EXTRACTION OF PERCEPTUAL FACTORS OF SHU EMBROIDERY PATTERNS AND INNOVATIVE APPLICATION IN WOMEN'S SHOES DESIGN

Luming YANG[1,2], Wantong ZHAO[2], Duanyi CAI[3*]

[1]National Engineering Laboratory for Clean Technology of Leather Manufacture, Sichuan University, Chengdu 610065, P.R.China, ylmll1982@126.com

[2]Key Laboratory of Leather Chemistry and Engineering, Ministry of Education, Sichuan University, Chengdu 610065, P.R.China, ylmll1982@126.com

[3]College of Arts, Sichuan University, Chengdu 610207, P.R.China, caiduanyi@scu.edu.cn

Received: 18.06.2024 Accepted: 25.09.2024 https://doi.org/10.24264/lfj.24.3.4

EXTRACTION OF PERCEPTUAL FACTORS OF SHU EMBROIDERY PATTERNS AND INNOVATIVE APPLICATION IN WOMEN'S SHOES DESIGN

ABSTRACT. Shu embroidery, an important intangible cultural heritage of China, boasts a long history and exquisite needlework techniques. As the times have progressed, consumers' demand for personalization of women's shoes has increased, and women's shoe design has shown shortcomings such as insufficient innovation and lack of traditional Chinese cultural characteristics. As the core carrier of embroidery to express the theme and aesthetics, Shu embroidery pattern reflects the deep heritage of traditional Chinese culture, and its innovative fusion with women's shoe design gives women's shoe products a unique style and charm. This paper proposes a design process based on the principles of Kansei Engineering and Shape Grammar to explore the perceptual cognitive expressiveness of Shu embroidery patterns, by selecting representative patterns favored by consumers, deconstruct and reorganize them in combination with shape grammar, and innovatively apply them to the design of women's leather shoes. The study indicates that: using Kansei Engineering principles to quantify consumers' perceptual evaluation of Shu embroidery patterns can provide scientific theoretical and data support for the extraction of the perceptual factors; the innovative application of Shu embroidery patterns in women's leather shoes design can improve the personalization level of products, enhance market competitiveness and provide a paradigm for the women's shoe brands and designers to apply.

KEY WORDS: Shu embroidery; pattern; perceptual engineering; shape grammar; women's leather shoes

EXTRAGEREA FACTORILOR DE PERCEPȚIE DIN MODELELE DE BRODERIE SHU ȘI APLICAREA INOVATOARE A ACSETORA ÎN DESIGNUL ÎNCĂLȚĂMINTEI PENTRU FEMEI

REZUMAT. Broderia Shu, un important patrimoniu cultural imaterial al Chinei, se mândrește cu o istorie îndelungată și tehnici de cusut rafinate. Odată cu trecerea timpului, cererea consumatorilor pentru personalizarea pantofilor de damă a crescut, iar designul încălțămintei pentru femei a prezentat deficiențe, cum ar fi inovația insuficientă și lipsa caracteristicilor culturale tradiționale chinezești. Ca suport de baz[care exprimă tematica și estetica, modelul de broderie Shu reflectă moștenirea profundă a culturii tradiționale chineze, iar fuziunea sa inovatoare cu designul încălțămintei de damă conferă produselor un stil și un farmec unice. Această lucrare propune un proces de design bazat pe principiile ingineriei Kansei și ale gramaticilor formelor pentru a explora expresivitatea cognitiv-perceptuală a modelelor de broderie Shu, selectând modele reprezentative preferate de consumatori, deconstruindu-le și reorganizându-le în combinație cu gramatica formelor și aplicându-le inovator în designul încălțămintei de piele pentru femei. Studiul indică faptul că: utilizarea principiilor ingineriei Kansei pentru a cuantifica evaluarea perceptuală a consumatorilor asupra modelelor de broderie Shu poate oferi suport teoretic și științific bazat pe date pentru extragerea factorilor de percepție; aplicarea inovatoare a modelelor de broderie Shu în designul încălțămintei de piele pentru femei poate îmbunătăți nivelul de personalizare al produselor, spori competitivitatea pe piață și oferi un model pentru brandurile și designerii de pantofi de damă.

CUVINTE CHEIE: broderie Shu; model; inginerie perceptuală; gramatica formelor; pantofi din piele pentru femei

L'EXTRACTION DES FACTEURS PERCEPTUELS DES MOTIFS DE BRODERIE SHU ET LEUR APPLICATION INNOVANTE DANS LA CONCEPTION DES CHAUSSURES POUR FEMMES

RÉSUMÉ. La broderie Shu, un important patrimoine culturel immatériel de la Chine, se distingue par une longue histoire et des techniques de broderie exquises. Avec le temps, la demande des consommateurs pour la personnalisation des chaussures pour femmes a augmenté, et la conception des chaussures pour femmes a montré des lacunes telles que l'innovation insuffisante et le manque de caractéristiques culturelles traditionnelles chinoises. En tant que support principal de la broderie pour exprimer le thème et l'esthétique, le motif de broderie Shu reflète l'héritage profond de la culture traditionnelle chinoise, et sa fusion innovante avec la conception des chaussures pour femmes confère aux produits une touche unique et un charme distinctif. Cet article propose un processus de conception basé sur les principes de l'ingénierie Kansei et de la grammaire des formes pour explorer l'expressivité cognitive et perceptuelle des motifs de broderie Shu. En sélectionnant des motifs représentatifs appréciés par les consommateurs, en les décomposant et en les réorganisant en combinaison avec la grammaire des formes, ces motifs sont appliqués de manière innovante à la conception de chaussures en cuir pour femmes. L'étude indique que l'utilisation des principes de l'ingénierie Kansei pour quantifier l'évaluation perceptuelle des consommateurs des motifs de broderie Shu peut fournir un soutien théorique et scientifique basé sur des données pour l'extraction des facteurs perceptuels ; l'application innovante des motifs de broderie Shu dans la conception de chaussures en cuir pour femmes peut améliorer le niveau de personnalisation des produits, accroître la compétitivité sur le marché et offrir un modèle pour les marques et les concepteurs de chaussures pour femmes.

MOTS CLÉS : broderie Shu ; motif ; ingénierie perceptuelle ; grammaire des formes ; chaussures en cuir pour femmes

[*] *Correspondence to: Duanyi CAI, College of Arts, Sichuan University, Chengdu 610207, P.R.China, caiduanyi@scu.edu.cn*

INTRODUCTION

Shu embroidery, also known as "Chuan embroidery," is a traditional Chinese embroidery craft, recognized as one of the four great embroideries of China. It is also one of the oldest forms of embroidery in China, with a history dating back over 2,000 years [1]. Shu embroidery was included in China's national intangible cultural heritage list in 2006, which indicates that it has extremely important value for the protection and development of China's rich cultural heritage [2]. Shu embroidery is not only a handicraft, it also contains rich cultural connotations, creating extremely delicate and vivid patterns through different combinations of stitches. The themes of Shu embroidery works are expressed through the content and subject matter of the patterns. Many creations are rooted in traditional Chinese culture and folklore, showcasing exquisite folk craftsmanship and conveying profound cultural and educational significance.

