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From Intangible Heritage to Structured Data: A Sustainable Digital Cultural Knowledge of Zhuang Brocade Patterns

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Abstract

Zhuang brocade is an important representative of China's intangible cultural heritage, serving not only as a traditional textile craft but also as a vivid carrier of the Zhuang people's history, beliefs, and cultural identity. However, rapid industrialisation and modernisation have posed significant challenges to its preservation, while its transmission continues to rely heavily on the oral traditions of experienced artisans. Although previous studies have examined the history, patterns, and preservation of Zhuang brocade, few have systematically organised its patterns into a structured digital repository. Such a repository is essential for pattern classification, academic research, and contemporary creative applications. To address this gap, this study integrates visual semiotics and cultural memory theory as its theoretical framework. All are under research: 1. Systematically analyze the structure and meaning of Zhuang brocade patterns. 2. Digitize Zhuang brocade patterns and construct a pattern classification model. 3. Evaluate the pattern classification model by experts. This study employed qualitative research methods, including the use of "root mean square" (RMS) and "red-green-blue" (RGB) approaches to analyze pattern characteristics. From the initial analysis, the author constructed a pattern classification model based on pattern structure, color distribution, creation difficulty, and the cultural and symbolic meanings they carry. Finally, the author conducted semi-structured interviews with five experts, including one national-level inheritor, two municipal-level inheritors, and two pattern designers, to evaluate the constructed Zhuang brocade classification model. The research results show that Zhuang brocade patterns express the collective memory, beliefs, and cultural identity of the Zhuang people through geometric structures and stylized patterns. A Zhuang brocade patterns classification model was created and evaluated. Expert evaluation indicates that the systematic approach to classify Zhuang patterns helps protect intangible cultural heritage and serves as a resource for modern cultural and creative design, making it valuable for both academic research and industry transformation. This study connects the preservation of traditional Zhuang brocade with its modern use, creating a structured classification model for keeping the craft alive and bringing new ideas to it.

Keywords: Zhuang brocade, Intangible cultural heritage, Digital pattern classification model, Semiotic analysis, Cultural sustainability

Introduction

Zhuang brocade encodes the collective memory and totemic beliefs of the Zhuang people through complex geometric patterns (Tian & Sikka, 2025). However, reliance on fragile physical mediums and oral transmission risks skill attrition, while fragmented documentation creates "data silos" that impede contemporary design translation (Belteki et al., 2025).

To mitigate this, large-scale projects like Huang Qingsui's Wenzang database archive thousands of motifs as visual assets. Concurrently, academic scholarship has advanced toward extracting artisans' and consumers' emotional/visual responses via Kansei engineering (Huang & Pan, 2021) or enhancing public dissemination through digital virtual exhibition halls

(Shilian & Bianus, 2025). Yet, a critical gap remains: these repositories and dissemination platforms function primarily as flat illustrative archives or sensory displays, largely overlooking the intrinsic structural "grammar" of the woven craft. Lacking a verifiable taxonomy to decode weaving symmetry and color distribution alongside indigenous cultural semantics, current databases remain aggregations of disconnected images rather than structured knowledge systems.

Bridging this gap, this study shifts from numerical enumeration to structural taxonomy by developing a multi-dimensional digital knowledge framework. Adopting a typological approach, the model utilizes three canonical archetypes—substantiated by 21 visual samples (Table 3) — as a methodological proof of concept. By coupling quantitative metrics (RMS symmetry and RGB color paradigms) with qualitative totemic semantics and expert validation, this study transitions digital preservation from passive documentation to active knowledge activation for heritage sustainability.

Research objectives

1. To systematically analyze the structure and significance of Zhuang brocade patterns.

2. To digitize and categorize the Zhuang brocade patterns as a digital pattern classifier model.

3. To have the digital pattern classifier model evaluated by experts.

Research method

This research was organized into three sequential phases: 1. Sample selection and analysis, 2. Develop a pattern classifier model. 3. Expert validation of the model. The research has received formal approval from the university's Institutional Review Board (IRB) / Human Research Ethics Committee. The formal approval serial number is REC 67. 0507- 609- 3131, confirming that the research complied with ethical standards.

Sample selection and analysis

The selection criteria for this study, including the intricacy of Zhuang brocade motifs, are derived from historical records, literature sourced from CNKI and Scopus from 2015 to 2025, and affirmations from national- level inheritors. Consequently, three exemplary original Zhuang brocade patterns were chosen, each comprising a minimum of five distinct classic motifs (such as the phoenix, swastika, frog motif, etc.) as central designs. Physical traits are extracted by semiotic visual analysis utilizing RMS (Root Mean Square) and RGB tools. This phase seeks to enable the essential shift from "physical artifacts" to "structured data."

Development of the Zhuang pattern classifier model

Utilizing the data acquired in the previous phase, each sample was systematically coded using a "Digital Pattern Coding Framework." Color Distribution: Obtained from RGB data. Complexity Level: Categorized according to RMS data into "Novice," "Intermediate," and "Master" tiers. Cultural Metaphor: Through the synthesis of ethnographic literature, abstract patterns are linked to their essential symbolic meanings (e.g., "Frog = Reproduction/Prosperity"). With this method, the author were able to develop a Zhuang pattern classifier model.

