Evaluation and Design of Dining Room Chair Based on Analytic Hierarchy Process (AHP) and Fuzzy AHP

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From the perspective of user needs, a design evaluation system for dining room chairs that can meet user needs was established. Based on the analytic hierarchy process (AHP), the user needs of a dining room chair were quantitatively analyzed by combining qualitative and quantitative methods. Moreover, the comprehensive weight ranking of 14 factors in the object hierarchy was obtained, which provided the design focus and quantitative indexes for designers in the early stage of dining room chair design. Then, in the later stage of dining room chair design, the fuzzy analytic hierarchy process (FAHP) method was used to quantitatively evaluate the three design schemes and obtain the optimal design scheme. The experimental results showed that the user needs evaluation results were positively correlated with the "excellent" grade in the FAHP method. This indicated that the evaluation system realized a symmetry, reliability, and effectiveness between the user needs evaluation and FAHP. Therefore, it can be concluded that this evaluation system based on AHP and FAHP proposed in this study has reliability and validity, and it can be used for design evaluation to judge the popularity of products, enhance the competitiveness of products, and reduce product design costs.

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INTRODUCTION

Since the chair was created, it has become an indispensable tool in human life, with both practical functions and artistic aesthetics. A chair is no longer a simple piece of furniture, but a symbol of lifestyle. Thousands of chairs have been designed from the Victorian era to the present (Ferebee and Byles 2011), such as Thonet's No 14 chair in 1859, Wright's high-back chair in 1904, Rietveld's Red and Blue Chair in 1918, Aalto's Paimio chair in 1932, Wegner’s Peacock chair in 1947, Jacobsen’s Egg chair in 1958, Starck's Von Volgelsang chair in 1984, Starck’s Louis Ghost chair in 2002, and so on. As the design and manufacture of chairs moved away from the domain of the craftsman towards that of the industrial production process, designers were also ideally positioned, with their background knowledge of engineering, to pioneer innovative chair designs within the constraints of modern manufacturing technology (Euychul 2002; Hu 2008). In addition to the problems of modeling, function, and structure, the fundamental worth of chairs at present lies in their communication of attitudes, ideas, and values. Chairs have become an ideal medium for designers to make their visual statements and construct their individual manifestos (Peng and Zhang 2002). Hans Wegner designed chairs with appropriate proportions, elaborate structure, light weight, and simple modelling, and they showed the essence of Danish modernism for mass production. Wegener designed and manufactured hundreds of chairs, which demonstrated the essence of chair design through a fully structured prototype and linearized form. The hundreds of designs show his passion, craftsmanship, pursuit of quality of life, and the value of eternal design as a designer; the results were loved by people of modern times (Sang-Kwon 2017).

Liu (2014) and Pang (2003) reshaped modern furniture design culture from the perspective of inheriting and applying the furniture design language of the Ming and Qing Dynasties (China). Based on the context of modern furniture design, combined with the cultural connotation and design elements from this time period, the furniture design language of the Ming and Qing Dynasties was applied to modern furniture design. Liu designed two new Chinese style chairs, which provided ideas and opportunities for the inheritance and development of the furniture culture of the Ming and Qing Dynasties, and broadened the vision of modern chair design. Zhang and Xu (2020) reconstructed the shape of the chair according to the shape of the chair in Tang Dynasty (China) paintings, the proportions of the chairs compared to people in the paintings, the information regarding the size of the surviving Tang dynasty chairs, and the information recorded in ancient paintings. According to the molding of these chairs, the proportion and form of chairs in the Tang Dynasty were estimated. The line drawing of chairs in the Tang Dynasty was described by the drawing principle of two-point perspective, which allowed for the analysis of the design style and structural art of chairs in the Tang Dynasty, and played an important role in the design and cultural appreciation of modern chairs.

