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Evaluating User Experience Satisfaction of LED Desk Lamp Using FAHP-FCE Approach

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Abstract
Technology development has effectively guided the design and development of light-emitting diode (LED) desk lamps, and the design and development of desk lamps are closely related to users. However, studies on user satisfaction when using desk lamps are still under explored. To this end, this paper proposes a satisfaction evaluation method that combines the fuzzy analytic hierarchy process (FAHP) and fuzzy comprehensive evaluation (FCE). This research results could provide an effective theoretical and practical reference for the experience design of LED desk lamps to improve and meet users' needs, thereby potentially improving the design of LED desk lamps for better customer satisfaction.

Keywords: LED desk lamp, user experience, product design and development, satisfaction evaluation;

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1.0 Introduction

Desk lamps have become a common tool in people's lives (Huang et al., 2015). At the same time, with the globalization of the economy and the improvement of national living standards, the consumer market has entered the era of experience economy (Tu et al., 2019), and users pay more attention to the experience of using light-emitting diode (LED) desk lamps (Offermans et al., 2014). However, lamp products on the market are increasingly unable to meet modern people's desire for the constant pursuit of quality and emotional attitude towards life (Liang, 2011). This means that there are still many areas to be improved in the field of LED lamp design, and the most important thing is to pay more attention to the user experience in product design and development (Liu & Li, 2019). Because the user experience analysis of LED desk lamps is an essential aspect of product design, user satisfaction is the performance of user experience, and the two are positively correlated (Yoon et al., 2022).

A good user experience satisfies users and provides social and economic benefits (Lin, 2018). In this context, the fuzzy analytic hierarchy process (FAHP) and the fuzzy comprehensive evaluation (FCE) method can be used as satisfaction evaluation tools. First, the evaluation system of user experience satisfaction of LED desk lamps is constructed by obtaining the factors that affect user satisfaction. Then to obtain a more objective index weight, the index weight was calculated by FAHP. Finally, adopting the FCE which combines the degree of human incomprehensibility and the membership degree theory based on fuzzy mathematics. It is helpful because of the ambiguity of user satisfaction evaluation, and qualitative evaluation can be transformed into quantitative evaluation, thus greatly improving the objectivity of data analysis and the uncertainty of evaluation results (Liang et al., 2021). Therefore, this research focuses on identifying suitable evaluation methods for evaluating user satisfaction when using the LED desk lamp. The second objective is to evaluate factors that influence user satisfaction using FAHP and FCE based on actual user experience. Lastly, this research also aims to identify the degree of satisfaction of the LED desk lamp in each factor evaluated. The findings of this research will help designers understand some improvements needed to increase user satisfaction when designing LED desk lamps.

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2.0 Literature Review

With the rapid development of technology in recent years, many researchers have focused on improving the lighting technology of LED desk lamps in the research and evaluation of LED desk lamps. As Ye et al. (2020) researched, to realize an anti-glare LED desk lamp without a second optical element, a light module model with an optimized luminous intensity field was proposed; Yawale et al. (2022) suggested optimizing the LED and observer positions to minimize glare discomfort. Research on colour temperature and human behaviour has also been carried out. Fu et al. (2023) explored the impact of colour temperature and light level on visual comfort, offering insights for ergonomic lighting tool design. In addition, research has been proposed on the uniformity of LED desk lamp illumination and improvement methods (Lin & Chen, 2023). Given the problem of heat dissipation in LED desk lamps, Chu et al. (2015) adopted the design of 12 cooling holes on both sides of the heat sink to produce a chimney effect through natural convection to reduce the temperature.