Expert evaluation

Upon the development of the Zhuang brocade pattern classification model, the author engaged five experts (Table 1) to assess the validity of the research data. The inheritors assessed the deviations of RGB color reproduction and RMS difficulty grading from conventional standards; the designers analyzed the transformative potential of the Zhuang brocade digital pattern classifier model in contemporary cultural design.

Research results

Analysis of the Zhuang brocade patterns

The examination of Zhuang brocade literature has provided insights into the cosmology of "totem worship," the ritual of "group order," and the philosophical viewpoint of "animism" within the Zhuang ethnic group (Zhang, 2023). The author analyzed 30 Zhuang brocade samples and utilized principles of aesthetic composition to perform a morphological study of their structural configurations. Three prevalent patterns are central symmetry, axial symmetry, and oppositional symmetry. This study picked the "Python-Dragon" pattern, the "Fortune and Wisdom" pattern, and the "Phoenix and Tree" "pattern

as exemplars of the previously identified frequent patterns.

1.1 Common Zhuang brocade patterns

1.1.1 The "Python-Dragon" pattern

The Python- Dragon Pattern (Figure 1) is regarded as a fundamental symmetry archetype. The dragon in Zhuang brocade differs from the conventional five- clawed dragon of the Han tradition, which represents the emperor. The Zhuang dragon functions as a complex amalgamation of a water deity, an ancestral spirit, and a protector of nature.

This design, exhibiting a morphology that can vary between a serpent, a dragon, and a jiao (a legendary aquatic creature), is commonly found in ancient Zhuang textiles and related bronze drum decorations. The Manglong symbolizes rivers, precipitation, and terrestrial sustenance, reflecting the deep reliance of paddy- rice agricultural societies on water resources (Wen, 1948). In the Zhuang mythological framework, Manglong is revered as a tribe ancestor or incarnation, serving protective roles to defend the community and repel bad forces. Moreover, its undulating and helical design signifies natural cycles, the perpetuity of life, and the cosmic order, embodying the Zhuang people's deep reverence for nature, water-source spirituality, and the endless cycle of existence (Lan & Tan, 2023).

Table 1 The Experts' Profiles.

Field of Expertise	Name	Photo	Qualification
Zhuang Brocade Inheritor	Tan Xiangguang		Master of Chinese brocade weaving, Master of Chinese Arts and Crafts, Inheritor of Intangible Cultural Heritage at the Autonomous Region level of Guangxi.
	Huang Aiqun		Intangible Cultural Heritage (Binyang Brocade Weaving Technique) - Municipal-level Inheritor of Intangible Cultural Heritage of Nanning City, Manager of Xiangguang Brocade Weaving Workshop in Binyang County.
	Fan Lihuang		Intangible Cultural Heritage (Binyang Brocade Weaving Technique) - Municipal-level Inheritor of Intangible Cultural Heritage of Nanning City, Xiangguang Brocade Workshop in Binyang County, Guangxi and Design Manager of Najiayi Jin Culture Communication Co., Ltd. in Nanning City, Guangxi.
Pattern Art	Li Fuyan		Professor, Member of the China Artists Association, Director of the China Oil Painting Society, Deputy Director of the "Belt and Road" Ethnic Art Education Alliance, Project Manager of Visual UI Design at SenseTime Technology.
	Huang Qinsui		Professor, initiator of the Chinese Pattern Database, founder of the Zhuangzhi Design Alliance, creator of WenZang China, and an expert in Chinese patterns.

1.1.2 The "Fortune and Wisdom" pattern

The "Fortune and Wisdom" pattern (Figure 2) is a prime example of the Axial Symmetry archetype. The pattern is propitious in Zhuang brocade, distinguished by its semantic nomenclature. Notably, it is not an indigenous Zhuang linguistic term but represents a culturally integrated naming convention developed through later interpretations of Zhuang textiles, blending folk auspicious ideologies with Han cultural influences.

In this context, "Fu" (fortune) signifies abundance in life and physical existence, symbolizing bountiful

harvests, the prosperity of progeny, domestic stability, and financial affluence. "Hui" (wisdom) is expressed through sagacity, ethical integrity, and the impartation of craft skills, indicating an intuitive grasp of natural laws, expertise in weaving processes, and the definitive representation of feminine intellect. The philosophical principle of assigning equal importance to both Fu and Hui indicates that Zhuang civilization seeks not only unilateral material wealth but also prioritizes a whole framework of "skillful living, understanding of nature, and ethical behavior" (Han et al., 2025).



Figure 1 The "Python-Dragon" pattern.



Figure 2 The "Fortune and Wisdom" pattern.

1.1.3 The "Phoenix and Tree" pattern

The "Phoenix and Tree" pattern represents a design of oppositional balance. This design is a distinctive composite auspicious motif in Zhuang brocade, often organized around a central tree structure combined with the mythical phoenix, floral petals, and winding vines. It is part of the traditional "Arbour Vitae" (Tree of Life) type commonly found in Zhuang textiles. In this iconography, the tree represents ancestral roots, kinship, and the intergenerational transmission of tradition, whilst the birds and flowers denote rebirth and aspiration.