With the progress of modern technology and the subdivision of design, designers are continuously exploring design methods and user needs of chairs. According to the test of five chairs during 10-min sitting on each chair, Makhsous *et al*. (2012) and Xu (2008) found that chair design significantly affected the distribution of the sitting pressure and buttock-thigh tissue perfusion. In all tested chairs, the contact pressure on the front of the chair was the lowest. Chair design and soft materials of the chair significantly influence the sitting interface pressure distribution and tissue perfusion in the sitting area. An investigation of postural and chair design impacts upon seat pan interface pressure has been performed by Vos *et al*. (2006), to determine whether the difference in posture or chair design result in a greater pressure difference. It was found that if the chair is not suitable or comfortable, the person’s body will be hurt. Similarly, if the dining room chair design is not beautiful or does not match the restaurant environment, it cannot bring pleasure to users. For example, a seat that is too narrow not only can make users feel discomfort, but also it can compress the nerves and blood vessels, leading to increased incidence of hemorrhoids (Yuan and Jiang 2020). By contrast, a seat that is too spacious can make users lean on one side, increasing the stress of the side that may lead to deformation of the trunk. Further evaluation of these test results can provide useful information to correlate chair design with sitting comfort.

According to ergonomic characteristics of dining room chairs and the demand analysis on senior-friendly dining room chair design, Chen *et al*. (2022) and Jung *et al.* (2010) analyzed the category and design components of the dining room chairs. Older adults' needs for a dining room chair were identified according to user interview and observation, experimental measurement of older adults' motion, electromyography, and body pressure during the use of the dining room chair. Then, older adults' characteristics for the use of the dining room chair were identified. Finally, the design direction for the chair was proposed to improve older adults’ satisfaction. Chair design based on anthropometric data analysis was recommended by Mahmoudi and Bazrafshan (2013). He studied chairs with backrests and armrests used by weavers in carpet-weaving workshops. An anthropometric survey was conducted among weavers to design a flexible chair and to improve its comfort based on design dimensions. He focused on the design dimensions of the chair for weavers and its recommended design dimensions, which also provided a design reference for the design of the dining room chair.

According to the current product design situation of furniture enterprises, although the leading enterprises in the dining room chair market have many brands and excellent design works, they have gradually moved towards high-quality design products, and have implemented a design and manufacturing strategy focusing on differentiation and personalization (Pushthink 2019; Zhang *et al.* 2022). The production mode has gradually transformed from mass production to personalized customized production. The analytic hierarchy process (AHP) was used to analyze user needs, and the user needs weight analysis and design evaluation model were applied to the field of chair design (Yuan and Jiang 2020).

To study how to design different grades of individualized chairs according to user needs, Yuan and Guan (2014) proposed a personalized chair design method based on AHP. The AHP model determined the relative user needs weight, the sub-functions of chairs and their attributes were given. On this basis, the weight coefficients were calculated. Therefore, the designers can comprehensively analyze the modeling, color, size, comfort, function, price, and other aspects of the dining room chair according to these weighting coefficients and thereby design some dining room chairs that meet the needs of users. The method can be used to design personalized chairs, greatly improving the product quality and customers' satisfaction, while reducing design time and cost. According to the literature review, few studies have been conducted on the dining room chair system design and evaluation analysis.

EXPERIMENTAL

Experimental Process

Factors that affect consumers' purchase of dining room chairs are not only affected by personal subjective factors, such as cultural background, age, income level, aesthetic level, but also by objective factors, such as information receiving channels, price, sales strategy, *etc.* Thus, it is difficult for the designer to specify user needs from the existing sales information and obtain more accurate user needs regarding a dining room chair. Similarly, in the process of dining room chair design, it is difficult to obtain objective and quantitative results from the traditional dining room chair evaluation. Therefore, based on the analytic hierarchy process, combined with the fuzzy comprehensive evaluation method (the AHP was a multi criteria decision-making method, established by T. L. Saaty, Pittsburgh), and according to the methods of questionnaire survey and user interview, 3 factors and 14 functions were determined.

Each function was assigned the same score according to the criteria by which the grades were assigned. The study established the dining room chair user needs by weight analysis and design evaluation model. Thus, according to the comprehensive weight value of each function, the priority level of general dining room chair function design was determined. The specific experimental process is shown in Fig. 1.