2.1 Finding evaluation method to evaluate user satisfaction when using LED desk lamp design

Although it is necessary to consider the technology in the design and production, the application of technology must return to the consumer's use of the product and consider the consumers' feelings about the use of LED desk lamps. However, studies on user satisfaction when using desk lamps are still under explored. Therefore, the FAHP and FCE methods will be combined to evaluate the satisfaction of LED desk lamps. The combination of these two methods is widely used in various fields. Sun et al. (2022) used FAHP and FCE to assess the risk of water inrush in karst tunnels. Chen et al. (2015) proposed a teaching performance evaluation system based on the combination of FAHP and FCE, which effectively reflects the situation of each factor. Hu et al. (2018) used FAHP and FCE to evaluate earthquake risk in hydraulic fracturing areas. These studies revealed the applicability of the FAHP and FCE methods for solving practical problems. Therefore, FAHP and FCE are also suitable for evaluating user satisfaction with LED desk lamps.

3.0 Methodology

3.1 Fuzzy analytical hierarchy process (FAHP)

The fuzzy analytical hierarchy process (FAHP) solves the problems of ambiguity and difficult quantification. It mathematically processes people's subjective judgments to make the evaluation results more objective and reasonable (Qin et al., 2021).

The FAHP operation can be divided into the following seven steps:

Step 1: Define the decision problem.

Step 2: Establish an evaluation system. Taking the highest level as the target, the second level is the main factor layer, and the third level is the sub-factor layer.

Step 3: Create a pairwise fuzzy comparison matrix. Table 1 is the linguistic variables and triangular fuzzy number scale.

Table 1: Linguistic variables and triangular fuzzy number scale

Scale	Linguistic variables	Triangular fuzzy number (l, m, u)
1	Equally important	(1, 1, 1)
3	Slightly important	(2, 3, 4)
5	Fairly important	(4, 5, 6)
7	Strongly important	(6, 7, 8)
9	Extremely important	(9, 9, 9)

Step 4: Calculate Factor Weight Values. Normalize the geometric mean of the resulting fuzzy comparison matrix to generate standard fuzzy weights (Buckley, 1985), calculated as equations (1) and (2):

$$\tilde{z}_i = \left(\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \tilde{a}_{in}\right)^{1/n} \tag{1}$$

$$\tilde{w}_i = \tilde{z}_i \otimes \left(\tilde{z}_1 \oplus \tilde{z}_2 \oplus \cdots \tilde{z}_n\right)^{-1} \tag{2}$$

Step 5: The blurred values are transformed into the best non-blurred performance (BNP) values through the defuzzification process, which is calculated as equation (3) (Koçak & Yercan, 2021):

$$BNP_i = \frac{u_i - l_i + (m_i - l_i)}{3} + l_i \tag{3}$$

Step 6: Normalize the deblurred weight value to obtain the normalized weight value (W), calculated as equations (4) (Koçak & Yercan, 2021):

$$W_i = \frac{BNP_i}{\sum_{i=1}^{n} BNP_i} \tag{4}$$

Step 7: To ensure the consistency, stability, and reliability of the measurement results, the consistency of the fuzzy pairwise comparison matrix needs to be checked. Saaty (1994) recommends that the obtained consistency index (CI) ≤ 0.1 and consistency ratio (CR) ≤ 0.1 are acceptable ranges, as in equations (5) and (6).

$$CI = (\lambda \max - n)/(n-1) \tag{5}$$

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

Where n is the number of evaluation factors, λ_{max} is the largest eigenvalue, and RI represents the random index (Saaty, 1994), as shown in Table 2.

Table 2: RI values

n	1	2	3	4	5	6	7	8
RI	0.00	0.00	0.58	0.89	1.12	1.24	1.32	1.42

3.2 Fuzzy comprehensive evaluation (FCE)

Fuzzy comprehensive evaluation (FCE) is based on the application of fuzzy mathematics, which can effectively and comprehensively evaluate phenomena affected by various factors (Cao et al., 2021). The FCE method can be described as five steps (Chen et al., 2015):

