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Research on the Decoding and Innovative Design Framework of the Chinese Song Brocade Eight-Treasures Halo Pattern (Badayun Pattern) Based on Gene Theory

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Article

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ABSTRACT

This study adopts Cultural Gene Theory as its foundation to decode the structural framework, colour system, and symbolic semantics of the Eight-Treasures Halo Pattern in Chinese Song Brocade. By constructing a Cultural Gene Map and applying the AHP (Analytic Hierarchy Process) method, both explicit and implicit cultural factors are quantitatively evaluated. Key visual features and semantic meanings are extracted as the basis for redesign. The study proposes a systematic methodology linking traditional patterns, cultural symbols, and modern design, offering theoretical support and practical models for pattern recognition, visual communication, and cultural innovation in the context of intangible cultural heritage (ICH).

KEYWORDS

cultural gene theory, meme theory, AHP method, Song brocade Badayun pattern, design Innovation

INTRODUCTION

The digitisation of intangible cultural heritage (ICH) has become a key strategy in global efforts to preserve cultural diversity and promote sustainable cultural development. Traditional patterns, as vital components of ICH visual systems, embody the historical memory of ethnic symbols while also carrying profound socio-cultural semantics. However, under the dual pressures of the digital divide and technological gaps, many localised traditional patterns now face the risk of loss and misinterpretation.

Research on ICH Transmission from a Meme Perspective

The preservation of intangible cultural heritage (ICH) has progressively shifted from mere display toward the analysis of deep cultural structures and digital reconstruction. Within this trend, "meme theory" has gained increasing attention. By drawing analogies from biological genetics—such as replication, variation, and recombination—meme theory aims to build cultural coding systems that are both inheritable and adaptable. Researchers like Ignatowicz et al. proposed integrating neural networks with knowledge graphs to achieve structural recognition and semantic mapping of ICH images, advancing technical pathways for making cultural schemata "computable and transmissible" [1]. Quan et al., in their digital preservation of Miao batik, applied knowledge graphs and deep learning models to propose a dual-channel modelling mechanism for image-text semantics, establishing standards for pattern-semantic matching [2].

Furthermore, the ArCo cultural heritage knowledge graph developed by Carriero et al. has formed a reusable ontology design paradigm in the semantic modelling of Italian cultural heritage, offering a valuable reference for modelling the cultural memes of China's indigenous ICH patterns [3]. Overall, research on cultural memes is no longer confined to metaphorical or conceptual dimensions but is progressively evolving toward "structured, " "parametric, " and "visualised" approaches.

In this study, we use the term “cultural gene” as the central analytic concept, referring to the fundamental structural, symbolic, and visual elements derived from traditional patterns that possess heritability and translatability. This framework draws upon meme theory, where a “meme” represents a unit of cultural transmission; however, the term “cultural gene” is adopted throughout this research to ensure specificity. These cultural genes are further divided into dominant genes (tangible, visible forms such as colour, structure, and motifs) and recessive genes (intangible meanings and connotations). The term “cultural factor” refers to measurable dimensions within the AHP evaluation framework and is used to quantify aspects of cultural genes, rather than as a standalone theoretical term.

Current Research on Song Brocade and the Logic of Pattern Evolution

As a representative of traditional Chinese brocade craftsmanship, Song brocade has been designated as a national-level intangible cultural heritage (ICH) item due to its rigorous structural design, rich geometric schemata, and unique cultural semantics. Within its pattern system, the "Badayun" motif stands as a quintessential example, integrating eight-direction symmetry, central expansion, and auspicious imagery. This pattern exhibits a high degree of visual orderliness and semantic encoding characteristics.

Existing research has primarily focused on the technical reconstruction and aesthetic analysis of Song brocade patterns. However, systematic studies on their evolutionary mechanisms, the deconstruction of cultural memes, and pathways for cultural re-creation remain notably scarce. Currently, only a few scholars, such as Lorente et al., have attempted to apply digital recognition and vector-based pattern reconstruction to the preservation of jacquard textiles. Their work achieved high-precision pattern reconstruction through image segmentation and error-correction algorithms [4].

Nevertheless, for pattern systems like Song brocade-characterised by complex semantic nesting and a tradition of schematic evolution-traditional image recognition methods alone remain insufficient for supporting deep semantic extraction. Therefore, there is a need to introduce modelling mechanisms with greater "cultural discernment capability, " such as cultural symbol ontologies, cognitive indexing, and meme factor mapping.

Application of the AHP Method in Design Factor Extraction

The Analytic Hierarchy Process (AHP), as a multi-criteria decision-making tool, is widely applied in product design, graphic recognition, user research, and related fields. Its strength lies in quantifying subjective judgments and conducting consistency verification, thereby enabling the scientific evaluation of the relative weights of multiple indicators within a decision-making system. In design studies, AHP is commonly used for visual factor prioritisation, pattern innovation strategy assessment, and user preference analysis [5].

Within the domain of intangible cultural heritage (ICH) graphic design, AHP can be synergised with meme theory to construct a three-dimensional decision-making model encompassing "cultural symbols – design transformation factors – user acceptance." For instance, this study employs AHP to conduct weight analysis on both explicit factors (colour structure, geometric rules, etc.) and implicit factors (symbolic meanings, cognitive expectations, etc.) within the Eight-Treasures Halo Pattern. This provides a scientific foundation for the contemporary redesign of traditional patterns.

METHODOLOGY

Pattern Decoding from a Meme Perspective

In the transmission of intangible cultural heritage, patterns are not merely formal presentations but also encoded carriers of cultural essence. This study adopts a meme theory perspective, integrating theoretical frameworks from cultural computing and cognitive semiotics. It treats Song brocade patterns as concretised "cultural meme fragments, " attempting systematic decoding of these cultural memes through their structure, meaning, and symbolic relationships.

First, representative samples of Song brocade patterns are collected. Through image analysis and cross-referencing with historical literature, their constituent units are identified. These include geometric structures, totemic animals, botanical symbols, and traditional colour systems. These units constitute the fundamental "cultural memes" of Song brocade patterns. Each pattern element is regarded as the smallest unit of inheritance and variation within the cultural system, and its combinatorial logic reveals the underlying cultural principles and aesthetic paradigms of Song brocade.

Second, the "Cultural Meme Map Construction Method" is employed to encode these cultural memes into a structured map. This method involves the following steps:

(1) Cultural Meme Unit Extraction: Isolating distinct pattern elements.

(2) Semantic Classification and Tagging: Categorising units based on meaning and applying descriptive labels.

(3) Modelling Logical Relationships & Visual Representation: Defining connections between memes and visualising the network.

This process ultimately forms the "Cultural Meme Map Construction Framework, " which is then used to generate a specific "Cultural Meme Map."

This approach not only achieves the translation of pattern elements from sensory forms to cultural semantics but also provides a stable, clearly structured basis for subsequent evaluation models. It offers theoretical support for cultural heritage design research that integrates quantitative and qualitative approaches.