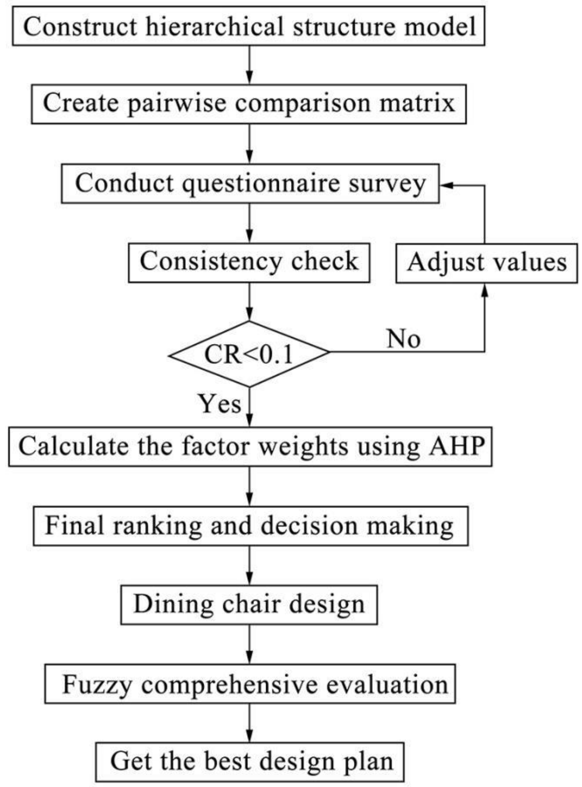

Fig. 1. Experimental process

To confirm whether the AHP can be used to judge consumer's subjective evaluation of dining room chairs, the authors verified it *via* an experiment. In this experiment, 3 design schemes of dining room chair were selected as experimental samples. The feelings brought by visual stimulation can determine the subjective feelings of customers, so the authors provided experimental samples for the subjects in the form of pictures.

Constructing Hierarchical Structure Model of User Needs

The decision-making process of the AHP method started with problem definition (Pan *et al.* 2018). The hierarchical structure of the model was defined with the following hierarchy (from left to right): target hierarchy, criterion hierarchy, and object hierarchy (Deng and Zhu 2018).

First, the questionnaire was distributed to youth groups (18 to 40 years old) of different occupations and income levels. Then, it took the user needs factors of dining room chair as the target level, took the appearance factors, function factors, and value factors corresponding to Maslow's demand level as the criterion level, and extracted 14 perceptual words from the user needs vocabulary of typical user interviews as the object level to guide the design of dining room chair appearance, function, and value.

Figure 2 shows the analytic hierarchy process model of user needs factors of dining room chairs.