The composition of Shu embroidery patterns determines the artistic style and characteristics of the embroidery works [3] with their intricate and exquisite visual effects offering significant artistic and design value. Innovatively transforming Shu embroidery patterns and incorporating them into the design of women's leather shoes is an effective approach for the modern application of traditional elements. Scholars have conducted research on the innovative application of traditional elements in footwear: Ho Sun Lim [4] explores the innovative use of traditional Korean muntin patterns in the design of 3D printed shoes. The study aims to create customized shoe designs that are unique and different from existing products by integrating traditional patterns with modern 3D printing technology. A. Karaseva *et al*. [5] research on traditional Mongolian costumes in modern footwear design shows high market demand for ethnic-style designs. The study highlights the integration of ethnic themes and designers' creative interpretations, recommending new footwear models with traditional Mongolian elements to enhance competitiveness. Zhonghua Cao *et al*. [6] incorporated traditional Chinese cultural elements, such as Confucianism and Taoism, into parent-child shoe designs. Using panda imagery and traditional ink painting techniques, they created unique panda-themed designs, which were applied to various shoe styles for toddlers and women, combining both functional and aesthetic elements. Traditional patterns feature diverse color combinations, rich curves, and strong regional cultural significance, providing abundant inspiration for contemporary art and design [7]. Using Kansei Engineering methods, the study quantitatively analyzes consumers' emotional perceptions of Shu embroidery patterns, offering a crucial basis for innovative design. Additionally, combining shape grammar facilitates the derivation and regeneration of fundamental factors in Shu embroidery patterns, applied to women's leather shoes as a medium. This innovative design process enables designers to better understand and meet market and consumer demands, effectively merging consumers' emotional expectations with the inheritance and development of traditional art.

RESEARCH METHODS AND PROGRAM DEVELOPMENT

Principles of Kansei Engineering

Kansei engineering, as a representative method in emotional design, captures and quantifies users' emotional responses to specific product attributes. This establishes a connection that provides clear guidance for the formulation and evaluation of design schemes [8]. It encompasses various research methods, including semantic differential analysis [9], surveys, factor analysis, aiming to deeply understand individuals' perceptions of products, specifically their psychological expectations and emotional responses. Kansei images reflect the emotional connection humans have with objects, representing the deeper expression of emotional reactions [10].

Shape Grammar Principle

Shape grammar is a design reasoning method primarily based on shape operations. It generates new shapes by arranging and combining one or more basic shapes according to grammatical relationships and rules of the shapes [11]. Shape grammar has the ability to transform initial shapes into new shapes following specific rules, while ensuring the new shapes retain the properties of the initial shapes. This characteristic offers good inheritance. Shape grammar is represented by a four-tuple formula, which includes: $\mathrm{SG} = (\mathrm{S}, \mathrm{L}, \mathrm{R}, \mathrm{I})$. In this formula, SG represents the set of shapes derived from shape S through operations such as scaling and rotation; S denotes a finite set of shapes; L represents a finite set of labels; R stands for a finite set of inference rules; and I indicates the initial shape [12].

Research Programming

The article proposes a design methodology that integrates Kansei Engineering with shape grammar. Initially, Shu embroidery patterns are selected as the research subject. Patterns are collected and depicted in stimulus images, while relevant affective words are identified. Next, an evaluation experiment of affective semantics is conducted, with results organized and analyzed for factors and grey relational analysis to identify Shu embroidery samples for innovative design. Selected samples are then deconstructed and reorganized into basic units, transformed using shape grammar rules to generate regenerative elements, and experimented with in various color styles. Finally, these regenerative elements are applied in “dot, line, surface” forms in the integrated design of women’s leather shoes. The design process is illustrated in Figure 1.

