How Can Regional Cultural Symbols be Integrated into Public Seating Design? An Innovative Exploration Using Marbled Porcelain Patterns as an Example

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A systematic approach was used to explore integrating regional cultural elements into public seating design, aiming to enhance the synergy between cultural heritage and contemporary aesthetics. Drawing inspiration from marbled porcelain from Dangyangyu, Henan Province, the study extracted core visual motifs and incorporated them into conceptual seating designs. The FKANO model was employed to identify and translate user needs into concrete design criteria, while the DEMATEL method was used to analyze causal relationships among these criteria to determine their relative importance. Based on these insights, three design proposals were developed. The TOPSIS was then applied to evaluate and optimize the alternatives. The optimal design is subsequently validated by expert evaluation, with an emphasis on environmental sustainability and ergonomic performance. The findings contribute a structured methodology for transforming regional culture into modern design language and provide a robust, evidence-based framework for evaluating public seating in urban environments, offering both theoretical and practical value.

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INTRODUCTION

Urban public seating constitutes a unique category within the broader field of furniture design, fulfilling functional needs and also serving as a medium for expressing cultural identity. As global urbanization continues to accelerate, the design of public furniture has increasingly emphasized visual appeal, often at the expense of integrating local cultural and geographic characteristics. One of the key challenges in contemporary urban design is how to meaningfully integrate regional cultural elements into public seating to reflect a city's unique identity and character.

In recent years, researchers have increasingly examined the relationship between urban furniture and its users, prompting a surge of interdisciplinary studies. For example, Wang *et al*. (2021) investigated the interactions among people, the environment, and public seating in the Shanghai Botanical Garden from an environmental psychological perspective, aiming to refine seating design principles in urban green spaces. Lin *et al*. (2024) employed the KANO model to evaluate the key factors influencing elderly users' satisfaction with public seating and proposed sustainable design strategies accordingly. Yu (2017) used environmental psychology to extract classical cultural elements and spatial narratives, incorporating the traditional Chinese instrument guqin into bench design as a cultural symbol. More recently, Wei and Nie (2023) applied deep learning algorithms and multi-scale semantic feature analysis to examine the use of color in historic urban districts, developing a model to preserve and apply culturally significant color schemes in urban environments.

To address this design challenge, the present study adopted a regional cultural perspective and employed a data-driven approach methodology to extract ornamental design elements for public seating. The research was organized around three primary objectives: (i) to identify and extract representative cultural motifs from marbled porcelain, a unique regional ceramic art form; (ii) to construct a comprehensive evaluation framework using the Fuzzy KANO (FKANO) model and Decision-Making Trial and Evaluation Laboratory (DEMATEL) method, thereby translating qualitative cultural characteristics into quantifiable design criteria and generating three design proposals; and (iii) to apply the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) to optimize the proposed designs, followed by ergonomic and sustainability assessments to validate usability and long-term viability.

This study seeks to explore how the integration of regional cultural symbols and their interaction with users can help refine public seating design. Through employing a mixed-methods approach that combines qualitative insights with quantitative rigor, this research offers a practical framework for embedding traditional cultural heritage into contemporary public design practices, thereby enhancing both the emotional resonance and cultural expressiveness of urban public furniture.

LITERATURE REVIEW

Seating Design In Public Spaces

Recent academic research on public seating has primarily focused on dimensions such as interaction design, spatial environment, and parametric modeling. For instance, Yan *et al.* (2019) analyzed users' unconscious swinging behavior and applied interactive design principles by mapping user motion to specific musical segments, which were ultimately synthesized into a complete musical piece that informed the seating concept. Zhou *et al*. (2015) conducted quantitative data collection and behavioral observations in windy outdoor environments, deriving design strategies for seating under high-wind conditions based on empirical evidence. Zhang and Sun (2024) employed a comprehensive AHP-QFD-FBS framework in the context of the Gumei Community Park in Shanghai to quantify user needs and develop sustainable public seating product lines. Similarly, Wang and Chen (2024) utilized the KANO model to classify user requirements and applied the FAST method to convert these needs into functional components, promoting innovation in auditorium seating design. Drawing on Norman's three-level emotional design theory and the KANO model, Wang *et al.* (2024) systematically analyzed users' emotional needs, identifying a strong preference for high-density street furniture that integrates traditional Chinese cultural elements in urban settings, thereby proposing emotion-driven design strategies.

While existing studies have significantly advanced the functional and aesthetic aspects of public seating—often from a spatial or user-centered perspective—there remains limited exploration of environmentally sustainable materials and the integration of regional cultural elements. This gap reflects a broader deficiency in ecological consciousness and cultural specificity in current design approaches. As cities continue to grow and evolve, the demand for public seating that reflects local identity, fosters emotional connection, and adheres to sustainable principles has become increasingly pressing. In response, this study incorporates visual and symbolic elements from marbled porcelain—a culturally distinctive ceramic technique—into public seating design, and proposes a systematic evaluation framework to assess its effectiveness.

Regional Culture In Furniture

The cultural attributes embedded in urban furniture serve as a powerful medium for expressing a city's identity, facilitating deeper public engagement with local heritage. This has led to a growing body of scholarly work exploring the integration of regional culture into furniture design. Qian (2017) examined interplay between cultural symbols and street furniture, proposing innovative design approaches that enhance both aesthetic and ethnocultural value. Xue and Chen (2025) used shape grammar techniques to integrate Suzhou cultural motifs into furniture forms, resulting in novel wooden stool designs that act as both semantic and visual carriers of local identity. Cong (2013) investigated the application of traditional decorative elements in contemporary furniture, proposing strategies, such as abstraction, cross-cultural integration, and heritage reconfiguration, to meet modern consumer needs. Wang *et al*. (2025) investigated the relationship between emotional vocabulary and cultural expression, applying a comprehensive evaluation model combining AHP, entropy weight method, and QFD to optimize Chinese-style furniture design and strengthen users' emotional resonance. Wen *et al*. (2025), operating within an agile design context, constructed a designer requirement model using FKANO, DEMATEL, and QFD methods, offering an empirical framework to enhance design efficiency during rapid prototyping.

