01	5.34	4.62	4.49	3.04
7	4.91	5.25	3.79	4.26	3.12	4.97	4.41	3.69	2.91
8	3.62	2.80	5.34	5.41	5.35	4.91	4.64	3.31	5.06
9	5.15	4.59	4.69	3.45	3.35	4.86	4.45	4.61	2.88
10	4.12	3.90	4.06	5.19	3.68	4.95	4.15	3.24	3.75
11	4.55	4.44	5.03	3.85	3.95	4.91	4.85	4.65	2.84
12	4.28	3.80	5.09	4.96	4.41	5.03	4.78	3.41	4.06

Table 7. Total Variance Explained

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.626	62.507	62.507	5.626	62.507	62.507	4.177	46.412	46.412
2	1.596	17.735	80.242	1.596	17.735	80.242	2.978	33.092	79.504
3	1.238	13.754	93.996	1.238	13.754	93.996	1.304	14.492	93.996
4	.193	2.146	96.142						
5	.165	1.830	97.971						
6	.082	.913	98.884						
7	.056	.620	99.504						
8	.023	.258	99.762						
9	.021	.238	100.000						

Furthermore, within this section, the principal component analysis method was employed as the extraction technique for factor analysis. This method can reduce dimensionality and clustering Kansei words while retaining their explanatory power. Eigenvalues greater than 1 were set as the criterion for extraction. The rotation method is Varimax with Kaiser normalization. Total variance explained is detailed in Table 7, a scree plot is illustrated in Fig. 2, and a rotated factor matrix is provided in Table 8.

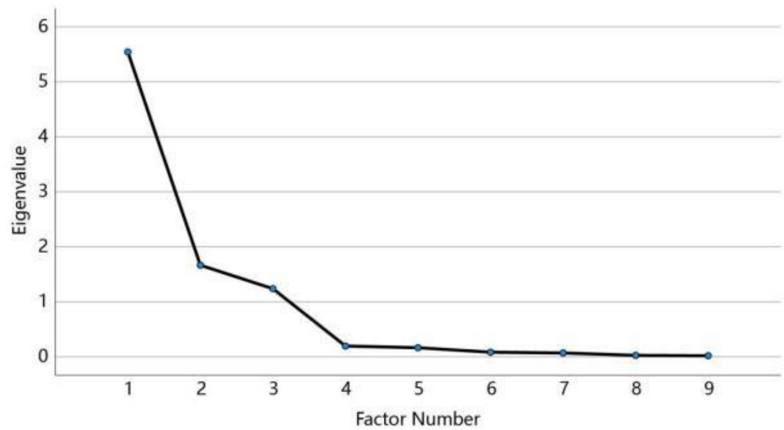


Fig. 2. Scree plot

Table 8. Rotated Factor Matrix

Kansei Word	Factor		
	1	2	3
Natural	-0.845		
Simple	-0.695		
Steady	0.953		
Ethereal	-0.935		
Stately	0.832		
Opulent		0.742	
Elegant		0.911	
Exquisite		0.909	
Well-proportioned			0.981

In conclusion, a qualitative analysis was conducted on the graphical and tabular data presented above. Upon observing Table 9, it is evident that by the third factor, the cumulative explained variance percentage reaches 93.996%, exceeding the threshold of 90%. The scree plot indicates the presence of three factors with eigenvalues greater than 1, signifying the extraction of three key factors through this principal component analysis. Analyzing Table 10 reveals that Factor 1 is composed of five Kansei words, namely natural, simple, steady, ethereal, and stately. These terms suggest that the furniture form retains a more natural and simplistic character without excessive artificial intervention. Therefore, it is labeled as "Natural Factor." Factor 2 consists of three Kansei words, opulent, elegant and exquisite, indicating a distinct presence of artificial decorative features in the furniture form. Consequently, it is named "Artificial Factor." Factor 3 solely includes the Kansei word "well-proportioned," highlighting that this factor differentiates itself from the style attributes of Factors 1 and 2. Instead, it characterizes the harmonious relationship of furniture form and proportions, and thus, it is named "Well-proportioned Factor."

Using HFAHP to Determine the Weight of Kansei Words

Factor 1, denoted as the "Natural Factor," and Factor 2, termed the "Artificial Factor," manifest as two distinct styles of furniture form, thus delineating two divergent trajectories in the development of rosewood furniture. Factor 3, referred to as the "Well-proportioned Factor," assumes the role of evaluating the congruity of furniture form and proportion, serving as an initial assessment criterion for subsequent design proposals.

Initiating the process, a hierarchical model for Kansei words related to rosewood furniture is established. This model comprises three hierarchical tiers: The topmost layer, designated as the goal layer, the intermediate layer known as the criteria layer, housing the two product development paths, and finally, the bottom layer, recognized as the sub-criteria layer, which integrates eight distinct customer's emotional requirements. This arrangement is visually presented in Fig. 3.