Step 1: Establish the set of evaluation factors. According to the characteristics of the evaluation index system, determine the set of factors in the evaluation relationship. The evaluation factor set is defined as:

$$U = \{U_1, U_2, U_3 \cdots U_n\} \tag{7}$$

Step 2: Determine the comment set *V*. The set of comments will be used to finalize satisfaction with each factor outcome. Five evaluation levels were established for the study results:

$$V = \{v_1, v_2, v_3, v_4, v_5\} \tag{8}$$

Step 3: Establishing a fuzzy evaluation matrix *R*. From *U* to *V*, the evaluation result of each factor is a fuzzy set of the comment set, and all the single factor evaluations constitute a fuzzy relation matrix:

$$R = (\mathrm{r}_{ij})_{n*m} = \begin{bmatrix} \mathrm{r}_{11} & \mathrm{r}_{12} & \cdots & \mathrm{r}_{1m} \\ \mathrm{r}_{21} & \mathrm{r}_{22} & \cdots & \mathrm{r}_{2m} \\ \cdots & \cdots & \vdots & \cdots \\ \mathrm{r}_{n1} & \mathrm{r}_{n2} & \cdots & \mathrm{r}_{nm} \end{bmatrix} \tag{9}$$

Step 4: Generate Evaluation Results. The FAHP determines the weight of the evaluation factors *W*. Therefore, the factor weight can be multiplied by the factor evaluation matrix *R* to obtain the evaluation result:

$$B = W_i * R_i = \{b_1, b_2, b_3, \cdots b_m\} \tag{10}$$

Step 5: Satisfaction level evaluation. Combining the obtained FCE matrix with the five satisfaction levels *V* to obtain the satisfaction score S_i:

$$S = B_i * V = \{s_1, s_2, s_3, \cdots s_n\} \tag{11}$$

4.0 Findings

4.1 Establish an LED desk lamp user experience satisfaction index system

Establishing the user experience satisfaction index system for LED desk lamps is the key to evaluating user satisfaction. It is necessary to design the evaluation index system from different angles to evaluate user satisfaction accurately. First, through interviews and investigations, combined with the previous literature on LED desk lamp design to find relevant factors; secondly, the selected main factors and sub-factors are based on the rich experience of colleges and universities industrial design teachers and corporate designers discuss, revise and synthesize in China; finally, the LED desk lamp experience evaluation index framework is established, which is divided into three levels: the first-level index is the target level, namely, the overall satisfaction of consumers; the second-level index is the main factor layer including styling features (U_1), material characteristics (U_2), practical features (U_3), security features (U_4), interesting characteristics (U_5), and characteristics of humanistic environment (U_6); the third-level indicators are the sub-factor layer, which is the embodiment of the second-level indicators, including the aesthetics of the shape (U_{11}), aesthetics of the colour (U_{12}), product style (U_{13}), human scale (U_{14}) and other 16 index factors, as shown in Fig. 1.

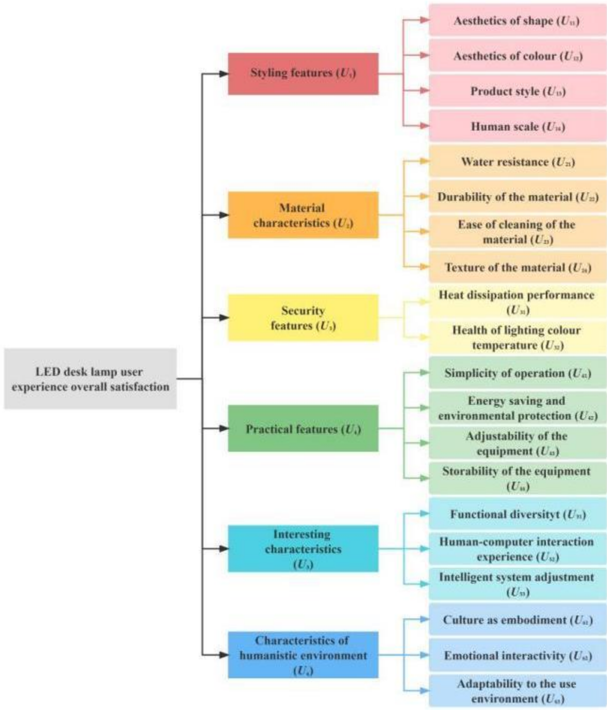

Fig. 1: LED desk lamp user satisfaction index system

4.2 Calculation of weights with the FAHP

To calculate the weights of the main factors and sub-factors, we searched for ten decision-makers, including experienced industrial design teachers and designers. FAHP questionnaire based on a nine-point rating scale to understand their views. The resulting questionnaires will be used to form a comparison matrix for each decision-maker. Finally, the results obtained according to the FAHP calculation program are shown in Table 3.