Despite notable progress, most research in this area still emphasizes broader themes, such as public space and urban landscape, with relatively few systematic investigations focused on embedding regional culture into urban furniture specifically. To address this gap, the present study centers on the culturally significant craft of Dangyangyu marbled porcelain, extracting its core visual elements and integrating them into public seating design. A comprehensive methodology combining the FKANO model, the DEMATEL method, and the TOPSIS technique is employed to systematically translate user needs and cultural features into concrete design criteria, analyze their interrelationships, and evaluate alternative design solutions. Human factors analysis and expert evaluation are further applied to validate the usability and effectiveness of the final proposals in urban environments.

METHODOLOGY

Proposed Framework

This study aims to establish a systematic approach for integrating regional cultural elements into public seating design by constructing a scientifically grounded evaluation and decision-making model. To achieve this goal, a structured research framework is proposed (Fig. 1), incorporating the Fuzzy KANO, DEMATEL, and TOPSIS methods. The methodology consists of the following sequential steps:

- A comprehensive review of existing literature was conducted to collect and analyze information related to marbled porcelain from Dangyangyu, with the aim of identifying culturally significant visual and symbolic elements for design extraction.

- A design-oriented questionnaire was developed and distributed to target users. The FKANO model was then employed to categorize user needs, allowing for the prioritization and translation of these needs into actionable design criteria that guide the subsequent stages of design development.
- An expert survey was conducted, targeting professionals in relevant design and cultural fields. Using the DEMATEL method, a causal relationship matrix was constructed to assess interdependencies among the identified design criteria. The comprehensive influence degree of each factor was calculated, and their relative weights were derived accordingly.
- Based on functional requirements for urban public seating and the weighted design criteria, three distinct design proposals were created. These designs aimed to reflect both practical usability and cultural identity through the integration of marbled porcelain motifs.
- A decision matrix was compiled using expert evaluation scores for each design proposal across all criteria. The TOPSIS method was applied to calculate the geometric distance between each alternative and the ideal and negative-ideal solutions. The proposal with the highest relative closeness to the ideal solution was identified as the optimal design.
- Human factors analysis was performed to assess the ergonomic suitability and usability of the selected design. Additionally, a sustainability assessment was conducted to evaluate environmental performance, particularly focusing on the use of eco-friendly materials and lifecycle considerations. Based on the findings, targeted improvement recommendations were proposed.

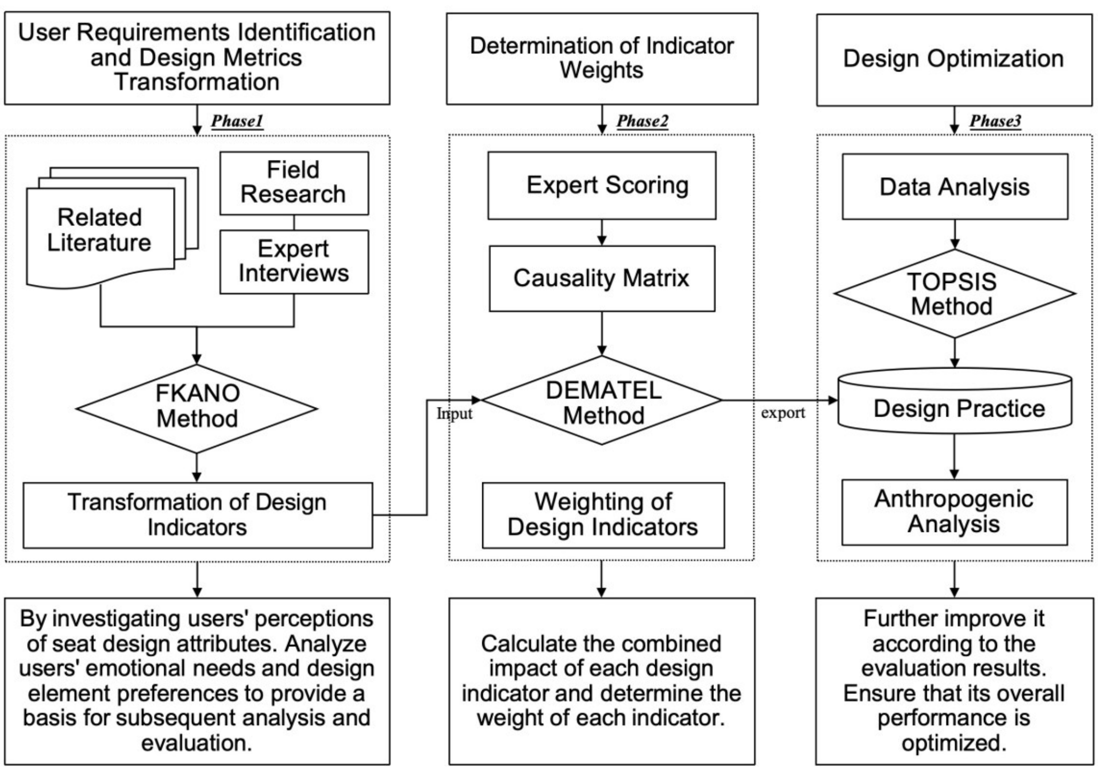


Fig. 1. Overall flow chart of the study

Fuzzy KANO Model

The FKANO model is an advanced method for analyzing user requirements that integrates fuzzy set theory with the classical KANO model. This hybrid approach enhances the model's ability to handle uncertainty and subjectivity in user feedback. Through introducing fuzzy sets and membership functions, the FKANO model converts users' vague and imprecise evaluations into quantifiable data (Barsalou 2023), thereby overcoming the limitations of the traditional KANO model in dealing with ambiguous inputs.