Identification and Classification of Cultural Memes

The cultural memes manifested in the Song brocade Eight-Treasures Halo Pattern represent the core elements within its traditional culture that exhibit heritability, symbolism, and regenerative capacity. In cultural studies, identifying and classifying these cultural memes aids in understanding and grasping the intrinsic logic of cultural transmission and development. Cultural memes are generally categorised into two types: dominant memes and recessive memes. In genetics, a dominant gene is one that, within a pair of alleles, masks the effect of the other allele and thereby expresses its trait. Dominant genes are conventionally represented by uppercase letters (e.g., A), while their corresponding recessive genes are denoted by lowercase letters (e.g., a). If an individual possesses either two identical alleles (homozygote, AA) or two different alleles (heterozygote, Aa), only the trait controlled by the dominant gene (A) will manifest in the phenotype. Only individuals with the homozygous recessive genotype (aa) will express the trait controlled by the recessive gene (a). As elucidated by scholar Bai Guixi in his work "Types of Cultural Memes and Their Identification Principles: A Framework Based on Ethnic Craft Culture" [6], Dominant Memes refer to materialised carriers directly perceivable through the senses, manifested as concrete elements such as colour, material, and imagery. Their phenotypic characteristics are intuitive and measurable. Recessive Memes denote abstract cores requiring cultural decoding for identification. These include symbolic systems, cognitive logic of craftsmanship, value and ethical concepts, etc. Their phenotypic characteristics are implicit and require interpretation.

By analysing the evolution and artistic characteristics of the Song brocade Eight-Treasures Halo Pattern, its cultural connotations are identified. From a biological analogy perspective, its cultural memes are classified into two major categories: Dominant Memes (Tangible Cultural Memes) and Recessive Memes (Intangible Cultural Memes). Dominant Memes include Structural Skeleton Factors\Pattern Motif Factors\Colour Factors; Recessive Memes include Implied Meaning Factor and Semantic Factors. Figure 1 illustrates the logical construction of the cultural gene map, including five primary categories: structural skeletons, pattern motifs, colour elements, semantic symbols, and implied meanings. Each element is represented with specific symbols and connective lines to show inheritance and transformation pathways. Figure 2 presents the finalised cultural gene map, where nodes of different colours (e.g., red for structure, blue for meaning) visually encode the classification of dominant and recessive genes. Arrows indicate directional relationships among gene units, such as transmission, transformation, or influence.

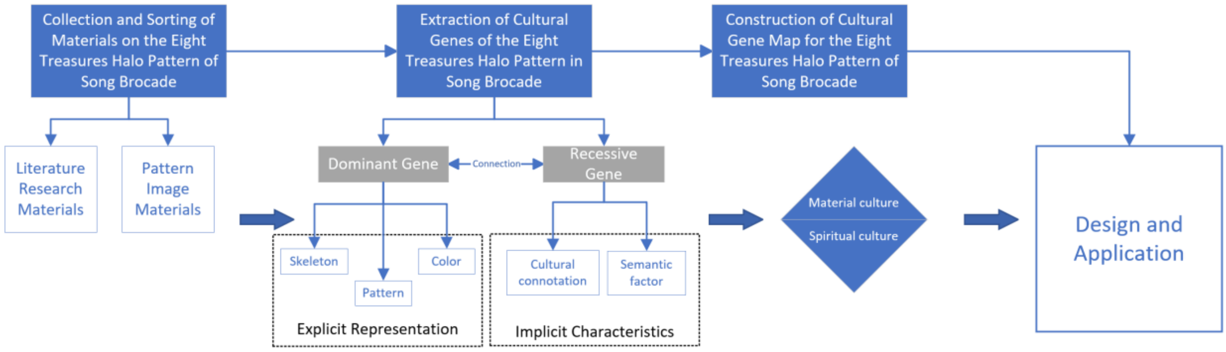


Figure 1. Construction of the cultural gene map of the Eight-treasure Halo pattern in Song brocade

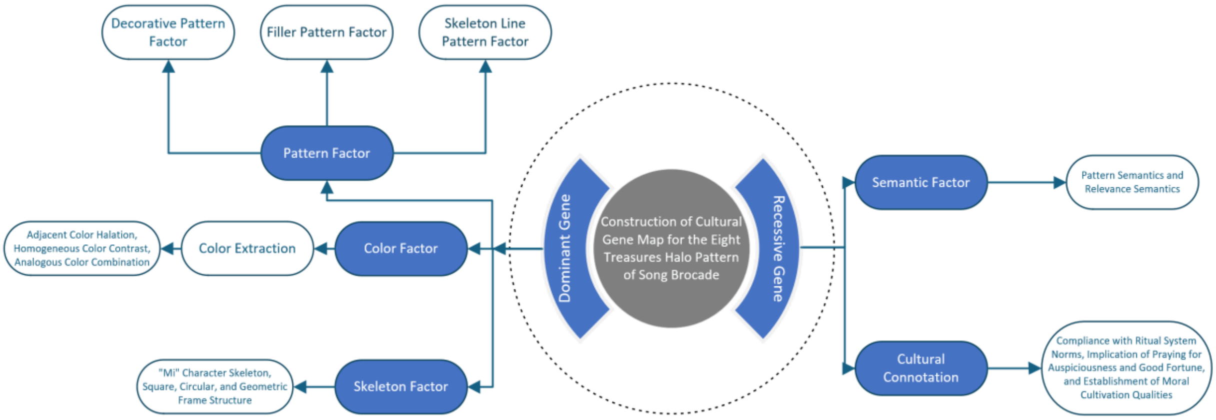


Figure 2. Gene map of the Eight-treasure Halo pattern in Song brocade

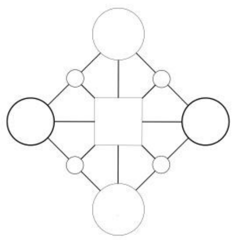
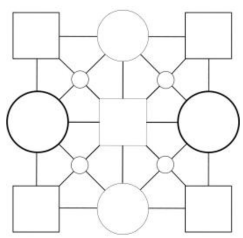
Extraction of Dominant Genes

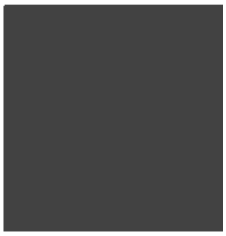
Skeleton Factor

As can be seen from Table 1, the skeleton factor of the Song brocade Eight-Treasures Halo Pattern exhibits characteristics such as symmetry, divisibility, hierarchy, and line fluidity. Symmetry: The Eight-Treasures Halo Pattern exhibits bilateral symmetry both horizontally and vertically, reflecting the traditional Chinese aesthetic pursuit of harmony and balance. This symmetry enhances the pattern's coordination, unity, and sense of order. Divisibility: The skeleton divides the pattern into eight equal parts, forming a "米" (mi)-shaped skeleton framework, resulting in a highly regular structure. Hierarchy:

Artisans often express hierarchical relationships within the skeleton factor through variations in the thickness of skeleton lines and the depth of colours. This not only imparts a three-dimensional effect and richness to the pattern but also increases its visual impact. Line Fluidity: Another key characteristic of the Badayun skeleton structure is the fluidity of its lines. The lines constituting the pattern flow smoothly and naturally, devoid of abrupt turns. This fluidity contributes significantly to the overall harmonious and aesthetically pleasing appearance of the pattern. In the later innovative applications of this study, these skeleton factors can be transformed and combined using different design techniques and decorative elements.