The trunk, rooted in the ground, and the leaves, reaching into the sky, serve as a symbolic link between the human, natural, and spiritual domains, creating a tripartite cosmological framework. This arrangement expresses the Zhuang people's deep hopes for biological proliferation and ethnic continuity. Moreover, in the conventional weaving practice, this motif is mostly created by women, quietly reflecting a reverence for motherhood and the essential creative energies of life (Han et al., 2025).

The three previously described pattern samples encompass the compositional logic intrinsic to Zhuang brocade and each comprises 5–7 different geometric primitives, hence establishing enough representativeness for this study.



Figure 3 The "Phoenix and Tree" pattern.

1. 2 Pattern analysis and cultural connotation based on RMS

This study extracted the physical features of the three samples described above and conducted a detailed comparison of structural and compositional dimensions, visual impact, and color proportions.

1.2.1 Structure and complexity

Root Mean Square (RMS) calculations revealed a positive correlation between pixel brightness standard deviation and weaving intricacy (Figure 4).

Table 2 illustrates that the mean RMS value surpassed 0.75 across samples, quantitatively affirming the high-density craftsmanship attribute of Zhuang brocade.

As Table 2 shows, despite universally high structural complexity, the symmetry distributions reveal distinct compositional strategies. For instance, the "central symmetry" prototype exhibits a strong vertical orientation (0.87), while the "axial symmetry" prototype leans toward horizontal balance (0.81)—differences that directly reflect specific warp-and-weft interlacing techniques. Culturally, the consistently high scores across all axes (>0.75) transcend mere aesthetics. Validated by RMS analysis, this rigorous geometric precision symbolizes cosmic order, balance, and the Zhuang people's profound reverence for nature's inherent harmony.

1.2.2 Color distribution and visual tension

According to Maitra (2026), the use of RMS can transform chromatic data into visualized information. The author utilized a dual computational model to address the subjectivity inherent in traditional color studies, employing the K-Means algorithm (k = 8)

to extract representative ‘color cores’ from millions of pixels and incorporating RMS contrast to quantify the visual tension of Zhuang brocade patterns.

