




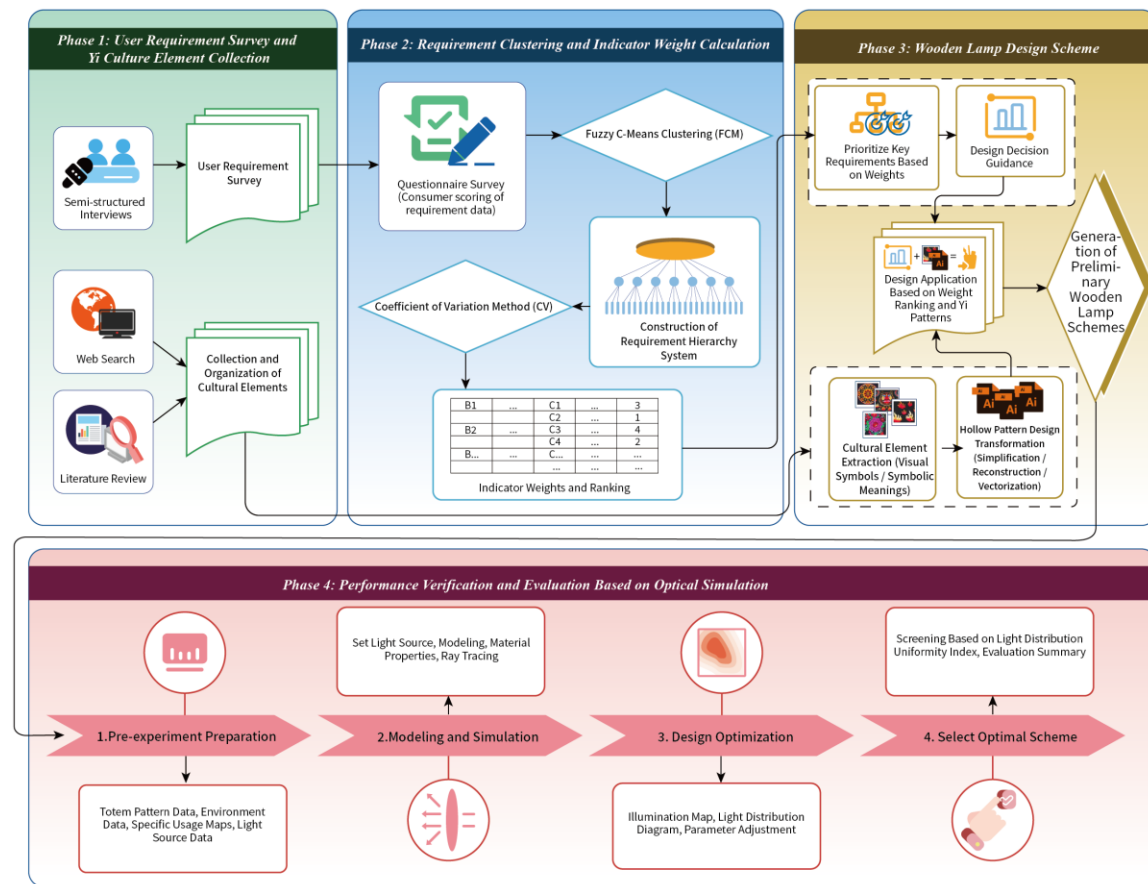
Cultural Semantics-Driven Wooden Lamp Design: An Integrated Framework of Needs Analysis, Symbol Transformation, and Optical Simulation

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GRAPHICAL ABSTRACT



Cultural Semantics-Driven Wooden Lamp Design: An Integrated Framework of Needs Analysis, Symbol Transformation, and Optical Simulation

Jintao Wu ^a, Chunyan Liang ^b, and Qiang Sun ^{a,*}

To address widespread product homogeneity and the scarcity of cultural value in the current lighting market, this study proposes a systematic design framework integrating user needs, cultural elements, and optical performance. The objective is to fabricate wooden lamps that combine cultural significance with optimal user experience and scientific lighting capabilities. User needs were gathered through interviews and questionnaires and then categorized using the Fuzzy C-Means clustering algorithm. Concurrently, the Coefficient of Variation method was employed to objectively determine the weight of each requirement, establishing a quantitative evaluation system. Yi ethnic totem elements were derived through literature review and field research. These cultural symbols were translated into openwork patterns adapted for wooden lamp structures. Guided by the weighted requirements, two distinct design schemes were developed. Finally, TracePro software was utilized to simulate and verify optical performance, specifically analyzing illuminance distribution and luminous intensity uniformity across the prototypes. The results indicate that the configuration combining plant patterns with a frosted lampshade achieved the superior performance among four comparative groups, demonstrating the optimal balance between lighting uniformity and effective coverage area. This study validates the effectiveness of the proposed framework, highlighting the integration of quantitative needs analysis and scientific verification.

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Keywords: Wooden lamp design; Yi ethnic totems; Fuzzy C-Means clustering; Coefficient of Variation method; Optical simulation

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INTRODUCTION

With the continuous improvement of living standards and the evolution of residential lifestyles, the role of lighting design in contemporary interiors has transcended utilitarian functionality. It has become a pivotal medium for modulating spatial atmospheres and enhancing both the comfort and aesthetic quality of indoor environments. Recent academic contributions underscore this paradigm shift. For instance, Shen *et al.* (2024) leveraged Intangible Cultural Heritage (ICH) elements to develop original product designs, assessing their appeal across diverse global demographics. Similarly, Schielke (2019) investigated the application of semiotics as a methodology in lighting design, demonstrating its efficacy in elevating design quality. Despite the growing recognition of

functional and aesthetic values, the current lighting market faces significant challenges. Market saturation and product homogeneity are prevalent, often characterized by a deficit in creativity and personalization. Furthermore, the insufficient integration of regional cultural elements prevents products from differentiating themselves in a competitive market, thereby limiting brand recognition and the propagation of cultural value. To mitigate these challenges, recent studies have explored sustainability and cultural innovation in lighting. Kwon *et al.* (2025) introduced a “beeswax lamp” utilizing natural beeswax and water *via* an ice-casting process, which optimized mechanical strength and light diffusion while adhering to sustainable manufacturing principles. Additionally, Kang and Wang (2025) constructed an optimization method for traditional Chinese wood carving window patterns by combining the Stable Diffusion Model with the Intuitive Fuzzy VIKOR algorithm, successfully applying these generated schemes to wooden lamp design.

The existing literature exhibits a paucity of systematic frameworks specifically designed to validate the cultural expression and user perception of lighting products quantitatively. To address this limitation, this study focuses on wooden lamp design and makes the following primary contributions. (i) It systematically elicits consumer requirements across various dimensions and extracts representative cultural elements from Yi ethnic traditions. (ii) It constructs a robust quantitative evaluation system by applying the Fuzzy C-means (FCM) algorithm to cluster the collected data. Furthermore, the Coefficient of Variation (CV) method is employed to determine objective weights for each indicator, enabling a ranked prioritization of design requirements. (iii) Guided by these weighted user needs and integrated Yi cultural elements, the study proposes wooden lamp designs that are both culturally distinct and user-centric. These designs are then verified through TracePro optical simulation software to assess photometric performance metrics such as illuminance distribution and luminous intensity uniformity, facilitating the selection of the optimal scheme. These findings provide new decision-making strategies and scientific evidence for lighting design while enhancing product marketability.