Table 1. Comparative analysis of structural skeleton types in the Eight-treasures Halo pattern of Song brocade

Name	Graphic and Text Information	Skeleton Structure
Brocade for the Head of Zhongxing Ruiying Tu (Auspicious Omens of the Restoration) in the Song Dynasty	 a)	 Skeleton Framework Combining Square and Circle
Brocade for the Head of Gengjia Tu (Farming Picture) in the Yuan Dynasty	 b)	 Circular Skeleton Framework
Eight-Treasures Halo Brocade at the End of the Yuan Dynasty and the Beginning of the Ming Dynasty	 c)	 Inner "米 - character Skeleton Framework  Nested-type Skeleton Framework

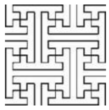
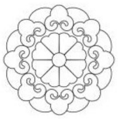
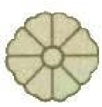
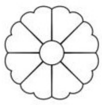
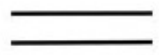
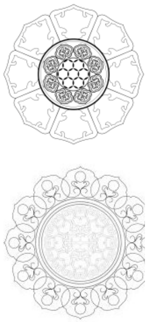
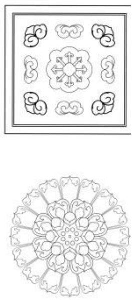
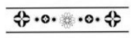
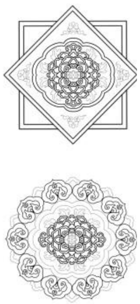
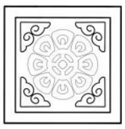
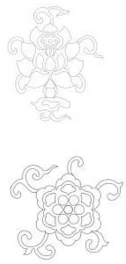
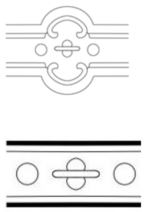
Name	Graphic and Text Information	Skeleton Structure	
Red - ground Brocade with Gold - woven Eight - Treasures Halo Pattern and Ruyi (Auspicious) Patterns Symbolising Wealth and Good Fortune in the Qing Dynasty.	 d)	 Circular - centred Skeleton Framework	 Composite Rhombus - centred Skeleton Framework

Note: The reference patterns in Table 1 are sourced from internationally recognised museum collections. Samples 1 and 2 are derived from the collections of the Metropolitan Museum of Art (USA), Sample 3 from the China National Silk Museum, and Sample 4 from the Palace Museum (China).

Pattern Factors

The pattern factors of the Song brocade Eight-Treasures Halo motif are composed of decorative patterns, filling patterns, and skeleton line patterns, which together form a harmonious and unified whole. Decorative patterns can be primarily classified into three major types: cluster floral decorative patterns, in which petals and leaves are arranged symmetrically and radially to produce a visual effect of eight-directional radiation, resembling motifs such as chrysanthemum and peony; treasure-flower decorative patterns, serving as highly typical and widely adopted ornamental elements, characterised by a centrally symmetrical "米"-shaped layout formed through the composite assembly of multiple floral forms, akin to lotus and peony structures; and animal-combined decorative patterns, which are enclosed within circular or square boundaries and embed motifs of auspicious animals such as flying dragons and dancing phoenixes. Filling patterns include continuous geometric filling patterns and individual filling patterns; the former comprises pattern types such as coin motifs, 卍 patterns, meander patterns, and grid motifs, while the latter consists of combinations of floral, auspicious cloud, and geometric elements, including lotus patterns, Eight-Treasures motifs, and cloud patterns. Skeleton line patterns function as structural dividers within the composition, contributing to the harmony and stability of the overall pattern structure. The extraction table of pattern factors for the Song brocade Eight-Treasures Halo motif is shown in Table 2.

Table 2. Categorisation and feature extraction of pattern motifs in the Eight-treasures Halo pattern

Reference Object	Decorative pattern factor	Decorative pattern factor extraction	Secondary decorative pattern factor	Secondary decorative pattern factor extraction	Filling pattern factor	Filling pattern factor extraction	Skeleton pattern factor	Skeleton pattern factor extraction
Pic (a)								
Pic (b)								
Pic (c)								
Pic (d)								

Colour Factor

The application of colour in the Song brocade Eight-Treasures Halo Pattern is highly exquisite, aiming to convey specific cultural symbolism and aesthetic sentiments through hues. The colour selection primarily draws from traditional Chinese colours, such as red, yellow, blue, green, purple, and metallic tones like gold and silver. Within traditional cultural contexts, each colour carries unique symbolic meanings. The Eight-Treasures Halo Pattern typically employs colours symbolising auspiciousness; hence, red and yellow frequently appear in its colour schemes, representing auspiciousness, jubilation, and prosperity. Red embodies fervour, vitality, and celebratory joy, while yellow signifies wealth and authority.

To enhance the pattern's three-dimensionality and sense of depth, the Badayun motif often utilises contrasting colours-such as light vs. dark tones and warm vs. cool palettes accentuate the main decorative elements. Harmonious colour combinations are equally critical in the Eight-Treasures Halo Pattern. Pairings like blue-green and purplish-red create cohesive and balanced visual atmospheres. Furthermore, the pattern exhibits smooth and natural colour transitions, achieved through gradients or shading techniques. This ensures seamless blending between hues, refining the pattern's delicacy and aesthetic appeal. The introduction of metallic colours (gold/silver) elevates the Eight-Treasures Halo Pattern's opulence and visual prominence, further enhancing its overall artistic impact. The extracted colour scheme of the Song brocade Eight-Treasures Halo Pattern is detailed in Table 3.

Table 3. Traditional colour schemes and symbolic interpretations in the Eight-treasures Halo pattern

Colour sample	Colour factor extraction	Colour sample	Colour factor extraction
	R:118 G:116 B:067; R:078 G:083 B:051; R:040 G:045 B:002 R:151 G:112 B:073; R:167 G:051 B:011; R:234 G:234 B:234 R:104 G:084 B:107; R:012 G:012 B:012		R:253 G:218 B:162; R:227 G:171 B:123; R:179 G:108 B:026 R:191 G:056 B:001; R:089 G:020 B:004; R:091 G:055 B:039
	R:216 G:216 B:182; R:204 G:203 B:149; R:151 G:151 B:091; R:119 G:119 B:57 R:103 G:112 B:065; R:068 G:068 B:038; R:128 G:142 B:106; R:065 G:090 B:084 R:050 G:054 B:063; R:106 G:074 B:053		R:163 G:199 B:153; R:039 G:115 B:102; R:192 G:142 B:050 R:235 G:089 B:116; R:220 G:001 B:000; R:062 G:036 B:061

Extraction and Transformation of Recessive Genes

The extraction of recessive genes often requires profound capabilities in historical research, cultural analysis, and artistic appreciation. The recessive genes of the Song brocade Eight-Treasures Halo Pattern refer to those deep-seated cultural elements not readily observable through direct examination. By studying historical literature and examining Song brocade Badayun textile artefacts, this research explores the cultural connotations of the Eight-Treasures Halo Pattern to a certain extent, extracting its recessive genes related to hierarchical order, auspicious symbolism, and moral edification. Specific meanings and culturally symbolic semantic factors embedded within the pattern's composition are extracted and transformed. The extraction results for the recessive genes of the Song brocade Eight-Treasures Halo Pattern are presented in Table 4.

Table 4. Symbolic semantics and cultural connotations of recessive genes in the Eight-treasures Halo pattern

	Recessive gene
Implied Meaning Factor	Social Institution--Normative Hierarchical Ritual System; Philosophical Perspective-- Education in Self-Cultivation and Moral Integrity through Unity of Heaven and Humanity
Semantic Factor	Structural Motif "ノ达--Four-cornered Spatial Accessibility Geometric Composition: Square-Circle Combination - "Round Heaven, Square Earth" "卍 Pattern--Continuity across generations; eternal perpetuation Coin Pattern--Attracting wealth and prosperity Lotus + Peony Combination-- Glory, Splendour and Nobility Ruyi Sceptre Pattern--Everything as Wished

AHP Evaluation Process

This study integrates the Analytic Hierarchy Process (AHP) with meme theory to analyse the Song brocade Eight-Treasures Halo Pattern. An evaluation hierarchy model for its cultural factors is constructed using AHP, with the evaluation results serving as a scientific basis for guiding subsequent innovative design applications.