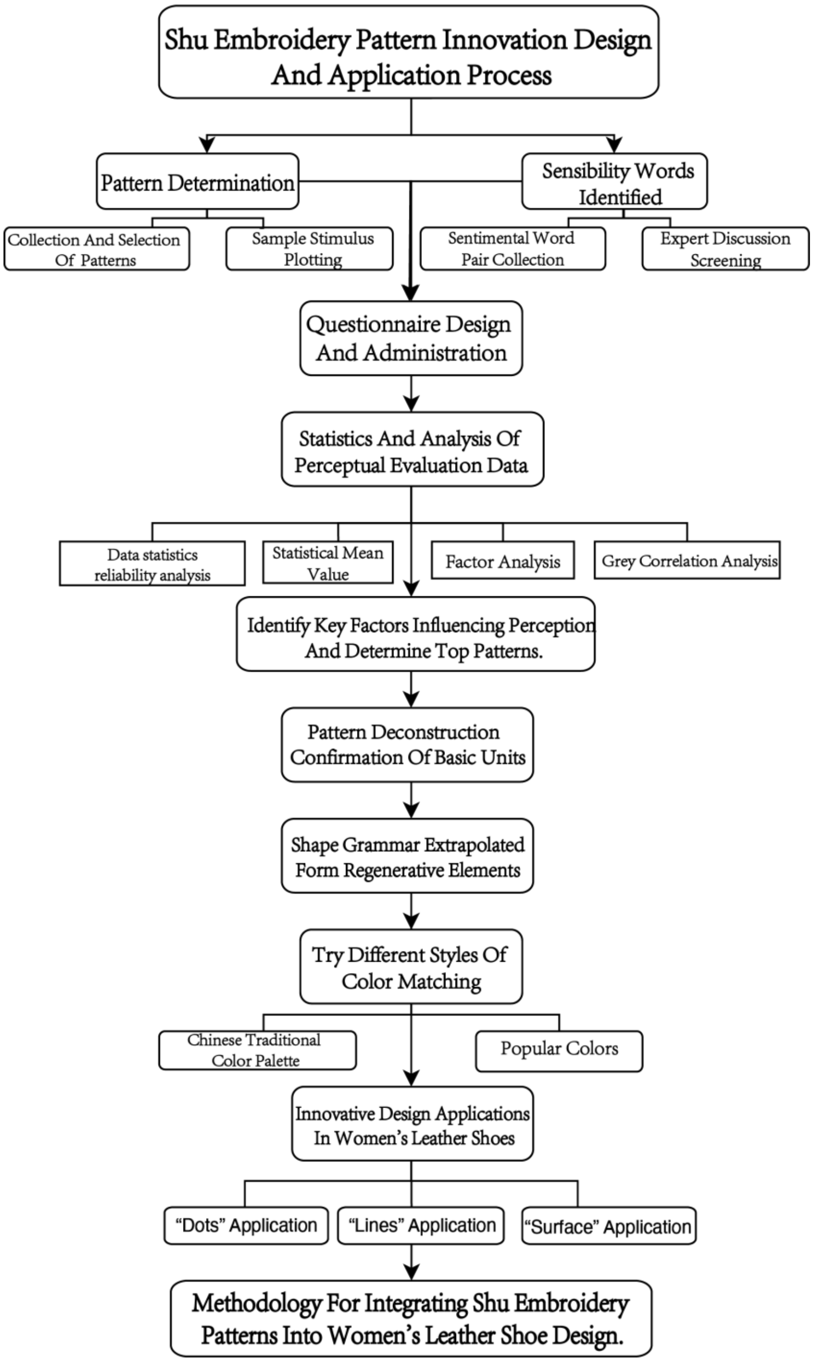

Figure 1. Shu embroidery pattern innovation design flow chart

RESEARCH PROCESS

Selection and Stimulation Pattern Design of Shu Embroidery

Focusing on Shu embroidery patterns as the research subject, pattern materials were collected from literature and field investigations. Through, organizing and summarizing the literature, Shu embroidery patterns can be broadly classified into five categories: animals, plants, humanities, artifacts, and geometric patterns. Four representative samples were selected from each category, resulting in a total of 20 patterns. To minimize the influence of color, texture, and stitching techniques on consumers' perceptual evaluations, black-and-white line drawings were created using Adobe Illustrator. In designing the questionnaire, the order of the stimulus images was randomized to enhance clarity and effectiveness. As shown in Figure 1, the random order of the Shu embroidery pattern stimulus images is as follows: patterns 01, 06, 11, and 16 belong to the animal category; patterns 04, 07, 12, and 17 belong to the plant category; patterns 03, 10, 15, and 20 belong to the humanities category; patterns 02, 08, 14, and 19 belong to the artifact category; and patterns 05, 09, 13, and 18 belong to the geometric pattern category.

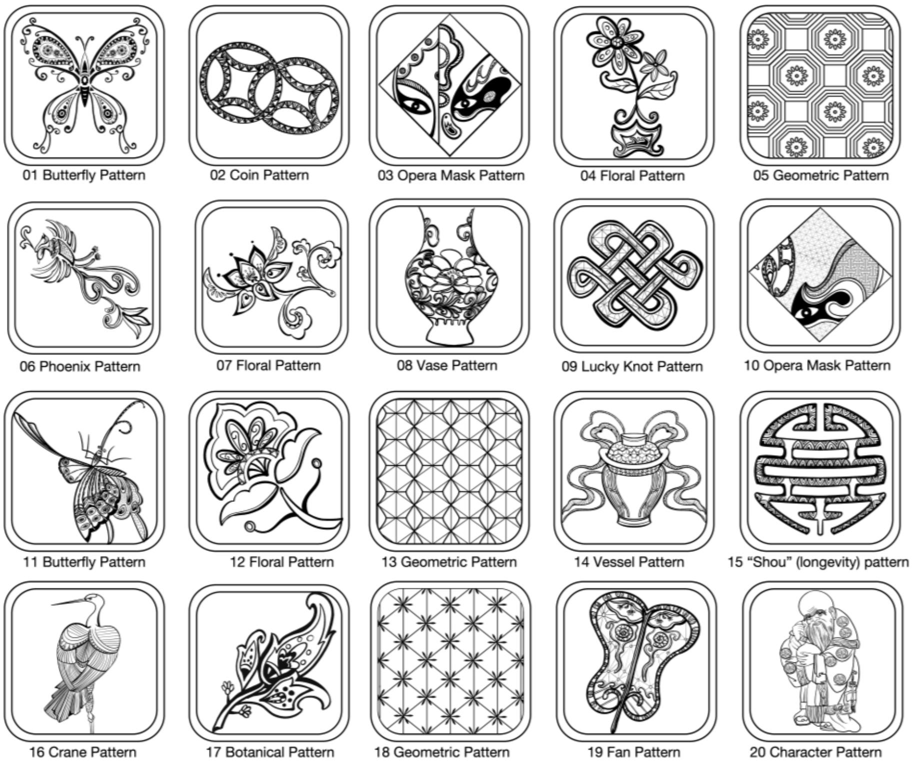

Figure 2. Shu embroidery sample stimulus images and number

Perceptual Word Pair Selection

We adopted a combined online and offline strategy to collect adjective pairs. Online collection was mainly conducted by reviewing literature and browsing relevant websites. Offline collection was achieved through gathering opinions and evaluations from relevant experts, including professors, Shu embroidery masters, industry professionals, design students, and designers. In total, more than 60 pairs of patterns were collected. Using the Semantic Differential (SD) method, which quantifies people’s attitudes and emotional responses toward an object, we eventually identified nine pairs of Kansei adjectives: concrete-abstract, simple-complex, graceful-lively, traditional-modern, dynamic-static, gentle-harsh, elegant-vulgar, boring-interesting, and dislike-like [13].

Questionnaire Design and Implementation

The survey questionnaire employed a 5-point Likert scale, with scores ranging from 1 to 5. To minimize page-turning time for respondents, a matrix format was used to arrange the nine pairs of adjectives. Each pair of adjectives was placed at the ends of a scale, with scores closer to the ends indicating a stronger feeling towards that adjective. For example, for “concrete—abstract,” 1 indicates very concrete, 2 indicates somewhat concrete, 3 indicates neutral, 4 indicates somewhat abstract, and 5 indicates very abstract.

The survey was distributed using the online platform Questionnaire Star. Each questionnaire included an introduction explaining the survey’s purpose, instructions, length, and estimated completion time. Respondents were asked to view 20 stimulus images and rate them using the 12 adjective pairs, with the images presented in random order.

DATA STATISTICS AND ANALYSIS

Data Statistics and Reliability Analysis

A total of 160 questionnaires were distributed and collected online. Among the respondents, 85.62% were familiar with Shu embroidery and its patterns. Specifically, 68.13% (109 individuals) learned about Shu embroidery through social media platforms, while nearly half were informed through films, museum visits, and literature. The respondents' familiarity with Shu embroidery ensured the reliability of the data.

Reliability analysis using SPSS 26.0 showed that the Cronbach's α coefficient for the eight pairs of affective adjectives was 0.975, and for preference ratings, it was 0.945, both exceeding 0.900, indicating excellent reliability of the questionnaire.

Mean Statistical Analysis

Each pattern stimulus map obtained 1440 scores (160 questionnaires * 9 pairs of perceptual adjectives), and the questionnaire results were mean-valued statistically using SPSS software. To analyze the emotional tendencies of the 20 Shu embroidery patterns, the "origin method" was used, with scores ranging from 1 to 5 and 3 as the origin. Scores less than 3 indicate a tendency towards the left adjective, while scores greater than 3 indicate a tendency towards the right adjective. The greater the deviation from 3, the more pronounced the affective tendency. For example, for pattern 01, the adjective pair "elegant—vulgar" had a mean score of 2.09, indicating a stronger inclination towards "elegant". The mean scores of the 20 patterns were ranked by the strength of their tendencies, with the top three adjectives for each pattern listed in Table 1. The adjectives shown in the table represent the primary feelings elicited by each pattern, such as pattern 01 being perceived mainly as elegant, gentle, and concrete.