This research employs a methodological framework combining semi-structured interviews, Fuzzy C-means clustering, and the Coefficient of Variation method. The study proceeds in three stages. Initially, semi-structured interviews were conducted to gather user requirements for wooden lamps, while literature reviews and field research were utilized to acquire Yi cultural elements. Subsequently, the FCM algorithm clustered these requirements into four distinct design categories. Based on these clusters, 126 questionnaires were analyzed to establish a comprehensive evaluation system comprising 4 primary indicators and 25 secondary indicators, with weights assigned via the CV method. Finally, openwork patterns were designed based on the extracted cultural elements. Two lamp design schemes were developed by synthesizing these patterns with the prioritized requirement weights. These schemes then underwent optical performance verification and optimization using TracePro software to ensure a balance between functional efficacy and aesthetic appeal.

Current Status of Home Product Design Research

Residential furnishings encompass a comprehensive array of items, including furniture, lighting fixtures, kitchenware, textiles, fixed installations, decorations, and appliances. Driven by the intensification of consumer demands for both aesthetic quality and functional utility in living environments, the design of these products is increasingly prioritizing a convergence of aesthetics, practicality, innovation, and environmental sustainability. In this context, wooden home products have emerged as central elements of

the interior environment, favored for their natural textures, unique craftsmanship, and warm visual appeal. Recent scholarship illustrates this focus on wood materiality and design optimization. Wang *et al.* (2025) optimized Chinese-style wooden furniture by correlating emotional vocabulary, cultural symbols, and user perception through Analytic Hierarchy Process (AHP), Entropy Weight Method (EWM), and Coupling Coordination Degree methods. This approach improved user experience and emotional resonance, offering new methodologies for innovation in traditional furniture design. Similarly, Mao *et al.* (2024) conducted a two-factor inter-group experiment to investigate aesthetic evaluations of wooden furniture colors in office spaces, providing empirical guidelines for workplace applications. Furthermore, Wu *et al.* (2024) analyzed design cases from prominent Taiwanese wooden furniture brands by decoding furniture characteristics into product DNA and symbols. Using product symbol triangulation, genealogy, and neighborhood axis methods, they elucidated how physical features translate into product representations and established a sequential relationship between form and function. By integrating Design Science Research (DSR) with traditional qualitative methods, Scherer *et al.* (2023) established parameters guided by sustainable behavioral design strategies to assist designers in developing innovative household products suitable for effective promotion.

Distinct from other home furnishings, lighting fixtures serve a dual function. They not only provide essential illumination but also modulate atmosphere and enhance spatial aesthetics. Wang *et al.* (2020) proposed integrating Life Cycle Assessment into the eco-design of lighting, demonstrating through comparative evaluation that new sustainable designs improved environmental performance by 27% to 58%. From a psychological perspective, Lee and Lee (2022) explored the impact of six light colors on pleasure and arousal, revealing that blue light was most pleasurable while red was least, with significant cultural backgrounds affecting these perceptions. Additionally, Shi *et al.* (2025) demonstrated that a user-centric design approach combining cognitive ergonomics with traditional Chinese cultural elements could elevate the aesthetic and cultural value of lighting, thereby enhancing user experience and supporting cultural heritage education.

Current research indicates a clear trajectory in home product design towards greater aesthetics, utility, and sustainability. While existing studies focus heavily on the sustainable design, evaluation, and consumer preferences regarding wooden furniture, or on the psychological and optical aspects of lighting in general, a significant research gap remains. Scholarship specifically addressing wooden lighting fixtures is notably scarce. As a unique category, wooden lamps require the synergy of material properties, lighting effects, and cultural semantics. To address this gap, this study explores the intrinsic link between user needs and cultural symbols. By combining qualitative and quantitative methods, it aims to elucidate the role of cultural symbols in wooden lamp design and validate their impact through specific design cases, thereby driving innovation in the field.

Application of Cultural Symbols in Design

Cultural symbols function as vital conduits of history and social meaning. With globalization and deepening cultural exchange, their application in design has emerged as a focal point of scholarly inquiry. Wang *et al.* (2025) proposed a comprehensive evaluation method involving AHP, EWM, and Quality Function Deployment to embed cultural symbols and emotional needs into Chinese furniture, aiming to reinforce cultural identity. Chen (2025) applied semiotics to analyze the symbolic language of Chaoshan peach cake molds, leveraging shape grammars to transfigure traditional patterns for paper packaging.

In the domain of children's furniture, Li *et al.* (2025) integrated sign duality theory with sustainable principles to digitize and reinterpret Dunhuang tile elements, proposing a trajectory that preserves heritage while enhancing product value. Ofori *et al.* (2023) developed a "Qualitative Aesthetics" model by synthesizing endangered symbols from four Ghanaian ethnic groups, fabricating wall hangings that safeguard cultural heritage and foster a sense of belonging for younger generations. Furthermore, Zhao *et al.* (2024) systematically evaluated historical symbols in Xuzhou's city branding using Grey System Theory and Fuzzy Comprehensive Evaluation, underscoring the imperative of symbol sustainability. Similarly, Weng *et al.* (2020) employed spatial narrative techniques, including topological optimization and hand-drawn symbols, to devise tourist maps for Xi'an, enhancing both functionality and artistic expression. Qin *et al.* (2025) investigated the impact of traditional pattern symmetry on the optimization of home textile design and examined its role in fostering consumer acceptance. Chang *et al.* (2025) drew inspiration from the marbled porcelain of Dangyangyu, Henan Province, integrating these aesthetic elements into conceptual seating designs. Zhang and Rui (2026) incorporated representative cultural elements of Yunnan into packaging design and quantitatively evaluated the design schemes using both subjective and objective metrics. Wu *et al.* (2023) investigated the preservation and innovation of traditional Chinese weaving techniques in modern daily life.

Despite significant progress in applying cultural symbols across furniture, packaging, and branding, most research is predominantly centered on the recontextualization of traditional symbols for modern contexts in general product design. A systematic investigation into the lighting sector remains notably deficient, particularly regarding how to scientifically integrate traditional elements into modern lamp design while harmonizing cultural depth with user experience. Consequently, this study integrates the visual and symbolic elements of Yi ethnic totems into lighting design. It establishes a systematic needs assessment framework combining FCM and CV methods to map user needs and cultural features onto specific design criteria. Furthermore, it employs optical software to verify the applicability and effectiveness of the resulting design schemes.

Research Gap and Innovation

While the aforementioned literature provides valuable insights into home product design, symbol application, and sustainable innovation, this study distinguishes itself from existing research through strategic innovations in research focus, methodological integration, and validation protocols.

Concerning the research focus, there is a notable scarcity of comprehensive research on wooden lamp design. This study explicitly targets wooden lamps as the medium, specifically exploring the integration of Yi totem culture through openwork techniques. This effectively bridges the gap regarding the application of cultural symbols within this specific lighting category.