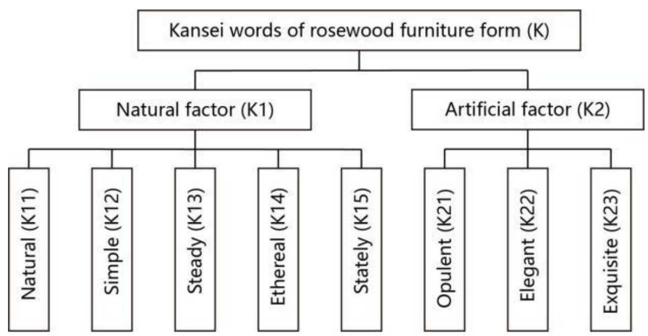


Fig. 3. Hierarchical model of Kansei words

Five experts with extensive experience in using rosewood furniture and engaged in furniture design and research were invited to form a focus group. The focus group conducted pairwise comparisons to determine the importance of Kansei words at the sub-criterion level, constructing a hesitant fuzzy judgment matrix to obtain the weights of the Kansei words. The subsequent narrative employs the scoring matrix calculation process for the five sub-criteria (K11 to K15) under the K1 criteria layer as an illustrative case.

Initially, a hesitant fuzzy judgment matrix was constructed following the standards outlined in Table 1. Subsequently, Eqs. 1 to 3 were utilized to assess the consistency of the matrix, revealing that it passed the consistency test. The fuzzy envelopes for the evaluation of criteria are illustrated in Table 9. The comparison matrix after transformation into trapezoidal fuzzy numbers is presented in Table 10.

Applying Eq. 9 yielded the fuzzy geometric mean for each row of the matrix, followed by the application of Eq. 10 to determine the trapezoidal fuzzy weights for the five sub-criteria. Subsequently, Eq. 11 was employed to defuzzify the five sets of trapezoidal fuzzy weight matrices, resulting in defuzzification weights. Finally, the normalized weights were obtained for the five sub-criteria.

Repeating the above steps, the same procedures were employed to acquire the normalized weights for three sub-criteria (K21 to K23) under the K2 criteria layer, as illustrated in Table 11.

According to the outcomes derived from the normalized weight calculations, the importance ranking of Kansei words under the Natural Factor is K11 (0.333), K12 (0.308), K13 (0.193), K14 (0.095), and K15 (0.071). For Kansei words under the Artificial Factor, the importance ranking is K22 (0.564), K21 (0.252), and K23 (0.183).

Table 9. Fuzzy Envelopes for the Evaluation of Criteria

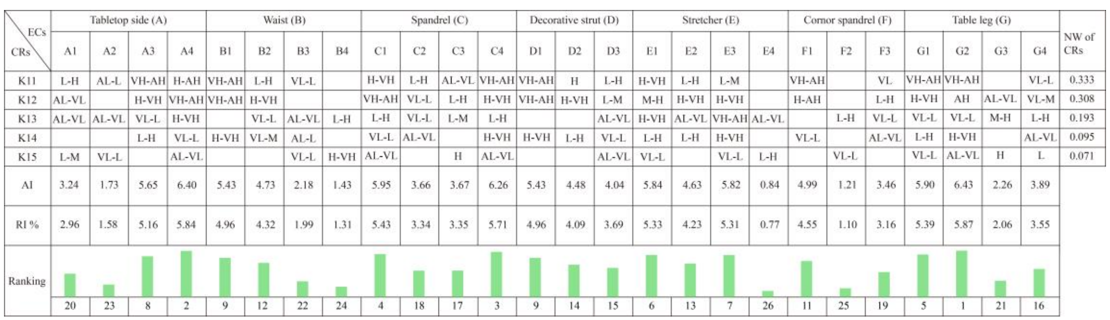
	K11	K12	K13	K14	K15
K11	EE	Between EE and EHI	Between EHI and WHI	Between WHI and ESHI	Between WHI and VHI
K12		EE	Between EHI and WHI	Between WHI and ESHI	Between WHI and VHI
K13			EE	Between EHI and WHI	Between WHI and ESHI
K14				EE	Between EE and EHI
K15					EE