Table 1: The main emotional and psychological vocabulary and scores of Sichuan embroidery pattern samples

Pattern number	Adjectives	Score	Pattern Number	Adjectives	Score	Pattern Number	Adjectives	Score
	elegant	2.09		elegant	2.4		abstract	3.46
1	gentle	2.17	8	traditional	2.46	15	elegant	2.64
	concrete	2.28		concrete	2.47		complex	3.34
	traditional	2.51		elegant	2.34		concrete	2.14
2	elegant	2.51	9	interesting	3.25	16	dynamic	2.19
	simple	2.59		concrete	2.77		elegant	2.23
	elegant	1.97		dynamic	2.16		elegant	2.48
3	dynamic	2.14	10	elegant	2.21	17	gentle	2.51
	interesting	3.76		abstract	3.7		dynamic	2.59
	dynamic	2.28		dynamic	2.28		simple	2.54
4	elegant	2.37	11	interesting	3.61	18	elegant	2.79
	gentle	2.41		elegant	2.41		graceful	2.83
	elegant	2.59		dynamic	2.39		elegant	2.31
5	graceful	2.66	12	gentle	2.39	19	dynamic	2.41
	simple	2.69		elegant	2.44		gentle	2.43
	elegant	2.08		abstract	3.46		concrete	1.93
6	dynamic	2.23	13	harsh	3.38	20	traditional	2.12
	gentle	2.26		static	3.31		complex	3.82
	gentle	2.15		dynamic	2.59			
7	elegant	2.16	14	traditional	2.6			
	dynamic	2.16		gentle	2.62			

The mean score of adjective pair "like - dislike" reflects the degree of favoritism of the 20 Shu embroidery patterns, the higher the value is, the higher the degree of favoritism, and the lower the value is, the relative degree of favoritism is lower. The favorability scores of each sample are shown in Table 2, from which it can be seen that the samples with higher favorability are mostly humanities, plants and animals.

Table 2: The popularity score of each Shu embroidery pattern sample

Pattern number	Favoritism	Pattern number	Favoritism
1	3.92	11	3.75
2	3.46	12	3.66
3	4.16	13	3.16
4	3.76	14	3.67
5	3.39	15	3.42
6	3.96	16	3.89
7	4	17	3.59
8	3.61	18	3.53
9	3.63	19	3.63
10	4.07	20	3.76

Factor Analysis

The eight adjective pairs (excluding the "like—dislike" pair, which was only used to evaluate the preference for the 20 Shu embroidery patterns and was not included in the factor analysis) were subjected to KMO and Bartlett's sphericity tests. The KMO value was 0.677, greater than 0.600, and the Bartlett's sphericity test significance was 0.000, indicating strong correlations among the data, making them suitable for factor analysis [14]. The adjective pairs were categorized and the perceptual factors were extracted through factor analysis, firstly, the Shu embroidery pattern stimulus images were downgraded and interpreted through principal component analysis to find out the number of common factors that could reflect more original data. Factor eigenvalue greater than 1 is considered to be able to be used as the main factor [15], as shown in Table 3, of total variance interpretation, the eigenvalue of factor 1 is 4.105, and the eigenvalue of factor 2 is 1.893, the eigenvalue of the 2 factors is greater than 1, and the cumulative contribution rate is 74.973%, which is more representative of the original variables, so these 2 factors can explain most of the perceptual information of the Shu-embroidery patterns better.

Table 3: Eigenvalues and variance contribution rate

Factor	Initial Eigenvalues			Sums of Squared Loadings		
	Total	Variance / %	Cumulative /%	Total	Variance / %	Cumulative /%
1	4.105	51.316	51.316	4.105	51.316	51.316
2	1.893	23.657	74.973	1.893	23.657	74.973
3	0.863	10.791	85.764			
4	0.697	8.709	94.474			
5	0.276	3.446	97.919			
6	0.096	1.199	99.119			
7	0.04	0.496	99.615			
8	0.031	0.385	100			

The factor loading matrix was rotated using the maximum variance method to make the factors interpretive [16]. The adjective pairs were categorized according to the rotated component matrix, and the main factors were named according to the grouping content. To clearly display the relationship between factors and adjective pairs, coefficients less than 0.3 were ignored. As shown in Table 4, the adjective pairs "dynamic—static," "boring—interesting," "gentle—harsh," "elegant—vulgar," and "simple—complex" had high absolute loadings on Factor 1, indicating that they primarily explain Factor 1. This set of adjective pairs describes the elegant yet dynamic and interesting characteristics of Shu embroidery patterns; therefore, Factor 1 was named the "Temperament Factor." The adjective pairs "traditional—modern," "graceful—lively," and "concrete—abstract" had high absolute loadings on Factor 2, indicating that they primarily explain Factor 2. This set of adjective pairs describes the stylistic features of Shu embroidery patterns; thus, Factor 2 was named the "Style Factor."

Table 4: Rotated component matrix

Adjective Pairs	Component	
	Factor 1	Factor 2
dynamic—static	0.967	—
boring—interesting	-0.962	—
gentle—harsh	0.922	—
elegant—vulgar	0.916	—
simple—complex	-0.622	—
traditional—modern	—	0.898
graceful—lively	—	0.825
concrete—abstract	—	0.607

Gray Relational Analysis

Gray relational analysis is a method used to assess the degree of correlation between two sets of factor sequences as they vary with a certain variable. If the degree of variation is consistent, it indicates a strong correlation between the two sets of factors; conversely, if the degree of variation is inconsistent, the correlation is weak [17]. To determine the degree of correlation between the two main factors of Shu embroidery pattern design and consumer preference, an evaluation matrix was established, and gray relational analysis was conducted. The specific steps are as follows.

Determination of the Evaluation Matrix

The mean scores of the affective evaluations for the five adjective pairs in the Temperament Factor and the three adjective pairs in the Style Factor were used as the indicator sequences $\{X_i(k),\ i=1,\ 2,\ k=1,\ 2,\ \ldots,\ 20\}$.

Here, $X_i(k)$ represents the mean affective evaluation score of the i-th stimulus image for the k-th adjective pair in each factor. The mean preference scores for the 20 Shu embroidery patterns were used as the reference sequence, $\{X_0(k),\ k=1,\ 2,\ \ldots,\ 20\}$, where, $X_0(k)$ represents the mean preference score of the k-th stimulus image. To display the matrix clearly, it was transposed, generating the following matrix:

$$(X_0,\cdots,X_2)^T = \begin{Bmatrix} 3.92 & 3.46 & \cdots & 3.63 & 3.76 \\ 2.62 & 2.83 & \cdots & 2.79 & 2.97 \\ 2.51 & 2.68 & \cdots & 2.50 & 2.30 \end{Bmatrix} \quad (1)$$

Normalization of Original Data

Due to the presence of multiple factors in the gray relational system, and the differences in units and meanings of the data for each factor, the resulting dimensions are also different. To facilitate data analysis and calculation, and to ensure the reliability of the analysis results, data are typically dimensionless [18]. This paper uses mean normalization for data processing. The normalization formula is as follows:

$$X_i'(k) = \frac{x_i(k)}{\overline{x_I}} \quad (2)$$

In the formula, $x_i(k)$ represents the original data of the i-th indicator for the k-th sample; $\overline{x_I}$ denotes the mean value of the i-th indicator; $x_i'(k)$ represents the normalized data of the i-th indicator for the k-th sample. Here, $(i=0,\ 1,\ 2,\ k=1,\ 2,\ \ldots,\ 20)$. The resulting matrix is as follows:

$$\left(X_0',\cdots,X_2'\right)^T = \begin{Bmatrix} 1.059 & 0.935 & \cdots & 0.981 & 1.016 \\ 0.938 & 1.012 & \cdots & 1.000 & 1.064 \\ 0.895 & 0.954 & \cdots & 0.891 & 0.818 \end{Bmatrix} \quad (3)$$