Methodologically, this study constructs a holistic framework encompassing "user needs elicitation" to "scheme synthesis" and "optical performance verification." By incorporating FCM and CV methods, it establishes a quantitative user needs evaluation system. This approach translates ambiguous emotional needs into concrete design weight indicators, ensuring that the integration of cultural symbols is rigorously user-centric.

Regarding validation, this study transcends mere user preferences for culture and aesthetics. It rigorously employs optical simulation software to verify the physical performance of the final designs. This ensures that the fundamental photometric function

is not compromised by aesthetic or cultural augmentations. This study aims to build a comprehensive framework spanning from cultural symbols to user needs and physical validation, providing a systematic decision-making model for lighting design that encompasses cultural depth, user-centricity, and technical feasibility.

In conclusion, the core distinction and innovation of this study reside in its specific focus on “wooden lamps” and the construction of an integrated design research methodology. This provides a new, scientifically grounded paradigm for the development of wooden lighting products in both theory and practice.

EXPERIMENTAL

Research Framework

This study proposes a systematic methodology for systematically integrating Yi totem culture into wooden lamp design. The primary objective is to synthesize design schemes that exhibit optimal performance in cultural expression, user satisfaction, and optical capabilities. To achieve this, the research integrates qualitative and quantitative tools, constructing a design decision model grounded in objective data. A structured research framework, depicted in Fig. 1, is proposed to realize this objective. This framework synergizes the FCM clustering algorithm, the CV method, and TracePro optical simulation software. The framework comprises four core steps.

(1) Initially, multi-dimensional user requirements for wooden lamps are elicited through semi-structured interviews. Concurrently, key visual and symbolic elements of Yi totems are cataloged, organized, and derived through systematic literature reviews and field investigations.

(2) The FCM clustering algorithm is employed to categorize user needs, thereby establishing a hierarchical user needs evaluation system. Subsequently, the CV method is utilized to determine the weight of each design indicator within this system, delineating the prioritization for subsequent design decisions.

(3) Yi ethnic pattern elements are abstracted and vectorized to ensure their applicability to wooden lamp structures. Guided by the weighted priorities obtained in the previous step, specific design parameters, encompassing morphology, material selection, dimensions, structure, and functional features, are defined. This process synthesizes the completion of two preliminary wooden lamp design schemes.

(4) TracePro optical simulation software is deployed to model and simulate the generated lamp design schemes. By defining specific light source and material parameters, data reports on critical optical performance metrics, such as illuminance distribution and luminous intensity uniformity, are generated and analyzed. These results provide an empirical engineering basis for scheme selection.

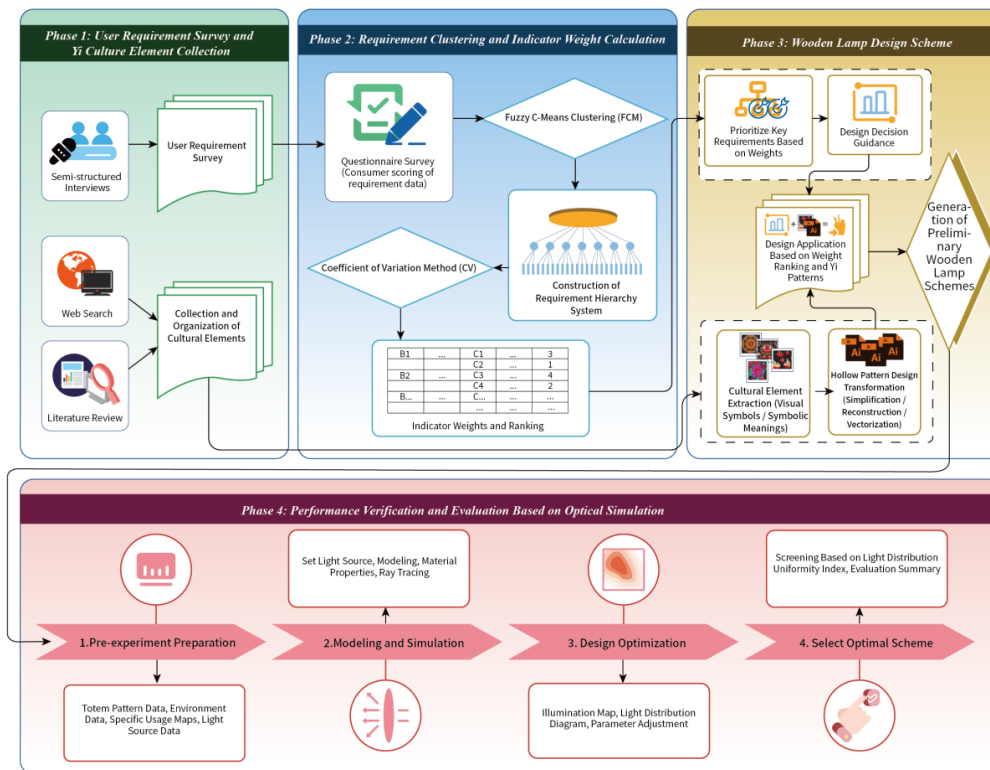


Fig. 1. The overall framework diagram of the research

Fuzzy C-means

This study employs the Fuzzy C-Means (FCM) clustering algorithm to partition the data. Based on fuzzy set theory, FCM aims to allocate data points from a dataset into multiple clusters while allowing each data point to belong to multiple clusters with varying degrees of membership. Unlike traditional K-means clustering, which produces hard partitioning results where a sample belongs exclusively to a single class, FCM characterizes the degree of belonging through membership functions. This feature makes it particularly suitable for addressing clustering problems with ambiguous boundaries (Dunn 1973). In this research, the FCM method is utilized to perform cluster analysis on user requirement importance ratings. Compared to traditional hard clustering methods, FCM aligns more closely with the inherent ambiguity of human perception and prevents information loss. It enhances the rationality of clustering results, thereby providing a robust data foundation for subsequent weight calculations. The computational procedure proceeds through the following steps.

Step 1: Membership initialization

A membership matrix $U^{(0)}$ is randomly generated that satisfies the following constraint.

$$u_{ki}^{(0)} \in [0,1], \sum_{k=1}^c u_{ki}^{(0)} = 1. \quad (1)$$

Step 2: Cluster center update

In the t -th iteration, the center of each cluster is updated according to $U^{(t)}$,

$$v_k^{(t)} = \frac{\sum_{i=1}^n (u_{ki}^{(t)})^m x_i}{\sum_{i=1}^n (u_{ki}^{(t)})^m} \quad (2)$$

where $k = 1, \dots, c$.

Step 3: Membership update

After obtaining the new cluster centers, the membership degrees are updated based on the distance from the samples to each center,

$$u_{ki}^{(t+1)} = \frac{1}{\sum_{j=1}^c \left(\frac{\|x_i - v_k^{(t)}\|}{\|x_i - v_j^{(t)}\|} \right)^{\frac{2}{m-1}}} \quad (3)$$

where $k = 1, \dots, c; i = 1, \dots, n$.