In this study, the FKANO model was employed to classify user needs related to public seating and assess their influence on user satisfaction. This approach enabled the accurate identification of critical user expectations and the translation of those expectations into actionable design criteria. The implementation process involved the following steps:

(1) After data collection, two binary matrices were constructed: matrix K, representing the presence of specific user requirements, and matrix L, representing their absence. Using these, an interaction matrix P was calculated to analyze the relationship between user attitudes and demand attributes in the context of urban public seating. The calculation is expressed as:

$$P = K^T \times L \tag{1}$$

(2) Each value in matrix P was mapped to a corresponding category in the FKANO evaluation table (Table 1), yielding a demand membership vector T. A confidence threshold of $\alpha = 0.4$ was applied. When a component of T satisfies $\alpha \geq 0.4$, the corresponding demand is assigned a value of $t = 1$; otherwise, $t = 0$. In cases where multiple demands satisfy $t = 1$, the final category is determined according to a predefined priority sequence: Must-be (M), One-dimensional (O), Attractive (A), Indifferent (I), and Reverse (R). The highest-priority category is selected as the final classification.

(3) Based on the proportions of each user need type, the satisfaction coefficient S_i and dissatisfaction coefficient D_i, were calculated to evaluate the influence of each need on user satisfaction. These coefficients indicate the degree of satisfaction increase when a function is present and dissatisfaction when it is absent. Additionally, the Better–Worse method was applied to quantify demand importance. The formulas are as follows:

$$S_i = \frac{A_i + O_i}{A_i + O_i + M_i + I_i} \tag{2}$$

$$D_i = -1 \cdot \frac{M_i + O_i}{A_i + O_i + M_i + I_i} \tag{3}$$

Table 1. FKANO Evaluation Table

User Needs		The Reverse Problem				
		Dissatisfied	Only Natural	Whatever	Barely Adequate	Dissatisfied
Forward-Looking Issue	Dissatisfied	*Q*	*A*	*A*	*A*	*O*
	Only Natural	*R*	*I*	*I*	*I*	*M*
	Whatever	*R*	*I*	*I*	*I*	*M*
	Barely Adequate	*R*	*I*	*I*	*I*	*M*
	Dissatisfied	*R*	*R*	*R*	*R*	*Q*

DEMATEL

The DEMATEL method is a multi-criteria decision-making approach based on expert evaluations. It is used to identify and quantify causal relationships among factors by constructing a direct-relation matrix, thereby revealing the core components within complex systems (Šmidovnik and Grošelj 2023). In this study, the DEMATEL method was adopted to analyze and rank the weights of core user needs in public seating design. This ensured that the proposed designs were aligned with the most influential user requirements, thereby supporting the development of an optimal solution.

(1) Based on the user needs classified as *M*, *O*, and *A* using the FKANO model, a direct-relation matrix was constructed. A panel of experts or experienced designers was invited to assess the degree of influence each need exerts on the others. Their evaluations formed an $n \times n$ direct influence matrix *A*:

$$A = \begin{bmatrix} 0 & x_{12} & \cdots & x_{1n} \\ x_{21} & 0 & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & 0 \end{bmatrix} = (A_{ij})_{n\times n} \quad (4)$$

Each value A_{ij} represents the degree to which factor i directly influences factor j, where $A_{ij} = 0$ when $I = j$, indicating that a factor does not influence itself. A 5-point scale was used in the expert survey, as shown in Table 2.

Table 2. Evaluation Scale

Scale	Hidden Meaning
0	A_i has no effect on A_j
1	A_i has a slight effect on A_j
2	A_i has an effect on A_j
3	A_i has a strong influence on A_j
4	A_i has a very strong influence on A_j

(2) To ensure consistency in scale, matrix *A* was normalized to obtain matrix *N*, using:

$$N = A/\max_{1\le i\le n} \sum_{j=1}^{n} A_{ij} = (n_{ij})_{n\times n} \quad (5)$$

(3) The total-relation matrix *T*, which includes both direct and indirect influences, was calculated using:

$$T = N_1 + N_2 + \cdots + N_n = N(I-N)^{-1} \quad (6)$$

(4) For each factor, the following were computed:

- h_i: the sum of row i, indicating the degree to which factor iii influences others (cause).
- q_j: the sum of column j, indicating how much factor j is influenced by others (effect).
- $F_i=h_i+q_j$: centrality, representing the total involvement of a factor.
- $E_i=h_i-q_j$: causality, indicating whether the factor is a cause (positive) or an effect (negative).

$$h_i = \sum_{i=1}^{n} T_{ij} \quad (7)$$

$$q_i = \sum_{j=1}^{n} T_{ij} \quad (8)$$

(5) An Influence Network Relation Map (INRM) was generated using the calculated h_i and q_j values. The horizontal axis (cause–effect: h_i–q_j) and the vertical axis (centrality: h_i+q_j) divide the map into four quadrants (Fig. 2), helping to identify key influential factors.

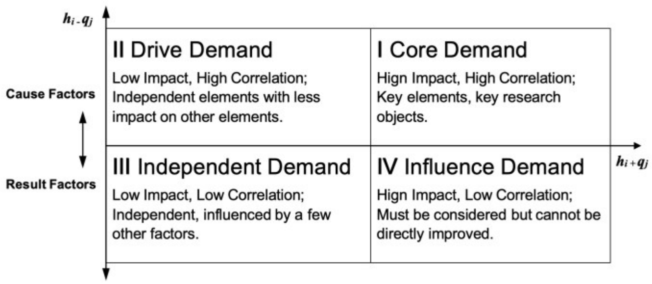


Fig. 2. Four-quadrant influence causality diagram (INRM diagram)

(6) Finally, the weight W_{Ui} for each user requirement was computed based on its centrality:

$$W_{U_i} = \frac{(h_i+q_j)}{\sum_{i=1}^{N'}(h_i+q_j)} \tag{9}$$

TOPSIS

TOPSIS is a widely adopted multi-criteria decision-making method that ranks alternatives based on their relative closeness to an ideal solution. It evaluates each alternative by comparing its Euclidean distance from both the positive-ideal (best-case) and negative-ideal (worst-case) solutions, making it especially suitable for assessing a finite set of design alternatives (Pinto-Dela Cadena *et al.* 2024). In this study, the TOPSIS method was applied to evaluate and rank three public seating design proposals. The procedure consists of the following steps:

(1) Suppose there are n alternatives and p evaluation criteria. The decision matrix is defined as:

$$X = \begin{pmatrix} x_{11} & \cdots & x_{1p} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{np} \end{pmatrix} \tag{10}$$

(2) To eliminate dimensional inconsistencies caused by varying units of measurement, the matrix is normalized using vector normalization:

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}, i = 1,2,3 \cdots, n; \tag{11}$$

The resulting normalized matrix is:

$$Z = \begin{pmatrix} x_{11} & \cdots & x_{1p} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{np} \end{pmatrix} \tag{12}$$

(3) For each criterion, determine the best and worst normalized values:

$$z^{+} = \max_{n}\left(z_1^{+}, z_2^{+}, \cdots, z_p^{+}\right), i = 1,2,3 \cdots, n; \tag{13}$$

$$z^{-} = \min_{n}\left(z_1^{-}, z_2^{-}, \cdots, z_p^{-}\right), i = 1,2,3 \cdots, n; \tag{14}$$

(4) Compute the distance of each alternative from the ideal and negative-ideal solutions:

$$D_i^{+} = \sqrt{\sum_{j=1}^{p} (z_{ij} - z_j^{+})^2}, i = 1,2,3 \cdots, n; \tag{15}$$

$$D_i^{-} = \sqrt{\sum_{j=1}^{p} (z_{ij} - z_j^{-})^2}, i = 1,2,3 \cdots, n; \tag{16}$$

(5) The relative closeness of each alternative to the ideal solution is calculated as:

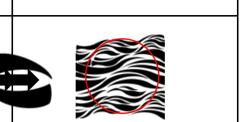
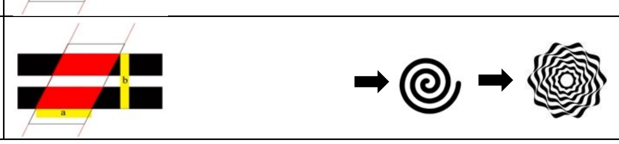
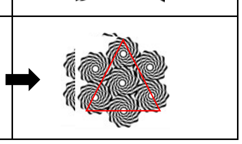
$$C_i = \frac{D_i^{-}}{D_i^{+} + D_i^{-}}, i = 1,2,3 \cdots, n; \tag{17}$$

CASE STUDY

Extracting Cultural Elements

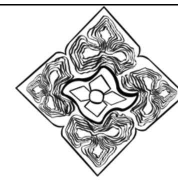
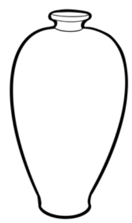
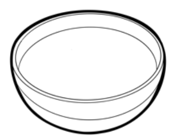
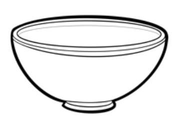
This study drew inspiration from the form and decorative patterns of *Dangyangyu* marbled ceramics, a representative form of local intangible cultural heritage, to extract and reinterpret visual elements for innovative public seating design. These ceramics are characterized by their distinctive textures, formed through the twisting and kneading of porcelain clays in different colors. The churning method—whether linear, curved, or spiral—produces diverse and visually unique patterns (Table 3).

Table 3. Churning Techniques in Marbled Porcelain

Churning Method	The Process of Change	Final Result
Straight Churning		
Curved Line Churning		
Spiral Churning		

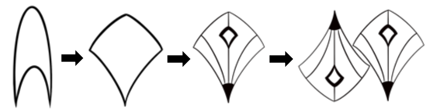
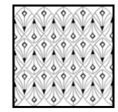
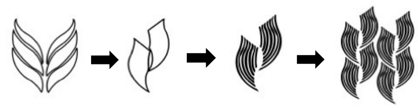
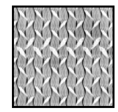
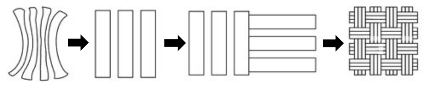
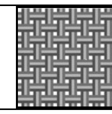
To better capture regional identity, the marbled patterns of Dangyangyu ceramics were classified according to their morphological variations (Table 4). Representative artifacts from major museum collections were selected as samples, including a Tang marbled tripod jar and a Song Dangyangyu kiln jar (Palace Museum), a Song bowl (Royal Ontario Museum), a Yuan dynasty vase with loop handles (Museum of Fine Arts, Boston), and a Dangyangyu marbled meiping vase (British Museum). Through detailed visual analysis, key contour lines were extracted and redrawn using abstract spline curves to generate highly distinctive and recognizable pattern graphics.

Table 4. Classification of Marbled Ceramic Samples

Designation	Sample Legend	Characteristics of Change	Feature Extraction	Pattern Extraction
Tang Dynasty three-legged marbled porcelain (M_1)		Nature patterns spiral churning		
Marbled porcelain pillow (M_2)		Geometric Patterns Curve Churning		
Dangyangyu marbled meiping (M_3)		Nature patterns curve churning		
Song Dynasty Dangyangyu marbled bowl (M_4)		Geometric patterns curve churning (mat weave)		
Marbled porcelain pot (M_5)		Nature patterns straight line churning (feather)		
Jin Dynasty marbled porcelain bowl (M_6)		Nature patterns straight line churning (wheat ears)		

Through applying transformation rules such as segmentation, rotation, symmetry, and recombination, typical patterns from Dangyangyu marbled ceramics were deconstructed and reconfigured. This process preserves the core visual similarity while enabling creative reinterpretation, resulting in a new set of design elements (Table 5).

Table 5. Motif Abstraction and Redesign Process

Designation	Primitive Form	Derivation Process	Innovative Graphics
Feather Patterns (P_1)			
Wheat Ears Patterns (P_2)			
Mat Weave Patterns (P_3)			

User Requirements Identification

To effectively understand and prioritize the needs of the target user group, this study synthesized insights from preliminary surveys and relevant public seating design standards. User requirements were categorized into three levels: functional, structural, and aesthetic. Based on this framework, a design requirement questionnaire was developed using the FKANO model. Within these three primary categories, 20 secondary requirement indicators were identified and systematically coded, as shown in Table 6.