Calculation of Absolute Differences Between Sequences

The absolute differences between the indicator series for the 20 stimulus images (the two principal factor mean score series) and the reference series (the preference mean score series) were calculated. The formula (4) is:

$$\Delta i(k)=|X_0'(k)-X_i'(k)| \quad (4)$$

In the formula, $\Delta i(k)$ represents the absolute difference, $X_0'(k)$ is the normalized reference series, and $X_i'(k)$ is the normalized indicator series. After calculating the absolute differences, the resulting matrix is as follows:

$$\begin{Bmatrix} 0.121 & 0.077 & 0.155 & \cdots & 0.019 & 0.048 \\ 0.164 & 0.019 & 0.030 & \cdots & 0.090 & 0.198 \end{Bmatrix} \quad (5)$$

Determination of the Range

Identify the minimum and maximum differences in the absolute difference matrix. From the matrix, it is evident that the minimum difference is 0.013, and the maximum difference is 0.257.

$$\min_i \min_k | X_0'(k)-X_i'(k) |= 0.013 \quad (6)$$

$$\max_i \max_k | X_0'(k)-X_i'(k)|=0.257 \quad (7)$$

Calculation of the Gray Relational Coefficients

Using the absolute differences from the matrix series and the maximum and minimum differences, the gray relational coefficients between the two principal factors and the preference levels are calculated. The calculation formula is:

$$\gamma_i(k) = \frac{\min_i \min_k | X_0'(k)-X_i'(k) |+\rho*\max_i \max_k | X_0'(k)-X_i'(k)|}{|X_0'(k)-X_i'(k)|+\rho*\max_i \max_k | X_0'(k)-X_i'(k)|} \quad (8)$$

In the formula, $\gamma_i(k)$ represents the gray relational coefficient for the i-th stimulus image's k-th principal factor and the preference level, and ρ is the distinguishing coefficient, which is typically set to 0.5 [19]. The resulting gray relational coefficient matrix is as follows:

$$\begin{Bmatrix} 0.567 & 0.689 & 0.499 & \cdots & 0.753 & 0.957 & 0.802 \\ 0.483 & 0.959 & 0.893 & \cdots & 0.589 & 0.648 & 0.434 \end{Bmatrix} \quad (9)$$

Calculation of the Gray Relational Degree

Using the gray relational coefficients obtained in the previous step, the degree of association between the two principal factors and the preference level is calculated. The formula is as follows:

$$\omega_i = \frac{1}{m}\sum_{k=1}^{m} \gamma_i(k) \quad (10)$$

In the formula, ω_i represents the average gray relational degree between the i-th principal factor and the preference level, and the magnitude of this value is directly proportional to the degree of association. Here, m is the total number of stimulus image samples.

Through calculation, the Temperament Factor : $\omega_1 = 0.717$, and for the Style Factor: $\omega_2 = 0.673$, Thus, the degree of association with the preference level is ranked as: $\omega_1 > \omega_2$, indicating that the Temperament Factor has a stronger association with the preference level.

Based on the principal component analysis of the Temperament and Style Factors, and combined with the scores of the main affective psychological words for each pattern sample in Table 1, it can be concluded that whether the pattern theme is lively and interesting, and whether the composition is simple yet smooth and unadorned, are the primary concerns of consumers. Shu embroidery patterns with lively and interesting themes, cultural flavor of the Sichuan-Chongqing region, and soft and elegant presentations are more likely to be favored by consumers. According to Table 1, patterns 03, 04, 05, 06, 07, 11, 12, 17, and 19 reflect the most characteristics of the Temperament Factor, making them more likely to be favored by consumers.

INNOVATIVE DESIGN OF SHU EMBROIDERY PATTERNS

Based on the above analysis, the patterns that align with the temperament characteristics favored by consumers were ranked according to their preference scores in Table 2. Pattern 03 ranked highest, indicating that the opera mask pattern possesses unique characteristics in terms of theme and composition, making it more likely to be favored by consumers. Therefore, the opera mask pattern was used for innovative design and extraction. The opera mask pattern is an innovative form that integrates Sichuan opera elements into Shu embroidery, being novel and vibrant, and highly accepted among younger consumers. Sichuan opera, as a significant cultural symbol of the Southwest region, endows Shu embroidery with regional characteristics and cultural depth. This integration helps deepen consumers' geographical impression of Shu embroidery art and improves the recognition and acceptance of Shu embroidery patterns.

Extraction of Basic Factors

Sichuan opera facial masks consist of abstract and geometric shapes made up of dots, lines, and surfaces, with the lines mostly being curves, offering fluidity and richness [20]. By using the deconstruction and reorganization method, the elements of the Sichuan opera mask patterns were disassembled and optimized. Some new elements were combined to derive deformed basic units that retain the details and characteristics of the original patterns, as shown in Figure 3.

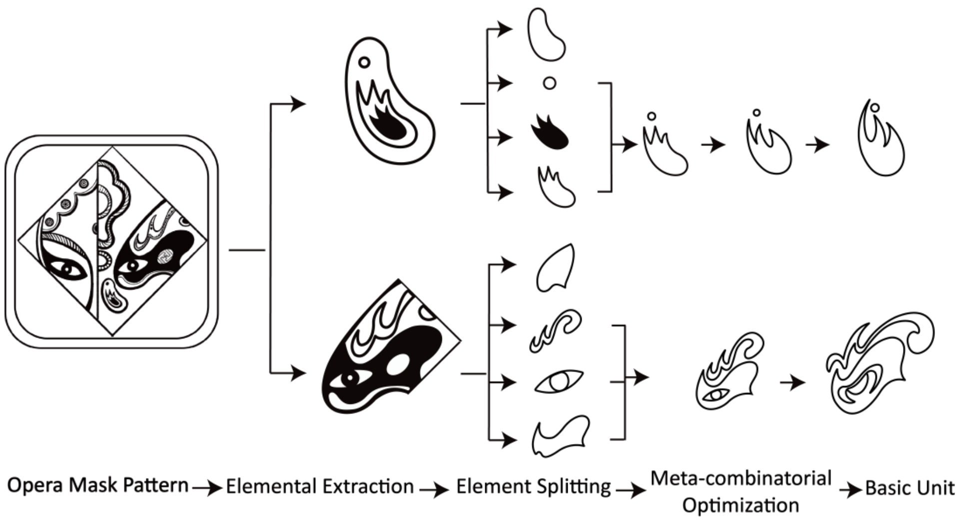

Figure 3. The Process of Deconstructing and Recombining Shu Embroidery Facial Patterns

Shape Grammar Derivation Process

The deconstructed and reorganized basic units were evolved according to shape grammar rules. The evolution rules are denoted by R, with R1 representing the horizontal mirroring rule, R2 the vertical mirroring rule, R3 the point rotation rule, R4 the central rotation rule, R5 the horizontal displacement rule, R6 the vertical displacement rule, R7 the reduction rule, R8 the enlargement rule, and R9 the addition and deletion rule. The deconstructed and reorganized basic units were used as the fundamental patterns for the derivation process, as shown in Figure 4.