Step 4: Convergence judgment

Steps 2 and 3 are repeated until the change in membership degrees between two adjacent iterations is sufficiently small:

$$\max_{k,i} |u_{ki}^{(t+1)} - u_{ki}^{(t)}| < \varepsilon \quad (4)$$

Alternatively, if the number of iterations reaches a preset limit, the algorithm is considered to have converged, yielding the final cluster centers.

Step 5: Category assignment

Based on the final membership matrix, samples are assigned to the cluster where they hold the maximum membership degree:

$$\text{label}(i) = \arg \max_k u_{ki}, i = 1, \dots, n \quad (5)$$

Coefficient of Variation Method

Following the construction of the user needs evaluation system, it is necessary to determine the relative importance, or weight, of each indicator within the system. The Coefficient of Variation Method (CVM) is a statistical approach that assigns objective weights based on the internal variability of the data (Chan and Vese 2001). This method operates independently of subjective human judgment, with weights determined entirely by the distribution characteristics of the survey data. The core principle posits that if a specific indicator exhibits significant value differences across all evaluated objects, its discriminating power is strong. Consequently, it provides a greater amount of information and should be assigned a higher weight in the comprehensive evaluation. Compared to the Range Method or Standard Deviation Method, the CVM eliminates the influence of dimensions and numerical magnitude on weights, making it applicable to indicators with different units or orders of magnitude. The process includes the following primary steps.

Step 1: Calculation of mean and standard deviation

The mean value \bar{x}_j and standard deviation s_j was calculated for each indicator as follows,

$$\bar{x}_j = \frac{1}{n} \sum_{i=1}^n x_{ij} \quad (6)$$

$$s_j = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_{ij} - \bar{x}_j)^2} \quad (7)$$

where x_{ij} represents the evaluation score of the i -th sample on the j -th indicator, and n denotes the total number of samples.

Step 2: Calculation of Coefficient of Variation

The coefficient of variation CV_j was calculated for each indicator. The coefficient of variation is the ratio of the standard deviation to the mean, used to eliminate the effects of different indicator units and magnitudes, thereby measuring the relative dispersion of the data.

$$CV_j = \frac{s_j}{\bar{x}_j} \quad (8)$$

Step 3: Normalization and weight calculation

The coefficients of variation were normalized to obtain the weight w_j for each indicator,

$$w_j = \frac{CV_j}{\sum_{j=1}^m CV_j} \quad (9)$$

where m represents the number of indicators. Through normalization, it is ensured that the sum of all weights equals 1.

RESULTS AND DISCUSSION

User Requirements Collection

This study utilized a qualitative research approach *via* semi-structured interviews to investigate user requirements for wooden lamps across various dimensions in domestic usage scenarios. A purposive sampling method was employed, inviting a total of 26 interviewees to participate in this investigation. The sample encompassed diverse consumers aged 18 to 50 with varied occupational backgrounds to ensure the heterogeneity and representativeness of the qualitative data. The 26 interviewees included 14 males and 12 females, with a professional distribution comprising 40% designers, 30% office workers, and 30% students to ensure diverse user perspectives. Upon completion of data acquisition, content analysis was applied to filter, synthesize, and refine the interview content. Ultimately, 25 representative wooden lamp design requirements were distilled from the interview transcripts (Table 1), forming the initial dataset for subsequent research.


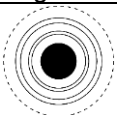




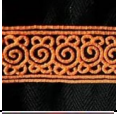
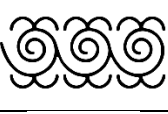










Through this process, ambiguous colloquial descriptions were successfully transformed into 25 distinct user needs, laying the data foundation for constructing a quantitative evaluation index system using the FCM clustering algorithm in the subsequent section.

Table 1. Original User Requirement Corpus List

No.	Requirement Indicator	Original Interview Excerpt (Translated & Synthesized)
1	Fluidity of Lines N1	"The contours of the lamp should be smooth. I prefer fluid designs over rigid, straight lines; it needs to possess a sense of design."
2	Energy-Efficient Design N2	"As a frequently used item, it must be energy-saving. LED sources are preferred to align with the concept of a green lifestyle."
3	Eco-friendly & Odorless N3	"The surface coating must be environmentally friendly. There should be no pungent smell of oil paint."
4	Visual Lightness N4	"Wood itself is heavy, so the morphological design should appear visually light rather than cumbersome."
5	Structural Stability N5	"Connections between parts must be robust. No wobbling is acceptable, and the base must be stable."
6	Morphological Uniqueness N6	"I want to avoid generic mass-market styles. I hope for a shape that is distinctive and unique."
7	Cable Management N7	"Long, dragging cables are messy. If the base could conceal excess wiring, the tabletop would look much tidier."
8	Modern Reinterpretation of Symbols N8	"I hope traditional symbols can be deconstructed and reorganized, creating a design that holds both modern sensibility and traditional value."
9	Visual Tension of Geometric Order N9	"I appreciate the rhythmic arrangement of regular geometric lines. It creates a strong visual impact."
10	Craftsmanship Precision N10	"Details determine success. Joints and hollowed-out edges must be processed cleanly and precisely."
11	Wood Material Selection N11	"The choice of wood is crucial. I like the deep tones of walnut or the fresh feel of ash wood."
12	Bionic Form Evolution N12	"If the lamp's shape simulates the growth forms of plants, making natural textures three-dimensional, it will be more vital than flat decoration.""
13	Thermal Safety N13	"Wood is sensitive to high temperatures. I worry about overheating after long use, so the heat dissipation structure must be well-designed."
14	Cultural Narrativity N14	"If there is a legend or auspicious meaning behind the design, I would consider it more collectible."
15	Innovation in Craft Fusion N15	"Do not overuse modern industrial technology, as the warmth of wood might be lost. I hope to combine modern precision structures with traditional mortise and tenon skills."
16	Spatial Integration N16	"I hope it is versatile enough to be placed by the bedside, in a tea room, or in the living room."
17	Ease of Operation N17	"Operation should not be complicated. One-touch adjustment for brightness or color temperature is preferred; it should be worry-free before sleep."
18	Emotional Resonance N18	"When lit, the lamp should give a sense of warmth and tranquility, making one feel grounded."
19	Cultural Recognizability N19	"As a product, it must have clear recognizability, allowing people to identify it as a design from a specific culture at a glance."
20	Visual Metaphor of Cultural Spirit N20	"The light should be a cultural metaphor, like the fire in a traditional fire pit, symbolizing brightness and inheritance, acting as a spiritual center for the home."
21	Durability & Maintenance N21	"Wood is prone to dampness and cracking. I hope it is mildew-proof, durable, and easy to maintain."
22	Aesthetic of Light & Shadow N22	"The light projected through the shade should not be chaotic. I hope for a unique rhythm of light and shadow on the wall, creating an interplay of void and solid."

23	Morphological Innovation N23	"Break the rigid form of traditional table lamps with added bases. A special shape would be better."
24	Safety of Edges N24	"Edges should be rounded. Avoid sharp corners, especially to prevent bumping into them when placed by the bedside."
25	Contemporary Application of Craft N25	"I hope to retain the traces of hand carving or polishing to reflect the warmth of handwork, but the processing standards must meet modern industrial quality."