Table 6. Product Requirements Summary

Level 1 Requirements	Requirement Number	Requirements Interpretation	Secondary Requirements
Functional	D_1	Focus on ergonomics	Comforts
	D_2	No safety hazards for long-term use	Surety
	D_3	Automatic adjustment of light brightness	Illumination
	D_4	Convenient electronic device range	Charge
	D_5	Storage space for your belongings	Storage
	D_6	Provide real-time information or guidance	Information display
	D_7	Touch or voice interaction	Interactivity
	D_8	Consideration of the needs of special groups	Barrier-free design
	D_9	Multi-user sharing	Simultaneous use
	D_{10}	Positioning and pathfinding	Navigation system
Structural	D_{11}	Comfortable and easy to use	Man-machine size
	D_{12}	Clearly defined functional areas	Rationalization
	D_{13}	Weather resistant	Suitable for outdoor environment
	D_{14}	Reduced maintenance costs	Easy to clean
	D_{15}	Flexible adjustment	Adjustable
Veneer	D_{16}	Recyclable materials	Eco-friendly material
	D_{17}	Clean and modern design	Atmospheric styling
	D_{18}	Incorporating humanized details	Emotional design
	D_{19}	Incorporating local symbols	Regional cultural
	D_{20}	Conforms to usage scenarios and psychological needs	Color matching

A fuzzy interval scale [0,1] was employed to quantify the intensity of user demands, enabling a detailed analysis of the prioritized features and functions. Based on this approach, the most critical user concerns were identified. A selection of the FKANO questionnaire items used during the user survey is presented in Table 7.

Table 7. FKANO Model Questionnaire (Partial)

Types	Code	User Needs		Like	Essential	Casual	Tolerable	Dislike
Functional	D_1	Comforts	Have	0.7	0.3			
			Not have			0.2	0.2	0.6
Structural	D_{15}	Adjustable	Have	0.3	0.4	0.3		
			Not have			0.2	0.2	0.6
Veneer	D_{19}	Regional cultural	Have	0.4	0.6			
			Not have			0.2	0.3	0.5

To process the collected user responses, a demand-present matrix K and a demand-absent matrix L were constructed. These were then used to compute an interaction matrix $P = K^T \times L$. Referencing the demand classification and the demand affiliation vector T (as shown in Table 1), enabled a more accurate categorization of user needs into Kano model types.

The structured questionnaire was administered to 100 participants, including 30 professional furniture designers and 70 urban residents, who were selected through purposive sampling to ensure diversity and relevance. The survey was conducted both online and in person, with clear instructions provided to ensure consistency. A pilot test with 10 participants was carried out to refine the questionnaire items. Due to the volume of data, this case study uses Requirement D_1 (from Table 7) as a representative example. For D_1, the matrices are as follows: K= [0.7 0.3 0 0 0], and the demand-absent matrix is L= [0 0 0.2 0.2 0.6].

$$S = \begin{bmatrix} 0 & 0 & 0.14 & 0.14 & 0.42 \\ 0 & 0 & 0.06 & 0.06 & 0.18 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{18}$$

From this, the demand affiliation vector is calculated as:

$$T_1 = \left(\frac{0.18}{M'}, \frac{0.42}{O'}, \frac{0.28}{A'}, \frac{0.12}{I'}, \frac{0}{R'}\right) \tag{19}$$

According to the classification rules of the FKANO model, when the demand vector contains two or more elements with a value of 1, the prioritization follows the sequence: M, O, A, I, and R, T_1 = (1, 0, 0, 0, 0), the corresponding attribute is classified as O. Subsequently, the Better-Worse satisfaction coefficients are calculated using Eqs. 1 and 2. A coefficient near zero indicates minimal influence on user satisfaction, while one approaching unity reflects substantial impact. Table 8 shows detailed results.

Table 8. Results of Questionnaire Research Based on Fuzzy Kano Model

Serial Number	Number of Attributes						Categorized Properties	Better	Worse
	A	O	M	I	R	Q			
D_1	45	7	11	17	15	5	A	0.65	-0.21
D_2	15	5	15	46	19	0	I	0.25	-0.24
D_3	15	7	9	50	19	0	I	0.27	-0.19
D_4	53	7	10	13	14	3	A	0.72	-0.20
D_5	51	5	12	15	13	4	A	0.67	-0.20
D_6	54	6	11	12	14	3	A	0.72	-0.20
D_7	72	17	2	5	1	3	A	0.83	-0.19
D_8	54	5	11	12	14	4	A	0.71	-0.19
D_9	17	8	14	44	17	0	I	0.30	-0.26
D_{10}	67	21	3	4	2	3	A	0.82	-0.25
D_{11}	11	38	3	31	17	0	O	0.59	-0.49
D_{12}	17	3	12	45	23	0	I	0.25	-0.19
D_{13}	12	17	42	16	13	0	M	0.25	-0.28
D_{14}	19	6	16	43	16	0	I	0.29	-0.26
D_{15}	54	9	11	12	14	3	A	0.72	-0.20
D_{16}	16	2	37	23	22	0	M	0.91	-0.17
D_{17}	18	32	15	17	18	0	O	0.30	-0.26
D_{18}	14	5	14	48	19	0	I	0.23	-0.23
D_{19}	12	4	40	17	27	0	M	0.92	-0.12
D_{20}	19	7	15	43	16	0	I	0.30	-0.26

In the FKANO model, Indifferent (I-type) requirements are regarded as having minimal impact on user experience and are therefore excluded from further analysis. This study focuses exclusively on M, O, and A attributes, which are more influential in shaping user satisfaction. Accordingly, subsequent design practices should prioritize demands related to regional cultural expression, environmentally safe materials, ergonomic dimensions, informational clarity, and interactive user engagement.