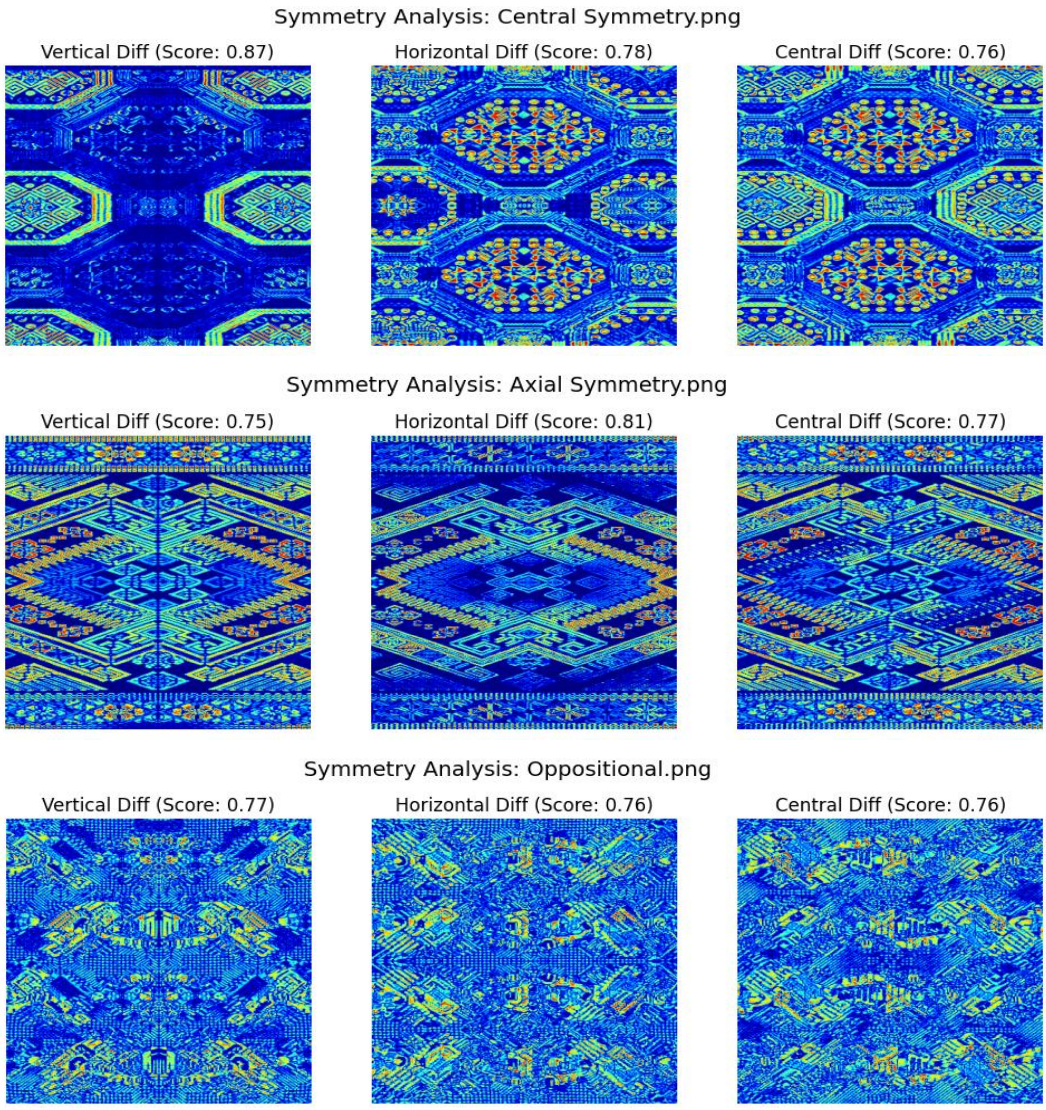


Figure 4 Symmetry analysis of the three pattern archetypes.

$$RMS=\sqrt{\frac{1}{N\text{-}1}\sum_{i=1}^{N}(I_i\text{-}\bar{I})^2}$$

Where I_i is the intensity of the i-th pixel, and $\bar{I}$ is the mean intensity. High RMS value (>60) indicates high contrast, which is a typical feature of Zhuang brocade. Medium RMS value (40-60) indicates balanced tonal transitions.

1.2.3 Supplementary dataset

To ensure data accuracy and minimize bias from selected samples, the author developed an additional validation dataset comprising identical structural types for each pattern type (Table 3). This inclusion is

essential, demonstrating precise compliance with the identified Zhuang brocade patterns.

1.3 Pattern analysis and cultural connotation based on RGB

The author analyzed the selected sample through RGB approach. The authorfirst analyzed the colors particularly about their distributions. Then, the author investigated their cultural meanings.

1.3.1 Color distributions

The "Python-Dragon" pattern (Figure 5) uses a complimentary opposition color scheme, demonstrating a color tension index of 0.603 (normalized RMS). As shown in Table 4, the chromatic disparity between main and secondary hues (blue/gold) varied from 120° to 180°, establishing a stereoscopic visual arrangement through the warm-cool dichotomy.

The "Fortune and Wisdom" pattern (Figure 5) employs a high-contrast color scheme characterized by a predominant deep black (R:34, G:34, B:36; 48.02%) juxtaposed with supplementary gold (10.53%) (Table 5). The significant disparity in luminosity produced the largest contrast (RMS 67.35), characterizing the ritualistic 'Black Background' style.

The "Phoenix and Tree" pattern (Figure 7) uses the analogous harmony color model (Table 6), distinct from the former, featuring a polychromatic analogous scheme (red/orange/purple). The dominant color accounted for only 19.24%, with a distribution range among the top five colors of less than 5%, indicating a balanced and rich aesthetic hierarchy.

1.3.2 The Cultural meanings of colors in Zhuang brocade

The Zhuang brocade color system (Table 7) serves as a cultural symbol that visually encodes dependence on ecological agriculture (cold tones), the hierarchy of cosmic rites (black tones), and the belief in vital reproduction (warm tones).

These quantitative metrics provide the essential data foundation for the subsequent construction of the digital pattern classification model.

2. The Zhuang brocade pattern classification model

2.1 The Zhuang brocade pattern classification model

Utilizing the empirical data presented in the preceding section, the author developed a digital classification model for Zhuang brocade patterns centered on four principal dimensions: A. pattern structure, B. color distribution, C. cultural and symbolic meaning, and D. manufacturing difficulties which the author consulted with Zhuang brocade inheritors for their insights. This establishes a triadic model of " image– data– culture to comprehensively classify Zhuang brocade patterns (Figure 7)."

This approach addresses the constraints of two-dimensional visual representations by transforming weaving processes into searchable and analyzable data, so offering a viable avenue for application in modern cultural and creative design.

2.2 The Zhuang brocade pattern classification model table

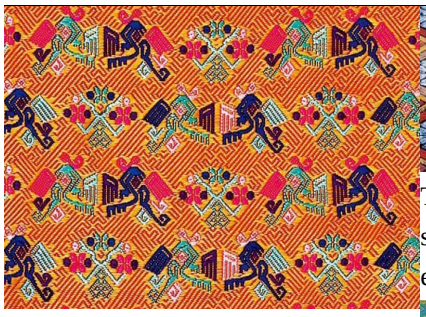
Here the authorapplied the Zhuang brocade pattern classification model in the form of a data visualization table (Table 8), allowing an easy approach to educate people in four dimensions: pattern structure, color usage, symbols & their meanings, and difficulty level.

Table 2 Symmetry analysis data of the three pattern archetypes.

Pattern archetype	Vertical axis score	Horizontal axis score	Central symmetry score
Central Symmetry	0.87	0.78	0.76
Axial Symmetry	0.75	0.81	0.77
Oppositional	0.77	0.76	0.76

Table 3 Zhuang brocade structural types and their samples.