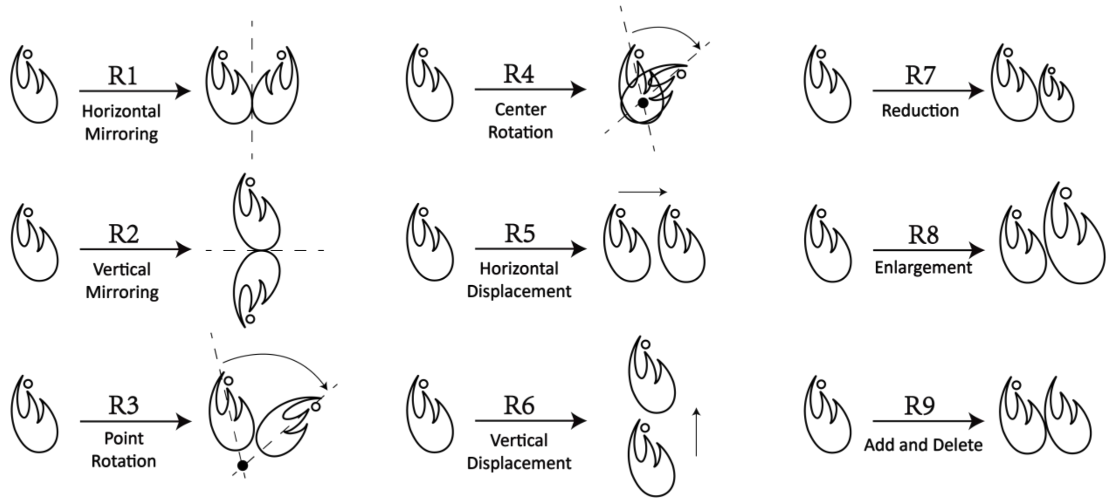

Figure 4. Schematic evolution diagram of basic patterns

The two basic units formed from the deconstructed and reorganized opera mask pattern underwent the first round of evolution according to the aforementioned rules, resulting in more complex regenerative elements, as shown in Figure 5. Basic unit A, after minor adjustments with the R4 rotation rule, underwent R1 horizontal mirroring, R2 vertical mirroring, and R9 addition and deletion rules to form regenerative element A1. Basic unit A, after R4 rotation adjustment and R9 addition rule for increased complexity, used the R3 rotation rule twice to form regenerative element A2. Basic unit B, after three R3 rotations, was reduced using the R7 rule to facilitate subsequent combinations, resulting in regenerative element B1. These regenerative elements serve as the foundational elements for further pattern design, facilitating their application in women's shoe design.

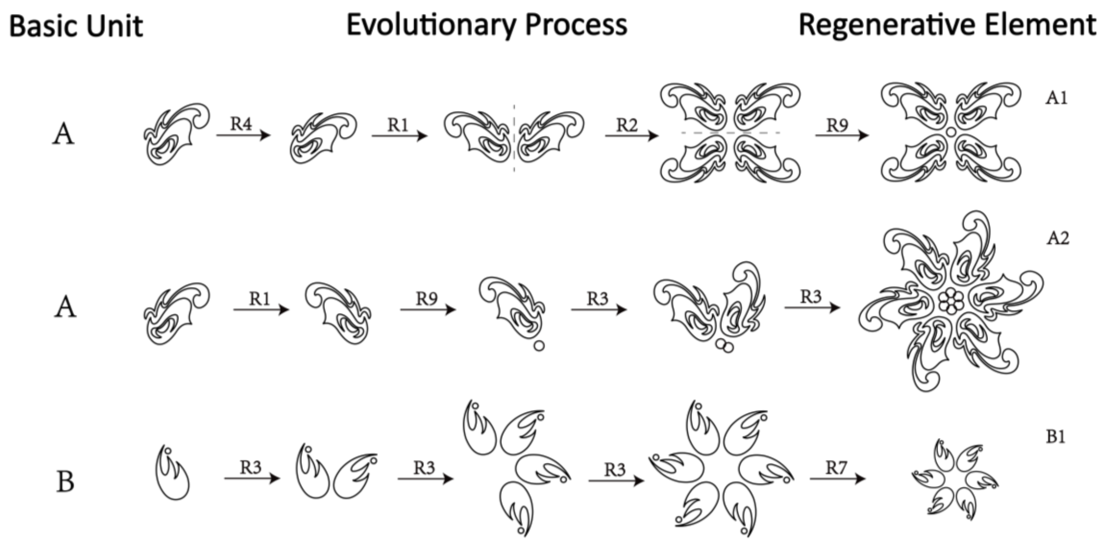

Figure 5. Schematic evolution of the basic unit

Color is an essential visible factor in design, with unique associative and emotional expression abilities that bring patterns to life [21]. Appropriate color combinations can guide consumer sensory experiences, reinforce the theme of the pattern, and create a specific design atmosphere. Initially, Photoshop was used to correct and extract colors from traditional Sichuan opera masks, resulting in a five-color palette, as shown in Figure 6.

The traditional Sichuan opera masks are brightly colored, with high saturation and strong visual tension, enriching the thematic effects and visual styles of the patterns. To provide designers with diverse color options, a fresh and natural trendy color, “Mint Mambo,” was also selected for color matching. Trendy colors reflect consumers’ fashion pursuits and current aesthetic elements [22]. The name “Mint Mambo” combines two concepts: “mint” (*mentha*), representing the freshest green of spring in ancient Greek, and “mambo,” a dance originating from South America known for its lively and free characteristics. At the 2024 Spring/Summer Fashion Week, international brands such as Versace, Louis Vuitton, and Chanel used “Mint Mambo” as the theme color for their collections, resulting in a five-color palette extracted from these designs, as shown in the color factor library.

Figure 6. Shu embroidery innovative pattern color factor library

APPLICATION OF INNOVATIVE PATTERNS IN WOMEN’S SHOES

The base shoe model selected for this innovative design is a pair of light-colored genuine leather pointed-toe high heels, featuring a fresh and elegant color palette, with a minimalist yet refined design. This classic style is highly versatile, suitable for women of various age groups and style preferences. As a timeless icon in the fashion industry, pointed-toe heels have remained popular for many years, as they visually elongate the legs and exude an air of elegance, making them a staple for both daily and formal wear [23]. In recent years, pointed-toe heels have been frequently featured on international fashion week runways, with designers blending traditional pointed-toe elements with modern design concepts, further cementing their status as a global classic. Notable brands such as Prada, Givenchy, and Loewe prominently showcased this iconic style in their 2023 collections, highlighting its enduring influence in the fashion world. By incorporating the evolved traditional facial pattern designs into pointed-toe high heels, this innovation not only enhances the artistic value of the footwear but also caters to the growing demand for personalized fashion among women.

In this study, the renderings of the application of innovative Shu embroidery facial mask on women’s shoes were created using the image processing software Adobe Illustrator. Correspondingly, the innovative patterns developed in this research can also be applied to 3D model of the shoes, demonstrating their versatility and potential for use in three-dimensional design. The specific application methods are categorized into three types: “dot” application, “line” application, and “surface” application [24].