Table 10. Comparison Matrix after Converting to Trapezoidal Fuzzy Numbers

	K11	K12	K13	K14	K15
K11	(1,1,1,1)	(1,1,1,3)	(1,1,3,5)	(1,3,5,7)	(1,4.78,5.22,9)
K12	(0.33,1,1,1)	(1,1,1,1)	(1,1,3,5)	(1,3,5,7)	(1,4.78,5.22,9)
K13	(0.2,0.33,1,1)	(0.2,0.33,1,1)	(1,1,1,1)	(1,1,3,5)	(1,3,5,7)
K14	(0.14,0.2,0.33,1)	(0.14,0.2,0.33,1)	(0.2,0.33,1,1)	(1,1,1,1)	(1,1,1,3)
K15	(0.11,0.19,0.21,1)	(0.11,0.19,0.21,1)	(0.14,0.2,0.33,1)	(0.33,1,1,1)	(1,1,1,1)

Table 11. Weight Information for the Sub-criteria Layers

Criterion	Sub-criterion	Trapezoidal Fuzzy Weight	Normalized Weight
Natural factor (K1)	Natural (K11)	(0.111,0.189,0.266,0.437)	0.333
	Simple (K12)	(0.089,0.189,0.266,0.351)	0.308
	Steady (K13)	(0.058,0.089,0.191,0.226)	0.193
	Ethereal (K14)	(0.037,0.047,0.072,0.138)	0.095
	Stately (K15)	(0.025,0.042,0.047,0.111)	0.071
Artificial factor (K2)	Opulent (K21)	(0.065,0.077,0.111,0.160)	0.252
	Elegant (K22)	(0.111,0.160,0.274,0.363)	0.564
	Exquisite (K23)	(0.040,0.065,0.077,0.111)	0.183



ECs / CRs	Tabletop side (A)				Waist (B)				Spandrel (C)			
	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4
K11	L-H	AL-L	VH-AH	H-AH	VH-AH	L-H	VL-L		H-VH	L-H	AL-VL	VH-AH
K12	AL-VL		H-VH	VH-AH	VH-AH	H-VH			VH-AH	VL-L	L-H	H-VH
K13	AL-VL	AL-VL	VL-L	H-VH		VL-L	AL-VL	L-H	L-H	VL-L	L-M	L-H
K14			L-H	VL-L	H-VH	VL-M	AL-L		VL-L	AL-VL		H-VH
K15	L-M	VL-L		AL-VL			VL-L	H-VH	AL-VL		H	AL-VL
AI	3.24	1.73	5.65	6.40	5.43	4.73	2.18	1.43	5.95	3.66	3.67	6.26
RI %	2.96	1.58	5.16	5.84	4.96	4.32	1.99	1.31	5.43	3.34	3.35	5.71
Ranking	20	23	8	2	9	12	22	24	4	18	17	3

ECs / CRs	Decorative strut (D)			Stretcher (E)				Cornor spandrel (F)			Table leg (G)				NW of CRs
	D1	D2	D3	E1	E2	E3	E4	F1	F2	F3	G1	G2	G3	G4	
K11	VH-AH	H	L-H	H-VH	L-H	L-M		VH-AH		VL	VH-AH	VH-AH		VL-L	0.333
K12	VH-AH	H-VH	L-M	M-H	H-VH	H-VH		H-AH		L-H	H-VH	AH	AL-VL	VL-M	0.308
K13			AL-VL	H-VH	AL-VL	VH-AH	AL-VL		L-H	VL-L	VL-L	VL-L	M-H	L-H	0.193
K14	H-VH	L-H	VL-L	L-H	L-H	H-VH		VL-L		AL-VL	L-H	H-VH		AL-VL	0.095
K15			AL-VL	VL-L		VL-L	L-H		VL-L		VL-L	AL-VL	H	L	0.071
AI	5.43	4.48	4.04	5.84	4.63	5.82	0.84	4.99	1.21	3.46	5.90	6.43	2.26	3.89	
RI %	4.96	4.09	3.69	5.33	4.23	5.31	0.77	4.55	1.10	3.16	5.39	5.87	2.06	3.55	
Ranking	9	14	15	6	13	7	26	11	25	19	5	1	21	16	

Fig. 4. The mapping model for natural factor

Using HFQFD to Construct the Mapping Model Between CRs and ECs

Two distinct engineering characteristic mapping models were developed, each addressing natural and artificial factors independently. The five Kansei words, alongside their standardized weights related to natural factors and derived through the HFAHP, were inputted into both the left and right sides of the HOQ. Concurrently, the 26 form elements were integrated into the upper side of the HOQ. With reference to Table 4, the determination of the aggregated trapezoidal fuzzy correlation was predicated on the strength of the association between Kansei words and form elements. Subsequently, this correlation was incorporated into the center of the HOQ. Computational procedures based on Eqs. 12 and 13 were employed to establish the importance of each morphological element, thereby acquiring significant design parameters. Figure 4 visually represents the mapping model for natural factors.