Weighting Analysis

To determine the interrelationships among user requirements, a DEMATEL-based questionnaire was developed and administered to a group of 10 participants, comprising both design experts and public seating users. The expert panel included four industrial design specialists, three graduate students specializing in furniture design, and three professors in furniture product research. Using a 0 to 4 Likert scale, the respondents evaluated a matrix of 13 user requirements to assess the direct influence of each factor on the others. The direct impact matrix was then normalized to obtain the normalized direct-relation matrix. In this context, 0 denotes no influence, 1 indicates weak influence, 2 reflects moderate influence, 3 signifies strong influence, and 4 represents very strong influence (see Table 9).

Table 9. Direct Impact Matrix

No.	D_1	D_4	D_5	D_6	D_7	D_8	D_{10}	D_{11}	D_{13}	D_{15}	D_{16}	D_{18}	D_{19}
D_1	0	1	3	1	1	2	1	3	3	2	1	2	2
D_4	1	0	1	3	2	3	4	2	3	2	2	3	2
D_5	2	1	0	2	1	2	1	3	2	1	1	1	2
D_6	1	3	1	0	1	2	1	1	2	1	3	2	3
D_7	1	1	2	2	0	1	1	1	1	1	2	3	2
D_8	3	2	2	1	1	0	3	2	3	3	1	2	2
D_{10}	2	3	1	3	1	3	0	1	2	1	3	1	1
D_{11}	3	2	3	2	1	2	3	0	4	3	2	1	2
D_{13}	3	1	2	1	1	3	1	2	0	3	2	2	2
D_{15}	3	1	2	1	1	3	2	3	3	0	1	1	2
D_{16}	4	3	2	2	2	2	2	2	3	3	0	2	3
D_{18}	2	1	2	1	3	1	1	1	1	2	2	0	3
D_{19}	3	2	2	4	3	2	2	2	3	2	4	4	0

Using the DEMATEL method, the total relation matrix Z was calculated, from which the influence degree (h_i) and influenced degree (q_j) of each factor were derived. The prominence F and relation E of each requirement were then computed. Finally, the relative weights W_{Ui} of all factors within the system were determined. The results for the prototype development platform are summarized in Table 10.

Table 10. DEMATEL Calculated Indicator Values

No.	Influence Degree (h_i)	Influenced Degree (q_i)	Central Degree ($F = h_i - q_i$)	Cause Degree ($n_i = f_i - q_i$)	Weights (W_{Ui})
D_1	2.475	3.177	5.652	-0.702	0.0805
D_4	3.106	2.35	5.456	0.756	0.0777
D_5	2.184	2.619	4.804	-0.435	0.0684
D_6	2.467	2.541	5.008	-0.074	0.0713
D_7	2.037	2.038	4.075	-0.002	0.058
D_8	2.787	2.926	5.713	-0.139	0.0814
D_{10}	2.517	2.459	4.976	0.059	0.0709
D_{11}	3.111	2.63	5.741	0.481	0.0818
D_{13}	2.598	3.358	5.956	-0.759	0.0848
D_{15}	2.599	2.747	5.346	-0.148	0.0761
D_{16}	3.345	2.673	6.018	0.672	0.0857
D_{18}	2.265	2.684	4.95	-0.419	0.0705
D_{19}	3.614	2.904	6.518	0.709	0.0928

To visually illustrate the causal and influence relationships among the design factors, an INRM was constructed, with the horizontal axis representing prominence and the vertical axis representing relation. A higher prominence value signifies a more influential factor.

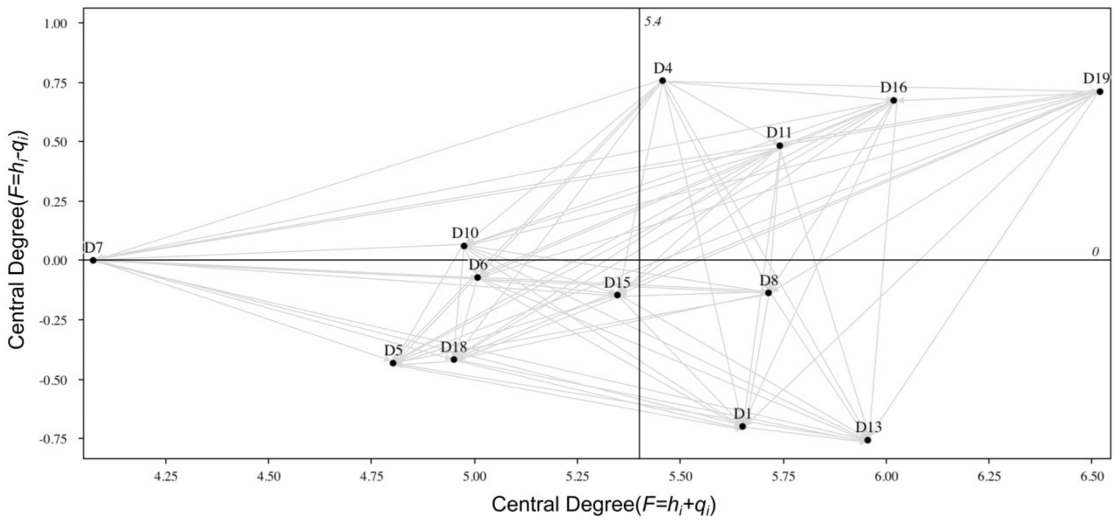


Fig. 3. Impact network relation map with class degree

Design Proposal

Based on the results of the integrated evaluation model, three distinct public seating design proposals were developed (Fig. 4):

Fig. 4. Design options

1. Cultural-Oriented Design: Guided by the DEMATEL analysis, with D_{19} and D_{16} identified as high-priority factors, this design emphasizes local identity through an elegant, streamlined form. The motif of wheat (P_2) is expressed in the color palette and seat surface. Structural inspiration is drawn from the silhouette of a Tang Dynasty marbled ceramic tripod jar (M_1), with softly upturned corners, while the leg profile and openwork elements reference the marbled ceramic vase (M_5), realized through bentwood

craftsmanship. Local ceramics and sustainable wood are used to balance aesthetic expression and environmental responsibility.