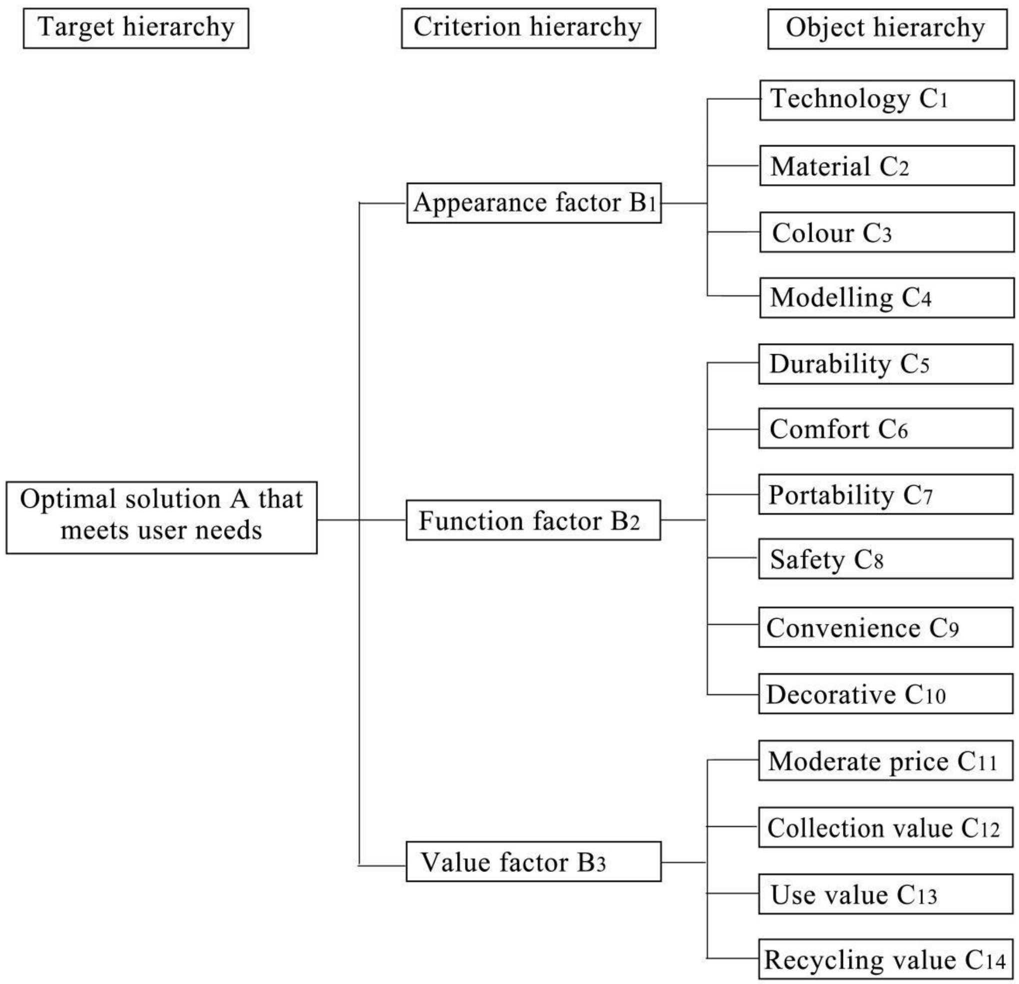

Fig. 2. Dining room chair user needs AHP model

Constructing Pairwise Comparison Matrix

Pairwise comparison is a fundamental step in the use of the AHP (Saaty 1987). The 1 to 9 point scale was recommended for use as an acceptable scale in the AHP (Harker and Vargas 1988).

Table 1. Conventional Scales and Definition of Judgment Matrix

Conventional Scales	Definition	Explanation
1	Equally important	Two factors have the same importance
3	Moderately important	One factor is slightly more important than the other
5	Strongly important	One factor is obviously more important than the other
7	Very strongly important	One factor is strongly more important than the other
9	Extremely important	One factor is extremely more important than the other
2,4,6,8	Intermediate values	Intermediate values of above adjacent comparisons

The advantage in using the 1 through 9 point scale is that it has qualitative distinctions and provides more options to assess the relative importance among the parameters, compared to smaller point scales. Furthermore, the 1 through 9 point scale is simple, straightforward, and easy to use. Recent studies show that the 1 through 9 point scale is widely used in numerous AHP applications (Pan *et al*. 2018). The detailed interpretation of the 1 through 9 point scale is described in Table 1, where conventional scales range from 1 to 9.

The pairwise comparison was undertaken between two parameters, for example, parameter *i* and parameter *j* to assess their relative importance. According to Table 1, each judgment was recorded in the form of a pairwise comparison matrix A of dimension $n \times n$, where n was the number of parameters to be compared, parameter *bij* was the result of comparing the contribution of parameter *bi* and parameter *bj* to the previous level. Equation 1 presents the pairwise comparison matrix A:

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

Methods

The experimental method was a questionnaire survey. Each subject was provided with a quiet and undisturbed questionnaire environment and a paper questionnaire. The questionnaire consisted of three parts: the first part was the basic information of the subjects, including gender, age, profession, and educational background; the second part was the subjective evaluation of the dining room chairs, where each sample corresponded to 14 subjective evaluation questions, which were scored by the 1 to 9 point scale (Table 1); the third part was a comprehensive evaluation, where the subjects selected the favorite dining room chair from 3 design schemes, according to the subjective feelings (Zuo and Wang 2020). A total of 100 subjects participated in the experiment, and the valid questionnaire data were from 94 of them. The gender distribution of the subjects was 50 males and 44 females; the subjects ranged in age from 18 to 40. The three advantages of AHP systematization, practicality, and simplicity were used to conduct the experiment (Wang and Gu 2020). The main steps of the AHP were given.

Step 1: Define the central questions, evaluation framework, choices, and judgment criteria.

Step 2: Construct pairwise comparison matrix according to the conventional scales in Table 1.

Step 3: Calculate the weight vector. The pairwise comparison matrix was normalized by Eq. 2; then, the average value of each row of the normalized pairwise comparison matrix was calculated by Eq. 3 to obtain the weight vector:

$$\overline{b_{ij}} = \frac{b_{ij}}{\sum_{k=1}^{n} b_{ki}}, i, j = 1,2,\ldots,n \tag{2}$$

$$W_i = \sum_{j=1}^{n} \frac{\overline{b_{ij}}}{n}, i = 1,2,\ldots,n \tag{3}$$

Step 4: The consistency index (CI) of the pairwise comparison matrix was calculated by Eqs. 4 and 5:

$$\lambda_{\max} = \sum_{i=1}^{4} \frac{(AW)_i}{(nW)_i} \tag{4}$$

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

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

Step 5: The consistency ratio (CR) was calculated by Eq. 6, where the random index (RI) value is shown in Table 2.