Table 2. Classification Table of Yi Totems

Category	Totem Name	Pattern Example	Morphological Analysis	Cultural Connotation and Narrative Meaning
Nature Worship	Sun Pattern			In Yi culture, the sun is the source of life and a symbol of brightness. It is often carved on the gables of houses to pray for the sun's protection and to drive away darkness.
	Fire flake Pattern			Fire is the soul of Yi traditions. The fire flake pattern represents the "eternal fire" of the hearth, symbolizing the continuity of the family lineage and warding off evil spirits.
	Water/Wave Pattern			Inspired by the rivers in mountainous regions, this pattern symbolizes the fluidity of life and the ancestors' hope for smooth, peaceful journeys through nature.
Animal Totems	Horn Pattern			As a symbol of the Yi people's nomadic history, the horn represents wealth and social status. It is frequently used in lacquerware to show power and dignity.
	Bull's Eye Pattern			The "eye" is believed to possess the power of spiritual insight. In decorative arts, it represents wisdom and the ability to foresee auspicious opportunities.
Plant/Floral	Ma Ying Azalea Pattern			Known as the "sacred flower," it represents tenacious vitality. It is often used in weddings and festivals to bless offspring with prosperity and pure love.
	Fern Pattern			As a common plant in the high-altitude habitats of the Yi people, the fern symbolizes tenacious vitality and reproduction. It is often used to express the hope for a thriving family and the healthy growth of offspring.
Geometric	Octagonal Pattern			This pattern represents the "eight directions of the universe" in Yi cosmology, serving as a spiritual anchor that symbolizes family unity and the stability of the world.
	Coin Pattern			The coin pattern, characterized by its circular or square-hole geometry, represents unity and completeness. It carries the symbolic meaning of perfection and the harmonious connection between people and nature.

Collection of Yi Cultural Elements

Yi culture, regarded as an Intangible Cultural Heritage, embodies profound ethnic spirit and symbolic significance. This study selected motifs from traditional Yi cultural elements as research samples to characterize their morphological and decorative features. The objective was to isolate design elements with strong symbolic resonance and visual impact, providing a foundational dataset for wooden lamp design. Through a systematic literature review and an analysis of material culture, including Yi lacquerware, silverware, and textile embroidery, traditional Yi graphic patterns were cataloged and organized. The research indicates that Yi visual aesthetics prioritize black, red, and yellow hues, and their patterns exhibit highly abstract geometric characteristics. Synthesizing these findings, the following four categories of representative core elements were identified: Nature Worship, Animal Totems, Botanical Motifs, and Geometric Ornamentation, as presented in Table 2. Although Yi aesthetics traditionally feature red, black, and yellow, this design prioritizes the natural texture of wood (N11) to meet the user's high preference for 'Eco-friendly' and 'Warm' perceptions.

Requirements Clustering Analysis

Building upon the 25 wooden lamp design requirements derived through user needs elicitation and analysis, this study employed the FCM clustering algorithm to systematically categorize the data. The objective was to mitigate issues related to indicator fragmentation and semantic overlap. A questionnaire utilizing a 7-point Likert scale was designed to quantify user preferences, inviting consumers to rate the level of importance for each requirement indicator. The scoring range extended from 1 (completely unimportant) to 7 (extremely important). The questionnaires were distributed through a combination of online and offline channels. A total of 135 questionnaires were disseminated. After excluding questionnaires with a completion time of less than 60 seconds or those showing repetitive response patterns, 126 valid questionnaires were retained, resulting in a valid response rate of 93%.

In the clustering analysis in Fig. 2, the FCM algorithm partitioned the 25 design requirements into four distinct clusters, representing different dimensions of needs in wooden lamp design:

Cluster 1 focuses on Craftsmanship & Safety. This cluster reflects user concerns regarding the physical attributes, safety, and manufacturing precision of wooden lamps. Specifically, it includes Eco-friendly & Odorless (N3), Structural Stability (N5), Craftsmanship Precision (N10), Wood Material Selection (N11), Thermal Safety (N13), Innovation in Craft Fusion (N15), and Durability & Maintenance (N21). Cluster 2 concentrates on Appearance & Aesthetics. It covers indicators related to the visual form, including Fluidity of Lines (N1), Visual Lightness (N4), Morphological Uniqueness (N6), Spatial Integration (N16), Morphological Innovation (N23), and Safety of Edges (N24). Cluster 3 summarizes requirements related to Functional Efficiency. It embodies user demands for the basic usage experience and product convenience, encompassing Energy-Efficient Design (N2), Cable Management (N7), and Ease of Operation (N17). Cluster 4 centers on Cultural Value & Translation. It comprises indicators such as Modern Reinterpretation of Symbols (N8), Visual Tension of Geometric Order (N9), Bionic Form Evolution (N12), Cultural Narrativity (N14), Emotional Resonance (N18), Cultural Recognizability (N19), Visual Metaphor of Cultural Spirit (N20), Aesthetic of Light & Shadow (N22), and Contemporary Application of Craft (N25).

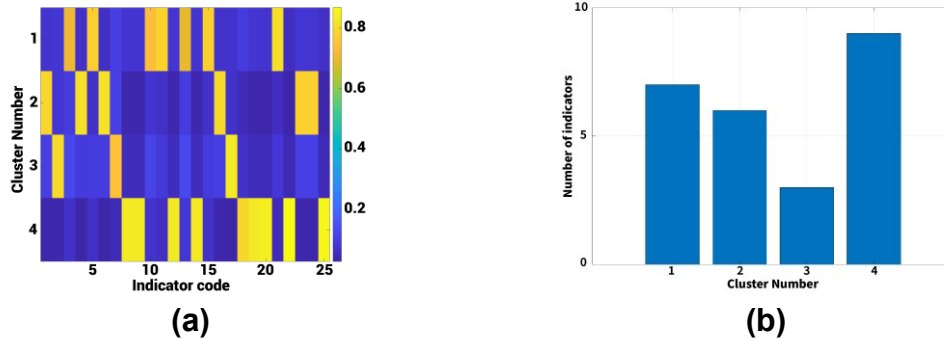


Fig. 2. FCM clustering results. (a) Heatmap of membership degree matrix and (b) sample quantity statistics by cluster

Through FCM clustering analysis, a rigorous and quantifiable design requirement indicator system for cultural wooden lamps was established. This system comprises three hierarchical levels: the target layer, primary indicators, and secondary indicators. The primary indicators correspond to the four demand clusters identified previously: Craftsmanship & Safety (B1), Appearance & Aesthetics (B2), Functional Efficiency (B3), and Cultural Value & Translation (B4). Within this framework, 25 specific secondary indicators were established and systematically encoded, as shown in Fig. 3.