2. Systemic Design: This design embodies the concept of "unity of interior and exterior," a cultural ethos reflected in the form and texture of marbled ceramics. The seat surface is covered in eco-friendly bamboo strips arranged in a woven mat pattern (P_3), symbolically echoing the underside of traditional ceramic pieces. This design fuses breathability, durability, and regional symbolism, combining hardwood support with bamboo's comfort and cultural significance.

3. Leisure-Oriented Design**:** Inspired by the form of a marbled ceramic vase (M_5), this design introduces a curved backrest achieved with laminated wood techniques to enhance comfort. A deconstructed feather motif (P_1), reinterpreted from local cultural imagery, is embedded in the back panel. The use of sustainable wood throughout the structure ensures a balance between aesthetic longevity and ergonomic support.

Determine the Optimal Solution

To comparatively evaluate the three design proposals, a scoring assessment was conducted involving 20 participants—comprising 15 urban residents and 5 experts in furniture design. Each design was evaluated based on five essential and expected criteria derived from the FKANO model. The average scores were computed to construct the initial decision matrix (Table 11). Following the TOPSIS methodology, the positive and negative ideal solutions, as well as the relative closeness coefficients, were calculated. Based on these values, a prioritized ranking of the design alternatives was established.

Table 11. Initial Evaluation Matrix

Evaluation Indicators	Option 1	Option 2	Option 3
Regional cultural D_{19}	5.2	3.7	4.5
Eco-friendly material D_{16}	4.1	4.0	3.9
Suitable for outdoor environment D_{13}	3.9	3.8	3.0
Man-machine size D_{11}	3.8	3.7	4.0
Atmospheric styling D_{17}	4.2	4.1	3.5

Based on the computed positive ideal solutions, negative ideal solutions, and relative closeness values (Table 12), Option 1 achieved the highest relative closeness score and is thus identified as the preferred seating design proposal according to the panelists.

Table 12. Calculation Result

Option	Positive Ideal Solution Distance (D_i^+)	Negative Ideal Solution Distance (D_i^-)	Overall Score Index C_i	Sort
Option 1	0.4123	0.6481	0.6112	1
Option 2	0.5831	0.5196	0.5712	2
Option 3	0.6708	0.5099	0.4319	3

Human Factors Functioning

Using the Man-machine efficacy software, the 3D model of Option 1 was integrated with seat and posture modules to simulate user interaction. The simulation enabled an ergonomic analysis of body comfort during the seating process (Fig. 5).

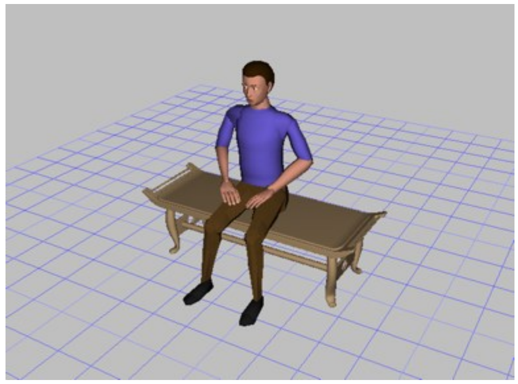


Fig. 5. Human-computer simulation environment

The core objective of the ergonomic simulation was to evaluate the impact of seat usage on lumbar stress, with particular focus on compressive forces exerted on the L4/L5 intervertebral discs. Using the built-in lower back analysis module in Man-machine efficacy software, the spinal load at L4/L5 was quantified. According to the guidelines established by the U.S. National Institute for Occupational Safety and Health (NIOSH), the maximum permissible compressive force on this region is 3400 N; exceeding this threshold may lead to lumbar fatigue or injury (Ashley 2015). As illustrated in Fig. 6, the pressure exerted in Design Scheme 1 remained below the critical limit, confirming the design's compliance with ergonomic safety standards.

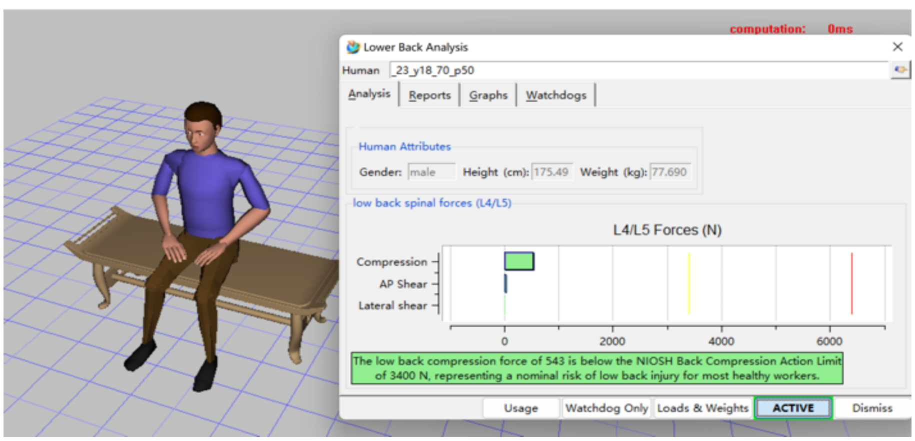


Fig. 6. Dynamic analysis of lumbar spine forces (L4/L5)

To evaluate seated comfort, a dedicated Comfort Assessment tool was employed to conduct a detailed analysis of user posture. The tool scores on a scale from 0 to 80, with lower values indicating greater comfort. As shown in Fig. 7, the overall comfort score was 47.6, suggesting a high level of user comfort. The fatigue score was 42.6, with specific scores for body regions as follows: left leg 13.8, right leg 13.5, left arm 19.1, right arm 0, buttocks 37.4, back 9.3, shoulders 15.2, and neck 12.6. All scores were below 60, indicating acceptable comfort across all regions. These results confirm that the seat design meets ergonomic expectations and provides detailed insights into regional comfort. This ergonomic validation process substantiates the overall rationality and user-centered focus of Design Option 1.