Step 6: The obtained CR was compared with the acceptable consistency value. If the value of CR was smaller than 0.1, the evaluation results of experts were considered reasonable, effective, and consistent (Saaty 2001), otherwise the pairwise comparison matrix needed to be adjusted to obtain an acceptable consistency. Generally, a smaller CR value, resulted in a better consistency of the matrix.

Table 2. Random Index (RI) for Matrices of Order 1 to 10

Order of Matrix	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49

RESULTS AND DISCUSSION

The Weight Analysis of Criterion Hierarchy

The weight vector was calculated by Eq. 3. In the criterion hierarchy (B), the weights of "Appearance factor B_1", "Function factor B_2", and "Value factor B_3" based on "Optimal solution A that meets user needs" are shown in Table 3.

Table 3. Weights of the Criterion Hierarchy

A	**B_1**	**B_2**	**B_3**	**Weights (W_A)**
B_1	1	3	5	0.63
B_2	1/3	1	3	0.26
B_3	1/5	1/3	1	0.11

Parameter values were W_A = (0.63; 0.26; 0.11), λ_{max} = 3.039, CI = 0.019, and CR = 0.037 < 0.1. The consistency ratio (CR) of the criterion hierarchy was smaller than 0.1, which indicated that the test team had passed the consistency test in the criterion hierarchy. That is, based on the “Optimal solution A that meets user needs”, the weights of “Appearance factor B_1”, “Function factor B_2”, and “Value factor B_3” were 0.63, 0.26, and 0.11, respectively.

The Weight Analysis of Object Hierarchy

The weight vector was calculated by Eq. 3. In the object hierarchy (C), the weights of "Technology C_1", "Material C_2", "Colour C_3", and "Modelling C_4" based on "Appearance factor B_1" is shown in Table 4.

Table 4. Comparison Matrix of Appearance Evaluation Index and Weights

B_1	C_1	C_2	C_3	C_4	Weights (W_{B1})
C_1	1	1/5	1/3	1/7	0.06
C_2	5	1	3	1/3	0.26
C_3	3	1/3	1	1/5	0.12
C_4	7	3	5	1	0.56

For Table 4, parameter values were W_{B1} = (0.06; 0.26; 0.12; 0.56), λ_{max} = 4.118, CI = 0.039, and CR = 0.044 < 0.1. The consistency ratio (CR) of the object hierarchy was smaller than 0.1, which indicated that the test team had passed the consistency test in the object hierarchy. That is, based on the "Appearance factor B_1", the weights of "Technology C_1", "Material C_2", "Colour C_3", and "Modelling C_4" were 0.06, 0.26, 0.12, and 0.56, respectively.

The weight vector was calculated by Eq. 3. In the object hierarchy (C), the weights of "Durability C_5", "Comfort C_6", "Portability C_7", "Safety C_8", "Convenience C_9", and "Decorative C_{10}" based on "Function factor B_2" are shown in Table 5.

In the table, W_{B2} = (0.04; 0.17; 0.10; 0.39; 0.23; 0.07), λ_{max} = 6.504, CI = 0.101, and CR = 0.080 < 0.1. The consistency ratio (CR) of the object hierarchy was smaller than 0.1, which indicated that the test team had passed the consistency test in the object hierarchy. That is, based on the "Function factor B_2", the weights of "Durability C_5", "Comfort C_6", "Portability C_7", "Safety C_8", "Convenience C_9", and "Decorative C_{10}" were 0.04, 0.17, 0.10, 0.39, 0.23, and 0.07, respectively.