Central Symmetry	Sample Patterns	
	 The maple leaf pattern symbolizes faithful love and a prosperous future.	 The Python dragon pattern symbolizes warding off evil spirits, protecting the home, and bringing favorable weather.
	 The sunflower and longevity character pattern: symbolizes both happiness and longevity, and eternal brightness.	 The phoenix tree and butterfly pattern symbolizes wealth, good fortune, happy love, and numerous offspring.
	 Two lions playing with a ball. May everything go smoothly and bring joy and good fortune.	 Double dragon and double phoenix pattern: symbolizes being a perfect couple, completeness and good fortune.
Axial Symmetry	**Sample Patterns**	
	 The swastika chrysanthemum pattern symbolizes unity, longevity, and nobility.	 The diamond-shaped chrysanthemum pattern symbolizes good fortune from all directions and a peaceful and stable home.
	 The swastika patterns with plum blossoms and chrysanthemums symbolize good fortune, longevity, health, and auspiciousness.	 The evergreen pattern， symbolizes evergreen life and the perpetual continuation of the home.

Central Symmetry	Sample Patterns	
		
	The Kui dragon pattern， symbolizes auspiciousness, warding off evil, authority and nobility.	The rhombus-shaped frog pattern symbolizes prosperous descendants and favorable weather.
Oppositional	**Sample Patterns**	
		
	The chrysanthemum square knot pattern symbolizes longevity, good fortune, and eternal unity.	The dragon pattern symbolizes authority, nobility, and auspicious protection for the home.
		
	The double fish pattern symbolizes abundance and good fortune year after year.	The butterfly pattern symbolizes a happy, fulfilling love and a perfect couple.
		
	The swastika chrysanthemum pattern symbolizes boundless blessings, longevity, and good health.	The elephant pattern with the character “寿” (longevity) symbolizes happiness, longevity, and lasting wealth and prosperity.

3. Expert evaluation of the Zhuang pattern classification model

The author conducted semi-structured interviews of five experts to assess the Zhuang brocade pattern classification model. The interview data were analyzed using thematic analysis. The result is a collective insight from experts regarding the classification model.

3.1 Authenticity evaluation of the Zhuang pattern classification model

To evaluate the model’s authenticity, three Zhuang brocade inheritors (one at the national level and two at the municipal level) were asked to review the classification model.

Tan Xiangguang observed that, despite her original belief that digital colors could seem artificially intensified, the red hue documented in the database (RGB 201, 56, 75) accurately matched the historically dyed Su Mu red utilized in authentic weaving techniques. She underscored that this chromatic precision maintained the unique traditional tonal character and protected the cultural spirit inherent in the trade.

Huang Aiqun confirmed that the difficulty levels specified in the database effectively depict the technical intricacy of the tong Jing duan wee (warp interruption and weft disconnection) weaving process, which is among the most technically challenging facets of brocade manufacture.

Fan Lihua noted that displaying patterns as autonomous structural units with their corresponding cultural significances increases learners' comprehension. She believes the database not only reconstructs the visual representation of Zhuang brocade patterns but also reinstates its intrinsic cultural meaning.

The classification model accurately reflects chromatic, technical, and cultural aspects, validating the efficacy of quantitative instruments for the graded preservation of intangible cultural resources.

3.2 Usability and transformation potential of the Zhuang pattern classification model

Two experts in the field of pattern art evaluated the classification model for its value in design applications.

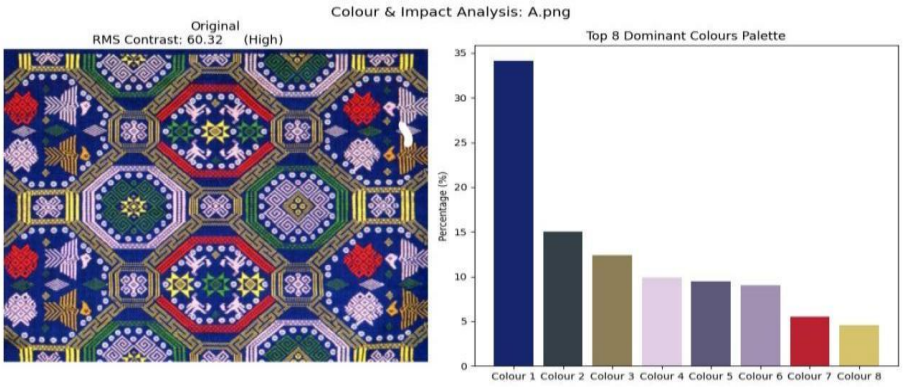
Li Fuyan indicated that the prior method for processing a historical Zhuang brocade photograph involved numerous phases, such as background extraction, tracing, and vectorization. The organized digital classification methodology facilitates the precise selection of pattern elements, potentially diminishing preparatory efforts by around 80% and allocating time for creative thinking.

Huang Qingsui indicated that the classification model elucidates symbolic meanings— such as frog representing fertility and wan signifying good luck— facilitating the application of cultural knowledge in contemporary design.

Both experts underscored the dual significance of the structural pattern categorization and symbolic labeling methodology. The methodology significantly alleviates technical burdens while tackling issues in cultural understanding, offering direct assistance for the development of modern cultural and creative products.