Based on the cultural gene framework of the Eight-Treasures Halo Pattern established earlier, the evaluation hierarchy model is structured as follows:

Objective Layer (A) - Cultural Genes of Song Brocade Eight-Treasures Halo Pattern

Criterion Layer (B) - B1: Dominant Genes B2: Recessive Genes

Sub-Criterion Layer (C) - C1: Skeleton Factor, C2: Pattern Motif Factor C3: Colour Factor C4: Semantic Factor C5: Implied Meaning Factor

Factor Layer (D) - Subsets extracted from the five elements in the Sub-Criterion Layer

The hierarchical evaluation model for the cultural genes of the Song brocade Eight-Treasures Halo Pattern is illustrated in Figure 3.

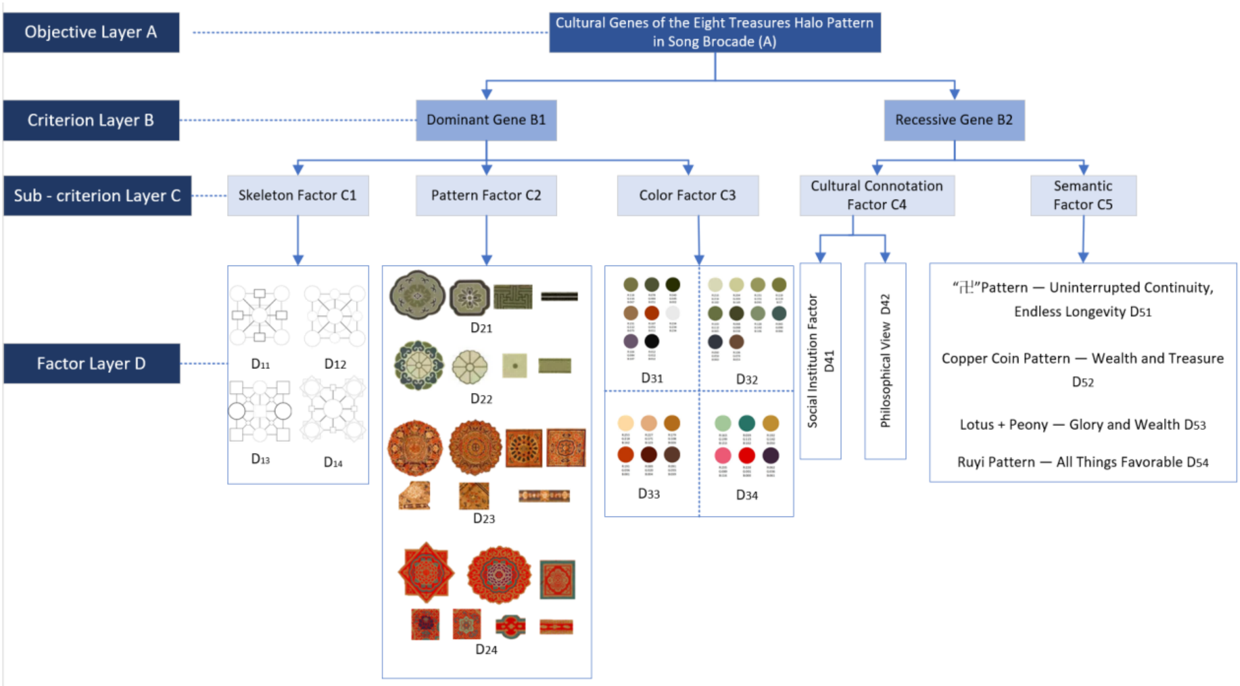


Figure 3. Evaluation model tree of cultural genes for Song brocade, Eight-treasures Halo pattern

RESULTS AND ANALYSIS

Extraction and Classification of Cultural Factors

In the comprehensive evaluation system for the cultural genes of the Eight-Treasures Halo Pattern in Song Brocade, there are 2 major criteria and 18 indicators, each with differing levels of importance in the comprehensive evaluation. Factors of greater significance should be assigned higher weights, while those of lesser importance should receive lower weights. The weight vectors for each evaluation indicator were calculated using the Analytic Hierarchy Process (AHP), as follows:

Building upon the hierarchical evaluation model of cultural genes for the Eight-Treasures Halo Pattern in Song Brocade, the Analytic Hierarchy Process (AHP) was applied to systematically assess the relative importance of factors across each level of the model. A judgment matrix was constructed by conducting pairwise comparisons of elements within the comprehensive evaluation layer. The scale values for these comparisons were defined using the standard 1–9 rating scale, with detailed interpretations provided in Table 5. To ensure the reliability of the evaluation, a group of 8 professional designers from a publicly listed company and 4 design students were invited to independently rate the importance of the factors at each level.

Table 5. Importance comparison and evaluation

Aij (indicator)	Definition	Aij (indicator)	Definition
1	Criteria A_i and A_j are of equal importance	2	Between equal and slightly more important
3	A_i is somewhat more important than A_j	4	Between slightly and moderately more important
5	A_i is more important than A_j	6	Between clear and strongly more important
7	A_i is significantly more important than A_j	8	Between very strong and absolute importance
9	A_i is more important than A_j	Reciprocal	If A_i is less important than A_j, then $a_{ij}=1/a_{ji}$

By analysing the relative significance among all indicators, a decision matrix for the target level was constructed. Table 6 displays the corresponding matrix for the criteria level.

Table 6. Judgment matrix of the criterion layer

Evaluation Indicator	Dominant gene B1	Recessive gene B2	Wi
Dominant gene B1	1	2	0.6667
Recessive gene B2	1/2	1	0.3333

As reflected in Table 6, the calculation results yield a maximum eigenvalue (λ_{max}) of 2.0000, a consistency index (CI) of 0.0000, a random index (RI) of 0, and a consistency ratio (CR) of 0.0000. These results confirm that the matrix meets the standard consistency requirement.

It is evident from the data that the Dominant Gene factor (B1) is considered twice as significant as the Recessive Gene factor (B2). According to the foundational principles of AHP, the priority weights for each can be calculated based on this ratio.

Table 7. Judgment matrix of the sub-criterion layer

Evaluation Indicator	Skeleton factor C1	Pattern factor C2	Colour factor C3	Wi
Skeleton factor C1	1	5	4	0.6908
Pattern factor C2	1/5	1	1	0.1488
Colour factor C3	1/4	1	1	0.1603

Referring to the data in Table 7, the computed values are as follows: the maximum eigenvalue λ_{max}=3.0055, the consistency index CI=0.0028, the random index RI=0.52, and the consistency ratio CR=0.0053. Since CR<0.1, the matrix is deemed to have acceptable consistency.

The weight calculation procedure for this judgment matrix proceeds as follows:

Multiply all elements in each row of the matrix to obtain the intermediate product values:

$$m_i = \prod_{j=1}^{n} a_{ij} = [20.0000, 0.2000, 0.2500] \tag{1}$$

Take the n-th root of each mi to derive the unnormalised weights:

$$w_i^* = \sqrt[n]{m_i} = [2.7144, 0.5848, 0.6300] \tag{2}$$

Normalise the vector to obtain the final weights

$$w_i = w_i^* / \sum_{i=1}^{n} w_i^* = [0.6908, 0.1488, 0.1603] \tag{3}$$

To compute the maximum eigenvalue λ_{max}, the following formula is used:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(Aw)i}{w_i} = 1/3 \times 9.0166 = 3.0055 \tag{4}$$

Where Aw [2.0763, 0.4473, 0.4819] is the product of the original matrix and the weight vector.