Table 5. Comparison Matrix of Function Evaluation Index and Weights

B_2	C_5	C_6	C_7	C_8	C_9	C_{10}	Weights (W_{B2})
C_5	1	1/5	1/3	1/5	1/5	1/3	0.04
C_6	5	1	3	1/3	1/3	3	0.17
C_7	3	1/3	1	1/5	1/3	3	0.10
C_8	5	3	5	1	3	5	0.39
C_9	5	3	3	1/3	1	3	0.23
C_{10}	3	1/3	1/3	1/5	1/3	1	0.07

The weight vector was calculated by Eq. 3. In the object hierarchy (C), the weights of "Moderate price C_{11}", "Collection value C_{12}", "Use value C_{13}", and "Recycling value C_{14}" based on "Value factor B_3" are shown in Table 6. In the table, W_{B3} = (0.54; 0.14; 0.24; 0.08), λ_{max} = 4.204, CI = 0.068, and CR = 0.077 < 0.1. The consistency ratio (CR) of the object hierarchy was smaller than 0.1, and the matrix had an acceptable consistency. Based on the "Value factor B_3", the weights of "Moderate price C_{11}", "Collection value C_{12}", "Use value C_{13}", and "Recycling value C_{14}" were 0.54, 0.14, 0.24, and 0.08, respectively.

Table 6. Comparison Matrix of Value Evaluation Index and Weights

B_3	C_{11}	C_{12}	C_{13}	C_{14}	Weights (W_{B3})
C_{11}	1	5	3	5	0.54
C_{12}	1/5	1	1/3	3	0.14
C_{13}	1/3	3	1	3	0.24
C_{14}	1/5	1/3	1/3	1	0.08

Consistency Evaluation

Consistency was used as a measure to evaluate whether the relative judgement given by the respondent was consistent or not. The judgement was considered to be consistent if it met the logic of preference of transitive property. Hence, this step provided a logical consistency of the judgement. Saaty (1980) proved that the λ_{max} was always greater than or equal to *n* for positive reciprocal matrices. In this consistency evaluation step, λ_{max} was then used as an important validating parameter to measure consistency (Eq. 4). According to Eqs. 3 and 6, the weights of criterion hierarchy and object hierarchy can be calculated, as well as the consistency evaluation parameters in the three criterion hierarchies and the 14 object hierarchies. All the consistency ratio (CR) values were smaller than 0.1, so this pairwise comparison matrix had an acceptable consistency, as shown in Tables 3 through 6.

Comprehensive Weights Ranking

Based on the user needs evaluation system, in the criterion hierarchy, the weight order of the three criteria was: Appearance factor > Function factor > Value factor. In the object hierarchy, the comprehensive weights of “Modelling”, “Material”, and “Safety” were 0.3528, 0.1638, and 0.1014, ranking in the top three in the comprehensive weights ranking, while the comprehensive weights of “Collection value”, “Durability”, and “Recycling value” were 0.0154, 0.0104, and 0.0088, ranking in the last three in the comprehensive weights ranking, as shown in Table 7.

Table 7. Comprehensive Ranking of the Object Hierarchy

Object Hierarchy	Weights	Comprehensive Weights	Comprehensive Ranking
C_1	0.06	0.0378	8
C_2	0.26	0.1638	2
C_3	0.12	0.0756	4
C_4	0.56	0.3528	1
C_5	0.04	0.0104	13
C_6	0.17	0.0442	7
C_7	0.10	0.0260	10
C_8	0.39	0.1014	3
C_9	0.23	0.0598	5
C_{10}	0.07	0.0182	11
C_{11}	0.54	0.0594	6
C_{12}	0.14	0.0154	12
C_{13}	0.24	0.0264	9
C_{14}	0.08	0.0088	14

Discussion

The order of importance in the criterion hierarchy (B) was as follows: appearance factor > function factor > value factor, which showed that appearance factor was more important for the design of dining room chairs, followed by function factor and value factor. According to the comprehensive ranking of the user needs, young people paid the most attention to the modelling design of dining room chairs, followed by material, safety, colour, convenience, moderate price, comfort, and technology, and they were less sensitive to other factors, including use value, portability, decorative, collection value, durability, and recycling value. The dining room chairs were designed based on the comprehensive ranking, and the design schemes are shown in Fig. 3. Oak material was used in the three design schemes. The structure of the dining room chairs adopted the traditional mortise-tenon joints, because mortise-tenon joints played a crucial role in wooden furniture to resist lateral loads.

The fuzzy analytic hierarchy process (FAHP) method is a highly developed analytic method from AHP. To model human preferences, the AHP method was combined with the paired comparison of fuzzy sets. Both methods followed a similar algorithm to check the consistency of the matrix. The difference came in the priority calculations conducted by AHP, while a secondary analysis was conducted by FAHP. The optimal solution for dining room chair was identified by FAHP, which can provide quantitative decision and precise definition for decision-makers or designers and simplify the decision-making process (Diaz *et al.* 2022). Therefore, the FAHP method was adopted to quantify the evaluation results of multiple factors.