The output results displayed in the lower side of the HOQ revealed the subsequent findings: Within the design characteristics of the tabletop side, both A4 and A3 demonstrate closely proximate higher scores, contributing 5.84% and 5.16%, respectively, to the overall scores. Regarding the design characteristic of waist, B1 and B2 exhibit higher scores, correspondingly representing 4.96% and 4.32%. In the context of the design characteristics of spandrel, C4 and C1 present higher scores, each contributing 5.71% and 5.43% to the total. Concerning the design characteristics of decorative strut, D1 and D2 achieve higher scores, both registering at 4.96% and 4.09%. Within the design characteristics of stretcher, E1 and E3 yield elevated scores, each encompassing 5.33% and 5.31% of the total. In the instance of the design characteristics of corner spandrel, F1's significance substantially surpasses that of the other form elements, contributing 4.55% of the overall score. Furthermore, within the design characteristics of table leg, G2 and G1 attain higher scores, accounting for 5.87% and 5.39% respectively. Therefore, guided by these outcomes, furniture designers can strategically select form elements with superior scores to drive their product development endeavors, while also prudently avoiding the inclusion of form elements such as A2, B4, C2, D3, E4, F2, and G3. Such a selective approach enables furniture products to effectively cater to the emotional requirements of consumers under the natural factor. In this manner, the goals of heightened user satisfaction and the reinforcement of emotional attachment to the product are aptly realized.

Applying consistent methodologies and procedures, matrices for artificial factors and design characteristics were formulated. The 3 Kansei words and their ultimate normalized weights associated with the artificial factor were incorporated into the left and right sides of the HOQ. Following this, the design characteristics and form elements were introduced into the upper section of the HOQ. After evaluating the degree of association between Kansei words under artificial factor and each form element, the importance and ranking of all form elements were integrated into the lower side of the HOQ. Figure 5 visually represents the mapping model for artificial factors.

ECs / CRs	Tabletop side (A)				Waist (B)				Spandrel (C)				Decorative strut (D)			Stretcher (E)				Cornor spandrel (F)			Table leg (G)				NW of CRs
	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4	D1	D2	D3	E1	E2	E3	E4	F1	F2	F3	G1	G2	G3	G4	
K21	VL-L	H-VH	AL				VH-AH	H-VH		VH-AH		AL-VL			VL-L	AL-VL		AL-VL	VH-AH		VH-AH	L-M	AL-VL		H-VH	VH-AH	0.252
K22	L-H	L-M	VL-L	AL-VL	AL-VL	VL-L	H-VH	M-H	AL-VL	VH-AH	VL-L	L-M	AL-VL	VL	H-VH	VL-L	AL-VL	VL-L	M-VH	AL-VL	H-VH	L-H	VL-L	AL-VL	M-VH	AH	0.564
K23	L-M	H-VH	AL-VL	AL		VL-L	H-VH	H-VH	VL	M-VH	AL-VL	AL-VL			VL-M				VH-AH		VH-AH	VL-L	VL-L		H-VH	M-H	0.183
AI	4.53	5.37	2.94	1.78	1.41	2.62	6.75	5.93	1.96	7.22	2.43	3.63	1.41	1.69	5.28	2.61	1.41	2.61	6.65	1.41	6.93	4.60	3.25	1.41	6.21	7.41	
RI %	4.56	5.40	2.96	1.79	1.42	2.63	6.79	5.96	1.97	7.26	2.44	3.65	1.42	1.70	5.31	2.62	1.42	2.62	6.69	1.42	6.97	4.63	3.27	1.42	6.24	7.45	
Ranking	11	8	14	20	22	15	4	7	19	2	18	12	22	21	9	16	22	16	5	22	3	10	13	22	6	1	