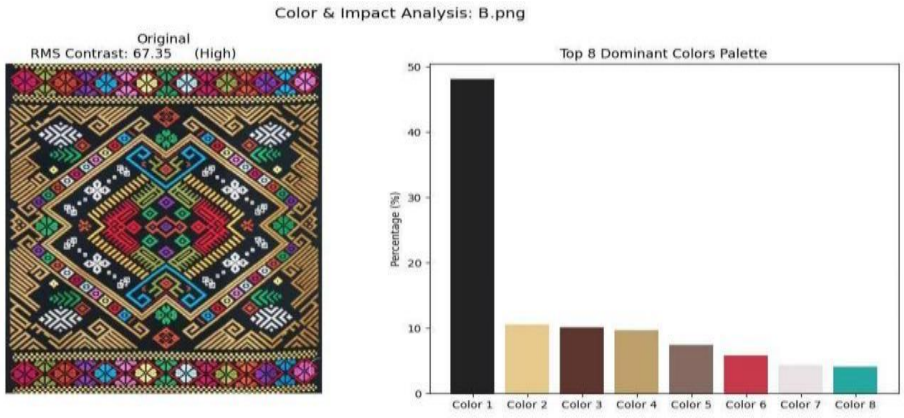
3.3 The experts' insights

The oral data obtained from the semi-structured interview sessions with five experts was analyzed, providing invaluable insights (Table 9).



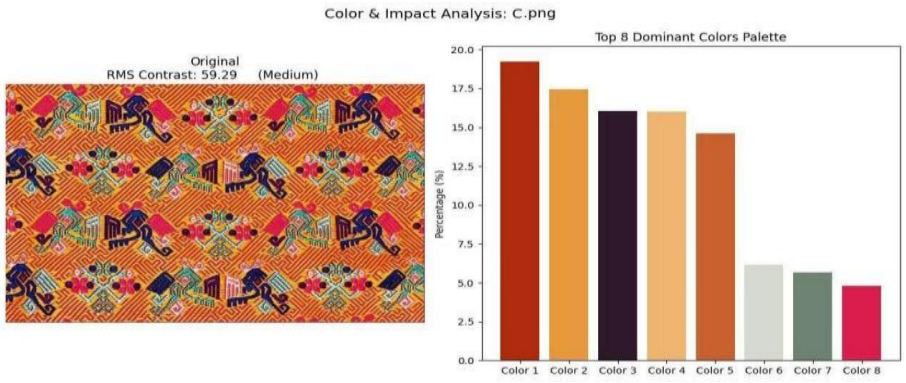
Rank	Color	RGB Value	Proportion (%)	Color Description
1		R: 22, G: 37, B: 110	34.14%	Deep Indigo - Main Base
2		R: 53, G: 63, B: 71	15.02%	Charcoal Grey
3		R: 141, G: 126, B: 85	12.42%	Dull Gold - Complementary Accent
4		R: 225, G: 205, B: 229	9.87%	Pale Lavender
5		R: 92, G: 89, B: 122	9.46%	Slate Blue
6-8		Others (Mixed)	19.10%	Secondary Gradients
RMS		60.32	-	High Visual Impact

Figure 5 Color distribution analysis of the "Python-Dragon" pattern.



Rank	Color	RGB Value	Proportion (%)	Color Description
1		R: 34, G: 34, B: 36	48.02%	Dark Black - Dominant Background
2		R: 230, G: 202, B: 142	10.53%	Pale Gold - High Contrast Accent
3		R: 93, G: 55, B: 47	10.11%	Dark Brown
4		R: 189, G: 160, B: 108	9.70%	Muted Gold
5		R: 132, G: 106, B: 96	7.43%	Taupe
6-8		Others (Mixed)	14.21%	Red & Green Accents
RMS		67.35	-	Highest Visual Impact

Figure 6 Color distribution analysis of the "Fortune and Wisdom" Pattern.



Rank	Color	RGB Value	Proportion (%)	Color Description
1		R: 176, G: 43, B: 16	19.24%	Rust Red - Primary Tone
2		R: 232, G: 153, B: 61	17.46%	Bright Orange
3		R: 48, G: 25, B: 44	16.05%	Dark Purple
4		R: 241, G: 181, B: 114	16.01%	Light Apricot
5		R: 202, G: 98, B: 47	14.63%	Burnt Orange
6-8		Others (Mixed)	16.62%	Green & Grey Accents
RMS		59.29	-	Medium Visual Impact

Figure 7 Color distribution analysis of the "Phoenix and Tree" Pattern.

Table 4 The Cultural Meanings of Different Colors in Zhuang Brocade.