Table 3: Weights of index factors

Main factor layer	Weights	Sub-factor layer	Weights
Styling features (U_1)	0.162	Aesthetics of shape (U_{11})	0.302
		Aesthetics of colour (U_{12})	0.231
		Product style (U_{13})	0.215
		Human scale (U_{14})	0.252
Material characteristics (U_2)	0.113	Water resistance (U_{21})	0.119
		Durability of the material (U_{22})	0.251
		Ease of cleaning of the material (U_{23})	0.338
		Texture of the material (U_{24})	0.293
Security features (U_3)	0.308	Heat dissipation performance (U_{31})	0.228
		Health of lighting colour temperature (U_{32})	0.772
Practical features (U_4)	0.211	Simplicity of operation (U_{41})	0.365
		Energy saving and environmental protection(U_{42})	0.282
		Adjustability of the equipment (U_{43})	0.187
		Storability of the equipment (U_{44})	0.165
Interesting characteristics (U_5)	0.114	Functional diversity (U_{51})	0.165
		Human-computer interaction experience (U_{52})	0.549
		Intelligent system adjustment (U_{53})	0.286
Characteristics of humanistic environment (U_6)	0.092	Culture as embodiment (U_{61})	0.204
		Emotional interactivity (U_{62})	0.481
		Adaptability to the use environment (U_{63})	0.315

According to equations (5) and (6), CI=0.087<0.1, CR=0.071<0.1, which indicates that the matrix has satisfactory consistency. Similarly, it can be obtained that the CI values of the sub-factor layers are all less than 0.1, and the CR is also less than 0.1, indicating that the evaluation values of the decision makers all meet the acceptable consistency standard.

4.3 Results of FCE calculation

The six main factors and 20 sub-factors collected above are made into a five-point Likert scale questionnaire to collect data. In addition, the questionnaire design research object is users aged 18-60 who use LED desk lamps as auxiliary lighting. The research place takes Sanyuan District, Sanming City, Fujian Province, China, as an example. In total 300 questionnaires were distributed, 269 valid responses were obtained, with an effective recovery rate of 86%. According to the calculation program of FCE, the degree of satisfaction grades is also divided into five levels (Zhang et al., 2021): strongly satisfied ($5.0 \geq S_i > 4.5$), relatively satisfied ($4.5 \geq S_i > 4.0$), general ($4.0 \geq S_i > 3.0$), relatively dissatisfied ($3.0 \geq S_i > 1.5$), strongly dissatisfied ($1.5 \geq S_i \geq 0$), the overall satisfaction and secondary index satisfaction results of LED desk lamp user experience are obtained, as shown in Table 4.

Table 4: LED desk lamp user experience satisfaction evaluation results

Index	Degree of satisfaction grades 5	4	3	2	1	S_i	Degree
Overall satisfaction	0.090	0.218	0.433	0.243	0.016	3.122	General
U_1	0.142	0.339	0.365	0.145	0.010	3.459	General
U_2	0.071	0.214	0.443	0.253	0.020	3.062	General
U_3	0.077	0.181	0.488	0.254	0.000	3.081	General
U_4	0.114	0.217	0.395	0.259	0.015	3.156	General
U_5	0.062	0.210	0.491	0.235	0.001	3.098	General
U_6	0.044	0.144	0.372	0.341	0.099	2.694	Relatively dissatisfied