"Dot" Application

The "dot" application focuses on individual patterns as concentrated visual elements, highlighting them clearly and concisely. Regenerative elements A2 and B1 were combined to form a single pattern with appropriate density and symmetrical harmony, as shown in Figure 7(a). The single pattern was colored using both traditional Sichuan opera mask colors and the "Mint Mambo" color scheme. The traditional color scheme is vibrant, while the trendy color scheme is fresh and natural, as shown in Figure 7(b). The pattern was used as a decorative element on the upper part of sandals, adding a delicate aesthetic touch, and placed on the heel to highlight the innovative design of women's shoes, as shown in Figure 7(c).

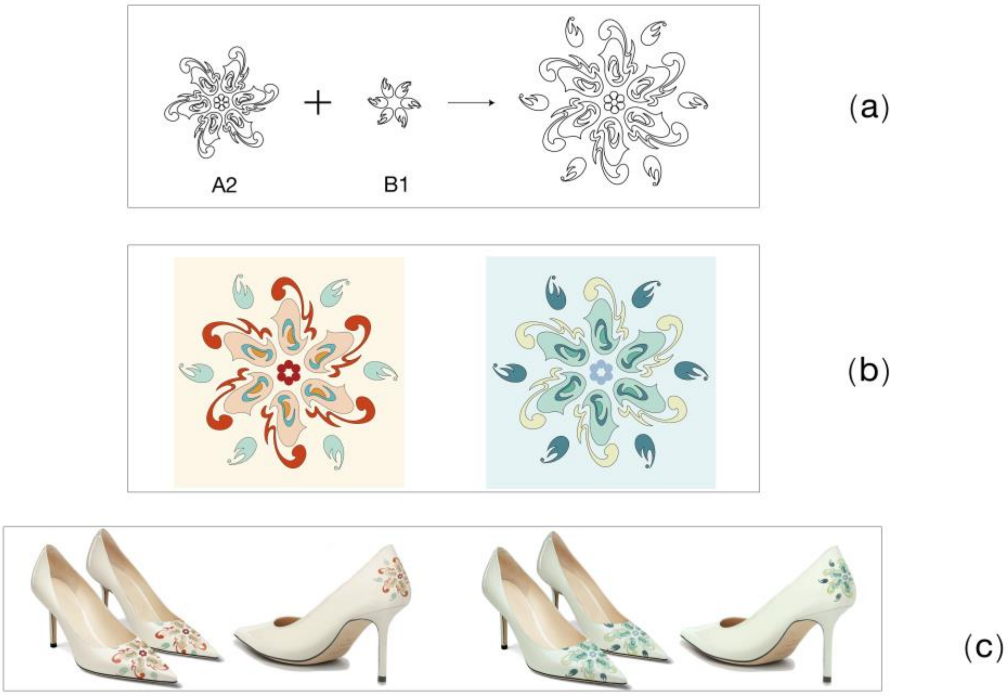

Figure 7. Individual pattern derivation process and its application in women's shoes: (a) Individual pattern derivation process; (b) Individual pattern color matching; (c) The application of "dot" form

"Line" Application

The "line" application primarily uses continuous patterns, visually rich in rhythmic beauty, showcasing unity in repetition and harmonious aesthetics. Regenerative elements A1 and B1 were combined using the R5 horizontal displacement rule to form a continuous pattern, as shown in Figure 8(a). These patterns were colored using both traditional Sichuan opera mask colors and the "Mint Mambo" color scheme, creating two distinct styles, as shown in Figure 8(b). The pattern was scaled down and adjusted to an arc shape, delicately adorning the upper part of the shoe, giving a gentle and soft overall style. Alternatively, the pattern was placed around the shoe opening, highlighting a stylish and capable feminine temperament, as shown in Figure 8(c).

Figure 8. Bicubic Continuous pattern derivation process and its application in women's shoes:
(a) Bicubic Continuous pattern derivation process; (b) Bicubic Continuous pattern color matching;
(c) The application of "line" form

"Surface" Application

The "surface" application primarily uses four-way continuous patterns, featuring distinctive styles and intricate details. Regenerative elements A2 and B1 were combined using the R4 central rotation rule and R7 reduction rule, then arranged using the R5 and R6 displacement rules to form a four-way continuous pattern, as shown in Figure 9(a). These patterns were then colored, as shown in Figure 9(b).

Adjusting the pattern density changes the overall style: lower density results in a more spaced-out, simple, and elegant look, while higher density creates a luxurious and intricate appearance. Both applications enhance the visual impact, enriching the decorative details of the footwear and showcasing unique personalized styles, as shown in Figure 9(c).

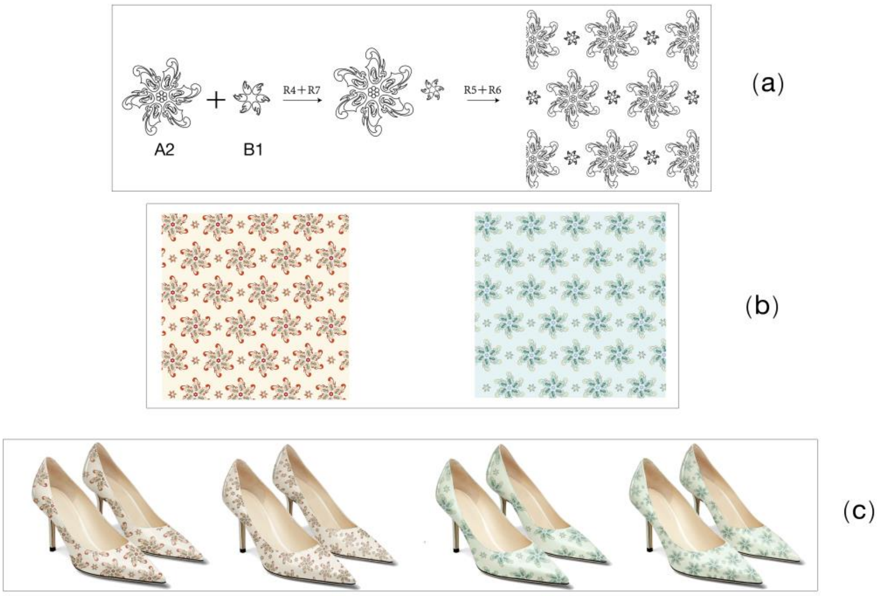

Figure 9. Fourth party continuous pattern derivation process and its application in women's shoes:
(a) Fourth party Continuous pattern derivation process; (b) Fourth party continuous pattern color matching;
(c) The application of "surface" form

CONCLUSION

Shu embroidery patterns encapsulate the essence and charm of Chinese culture, exhibiting high artistic value and creative potential in design. This study employs Kansei Engineering methods, utilizing mean statistics, factor analysis, and gray relational analysis to determine that the temperament factor of Shu embroidery patterns has the highest correlation with preference levels. The representative Shu embroidery pattern, the Sichuan opera mask, was selected based on its temperament characteristics.

The opera mask pattern was deconstructed, reorganized, and innovatively derived following shape grammar rules. It was colored using traditional Sichuan opera hues and the trendy "Mint Mambo" palette, and applied in women's shoe design in three forms: dot, line, and surface. This innovative integration of Shu embroidery patterns into women's shoe design provides a new pathway for the modern application of traditional elements, enhancing the innovation and unique appeal of women's footwear, thereby significantly improving market competitiveness. Furthermore, this design methodology offers a valuable reference for women's shoe brands and designers.