"Python-Dragon"	Color	Color Description	Cultural Meaning
		Deep Indigo - Main Base	It symbolizes the Zhuang people's reverence for the night sky and deep waters.
		Charcoal Grey	It represents the steadfastness of mountains and rocks and the simplicity of their homeland.
		Dull Gold - Complementary Accent	It symbolizes the ripe grains and hope of a bountiful harvest in rice cultivation.
		Pale Lavender	It metaphorically represents the romantic sentiments and gentle twilight in Zhuang culture.
		Slate Blue	It reflects the fluidity of water and its ability to nourish all things.
"Fortune and Wisdom"	**Color**	**Color Description**	**Cultural Meaning**
		Dark Black - Dominant Background	It represents the chaos and infinity of the universe.
		Pale Gold - High Contrast Accent	It symbolizes the radiance and supreme divinity of the sun god.
		Dark Brown	It carries the weight of the land and the roots of our ancestors.
		Muted Gold	It represents the accumulation of time and the inheritance of our family.
		Taupe	It reflects the raw texture of unbleached cotton and linen.
"Phoenix and Tree"	**Color**	**Color Description**	**Cultural Meaning**
		Rust Red - Primary Tone	It symbolizes the vitality of blood and the magical power to ward off evil.
		Bright Orange	It represents the intense heat of the subtropical sun and the joy of a bountiful harvest.
		Dark Purple	It hints at mysterious spiritual power and the dignity of tribal elders.
		Light Apricot	It symbolizes the vitality of newborn life and the blossoming of spring.
		Burnt Orange	It represents the warmth of the family hearth and the maturity of autumn.

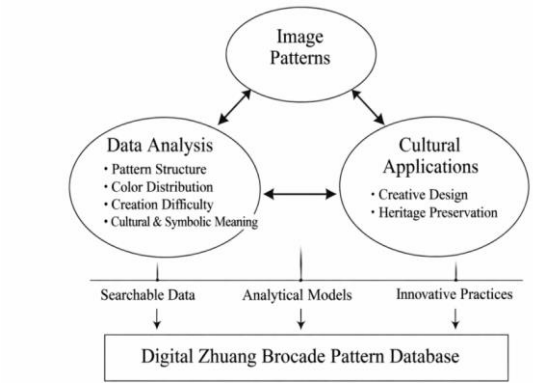
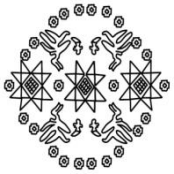
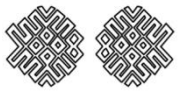
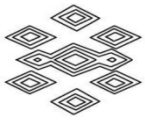
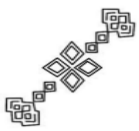
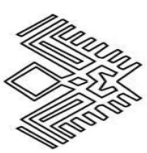
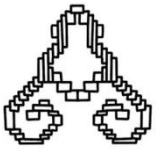
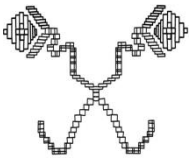
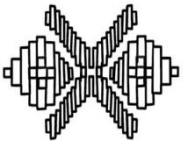
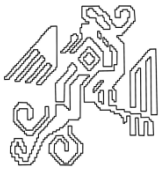


Figure 8 The triadic "image–data–culture" Zhuang brocade pattern classification model.

Table 5 Zhuang brocade pattern classification table based on four dimensions.

Pattern Structure	Color	Symbol	Cultural Meaning	Difficulty
	RGB(22,37,110) RGB(53,63,71) RGB(141,126,85) RGB(225,205,229) RGB(92,89,122) RGB(162,144,178) RGB(186,34,49) RGB(215,195,107)		Sun pattern: The most basic auspicious symbol in Zhuang brocade and the culture of southern ethnic minorities.	Advanced
			Dian Dragon pattern: Unlike the standard dragon pattern, it often features a winding, varied dragon shape.	Intermediate
			Four Phoenixes Facing the Sun: A common auspicious pattern in Zhuang and other southern ethnic minority brocades.	Advanced
			Cloud and thunder pattern: originating from Zhuang mythology and rural agricultural culture.	Advanced
			Double phoenix pattern: symbolizes a happy marriage and family bliss.	Intermediate
			Double fish pattern: Widely seen in Zhuang brocade, the fish motif is associated with rice culture and beliefs about water sources.	Advanced
	RGB(34,34,36) RGB(230,202,142) RGB(93,55,47) RGB(189,160,108) RGB(132,106,96) RGB(201,56,75) RGB(234,227,228) RGB(38,169,162)		Frog pattern: The frog is the guardian animal of rice and is closely associated with water sources, rainwater, and a good harvest.	Intermediate
			The "回" pattern： A symbolic composite in Zhuang brocade, often comprising geometric, animal, or plant elements.	Beginner
			Geometric patterns: the most basic and abstract decorative element in Zhuang brocade	Beginner
			Elephant patterns: Influenced by Southeast Asian culture, elephants are often regarded as a symbol of strength, good fortune, and wisdom.	Beginner
			Bird patterns: Common patterns in Zhuang brocade, including phoenixes, various birds, and common flying birds.	Intermediate

Pattern Structure	Color	Symbol	Cultural Meaning	Difficulty
	RGB(176,43,16) RGB(232,153,61) RGB(48,25,44) RGB(241,181,114) RGB(202,98,47) RGB(214,217,208) RGB(111,131,114) RGB(220,30,79)		Frog motif in the phoenix tree pattern: As an auxiliary element of the phoenix tree pattern, the frog motif symbolizes warding off evil and protecting the home.	Advanced
			The tree pattern in the phoenix flower tree pattern: The tree pattern is the skeletal structure of the phoenix flower tree pattern. The tree symbolizes strength and stability.	Advanced
			The flower pattern in the phoenix flower tree pattern: They usually adorn the branches or leaves, symbolizing the blossoming of life.	Advanced
			The phoenix motif in the phoenix tree pattern: an auspicious bird, often associated with women, marriage, and nobility.	Advanced
			The swastika pattern in the phoenix flower and tree design: a lucky symbol in Zhuang brocade, influenced by the fusion of Han Chinese Buddhism and the culture of southern ethnic minorities.	Beginner

Discussion

1. RMS and craft complexity

Experts assert a strong positive correlation between RMS- based complexity ratings and the embodied labor intensity of the interconnected warp-and-weft technique. This validates RMS as a meaningful proxy indicator for technical difficulty. The digital model thus translates tacit craft knowledge into quantifiable analytical data without detaching it from material reality.