From the FCE results, we can determine that overall satisfaction is 3.122, the evaluation level is "general", and the second-level index satisfaction is 3.459, 3.062, 3.081, 3.156, 3.098, and 2.694. The evaluation level is "general", "general", "general", "general", " general", and "relatively dissatisfied". Among them, the overall satisfaction of the user experience of the LED desk lamp is strongly satisfied, relatively satisfied, general, relatively dissatisfied, and strongly dissatisfied with the probability of 0.090, 0.218, 0.433, 0.243 and 0.016, respectively, and the evaluation score is 3.122. In this sense, we think that the current user experience satisfaction with LED desk lamps is at the "general" level, hovering between "satisfied" and "dissatisfied".

5.0 Analysis & Discussion

As shown in Fig. 2, users are most satisfied with the styling features index. Since styling is a critical factor in product design, users can feel the product's appearance more quickly and intuitively from multiple visual angles (Naderi et al., 2020). Therefore, good styling attracts users' attention and generates positive feelings to improve user satisfaction (Guo et al., 2022). In contrast, users have the lowest satisfaction with the characteristics of humanistic environment. The characteristic is more about the product's meaning and users' emotional tendencies (Alonso-García et al., 2020). Due to the deviation of the emotional distance between designers and users (Wang et al., 2022), designers do not understand users' emotions and users do not understand designers' design intentions.

Therefore, designers need to carefully examine the aspects of culture as embodiment, emotional interactivity, adaptability to the use environment, and other aspects. In addition, user satisfaction with material characteristics, security, practical, and interesting characteristics indicators are all at the "general" level. Designers should strive to improve user satisfaction based on maintaining the original advantages. In conclusion, we have extracted the decisive factors behind user experience satisfaction, according to the results of the user satisfaction survey. Our method can provide appropriate suggestions for LED desk lamp design guidance and advice to help designers better position design projects and help build stronger connections between users and designers (Koyaz & Ünlü, 2022).

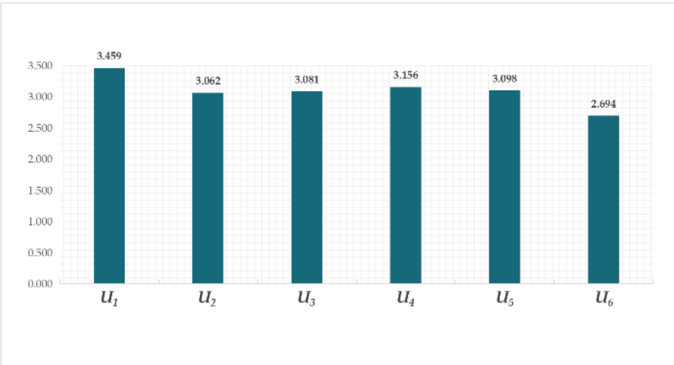

Fig. 2: Main factors index user satisfaction

6.0 Conclusion

This article achieves three objectives: 1) we determined a method based on the combination of fuzzy analytic hierarchy process (FAHP) and fuzzy comprehensive evaluation (FCE) method to evaluate product satisfaction; 2) we explored and evaluated the six main factors and 20 sub-factors that affect the user experience satisfaction of LED desk lamps; 3) we identified the user's overall satisfaction with the LED desk lamp experience and the satisfaction level in each evaluation factor. In this article, we present a study of LED desk lamp users in Sanming City, Fujian Province, China, delving into the user experience. The study found that the overall satisfaction of the user with the LED desk lamps is at a "general" level, which means that there is still much room for improvement in the user experience. In addition, through the reflection of relevant factors collected, it is helpful for designers to understand the areas that need to be improved, to improve the satisfaction of LED desk lamps. After all, good technology is used by people, and designers must be user-centred and strive to improve user experience.

However, due to the limitations of the experimental conditions, the index factors obtained may not be sufficient, but it provides a new way to establish the user experience and evaluation satisfaction model of LED desk lamps. Therefore, we sincerely hope that future researchers and designers can dig deeper into indicator factors and extend the research results to other fields.

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