The consistency index is determined by the formula:

$$CI = \frac{\lambda_{\max} - n}{n-1} \text{=(3.0055-3)/(3-1)=0.0028} \quad (5)$$

According to the standard RI table, the random index for a matrix of size 3 is 0.52. Therefore, the consistency ratio is:

$$\text{CR=CI/RI=0.0028/0.52=0.0053} \quad (6)$$

Since the CR value is well below the threshold of 0.1, the judgment matrix passes the consistency check.

Table 8. Judgment matrix of the evaluation factor B2 layer

Evaluation indicator	Implication factor C4	Semantic factor C5	Wi
Implication factor C4	1	1	0.5000
Semantic factor C5	1	1	0.5000

According to the data presented in Table 8, the results show that the maximum eigenvalue λ_{max} equals 2.0000, with a consistency index (CI) of 0.0000, a random index (RI) of 0, and consequently, a consistency ratio (CR) also equal to 0.0000. These values confirm that the consistency requirement is fully met.

The table further illustrates that the relative significance of the implication factor (C4) is equal to that of the semantic factor (C5). Following the fundamental principles of the AHP method, the respective weights for these two criteria can thus be calculated.

Table 9. Judgment matrix of skeleton factors for evaluation factor C1 layer

Evaluation Indicator	D11	D12	D13	D14	Wi
D11	1	1/2	1/3	1/5	0.0913
D12	2	1	1/2	1/2	0.1797

Evaluation Indicator	D11	D12	D13	D14	Wi
D13	3	2	1	3	0.4402
D14	5	2	1/3	1	0.2888

As indicated in Table 9, the computed values for the judgment matrix are as follows: the maximum eigenvalue λ_{max}=4.2521, the consistency index CI=0.0840, the random index RI=0.89, and the consistency ratio CR=0.0944. Since CR<0.1, the consistency of the matrix is within the acceptable threshold.

The procedure for calculating the weight values in this matrix includes the following steps:

Determine the product of the elements in each row of the comparison matrix:

$$m_i = \prod_{j=1}^{n} a_{ij} = [0.0333, 0.5000, 18.0000, 3.3333] \quad (7)$$

Compute the geometric mean of each row product to get the initial weight vector:

$$w_i^* = \sqrt[n]{m_i} = [0.4273, 0.8409, 2.0598, 1.3512] \quad (8)$$

Normalise the vector to obtain the final priority weights:

$$w_i = w_i^* / \sum_{i=1}^{n} w_i^* = [0.0913, 0.1797, 0.4402, 0.2888] \quad (9)$$

To calculate the maximum eigenvalue λ_{max} , the following expression is used:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(Aw)i}{w_i} = 1/4 \times 17.0085 = 4.2521 \quad (10)$$

Where Aw=[0.3857, 0.7268, 1.9399, 1.2515].

The consistency index is derived as:

$$CI = \frac{\lambda_{\max} - n}{n-1} \text{=(4.2521-4)/(4-1)=0.0840} \quad (11)$$

Referring to the RI table, the random index for a 4×4 matrix is 0.89. Thus, the consistency ratio is:

$$CR=CI/RI=0.0840/0.89=0.0944 \quad (12)$$

As this value remains below the commonly accepted threshold of 0.1, the consistency of the matrix is considered satisfactory.

Table 10. Judgment matrix of pattern factors for evaluation factor C2 layer

Evaluation indicator	D21	D22	D23	D24	Wi
D21	1	1/2	1/3	1/5	0.0873
D22	2	1	1/2	1/5	0.1366
D23	3	2	1	1	0.3196
D24	5	5	1	1	0.4566

According to the data in Table 10, the computed values are: maximum eigenvalue λ_{max}=4.1050, consistency index CI=0.0350, random index RI=0.89, and consistency ratio CR=0.0393. Since CR<0.1, the consistency level of the matrix is deemed acceptable.

The process of determining the weight vector from the judgment matrix involves the following steps:

Multiply all the elements within each row to obtain the intermediate products:

$$m_i = \prod_{j=1}^{n} a_{ij} \text{=[0.0333, 0.2000, 6.0000, 25.0000]} \quad (13)$$

Take the n-th root (here n=4) of each product value to generate the initial weights:

$$w_i^* = \sqrt[n]{m_i} = \text{[0.4273, 0.6687, 1.5651, 2.2361]} \quad (14)$$

Normalise the initial weights to obtain the final priority vector:

$$w_i = w_i^* / \sum_{i=1}^{n} w_i^* = [0.0873, 0.1366, 0.3196, 0.4566] \quad (15)$$

To compute the maximum eigenvalue λ_{max}, the formula used is:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(Aw)i}{w_i} = 1/4 \times 16.4200 = 4.1050 \quad (16)$$

Where the resulting product A_w=[0.3534, 0.5622, 1.3111, 1.8952]

The consistency index is calculated as:

$$CI = \frac{\lambda_{\max} - n}{n-1} = (4.1050-4)/(4-1) = 0.0350 \quad (17)$$

Referring to the RI value for a 4-order matrix, RI=0.89, the consistency ratio is:

$$CR = CI/RI = 0.0350/0.89 = 0.0393 \quad (18)$$

Since the value is well below 0.1, the consistency check is considered passed.

Table 11. Judgment matrix of colour factors for evaluation factor C3 layer

Evaluation indicator	D31	D32	D33	D34	Wi
D31	1	1	1/5	1/2	0.1260
D32	1	1	1/2	1/2	0.1585
D33	5	2	1	1	0.3985
D34	2	2	1	1	0.3170

As shown in Table 11, the calculated results are: the principal eigenvalue λ_{max}=4.1061, the consistency index CI=0.0354, the random index RI=0.89, and the consistency ratio CR=0.0397. Since the value of CR is less than 0.1, the matrix meets the acceptable consistency threshold.

The process for computing the weights from the judgment matrix is detailed below:

Compute the product of the elements in each row of the comparison matrix:

$$m_i = \prod_{j=1}^{n} a_{ij} = [0.1000, 0.2500, 10.0000, 4.0000] \quad (19)$$

Take the fourth root (since the matrix order is 4) of each row product to derive the initial weights:

$$w_i^* = \sqrt[n]{m_i} = [0.5623, 0.7071, 1.7783, 1.4142] \quad (20)$$

Normalise these values to obtain the final priority vector:

$$w_i = w_i^* / \sum_{i=1}^{n} w_i^* = [0.1260, 0.1585, 0.3985, 0.3170] \quad (21)$$

The principal eigenvalue λ_{max} is calculated using the formula:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(Aw)i}{w_i} = 1/4 \times 16.4244 = 4.1061 \quad (22)$$

Where the product vector A_w=[0.5227, 0.6423, 1.6626, 1.2845]

The consistency index is then computed as:

$$CI = \frac{\lambda_{\max} - n}{n-1} = (4.1061-4)/(4-1) = 0.0354 \quad (23)$$

According to the RI table, a 4-order matrix has a random index of 0.89. Therefore, the consistency ratio is:

$$CR=CI/RI=0.0354/0.89=0.0397 \quad (24)$$

Since this value is less than 0.1, it confirms that the consistency of the matrix is acceptable.