2. RGB and cultural chromatics

The study reveals that RGB extraction accurately captures traditional plant-dyed "cultural hues." This indicates that digital color modelling does not merely approximate surface appearance but preserves chromatic identity embedded in craft practice. The RGB system therefore demonstrates high visual fidelity and supports claims of digital authenticity.

This means the RMS– RGB dual system effectively converts weaving knowledge into measurable digital parameters while maintaining correspondence with traditional practice.

3. Cultural transmission and knowledge structuring

Decomposing patterns into independent structural units can enhance systematic cultural transmission. Modular classification provides "standard references," reducing the risk of distortion during intergenerational inheritance. This finding supports the structural logic of the four-dimensional database model: Pattern structure is not merely visual segmentation, for it functions as a knowledge-preservation mechanism.

Table 6 Experts' insights regarding the Zhuang pattern classification model.

Field of Expertise	Name	Question	Expert's Insights
Zhuang Brocade Inheritor	Tan Xiangguang	How do the extracted RGB digital colors compare to traditional plant-dyed materials? Does it retain "cultural authenticity"?	The RGB data successfully captured specific "cultural hues" (e.g., traditional plant dyes), ensuring visual authenticity.
	Huang Aiqun	Does the RMS-based "complexity rating" correspond to the actual physical difficulty of the "interconnected warp and weft" technique?	There is a strong positive correlation between RMS values and the physical labor/technical skills required for traditional weaving.
	Fan Lihua	Does breaking patterns into independent units facilitate the systematic transmission of Zhuang cultural knowledge?	Independent pattern structures serve as "standard references" to prevent cultural loss during intergenerational transmission.
Pattern Art	Li Fuyan	Is it meaningful to build a pattern digital library?	Databases, as an efficient tool, have significantly reduced the technical investment required for "cultural translation".
	Huang Qingsui	What are the advantages of building a pattern digital library?	"Pattern culture" bridges the cognitive gap, enabling designers to construct authentic cultural narratives for the market.

Limitations and future work

While this study successfully establishes a multi-dimensional implementation pathway for the digital preservation of Zhuang brocade, certain contextual boundaries must be acknowledged. First, from a typological perspective, this framework was constructed and tested using three canonical structural archetypes and their twenty-one variants as a methodological proof of concept. Although these archetypes capture the foundational structural "grammar" and totemic coding of the craft, they do not yet represent the exhaustive graphic diversity of the living heritage. Future research will focus on algorithmic scaling, translating the established Root Mean Square (RMS) and Red-Green-Blue (RGB) classification metrics into automated data-ingestion models capable of processing massive pattern repositories.

Second, as a study primarily dedicated to mechanism construction and pathway development, the qualitative consultation with national and municipal inheritors functioned as formative system-design inputs rather than a post-implementation empirical evaluation. To advance this line of inquiry, subsequent phases of this research focus on expanding this validated framework into a large-scale, production-ready digital database. Future work will transition from framework development to socio-technical impact assessment, empirically evaluating how this structured digital knowledge asset enhances contemporary creative industries.

Conclusion

This study has shown that converting Zhuang brocade from intangible textile heritage into organized digital knowledge is both methodologically viable and culturally significant. The robust association between RMS values and embodied craft complexity validates the dependability of computational metrics in representing material practice, whereas RGB analysis effectively maintained traditional plant-dyed tonal identities.

The four-dimensional classification model—comprising pattern structure, color distribution, cultural symbolism, and production complexity— transcends

traditional two- dimensional visual documentation. It implements a triadic "image–data–culture" framework that systematically incorporates structural logic and symbolic significance, allowing patterns to operate as standardized units of cultural knowledge. Validation from experts and design researchers substantiates the model's validity, instructional clarity, and practical significance for graded heritage protection.

This research establishes a sustainable digital framework for the preservation and revitalization of Zhuang brocade. It offers a repeatable methodological framework for many forms of intangible textile legacy, illustrating the integration of computational analysis and cultural interpretation to promote continuity, creativity, and enduring cultural resilience in the digital age.

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Declaration of generative AI in scientific writing

During the preparation of this work, the authors used QuillBot, an AI-powered grammatical editing tool, solely to enhance language clarity, refine academic phrasing, and correct structural fluency. After utilizing this tool, the authors thoroughly reviewed, verified, and edited the text content to ensure scientific accuracy. The authors take full responsibility for the academic integrity, originality, and the final interpretations and results of this work.

CRediT author statement

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