Fig. 5. The mapping model for artificial factor

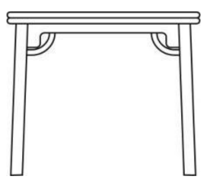
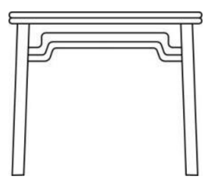
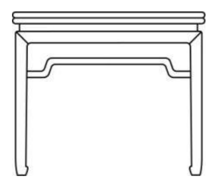
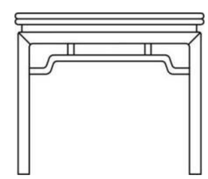
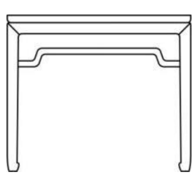
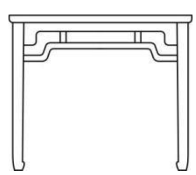
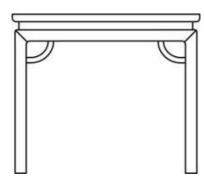
The output results displayed in the lower side of the HOQ revealed the subsequent findings: Within the design characteristics of the tabletop side, both A2 and A1 demonstrate closely proximate higher scores, contributing 5.40% and 4.56%, respectively, to the overall scores. Regarding the design characteristic of waist, B3 and B4 exhibit higher scores, representing 6.79% and 5.96% correspondingly. In the context of the design characteristics of spandrel, C2 presents a higher score, contributing 7.26% of the overall score. Concerning the design characteristics of decorative strut, D3 achieves a higher score, contributing 5.31% of the overall score. For the design characteristics of stretcher, E4 is of higher importance, contributing 6.69% of the overall score. Within the design characteristics of corner spandrel, F2 yields elevated score, contributing 6.97% of the overall score. Furthermore, within the design characteristics of table leg, G4 and G3 attain higher scores, accounting for 7.45% and 6.24% respectively. Hence, considering the outcomes, furniture designers can select morphological elements characterized by elevated scores as delineated above. Concurrently, it is imperative to abstain from incorporating elements with lower scores into the design, specifically denoted as A4, B1, C1, D1, E2, F1, and G2. This strategic approach enables designers to formulate an optimal furniture product that resonates with the emotional requirements of consumers pertaining to the artificial factor, consequently bolstering product sales.

Design Practice

To create an optimal product scheme that strongly resonates with consumers' emotional needs and demonstrate a well-proportioned morphological arrangement, an evaluation phase is implemented in the design process. The purpose of this phase is to address potential issues related to morphological disharmony in proposed designs and enhance the objectivity of the schemes. This section employs the furniture development path associated with the Natural factor as a case study. Within this context, designers carefully choose significant form elements from various design characteristics to construct orthogonal combinations. Following the generation of multiple preliminary schemes, the Well-proportioned factor is employed as an evaluation criterion. This approach aims to conserve resources and reduce trial-and-error costs while achieving the objective of crafting products that are highly attuned to consumer preferences and boast a well-proportioned design composition.

First, based on the quantified results from HFQFD, tabletop side selected A3 and A4 as alternative form parameters, waist opted for B1 and B2, spandrel went with C1 and C4, decorative strut chose D1 and D2, stretcher involved E3 and E1, corner spandrel was represented by F1, and table leg featured G1 and G2. If the comprehensive testing criteria were followed, it would result in the generation of 2×2×2×2×2×2 = 64 preliminary schemes, leading to an increase in the workload for designers and pressure on respondents. Therefore, this section adopted an Orthogonal Experimental Design to simplify the testing process. This method is known for its high efficiency and low cost, effectively dispersing all elements, and selecting representative test combinations. Ultimately, 12 sets of test samples were generated. Due to structural limitations on furniture form, the analysis of the samples revealed the following: Firstly, there was a structural conflict between B2 and C4, making it impossible for both to appear in a single piece of furniture. Secondly, D2 required E1 as lower support to be used. Among these experiments, schemes 2, 3, 4, 5, 7, 9, and 10, a total of 7 schemes, adhered to the structural principles of rosewood furniture and could be selected as preliminary design schemes. Adobe Illustrator software was used to create 2D elevation drawings for the preliminary designs, and the dimensions were standardized to a total height of 750 mm, total width of 880 mm, and depth of 880 mm. Table 12 presents these preliminary design schemes.

Table 12. Preliminary Design Schemes

NO.2	NO.3	NO.4	NO.5
			
NO.7	NO.9	NO.10	
			

Second, Factor 3, known as the "Well-proportioned Factor," was employed as the criterion for evaluating the design. A survey was formulated and administered to a sample of 130 consumers, utilizing a 7-point Likert scale. These participants were invited to assess and determine the level of congruence in the form of the 7 preliminary design schemes. After gathering the responses, 28 ineffective questionnaires were excluded, resulting in 102 effective questionnaires for analysis. Notably, NO.9 Scheme achieved the highest average score (5.79 points). This finding underscored that the scheme not only intricately aligned with consumers' emotional requirements but also boasted an exceptionally harmonious overall morphological composition. It emerged as the optimal product scheme within the developmental path of the natural factor.

Lastly, the NO.9 scheme underwent a refinement process using Rhino software. The 2D elevation drawings were converted into a 3D model, followed by rendering, culminating in the definitive rosewood furniture design scheme within the framework of the natural factor. Figure 6 presents the 3D model depicting the optimal design scheme.