Acknowledgements

This work was supported by the Humanities and Social Sciences Foundation of the Ministry of Education of China under Grant Nos. 21YJC850013. The authors declare no conflicts of interest in this work and express their gratitude to all survey participants.

REFERENCES

1. Zhong, X., Chudasri, D., A Review of Traditional Embroidery from China in Relation to Knowledge Management and Design, Joint International Conference on Digital Arts, Media and Technology with ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunications Engineering (ECTI DAMT-NCON), IEEE, **2019**, https://doi.org/10.1109/ECTI-NCON.2019.8692256.
2. Yuan, Y., Design Innovation and Exploration of Sichuan Embroidery and Sichuan Brocade Tourist Souvenirs, *Canadian Social Science*, **2015**, 11, 1, 88.
3. Zhao, M., *Chinese Shu Embroidery: Intangible Cultural Heritage of China* (In Chinese), Sichuan Science and Technology Press, **2011**.
4. Lim, H.S., Development of 3D Printed Shoe Designs Using Traditional Muntin Patterns, *Fashion and Textile Research Journal*, **2017**, 19, 2, 134-139, The Korean Society for Clothing Industry, https://doi.org/10.5805/SFTI.2017.19.2.134.
5. Karaseva, A., Sulaimanova, D., Karasev, D., Konareva, Y., Litvin, E., Functioning of Ethnocultural Style in Modern Footwear Design, *AIP Conf Proc*, **2022**, 2430, 1, https://doi.org/10.1063/5.0077703.
6. Cao, Z.H., Yuan, G.X., Sheng, R., Liu, S.Y., The Influence of Chinese Cultural Elements in Footwear Design, *Textile Science and Economy*, **2022**, 10, 88-94.
7. Guo, X.J., Exploring the Innovative Application of Traditional Motifs in the Design of Cultural and Creative Products, *Frontiers in Art Research*, **2023**, 5, 5, https://doi.org/10.25236/FAR.2023.050515.
8. Ho, A.G., Siu, K.W.M.G., Emotion Design, Emotional Design, Emotionalize Design: A Review on Their Relationships from a New Perspective, *Des J*, **2012**, 15, 1, 9–32, https://doi.org/10.2752/175630612X13192035508462.
9. Marcum, J.W., *A New American TQM: Four Practical Revolutions in Management*, *Natl Product Rev*, **1994**, 13, 2, 316-317.
10. Lin, S., Shen, T., Guo, W., Evolution and Emerging Trends of Kansei Engineering: A Visual Analysis Based on CiteSpace, *IEEE Access*, **2021**, 9, 111181-111202, https://doi.org/10.1109/ACCESS.2021.3102606.
11. Esmaeilian Toussi, H., Etesam, I., Mahdavinejad, M., The Application of Evolutionary Algorithms and Shape Grammar in the Design Process Based upon Traditional Structures, *Bagh-e Nazar*, **2021**, 18, 95, 19-36, https://doi.org/10.22034/bagh.2019.161797.3914.
12. Wang, J., Zhang, S., Fan, W., Application of Shape Grammar to Vernacular Houses: A Brief Case Study of Unconventional Villages in the Contemporary Context, *J Asian Archit Build Eng*, **2024**, 23, 3, 843–859, https://doi.org/10.1080/13467581.2023.2247465.
13. López, Ó., Murillo, C., González, A., Systematic Literature Reviews in Kansei Engineering for Product Design—A Comparative Study from

1995 to 2020, *Sensors*, **2021**, 21, 19, 6532, https://doi.org/10.3390/s21196532.
14. Francis, E.B., Senyefia, B.A., Joseph, O., Modeling Macroeconomic Variables Using Principal Component Analysis and Multiple Linear Regression: The Case of Ghana's Economy, *Journal of Business and Economic Development*, **2020**, 5, 1, 1-9, https://doi.org/10.11648/j.jbed.20200501.11.
15. Nag, M.B., Ahmad Malik, F., Data Analysis and Interpretation, In: *Repatriation Management and Competency Transfer in a Culturally Dynamic World*, Singapore: Springer Nature Singapore, **2023**, 93-140, https://doi.org/10.1007/978-981-19-7350-5_5.
16. Yang, C., Liu, F., Ye, J., A Product Form Design Method Integrating Kansei Engineering and Diffusion Model, *Adv Eng Inform*, **2023**, 57, 102058, https://doi.org/10.1016/j.aei.2023.102058.
17. Hamdi, A., Merghache, S.M., Application of Artificial Neural Networks (ANN) and Gray Relational Analysis (GRA) to Modeling and Optimization of the Material Ratio Curve Parameters when Turning Hard Steel, *Int J Adv Manuf Technol*, **2023**, 124, 10, 3657–3670, https://doi.org/10.1007/s00170-023-10833-3.
18. Liu, D., Zhang, J., Wang, C., Ci, W., Wu, B., Quan, H., Integrated Triangular Fuzzy KE-GRA-TOPSIS Method for Dynamic Ranking of Products of Customers' Fuzzy Kansei Preferences, *J Intell Fuzzy Syst*, **2024**, 46, 19-40, https://doi.org/10.3233/JIFS-234549.
19. Wang, P., Chu, J., Yu, S., Chen, C., Hu, Y., A Consumers' Kansei Needs Mining and Purchase Intention Evaluation Method Based on Fuzzy Linguistic Theory and Multi-Attribute Decision Making Method, *Adv Eng Inform*, **2024**, 59, 102267, https://doi.org/10.1016/j.aei.2023.102267.
20. Ran, S.Y., Liu, H., Yang, L.M., Zhou, A.H., Preliminary Study on the Application of Facial Makeup Art of Sichuan Opera in the Leather Product Design (In Chinese), *J Leather Sci Eng*, **2020**, 30, 6, 62-66, https://doi.org/10.19677/j.issn.1004-7964.2020.06.012.
21. He, F., He, Y., Sun, L., Gender Differences in Color Perceptions and Preferences of Urban Façades Based on a Virtual Comparison, *Build Environ*, **2023**, 245, 110907, https://doi.org/10.1016/j.buildenv.2023.110907.
22. Zailskaitė-Jakštė, L., Ostreika, A., Jakštas, A., Stanevičienė, E., Damaševičius, R., Brand Communication in Social Media: The Use of Image Colours in Popular Posts, 2017 40th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), Opatija, Croatia, **2017**, 1373-1378, https://doi.org/10.23919/MIPRO.2017.7973636.
23. Prokop, P., High Heels Enhance Perceived Sexual Attractiveness, Leg Length and Women's Mate-Guarding, *Curr Psychol*, **2020**, 41, 5, 1-11, https://doi.org/10.1007/s12144-020-00832-y.
24. Lee, L., Application of Point, Line and Plane in Landscape Design, Proceedings of the 6th International Conference on Arts, Design and Contemporary Education - ICADCE **2020**, 6, https://doi.org/10.26914/c.cnkihy.2020.053057.

© 2024 by the author(s). Published by INCDTP-ICPI, Bucharest, RO. This is an open access article distributed under the terms and conditions of the Creative Commons Attribution license (http://creativecommons.org/licenses/by/4.0/).