Design scheme A

Design scheme B

Design scheme C

Fig. 3. Three design schemes of dining room chair

Determining Evaluation Criteria

The evaluation results of design schemes were mainly decided by the subjective evaluation of the evaluator. In this experiment, the evaluation criteria were divided into 4 grades, which were: excellent, good, relatively good, poor, and each grade was given a different value. Therefore, the assignment vector was β = (90; 80; 70; 60). Three dining room chair marketers, two furniture designers, and five consumers were selected to evaluate the three design schemes in Fig. 3.

Then, the fuzzy comprehensive evaluation matrix was constructed according to the evaluation results of 10 evaluators, and 10 evaluators evaluated each factor in the object hierarchy according to the evaluation grade. The difference factors in the three design schemes were the size of the armrest and backrest, the position and color of the seat cushion, the height of the chair and the pattern of the seat cushion, and the bending degree of the armrest, and so on. After the evaluation, the number of evaluations received by each grade of each factor was counted. For example, if the number of excellent grades obtained by C_1 factor was 5 times, which was recorded as 0.5, 10 evaluators should evaluate each factor once. That is, each factor will get 10 evaluation values. The evaluation matrix was constructed with the obtained evaluation results, and M_1 represented the evaluation results of each factor in the appearance factor criterion hierarchy, M_2 represented the evaluation results of each factor in the function factor criterion hierarchy, and M_3 represented the evaluation results of each factor in the value factor criterion hierarchy. The final statistical evaluation results of design scheme A, B, and C were as follows in Table 8.

Table 8. Evaluation Results of Each Element in the Criterion Hierarchy

Criterion Hierarchy	Evaluation Results of Design Scheme A	Evaluation Results of Design Scheme B	Evaluation Results of Design Scheme C
Appearance M_1	0.4 0.4 0.2 0.0 0.5 0.3 0.1 0.1 0.4 0.4 0.1 0.1 0.3 0.5 0.1 0.1	0.4 0.5 0.1 0.0 0.6 0.3 0.1 0.0 0.5 0.4 0.1 0.0 0.4 0.4 0.1 0.1	0.5 0.4 0.1 0.0 0.7 0.3 0.0 0.0 0.7 0.2 0.1 0.0 0.7 0.3 0.0 0.0
Function M_2	0.3 0.3 0.4 0.0 0.4 0.3 0.2 0.1 0.1 0.3 0.5 0.1 0.6 0.4 0.0 0.0 0.5 0.4 0.1 0.0 0.3 0.3 0.4 0.0	0.4 0.5 0.1 0.0 0.4 0.4 0.2 0.0 0.2 0.3 0.5 0.0 0.6 0.4 0.0 0.0 0.5 0.4 0.1 0.0 0.4 0.5 0.1 0.0	0.5 0.4 0.1 0.0 0.6 0.4 0.0 0.0 0.3 0.4 0.3 0.0 0.7 0.3 0.0 0.0 0.7 0.3 0.0 0.0 0.8 0.2 0.0 0.0
Value M_3	0.5 0.4 0.1 0.0 0.0 0.2 0.7 0.1 0.5 0.4 0.1 0.0 0.6 0.3 0.1 0.0	0.5 0.5 0.0 0.0 0.1 0.2 0.6 0.1 0.6 0.3 0.1 0.0 0.6 0.4 0.0 0.0	0.6 0.3 0.1 0.0 0.5 0.4 0.1 0.0 0.7 0.3 0.0 0.0 0.6 0.4 0.0 0.0

Weight Value Analysis

According to the calculation results of the weight values in Tables 3 through 6, the weight sets of the factors in the criterion hierarchy and the object hierarchy were:

$$W_A = (0.63;\ 0.26;\ 0.11)$$

$$W_{B1} = (0.06;\ 0.26;\ 0.12;\ 0.56)$$

$$W_{B2} = (0.04;\ 0.17;\ 0.10;\ 0.39;\ 0.23;\ 0.07)$$

$$W_{B3} = (0.54;\ 0.14;\ 0.24;\ 0.08)$$

Fuzzy Evaluation Results

According to the weight set in the object hierarchy and its corresponding fuzzy evaluation results, the evaluation model results of design scheme A, B, and C in the object hierarchy were calculated by the formula, $A_n = W_{Bn} \times M_n$ (n was 1, 2, or 3, respectively), and the results were as follows in Table 9.