Fig. 6. The optimal design scheme of rosewood furniture

Discussion

Through the investigation of rosewood furniture enterprises and markets, as well as the review of previous studies, it is evident that the current design of rosewood furniture generally lacks a systematic and precise product form development pathway. On the one hand, design decision-making is crucial to the product development process; the professional background and prior knowledge of furniture designers contribute to unique and innovative product development. However, existing research has rarely considered the uncertainty in expert decision-making processes, which may affect the accuracy of final design decisions, making it difficult for products to gain consumer acceptance and resulting in the waste of precious wood, human resources, and capital. Therefore, improving the accuracy and systematic nature of the design decision-making process has become one of the urgent issues to be addressed. On the other hand, with the refinement of craftsmanship, structure, and functionality in rosewood furniture, distinctions among products from various manufacturers have progressively diminished. In the era of the aesthetic economy, there is an increased emphasis on the spiritual value of products. Form design serves as a pivotal means to meet consumers' emotional needs, playing a crucial role in circumventing product homogeneity and establishing a distinctive brand image.

Kansei engineering, as a scientific methodology employing engineering principles to investigate user emotions, primarily aims to develop a correlation model between CRs and ECs. In prior studies within the KE domain, a prevalent approach involved employing CA and T-test to assess the correlation magnitude between sensory semantics and product samples. However, this methodology falls short in mapping semantics to specific design elements. In contrast, QTT-I has been widely utilized by KE researchers for establishing a correlation model between CRs and specific ECs. Despite its application, QTT-I operates within the domain of multivariate linear mathematical models, which does not entirely align with the cognitive thinking characteristics of humans. Additionally, its computational process is intricate and time consuming. Certain researchers have opted for BPNN to construct a non-linear mapping model. Although this method boasts non-linearity and self-learning advantages, the predictability of results is not always assured. In recent years, some scholars have introduced HFQFD to create mapping models between CRs and ECs. This user-centered approach incorporates fuzzy set theory, aligning better with the uncertainty features inherent in human thinking. However, it falls short in capturing hesitation in decision-making processes involving multiple experts. To further mitigate information loss and refine the precision of the correlation between CRs and ECs, this study innovatively employs HFQFD to accurately construct a hesitant fuzzy correlation matrix. This method integrates Hesitant Fuzzy Linguistic Term Sets (HFLTS), considering the hesitation encountered in decision-making processes under uncertain conditions— a scenario that traditional QFD and FQFD struggle to address.

In contrast, the identification of significant CRs and ECs plays a pivotal role in enabling design and development practitioners to focus limited resources on genuinely pivotal design indicators. Initially, some researchers opt for a combined application of FA and CA to extract Kansei words. However, this method fails to produce weight values. Consequently, AHP or FAHP is employed to compute the weights associated with consumer demands. Nevertheless, these approaches also fall short in capturing the hesitation present in the decision-making process, leading to information loss. Thus, in this study, FA is utilized to reduce the dimensions of sensory vocabulary. The HFAHP is then employed to assess the importance of sensory vocabulary across various dimensions, calculate weights, and subsequently integrate the outcomes into the HOQ. Additionally, an abundance of ECs can impose a burden on the product development department.

Hence, within the context of KE, this investigation integrates the principles of Hesitant Fuzzy Set Theory to optimize the methodology of form design. This integration facilitates furniture design manufacturers in making more accurate design decisions, leading to the development of products that resonate with consumer preferences.

Table 13. Comparison of This Study with Previous Studies

Publication	CRs	Mapping Model	Research Field
This paper	FA, HFAHP	HFQFD	Rosewood furniture
Yang *et al*. (2023c)	FA	T-test, CA	Dyed fabrics of tea and tea stem
Ho and Hou (2015)	EGM	QTT-I	App Icons
Woo *et al*. (2022)	FA, CA	BPNN	Electric toothbrush
Yang *et al*. (2023b)	KM	QFD	Automated nursing beds
Kang *et al*. (2018)	FKM, FAHP	FQFD	Minicar
Kang and Nagasawa (2023)	CFKM	FQFD	Hybrid electric vehicle
Wang and Yang (2023)	EGM, GRA	FQFD	Wickerwork lamps
Fan *et al*. (2020)	FANP	FQFD	Cloud environment

Notes: CA: cluster analysis; EGM: evaluation grid method; KM: kano model; FKM: fuzzy kano model; CFKM: continuous fuzzy kano model; GRA: grey relationship analysis; FANP: fuzzy analytic network process