Table 12. Judgment Matrix of Connotative Factors at the C4 Level of Evaluation Factors

Evaluation index	Social system factor D41	Philosophy view D42	W_i
Social system factor D41	1	2	0.6667
Philosophy view D42	1/2	1	0.3333

Based on the results presented in Table 12, the values are as follows: the maximum eigenvalue λ_{max}=2.0000, the consistency index CI=0.0000, the random index RI=0, and the consistency ratio CR=0.0000. These results confirm that the matrix exhibits complete consistency.

The data also reveal that the social system factor (D41) is considered twice as important as the philosophy-related factor (D42). Following the foundational principles of the analytic hierarchy process, the corresponding weights for both elements can be determined accordingly.

Table 13. Judgment matrix of semantic factors at the C5 level of evaluation factors

Evaluation index	"卍 Pattern -- Continuous and endless for ten thousand generations D51	Copper Coin Pattern -- Attract wealth and bring in treasures D52	Lotus + Peony -- Prosperity and honor D53	Ruyi pattern -- Everything goes as desired D54	Wi
"卍 pattern -- Continuous and endless for ten thousand generations D51	1	1	1/3	1	0.1547
Copper coin pattern -- Attract wealth and bring in treasures D52	1	1	1/3	2	0.1840
Lotus + peony -- Prosperity and honor D53	3	3	1	6	0.5519
Ruyi pattern -- Everything goes as desired D54	1	1/2	1/6	1	0.1094

According to the data in Table 13, the computed values are: λ_{max}=4.0604, CI=0.0201, RI=0.89, and CR=0.0226. Since the consistency ratio is less than 0.1, the matrix can be considered acceptably consistent.

The following outlines the procedure used to derive the weights from the judgment matrix:

Multiply the elements across each row of the comparison matrix to get:

$$m_i = \prod_{j=1}^{n} a_{ij} = [0.3333, 0.6667, 54.0000, 0.0833] \quad (25)$$

Compute the 4th root (since n=4) of each row product:

$$w_i^* = \sqrt[n]{m_i} = [0.7598, 0.9036, 2.7108, 0.5373] \quad (26)$$

Normalise the initial weights to obtain the final priority vector:

$$w_i = w_i^* / \sum_{i=1}^{n} w_i^* = [0.1547, 0.1840, 0.5519, 0.1094] \quad (27)$$

To determine the principal eigenvalue, the following formula is used:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(Aw)i}{w_i} = 1/4 \times 16.2417 = 4.0604 \quad (28)$$

Where the resulting vector from the matrix–weight multiplication is 0.6320, 0.7414, 2.2243, 0.4481

The consistency index is calculated as:

$$CI = \frac{\lambda_{\max} - n}{n-1} = (4.0604-4)/(4-1) = 0.0201 \quad (29)$$

Based on the RI value of 0.89 for a 4×4 matrix, the consistency ratio is determined as:

$$CR=CI/RI=0.0201/0.89=0.0226<0.1 \quad (30)$$

Thus, the consistency condition is satisfied.

Finally, the overall weight for each indicator at the lowest level is calculated by multiplying the local weight by its corresponding relative weight from the upper level.

AHP Evaluation Results and Weight Ranking

Quantitative evaluation of the values in the above judgment matrices yields the weights of each cultural factor, which serve as the basis for subsequent innovative design applications. According to Table 14, among the B-level criterion layer factors, the dominant gene B1 ranks higher than the recessive gene B2, indicating that dominant genes require special consideration in the innovative design and application of cultural gene extraction factors for the Song brocade Eight-Treasures Halo Pattern.

In the evaluation of C-level sub-criterion layer factors, the skeleton factor has the highest weight, demonstrating that this factor is the foundation of the dominant genes of the Song brocade Eight-Treasures Halo Pattern and an indispensable design element in the innovative design and translation of the pattern. In the recessive genes, the semantic factor and the connotative factor are equally important, meaning that practical innovative applications should also focus on how to convey the cultural connotations and semantic meanings of the pattern.

Based on the above weight rankings, cultural factors D13, D24, D33, D41, and D53 are selected from each part of the D level. These selected cultural factors will be used as design elements for cultural translation and application.

Table 14. Factor weight values

Criterion layer	Relative weight	Sub-criterion layer	Relative weight	Index layer	Relative weight	Absolute weight	Ranking
Dominant gene B1	0.6667	Skeleton factor C1	0.6908	D11	0.0913	0.0421	9
				D12	0.1797	0.0828	5
				D13	0.4402	0.2027	1
				D14	0.2888	0.1330	2
		Pattern factor C2	0.1488	D21	0.0873	0.0087	18
				D22	0.1366	0.0135	16
				D23	0.3196	0.0317	11
				D24	0.4566	0.0453	7

Criterion layer	Relative weight	Sub-criterion layer	Relative weight	Index layer	Relative weight	Absolute weight	Ranking
Dominant gene B1	0.6667	Colour factor C3	0.1603	D31	0.1260	0.0135	17
				D32	0.1585	0.0169	15
				D33	0.3985	0.0426	8
				D34	0.3170	0.0339	10
Recessive gene B2	0.3333	Connotative factor C4	0.5000	D41	0.6667	0.1111	3
				D42	0.3333	0.0556	6
		Semantic factor C5	0.5000	D51	0.1547	0.0258	13
				D52	0.1840	0.0307	12
				D53	0.5519	0.0920	4
				D54	0.1094	0.0182	14

There are 5 secondary indicators, which can be divided into 2 judgment matrices and subordinated to 2 primary indicators.

The absolute weights of the primary indicators for the evaluation objectives are: 0.6667, 0.3333.

The indicator system has three levels, and the following is the overall consistency test for the secondary indicators:

CR=(0.6667*0.0028+0.3333*0.0000)/(0.6667*0.5200+0.3333*0.0000)=0.0018/0.3467=0.0053<0.1. It can be seen that the overall consistency passes the test.

There are 18 tertiary indicators, which can be divided into 5 judgment matrices and subordinated to 5 secondary indicators.

The overall weight assigned to a secondary-level indicator is determined by multiplying its local weight by the corresponding weight of the primary-level indicator it is associated with.

The absolute weights of the secondary indicators for the evaluation objectives are calculated as: 0.4606, 0.0992, 0.1069, 0.1667, 0.1667.

The indicator system has three levels, and the following is the overall consistency test for the tertiary indicators:

CR=(0.4606*0.0840+0.0992*0.0350+0.1069*0.0354+0.1667*0.0000+0.1667*0.0201)/(0.4606*0.8900+0.0992*0.8900+0.1069*0.8900+0.1667*0.0000+0.1667*0.8900)=0.0493/0.7417=0.0665<0.1. It can be concluded that the overall consistency has passed the test.

APPLICATION AND DISCUSSION

The innovative design process for the cultural factors of the Song brocade Eight-Treasures Halo Pattern involves translating its symbolic elements, refreshing its external representation with modern characteristics, while preserving its original symbolic connotations. Therefore, it is essential to fully understand the pattern's inherent meanings, grasp the aesthetic trends of modern design, and achieve a perfect integration of modernity and tradition in both form and spirit. This paper explores the application of the cultural factors of the Song brocade Eight-Treasures Halo Pattern in two aspects: 1. Direct application of cultural factors: The extracted cultural factors are used as basic design units. Modern design elements consistent with the pattern's connotations are integrated, and methods such as replication, arrangement, and combination are employed under the guidance of modern aesthetics to innovate the application of cultural symbols. 2. Colour and structural innovation: Based on the colour configuration rules of the original pattern, modern colour schemes with strong visual impact are adopted. While preserving the skeleton factor of the original pattern, the unit patterns are innovatively designed through repetition, rotation, deformation, and other techniques.