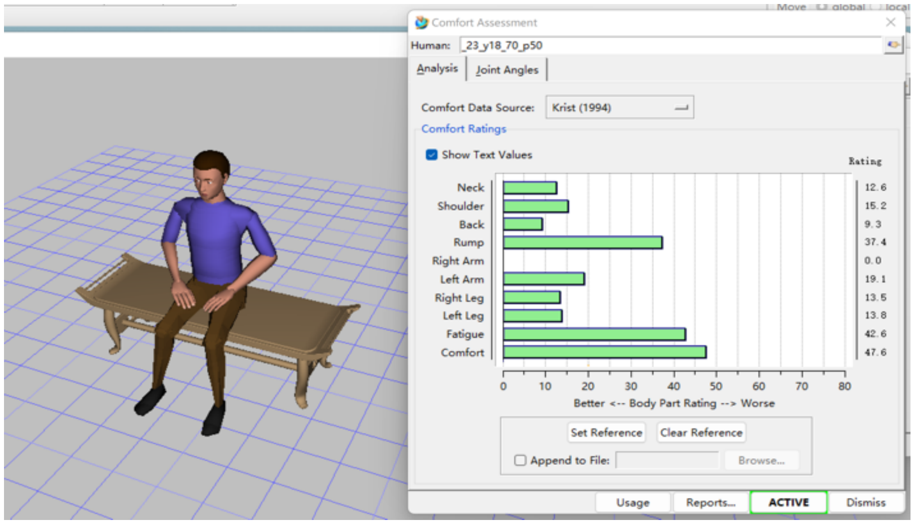


Fig. 7. Human Comfort Score

Sustainability Analysis

To verify the environmental sustainability of the optimal design, five evaluation criteria were established and assessed using a 0 to 5 point scale. Ten experts were invited to participate in the evaluation, including four environmental specialists, four design experts, and three professors specializing in sustainability research. The results indicate that all scores for Scheme 1 across the evaluation criteria exceeded 4 points, confirming that the design meets the requirements of sustainable design (Fig. 8).

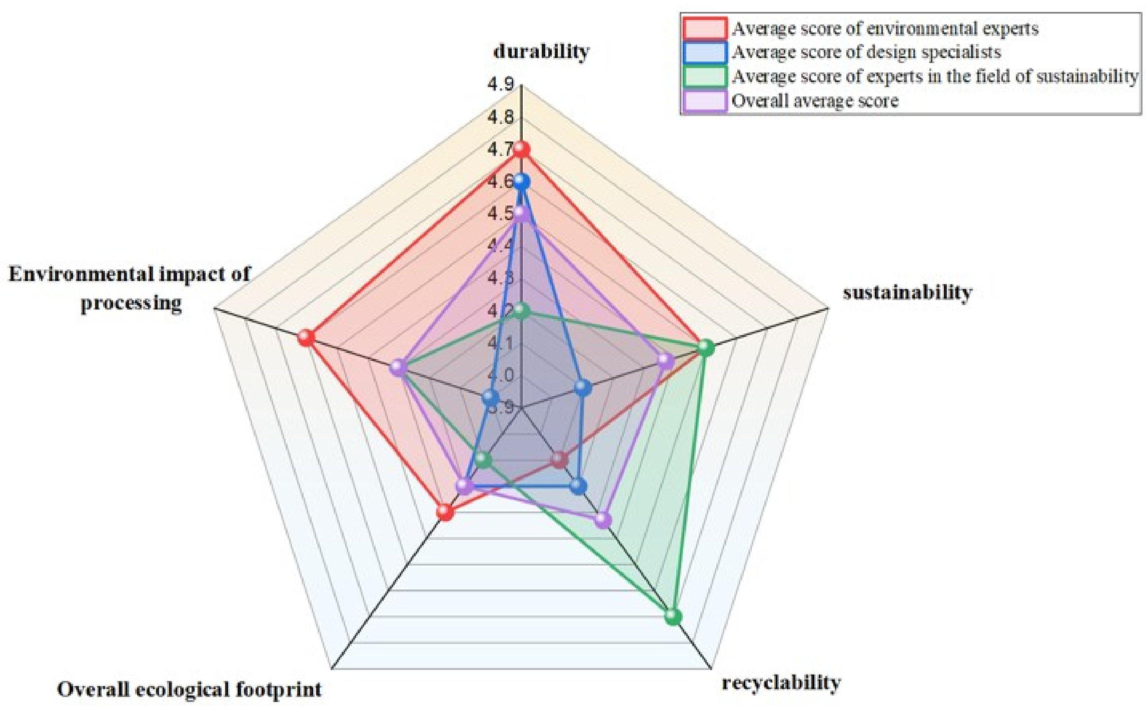


Fig. 8. Expert scoring results

CONCLUSIONS

1. This study explored the intricate relationship between regional culture and urban public seating, aiming to enhance emotional resonance and user experience through innovative design interventions. Through employing an integrated evaluation framework that combines both qualitative and quantitative methods, the research uncovered pivotal roles of emotional needs and cultural identity in the design of public seating.
2. This study first employed the F-KANO model to identify and translate user needs into concrete design criteria. To further inform the design process, the DEMATEL method was applied to analyze the causal relationships and degrees of influence among these criteria, providing a data-driven foundation for decision-making. Subsequently, by examining the forms and patterns of marbled porcelain from Dangyangyu, representative motifs are extracted and reinterpreted to develop three innovative design proposals. The optimal design is then determined using the TOPSIS method. Finally, a human-centered analysis combined with expert evaluations is conducted to assess the environmental sustainability of the optimized design, thereby validating the theoretical framework through empirical application.
3. This study offered a methodological reference for integrating regional cultural heritage into contemporary public design. By combining cultural symbolism with ergonomic and sustainable considerations, the designs demonstrate how traditional heritage can be innovatively reimagined through specific and user-centered design strategies. The findings provide a transferable methodological reference that can inform culturally responsive design practices in other domains, particularly where cultural identity and modern functionality must be carefully balanced.

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