CONCLUSIONS

1. This study proposes a method for designing rosewood furniture within the KE framework, integrating HFAHP and HFQFD. Seven design features of a rosewood square table were identified using morphological analysis. Through the KJ method, nine Kansei words were determined, and factor analysis identified three key Kansei factors: "Natural", "Artificial", and "Well-proportioned". The first two factors represent distinct directions in furniture development. Subsequently, HFAHP was used to weight the Kansei words for each factor. For the "Natural factor", the weight ranking of the five Kansei words is as follows: Natural, Simple, Steady, Ethereal, and Stately. For the "Artificial factor", the weight ranking of the three Kansei words is Elegant, Opulent, and Exquisite.
2. Based on HFQFD, the Kansei words representing CRs were translated into ECs using the HOQ. Taking the furniture development of the "Natural factor" as an example, design evaluation identified Proposal No. 9 as the optimal design solution that aligns with user emotional needs and overall form coordination. The design parameters for this optimal scheme are A4, B1, C4, D2, E1, F1, and G1.
3. This study proposes that integrating KE and HFQFD is useful in enhancing the scientific rigor and accuracy of the design decision-making process, aiding enterprises in developing rosewood furniture that aligns with consumer preferences and improves market competitiveness. The KE establishes a mathematical relationship between psychological measures of users and physical attributes of products. The HFQFD employs a correlation matrix to translate CRs into ECs, generating optimal product form combination parameters.

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REFERENCES CITED

Bloch, P. H. (1995). "Seeking the ideal form: Product design and consumer response," *Journal of Marketing* 59(3), 16-29. DOI: 10.2307/1252116

Böhme, G. (2003). "Contribution to the critique of the aesthetic economy," *Thesis Eleven* 73(1), 71-82. DOI: 10.4324/9781315538181-16

Buckley, J. J. (1985). "Fuzzy hierarchical analysis," *Fuzzy Sets and Systems* 17(3), 233-247. DOI: 10.1016/0165-0114(85)90090-9

Chen, Y., and Bian, J. (2024). "Research on color matching model for wood panel furniture based on a back propagation neural network," *BioResources* 19(2), 2383-2403. DOI: 10.15376/biores.19.2.2383-2403

Chen, Y., and Sun, W. (2023). "R&D strategy study of customized furniture with film-laminated wood-based panels based on an analytic hierarchy process/quality function deployment integration approach," *BioResources* 18(4), 8249-8263. DOI: 10.15376/biores.18.4.8249-8263

Demirbilek, O., and Sener, B. (2003). "Product design, semantics and emotional response," *Ergonomics* 46(13-14), 1346-1360. DOI: 10.1080/00140130310001610874

Ecke, G. (1991). *Chinese Domestic Furniture in Photographs and Measured Drawings*, Seismological Press, Beijing, China.

Ellsworth, R.H. (1971). *Chinese Furniture: Hardwood Examples of the Ming and Early Qing Dynasties*, Penguin Random House, New York, NY, USA.

Fan, J. S., Yu, S. H., Yu, M. J., Chu, J. J., Tian, B. Z., Li, W. H., Wang, H., Hu, Y. K., and Chen, C. (2020). "Optimal selection of design scheme in cloud environment: A novel hybrid approach of multi-criteria decision-making based on F-ANP and F-QFD," *Journal of Intelligent and Fuzzy Systems* 38(3), 3371-3388. DOI: 10.3233/jifs-190630

Filev, D., and Yager, R. R. (1998). "On the issue of obtaining OWA operator weights," *Fuzzy Sets Systems* 94(2), 157-169. DOI: 10.1016/s0165-0114(96)00254-0

Ho, C. H., and Hou, K. C. (2015). "Exploring the attractive factors of app icons," *KSII Transactions on Internet and Information Systems* 9(6), 2251-2270. DOI: 10.3837/tiis.2015.06.016

Hsiao, S.-W., Chiu, F.-Y., and Lu, S.-H. (2010). "Product-form design model based on genetic algorithms," *International Journal of Industrial Ergonomics* 40(3), 237-246. DOI: 10.1016/j.ergon.2010.01.009

Huang, T., Zhou, C., Wang, X., and Kaner, J. (2023). "A study of visual perception based on colour and texture of reconstituted decorative veneer," *Coatings* 14(1), 57. DOI: 10.3390/coatings14010057

Kang, X. H., and Nagasawa, S. (2023). "Integrating continuous fuzzy Kano model and fuzzy quality function deployment to the sustainable design of hybrid electric vehicle," *Journal of Advanced Mechanical Design Systems and Manufacturing* 17(2), 1-15. DOI: 10.1299/jamdsm.2023jamdsm0019

Kang, X. H., Yang, M. G., Wu, Y. X., and Ni, B. Q. (2018). "Integrating evaluation grid method and fuzzy quality function deployment to new product development," *Mathematical Problems in Engineering* 2018, Article ID 2451470. DOI: 10.1155/2018/2451470

Kates, G. N., Bieber, C. F., Kates, B. M., and Morrison, H. H. (1962). *Chinese Household Furniture: From Examples Selected and Measured by Caroline F. Bieber and Beatrice M. Kat*es, Dover Publications, New York, NY, USA.