Using the skeleton factor D13, pattern factor D24, semantic factor D53, and colour factor D33 selected earlier, and guided by the connotative principles of the D41 cultural factor in the cultural genes of the Song brocade Eight-Treasures Halo Pattern, modern symbols are integrated to fully utilise the cultural factors. Following the principle of balance and symmetry, elements are arranged and combined through rotation, movement, extraction, and transformation based on the skeleton factor D13, showcasing the pattern's balance and sense of order while embodying the Chinese aesthetic concepts of completeness and stability. The colour factor D33 is selected as the main design colour, with adjustments to saturation and proportion combined with popular colours to enhance vividness, ensuring overall harmony and unity and conveying the meaning of wealth and auspiciousness (see Figures 4 to 7).

This innovative design practice is applied to silk scarves, which serve as "mobile cultural carriers." As functional fashion accessories, silk scarves are suitable for multiple groups and scenarios. Compared with home furnishings and clothing, they are compact, affordable, and easy to circulate, often given as gifts. Through the use and gifting of silk scarves, the auspicious wishes of the Song brocade Eight-Treasures Halo Pattern are conveyed, endowing traditional patterns with contemporary vitality and reflecting the dynamic inheritance of cultural genes. This also achieves an accurate integration of traditional patterns with the modern market. To clarify the design logic in Figures 4 – 11, the application process followed a three-step approach: (1) Selection of high-weight cultural genes based on AHP analysis (e.g., skeleton factor D13, colour factor D33, semantic factor D53); (2) Colour strategy involved pairing traditional auspicious colours (such as red and gold) with modern trend palettes (e.g., contrasting purples or blue-greens) to ensure both cultural resonance and visual appeal; (3) Composition principles included symmetrical layout based on the “米” character framework, radial expansion for visual balance, and repetition-rotation techniques to create a sense of rhythm and harmony. These design operations ensured that the extracted cultural genes were faithfully translated into contemporary design forms while maintaining cultural integrity.

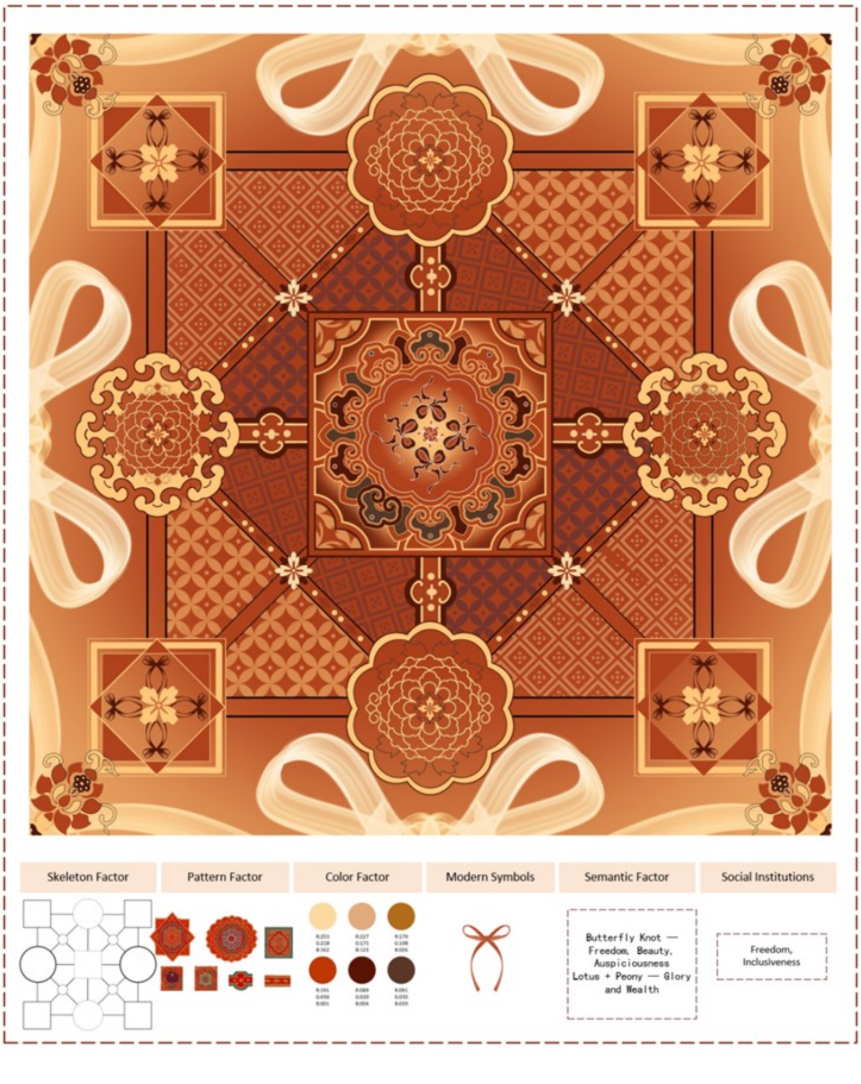


Figure 4. Wan Qi Cheng Xiang (Gorgeous silks present auspiciousness)

This design was driven by the high-weight skeleton factor D13 (0.4402), resulting in a symmetrical radial layout based on the traditional "米" character structure. The colour factor D33 (0.0426) contributed to the use of a red-gold palette, which evokes auspiciousness and celebration. The radial layering reflects the semantic concept of "abundance and prosperity."

Figure 5. Renderings of Wan Qi Cheng Xiang (Gorgeous silks present auspiciousness) series silk scarf products

Figure 6. Chi Jin Liu Fang (Aureate fragrance flows)

The floral motifs in this design are informed by the semantic factor D53 (0.0920)—specifically, the symbolic combination of lotus and peony indicating wealth and nobility. Meanwhile, the connotative factor D41 (0.1111), which relates to hierarchical order and harmony, is expressed through layered repetition and balanced spacing of the motifs. The layout adheres to the radial skeleton principle from D13, reinforcing compositional harmony.

Figure 7. Renderings of Chi Jin Liu Fang (Aureate fragrance flows) series silk scarf products

By changing the colour tone, retaining the skeleton factor D13, pattern factor D24, semantic factor 53, and modern elements (bows), and using modern colour systems and expressive techniques such as rotation, repetition, and abstraction, the figurativeness of traditional patterns is weakened, and the formal aesthetic appeal is strengthened. This makes the traditional cultural factors of the Song brocade Eight-Treasures Halo Pattern closer to modern aesthetic trends, as shown in Figures 8 to 11.