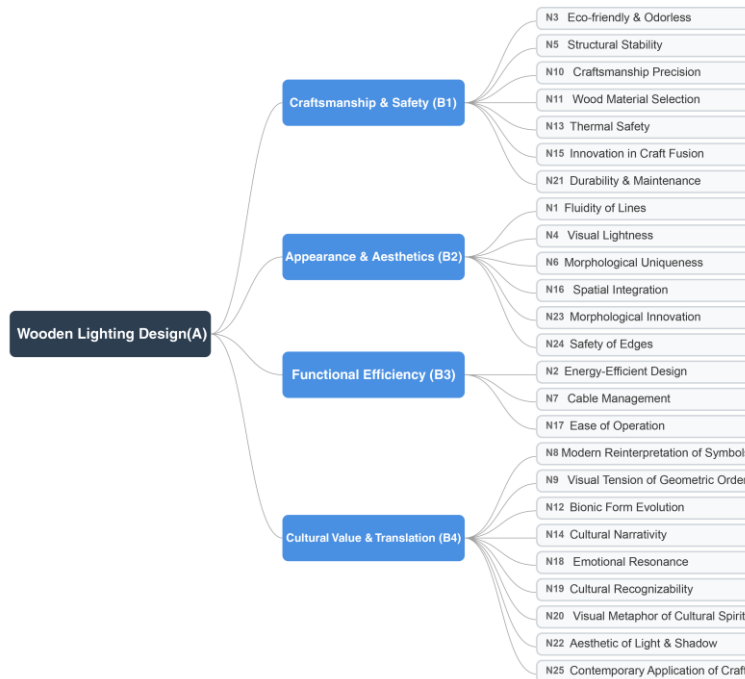


Fig. 3. Indicator system for design requirements of wooden lighting fixtures

This classification result effectively eliminates semantic overlap between indicators and clarifies the attribute classification of each element, providing a solid framework for constructing a quantitative evaluation system for wooden lamp design. Subsequently, this study builds upon these clustering results by introducing the CV method to objectively assign weights to indicators at each level, thereby quantifying the differences in importance among various design elements.

Weighting Analysis

To ascertain the relative importance of each indicator within the evaluation system, this study calculated the objective weights of the 25 indicators based on the constructed indicator system and questionnaire data employing the CV method (Table 3). This process quantified the relative significance of each design requirement within the hierarchical framework.

Table 3. Weight Calculation Results of Evaluation Indicators

Criterion Layer & Weight	Layer Weight	Indicator Code	Mean	Standard Deviation	Coefficient of Variation (CV)	Indicator Weight	Rank
B1	0.2633	N3	4.8016	0.8487	0.1768	0.0379	13
		N5	4.6746	0.7882	0.1686	0.0362	16
		N10	4.6667	0.8099	0.1736	0.0372	14
		N11	4.7143	0.8377	0.1777	0.0381	12
		N13	4.7143	0.8659	0.1837	0.0394	11
		N15	4.6667	0.8579	0.1838	0.0394	10
		N21	4.7698	0.7814	0.1638	0.0351	19
B2	0.1921	N1	5.6905	0.8145	0.1431	0.0307	25
		N4	5.7778	0.8662	0.1499	0.0321	22
		N6	5.7381	0.8502	0.1482	0.0318	23
		N16	5.6587	0.8869	0.1567	0.0336	20
		N23	5.6349	0.8635	0.1532	0.0329	21
		N24	5.6349	0.8159	0.1448	0.0310	24
B3	0.1081	N2	5.2381	0.8983	0.1715	0.0368	15
		N7	5.2222	0.8753	0.1676	0.0359	17
		N17	5.2619	0.8688	0.1651	0.0354	18
B4	0.4365	N8	3.7619	0.8893	0.2364	0.0507	1
		N9	3.7302	0.8041	0.2156	0.0462	8
		N12	3.8492	0.8861	0.2302	0.0494	5
		N14	3.7619	0.8336	0.2216	0.0475	6
		N18	3.8016	0.8297	0.2182	0.0468	7
		N19	3.7937	0.8793	0.2318	0.0497	4
		N20	3.8016	0.8101	0.2131	0.0457	9
		N22	3.7143	0.8751	0.2356	0.0505	2
		N25	3.7143	0.8659	0.2331	0.0500	3


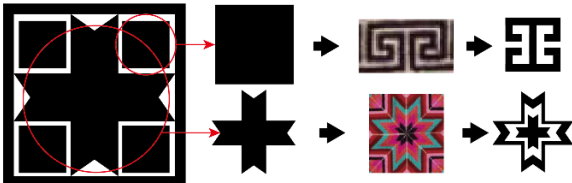

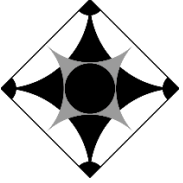
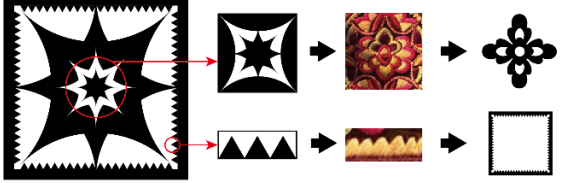

Based on the CV calculation results, the hierarchical prioritization of the demand indicators was established. The primary requirements are ranked as follows: B4 > B1 > B2 > B3. The ranking for key secondary indicators is N8 > N22 > N25 > N19 > N12 > N14 > N18 > N9 > N20 > N15. Among the primary indicators, Cultural Value & Translation (B4) attained the highest weight of 0.4365, indicating that cultural depth and symbolic expression should be the primary considerations in wooden lamp design. Craftsmanship & Safety (B1) occupies the second most significant position, suggesting that while users pursue cultural expression, they remain highly concerned with the product's craftsmanship and safety standards. Analysis of the secondary indicator rankings reveals that users are not satisfied with a superficial accumulation of traditional symbols. Instead, they desire a Modern Reinterpretation of Symbols (N8) combined with high-quality presentation. The high rankings of N8 and Aesthetic of Light & Shadow (N22) highlight that "symbolic form" and "light projection" are critical carriers for cultural

translation. Therefore, in subsequent design practice, it is essential to transcend two-dimensional decorative thinking. Designers must combine cultural symbols with light projection, utilizing the warm texture of wood to transform abstract cultural semantics into a perceptible lighting atmosphere, thereby creating more competitive wooden lamp products for users.

Design Proposal

Guided by the weighting analysis results, Cultural Value and Craftsmanship Quality were prioritized as the guiding design strategies. Synthesizing the earlier extraction and analysis of Yi cultural elements, the design process unfolded as follows: Regarding geometric patterns, the Octagonal Pattern was selected from Yi costumes and lacquerware due to its regular symmetric structure, aligning with the high-weight indicator Visual Tension of Geometric Order (N9). The Octagonal Pattern was selected not only for its geometric symmetry but also for its symbolic role as a “spiritual center”. Using geometric abstraction, complex traditional lines were simplified into concise vector structures suitable for laser cutting. While retaining the core “center-radiation” structure to ensure pattern simplicity and usability, the “Square Spiral Pattern” surrounding the octagon was extracted as a formal supplement for the corners. Additionally, the “Octagonal Star” element was reinforced by incorporating a black cross shape to ensure the physical stability of the wooden structure. Regarding natural patterns, the Ma Ying Azalea Pattern was chosen as a symbol of vitality, with the design process focusing on the flower’s radial symmetry, aligning with the high-weight indicator Bionic Form Evolution (N12). Through simplification and array arrangement, complex natural forms were transformed into continuous curves suitable for hollow carving. This approach retains the identifiable features of the plant while meeting the technical requirements for light transmission and structural integrity. The specific transformation of lamp design elements is illustrated in Table 4.