Table 9. Evaluation Model Results of Three Design Schemes

A_n	Design Scheme A	Design Scheme B	Design Scheme C
A_1	0.370 0.430 0.106 0.094	0.464 0.380 0.100 0.056	0.688 0.294 0.018 0.000
A_2	0.460 0.362 0.151 0.027	0.481 0.401 0.118 0.000	0.642 0.324 0.034 0.000
A_3	0.438 0.364 0.184 0.014	0.476 0.402 0.108 0.014	0.610 0.322 0.068 0.000

Based on the evaluation model results in Table 9, the second-order comprehensive evaluation matrix A_i (i was A, B, or C, respectively) was constructed according to A_1, A_2, and A_3.

$$W_i = W_A \times A_n = W_A \times \left\| \begin{matrix} A_1 \\ A_2 \\ A_3 \end{matrix} \right\| \tag{7}$$

According to the weight set of the factors in the criterion hierarchy and the second-order comprehensive evaluation matrix, we can get the overall evaluation model of design scheme i by Eq. 7, and the results were as follows in Table 10.

Table 10. Overall Evaluation Model of Three Design Schemes

W_A of Design Scheme A	W_B of Design Scheme B	W_C of Design Scheme C
0.401 0.405 0.126 0.068	0.470 0.388 0.106 0.037	0.667 0.305 0.028 0.000

According to the overall evaluation model W_i of design scheme i and the assignment vector β, we can get the final evaluation score of design scheme i by the formula: $S_i = W_i \times \beta$.

Table 11. Final Evaluation Scores of Three Design Schemes

Experimental Samples	Final Evaluation Scores (S_i)
Design scheme A	81.39
Design scheme B	82.98
Design scheme C	86.39

The final evaluation scores of the fuzzy comprehensive evaluation are shown in Table 11. It can be seen that the statistical result of design schemes' "excellent grade" was that design scheme C had the highest identification degree and the final evaluation score was 86.39, with 86 "excellent grade" (43%) in this design scheme. This was followed by design scheme B, in which the final evaluation score was 82.98, with 62 "excellent grade" (30%) in this design scheme. Design scheme A had the lowest identification degree and the final evaluation score was 81.39, with only 54 "excellent grade" (27%) in this design scheme. Therefore, design scheme C was selected as the optimal design scheme.

CONCLUSIONS

In this study, the factors affecting user needs in dining room chairs were comprehensively determined from three attributes based on the analytic hierarchy process (AHP). These factors were then incorporated into dining room chair design and evaluation indexes to establish the overall evaluation system. The main conclusions of this study are as follows:

1. The priority calculations of the design factors were conducted by AHP, while a secondary analysis was conducted by fuzzy AHP (FAHP). In the criterion hierarchy, the weight ranking of the influencing factors of dining room chair design was: Appearance > Function > Value. In the object hierarchy, the weight ranking of the top five influencing factors of dining room chair design was: Modelling > Material > Safety > Colour > Convenience, which provided a clear design direction and design focus for dining room chair.
2. The optimal solution for dining room chair design was identified by FAHP, which can provide quantitative decision and precise definition for decision-makers or designer and simplify the decision-making process. Through comparing the final evaluation scores, the ranking of the design schemes was as follows: design scheme C > design scheme B > design scheme A. The evaluation results verified the effectiveness of the evaluation model constructed by AHP for the optimization of dining room chair design.
3. Through a verification experiment with 3 representative design schemes as experimental samples, it can be concluded the subjective product evaluation system based on AHP proposed in this study has reliability and validity. It realizes a symmetry between subjective evaluation and comprehensive evaluation, making it possible to complete comprehensive evaluation of design schemes through the subjective feelings of evaluators without objective information of the product.
4. This subjective evaluation system can be used to analyze the characteristics of design schemes or products in different hierarchies to improve existing products or design new products that meet people’s purchase wishes. In the future, the authors will strive to further simplify this subjective evaluation system and develop a corresponding evaluation procedure for rapidly evaluating design schemes or products.

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