https://doi.org/10.31881/TLR.2025.033

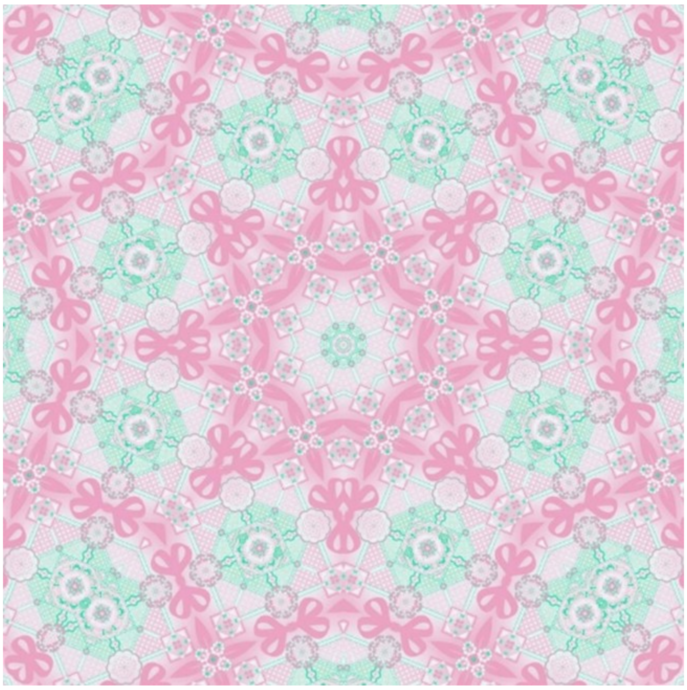


Figure 8. Die Ying Hua Yun (Butterfly shadows and splendid rhyme)

Inspired by colour factor D33, this design explores high-contrast hues such as purple and green, aligning with contemporary aesthetics while maintaining traditional symbolism. The abstracted butterfly motif represents transformation and auspicious energy, echoing semantic factor D53. The skeleton structure D13 is preserved in a more abstract radial arrangement to balance modern fluidity with cultural continuity.

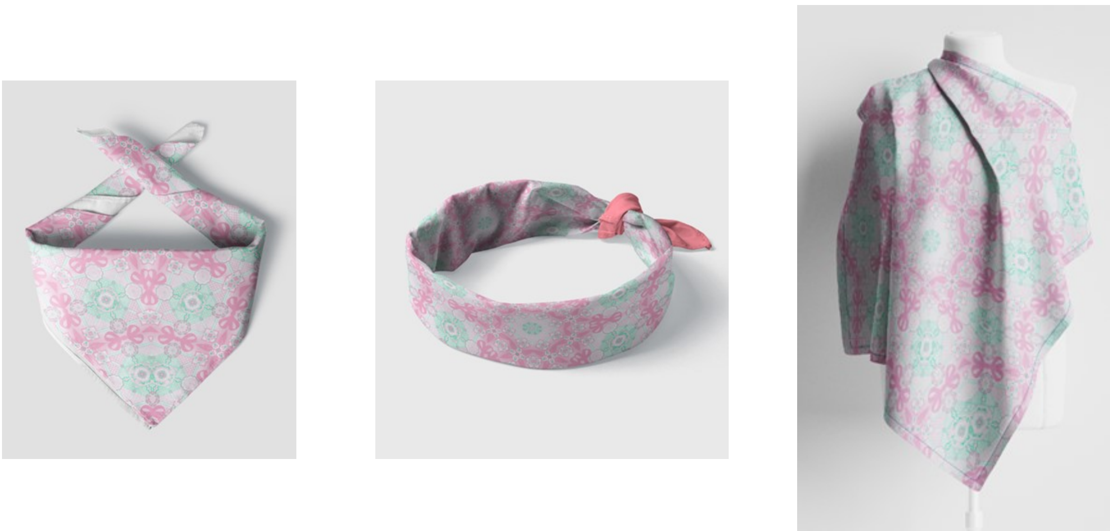


Figure 9. Renderings of Die Ying Hua Yun (Butterfly shadows and splendid rhyme) series silk scarf products

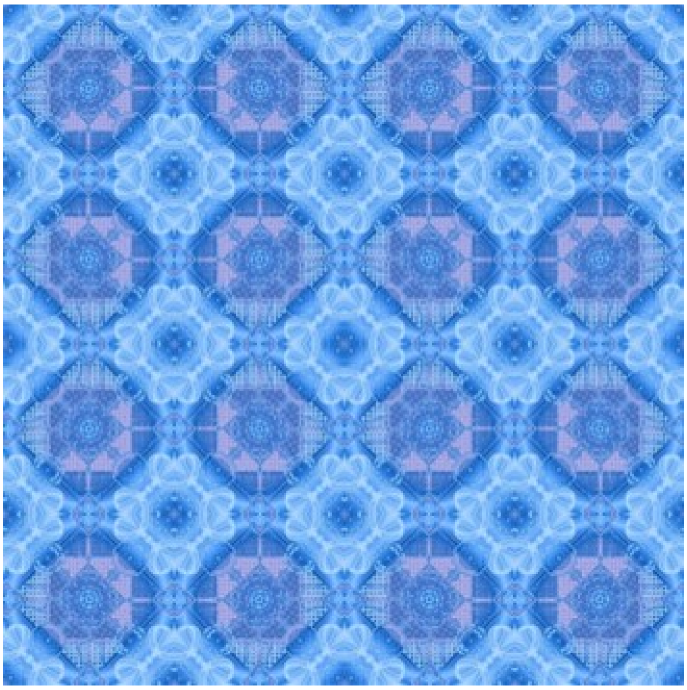


Figure 10. Die Jie Ying Yun (Butterfly knots reflecting halos)

Inspired by colour factor D33, this design explores high-contrast hues such as purple and green, aligning with contemporary aesthetics while maintaining traditional symbolism. The abstracted butterfly motif represents transformation and auspicious energy, echoing semantic factor D53. The skeleton structure D13 is preserved in a more abstract radial arrangement to balance modern fluidity with cultural continuity.

Figure 11. Renderings of Die Jie Ying Yun (Butterfly knots reflecting halos) series silk scarf products

CONCLUSION

This study takes the cultural gene theory as the core perspective to systematically decode the structural framework, pattern configuration, colour system, and symbolic semantics of the Song brocade Eight-Treasures Halo Pattern, proposing an innovative design framework of "cultural gene extraction-weight evaluation-modern translation." By constructing a cultural gene map and combining the AHP (Analytic Hierarchy Process) to conduct quantitative analysis of dominant and recessive cultural factors, the core status of skeleton factors and connotative factors in traditional patterns is clarified, guiding the key orientation of subsequent design practices.

The research shows that the Song brocade Eight-Treasures Halo Pattern has a high degree of systematicness in structural logic, visual rhythm, and cultural semantics. Its cultural genes are not only identifiable and modelable but also possess clear translatability and innovative potential. The proposed framework model achieves an effective integration from the deep-level identification of traditional cultural factors to modern design languages, providing a scientific basis and operational process for the digital translation, redesign pathways, and cross-media communication of intangible cultural heritage (ICH) visual elements.

Innovative design practices demonstrate that culture-gene-oriented recreation not only enhances the visual recognition and cultural communication power of patterns but also strengthens the cultural identity and market adaptability of design works. The research paradigm and evaluation model established in this paper exhibit strong versatility and can be extended to the structural decoding and contemporary expression of other ICH patterns, providing a theoretical foundation and methodological support for constructing a "cultural gene database of Chinese traditional patterns" and an "intelligent design assistance system."

Future research can further introduce emerging technologies such as generative artificial intelligence and graph neural networks to explore the adaptive evolution and intelligent generation mechanisms of cultural gene maps, thereby promoting the intelligent, systematic, and globalised development of cultural heritage protection.

Author Contributions

Conceptualisation – Wang C, Mei T and Yang C; Methodology – Wang C and Mei T; Formal analysis – Wang C and Mei T; Investigation – Wang C; Resources – Wang C; Writing - original draft preparation –

Wang C, Mei T and Yang C; Writing - review and editing – Wang C and Mei T; Visualisation – Wang C; Supervision – Wang C. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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