Table 4. Element Deconstruction and Redesign Process

Deconstruction of the original form	Derivation of the design process	Design result
		 <ul style="list-style-type: none"> ● Black: Wooden material ○ White: Perforated section
		 <ul style="list-style-type: none"> ● Black: Wooden material ○ White: Perforated section

With the highest-weighted indicator Modern Reinterpretation of Symbols (N8) as the core guide, the wooden lamp structure was divided into three modules: the hollowed-out pattern unit, the frame support module, and the lighting device. During the transition from traditional flat patterns to three-dimensional lamp structures, 3D software was utilized

for solid modeling simulation. This ensured that no structural weaknesses occurred while adapting the patterns to the two lamp frames. The design maintained the artistic integrity and cultural value of the patterns while optimizing the balance between the solid skeleton and light-transmitting areas. To balance decorative aesthetics with practical illumination, the hollow light-transmitting area for both lampshades was maintained above 70%, maximizing light output without compromising structural completeness. Ultimately, two design schemes with distinct visual tensions were completed, as shown in Fig 4.

To ensure structural stability and aesthetic balance, the overall physical dimensions of the wooden lamp were precisely defined. The total height of the lamp is 315 mm, comprising a top cap (25 mm), a main body frame (230 mm), a middle support (25 mm), and a base pedestal (35 mm). The lamp body has a maximum width of 250 mm, and the hollow pattern unit measures 210 mm × 160 mm. The main wooden panels maintain a consistent thickness of 5 mm. Subsequently, digital modeling and high-fidelity rendering were performed using 3D modeling software, providing a foundation for the subsequent manufacturing and generation stages. The selection of the final lamp design follows a sequential decision-making process based on the transition from Phase 3 to Phase 4. First, preliminary candidate schemes are developed by integrating Yi ethnic symbols into wooden lamp structures. These schemes are then subjected to systematic optical evaluation. The TracePro simulation results serve as the primary criteria for filtering the optimal scheme.



Fig. 4. 3D modeling views, pattern application, and scene rendering effects of the final design scheme

TracePro Optical System Simulation Experiment

TracePro, a widely utilized optical analysis software based on the Monte Carlo ray tracing algorithm, is extensively employed in stray light analysis, photometric efficiency simulation, and irradiance distribution testing for illumination systems. It is capable of realistically simulating light propagation paths and interactions within complex three-dimensional geometries (Rdhaounia *et al.* 2023). TracePro7.4 (Lambda Research Corp., Littleton, MA, USA) simulation software was utilized to construct an optical model of the wooden lamp, adopting Illumination Uniformity and Illumination Coverage Area as core evaluation indicators. The objective was to assess the rationality of the schemes and identify the optimal balance between visual comfort and lighting efficiency. Simultaneously, to deeply explore the specific impact of different material structures on

light and shadow quality, a comparative model was constructed in the experimental design. For the two wooden lamp design schemes, two internal configurations were set respectively. One configuration features an external semi-transparent lampshade responsible for light diffusion. The material was defined as frosted polymethyl methacrylate (PMMA), whose semi-transparent characteristic induces light scattering effects through surface microstructures, thereby homogenizing the luminous flux distribution. The other configuration employs a direct lighting structure without an inner shade, resulting in a more concentrated distribution of light energy. Based on this, four independent simulation groups (two designs \times two configurations) were established. By comparing and analyzing the candela distribution and irradiance values on a specific receiver surface for these four groups, scientific grounds for structural optimization of the final physical prototype was provided.

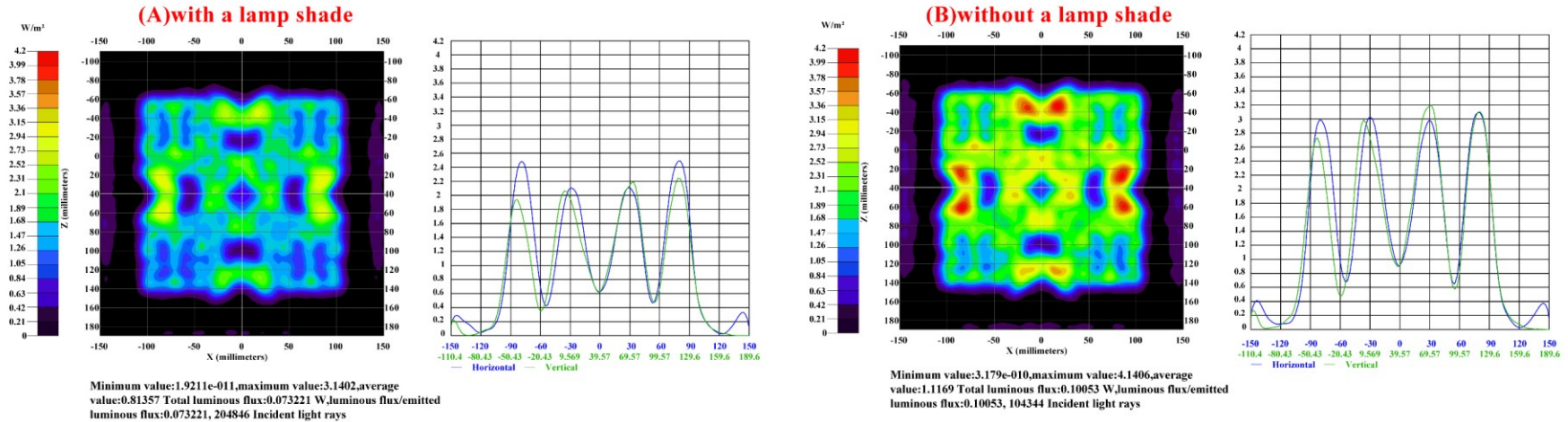
The models were exported from the 3D software in STEP format and imported into TracePro for the configuration of light source position, luminous intensity, and other parameters. The STEP format was chosen for export to maintain high-precision geometric topology and material boundary definitions during the transfer from CAD to optical simulation environments. In this setup, the light source was defined as a central cylindrical surface emitting red light with a radiant power set to 1 W. Ray tracing with a threshold of 1 million rays was generated to ensure the accuracy and smoothness of the Irradiance Map. Subsequently, the material for the different structural parts of the lamp was assigned. The openwork pattern units and frame support modules were defined as wood, while the material for the experimental groups with lampshades was set as Frosted PMMA with defined surface scattering properties. The dimensions of the created receiver surface were set slightly larger than the geometric dimensions of the hollow pattern unit (250 mm \times 250 mm) during simulation. This ensured that all emitted rays were completely sampled and minimized the impact of edge effects on the statistical results of illumination. Following the creation of the receiver surface, ray tracing simulation was conducted, yielding ray tracing diagrams and irradiance distribution analysis maps for the four independent simulation groups (Fig. 5). Finally, the light distribution uniformity for each group was calculated according to (DiLaura *et al.* 2011).