Kosamia, N., Sanchez, A., and Rakshit, S. (2023). "Multi-criteria decision analysis of succinic acid production using hesitant fuzzy analytical hierarchy process," *Industrial Crops and Products* 206, Article ID 117620. DOI: 10.1016/j.indcrop.2023.117620

Lin, Q. L., Cai, J., and Xue, Y. S. (2024). "Affective response difference to the viewing of different styles of solid wood furniture based on Kansei engineering," *BioResources* 19(1), 805-822. DOI: 10.15376/biores.19.1.805-822

Liu, H. B., and Rodríguez, R. M. (2014). "A fuzzy envelope for hesitant fuzzy linguistic term set and its application to multicriteria decision making," *Information Sciences* 258, 220-238. DOI: 10.1016/j.ins.2013.07.027

Liu, Z. H., Wu, J. F., Chen, Q. P., and Hu, T. (2023). "An improved Kansei engineering method based on the mining of online product reviews," *Alexandria Engineering Journal* 65, 797-808. DOI: 10.1016/j.aej.2022.09.044

Lu, P., and Hsiao, S. W. (2022). "A product design method for form and color matching based on aesthetic theory," *Advanced Engineering Informatics* 53, Article ID 101702. DOI: 10.1016/j.aei.2022.101702

Miao, Y., Yan, S., and Xu, W. (2024). "The study of children's preferences for the design elements of learning desks based on AHP-QCA," *BioResources* 19(2), 2045-2066. DOI: 10.15376/biores.19.2.2045-2066

Nagamachi, M. (1995). "Kansei engineering - A new ergonomic consumer-oriented technology for product development," *International Journal of Industrial Ergonomics* 15(1), 3-11. DOI: 10.1016/0169-8141(94)00052-5

Nagamachi, M. (2002). "Kansei engineering as a powerful consumer-oriented technology for product development," *Applied Ergonomics* 33(3), 289-294. DOI: 10.1016/s0003-6870(02)00019-4

Nagamachi, M., Okazaki, Y., and Ishikawa, M. (2006). "Kansei engineering and application of the rough sets model," *Proceedings of the Institution of Mechanical Engineers Part I-Journal of Systems and Control Engineering* 220(I8), 763-768.

Norman, D. A. (2004). *Emotional Design: Why We Love (Or Hate) Everyday Things*, Civitas Books, New York, NY, USA.

Onar, S. Ç., Büyüközkan, G., Öztayşi, B., and Kahraman, C. (2016). "A new hesitant fuzzy QFD approach: An application to computer workstation selection," *Applied Soft Computing* 46, 1-16. DOI: 10.1016/j.asoc.2016.04.023

Öztaysi, B., Onar, S. Ç., Boltürk, E., and Kahraman, C. (2015). "Hesitant fuzzy analytic hierarchy process," in :*2015 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE)*, Istanbul, Turkey, pp. 1-7.

Pu, A. (2012). *Mahogany Furniture of China*, The Forbidden City Publishing House, Beijing, China.

Shieh, M. D., Yeh, Y. E., and Huang, C. L. (2016). "Eliciting design knowledge from affective responses using rough sets and Kansei engineering system," *Journal of Ambient Intelligence and Humanized Computing* 7(1), 107-120. DOI: 10.1007/s12652-015-0307-6

Torra, V. (2010). "Hesitant fuzzy sets," *International Journal of Intelligent Systems* 25(6), 529-539. DOI: 10.1002/int.20418

Wang, S. (1999). *Study on Ming-style Furniture*, Joint Publishing (Hong Kong Company), Hong Kong, China.

Wang, T. X., and Yang, L. (2023). "Combining GRA with a Fuzzy QFD model for the new product design and development of wickerwork lamps," *Sustainability* 15(5), Article Number 4208. DOI: 10.3390/su15054208

Woo, J. C., Luo, F., Lin, Z. H., and Chen, Y. T. (2022). "Research on the sensory feeling of product design for electric toothbrush based on Kansei engineering and back propagation neural network," *Journal of Internet Technology* 23(4), 863-871. DOI: 10.53106/160792642022072304021

Yang, C. X., Liu, F., and Ye, J. N. (2023a). "A product form design method integrating Kansei engineering and diffusion model," *Advanced Engineering Informatics* 57, Article ID 102058. DOI: 10.1016/j.aei.2023.102058

Yang, C. X., Yuan, B. K., and Ye, J. A. (2023b). "A user-centered development model for innovation design in automated nursing beds," *Journal of Advanced Mechanical Design Systems and Manufacturing* 17(5), 1-21. DOI: 10.1299/jamdsm.2023jamdsm0062

Yang, L., Dai, X. D., Meng, Y. K., Zhou, L., and Yue, X. Y. (2023c). "Comparative study on dyed fabrics of tea and tea stem based on Kansei engineering," *Sustainability* 15(2), Article Number 1134. DOI: 10.3390/su15021134

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