$$U \text{ (uniformity)} = \frac{E_{min}}{E_{max}} \quad (10)$$

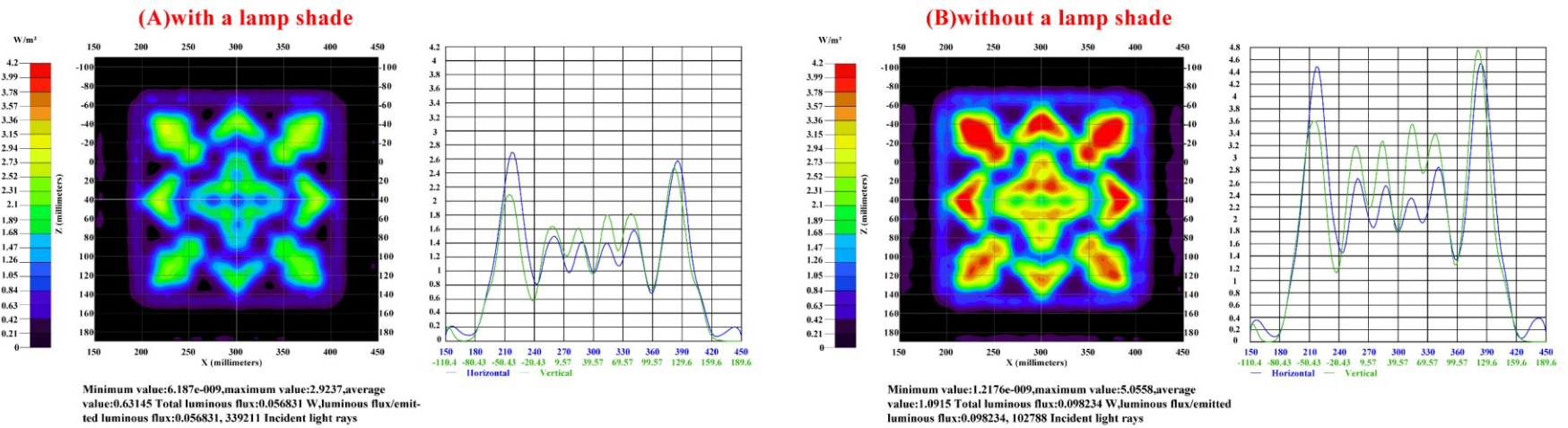
The illumination coverage range is presented in Table 5. The coverage range is represented by the dimensions of the effective illumination area in the receiver irradiance map. It is obtained by reading the maximum span in the X and Z directions, denoted as W and H , according to the coordinate axes. The coverage area A is calculated as $A = W \times H$ (Kang and Wang 2025). Because the boundary of the effective illumination area exhibits a continuous gradient characteristic, the dimensions of the light coverage were estimated by reading approximations from the coordinate axes. The values provided in the text are approximate.

The results indicate that the botanical pattern lamp outperformed the geometric pattern in light uniformity under both configurations, with the “Botanical Pattern with Frosted Shade” configuration achieving the highest uniformity. This is attributed to the frosted shade’s effect of smoothing intensity peaks and filling valleys, thereby significantly raising the minimum irradiance level. In contrast, after installing the lampshade on the geometric pattern lamp, the occlusion and shadow superposition caused by the straight lines and sharp angles in the pattern structure was intensified. This resulted in more

localized low-irradiance areas, leading to a decrease in uniformity. Regarding light coverage, removing the lampshade expanded the effective illumination area for both pattern types, with the “Botanical Pattern without Shade” scheme achieving the maximum light coverage. However, from a comprehensive perspective, the combination of the botanical pattern and the frosted lampshade possesses a distinct advantage in light uniformity, whereas the shade-less scheme is conducive to obtaining a larger coverage range. Nevertheless, based on a comprehensive performance analysis, the Botanical Pattern combined with the Frosted Lampshade achieved a more rational balance between light uniformity and coverage area. Consequently, it was selected as the optimal lighting design scheme in this study.



Wooden Lamp Design Scheme with Geometric Patterns



Wooden Lamp Design Scheme with Botanical Patterns

Fig. 5. Comparison of irradiance distributions for wooden lamps with different patterns under lampshaded conditions

Table 5. Comparison of Illuminance Uniformity and Coverage Range among Four Simulated Cases

No.	Pattern Type	Lamp Shade Status	E_{min} (W/m ²)	E_{max} (W/m ²)	Uniformity U	Coverage Dimensions (mm)	Coverage Area (mm ²)
A	Geometric Patterns	With	1.921×10^{-11}	3.1402	6.12×10^{-12}	300 × 240	72000
B	Geometric Patterns	Without	3.179×10^{-10}	4.1406	7.68×10^{-11}	300 × 260	78000
C	Botanical Patterns	With	6.187×10^{-9}	2.9237	2.12×10^{-9}	300 × 240	72000
D	Botanical Patterns	Without	1.2176×10^{-9}	5.0558	2.41×10^{-10}	300 × 270	81000

CONCLUSIONS

1. The research results indicate that user requirements for wooden lamps can be categorized into four major classes: Craftsmanship & Safety (B1), Appearance & Aesthetics (B2), Functional Efficiency (B3), and Cultural Value & Translation (B4). Among these, the demand for Cultural Value & Translation holds the highest weight in the overall requirement system, followed by Craftsmanship & Safety, while Appearance & Aesthetics and Functional Efficiency rank third and fourth, respectively. Each major class contains several secondary requirements, with the ranking result of key secondary indicators being $N8 > N22 > N25 > N19 > N12 > N14 > N18 > N9 > N20 > N15$ (and others as listed). Guided by these weighted indicators, two unique patterns, “Octagonal Pattern” and “Ma Ying Azalea Pattern,” were extracted as hollow pattern units for the lamps, and their modeling was completed in 3D software.
2. This study employed TracePro optical simulation software to conduct four groups of comparative experiments on different configurations. The simulations demonstrate that distinct morphological patterns and lampshade configurations significantly modulate the photometric performance of wooden lamps. Specifically, the “Botanical Pattern combined with Frosted Lampshade” design scheme achieved the optimal balance between light uniformity and coverage area. The frosted medium functioned to smooth the luminous intensity, effectively balancing the light distribution and eliminating excessive contrast between light and dark. It optimized the lighting effect while preserving the artistic layering of the pattern. Therefore, it was established as the optimal design scheme.
3. This study proposed a novel trajectory for integrating ethnic minority totem culture into modern wooden lamp design. It constructed a systematic design framework that synthesizes user needs, cultural translation, and optical performance. Furthermore, it validated the effectiveness of this comprehensive evaluation framework, which combines qualitative and quantitative methods, in reconciling the “Cultural Aesthetics” of traditional craft with the “Functional Needs” of modern products.
4. Future research will focus on the fabrication of physical prototypes to conduct empirical verification in real-world environments, thereby further validating the reliability of the simulation results. Additionally, subsequent studies could incorporate more diverse cultural elements and explore broader application scenarios to enhance the generalizability and practical value of the proposed design framework.

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Use of Generative AI

During the preparation of this manuscript, generative artificial intelligence tools (such as ChatGPT/Gemini/Grok) were used to polish the language and optimize expressions to enhance the fluency and accuracy of the text. All research content, data analysis, academic viewpoints, and conclusions within the article were completed independently by the author. AI tools were used solely to assist with linguistic expression and did not participate in any creative research processes.

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