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AHP-Based Quantification and Generative Rule Design for Sanjiang Dong Embroidery

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Article

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ABSTRACT

Research into the digitization of traditional embroidery is shifting from archiving designs toward auditable design translation. However, the prioritisation and operationalisation of cultural elements in Sanjiang Dong embroidery still lack verifiable traceability. Field imagery screened between May and October 2024 yielded 20 core vector samples used to construct a three-tier cultural memetic spectrum (material–behaviour–spiritual) comprising six factors: patterns, colours, composition, craftsmanship, environment, and symbolism. Thirty experts performed pairwise comparisons using the Saaty 1–9 scale to compute AHP weights with consistency control (CR < 0.10). The material layer ranked highest (0.521), followed by the spiritual layer (0.337), while the behavioural layer was lowest (0.142); overall consistency met the threshold (CR = 0.034). Within the material layer, patterns outweighed colour and composition; within the behavioural layer, craftsmanship outweighed environmental factors. These weights were compiled into a rule repository that classifies variables as mandatory retention, adjustable, or prohibited. Controlled generation on a Dong-embroidery–inspired silk scarf was used to examine the applicability of the rule set through dual-path inputs and audit-field logging. The study demonstrates, within a bounded case based on 20 curated core samples, that weight-gated rules can translate cultural evidence into executable and traceable design constraints for controlled digital regeneration.

KEYWORDS

Sanjiang Dong embroidery, cultural memes, genealogical framework, AHP weighting, generative design

INTRODUCTION

As digital heritage and design practice become more closely integrated, research on traditional textile patterns is advancing beyond mere “recording and display” toward computable structural modelling and design translation [1]. In this context, the primary design objective is not simply to reproduce visual similarity, but to develop translation rules that are auditable, repeatable, and reusable within digital media workflows.

Rapid modernisation is weakening intergenerational knowledge transfer in Dong clothing and textile arts, particularly in remote areas such as Sanjiang, Guangxi, thereby limiting systematic understanding and reuse. Although Dong embroidery has been registered as intangible cultural heritage, substantial gaps persist in translating cultural knowledge into operable design systems.

First, existing research is dominated by descriptive interpretation, with limited parameterisation and insufficient weighted evidence to inform contemporary design practice [2]. Second, while interactive and new-media initiatives (e.g., Web 3.0 platforms) have sought to present embroidery culture, they often lack verifiable standards for systematic element screening, weighting, genealogical organisation, and rule-based structuring [3]. Third, despite references to translation frameworks such as shape grammars, evidence-based sorting and standardisation remain weak, leaving designers unable to justify which cultural elements must be retained and which may be adapted.

Consequently, the primary deficiency lies in the absence of a closed-loop translation chain for Sanjiang Dong embroidery that integrates “cultural meme → genealogy structure → AHP → executable rule base,” a chain necessary to support reusable, verifiable, and auditable digital design translation.

This study develops a structured basis for translating Sanjiang Dong embroidery into design decisions. Cultural memes are used as the operational unit of analysis and are organised into a three-layer genealogy of material, behaviour, and spirit [4–6]. This structure links motifs, colours, composition, craft processes, environment, and symbolism in a traceable way. AHP is then used to weight these elements and determine their relative importance in design translation [7]. The weighted results are compiled into rule-based entries to support digital design use. Expert judgement provides auditable priority evidence, and consistency tests are used to check the reliability of the judgement matrices. The methodology, therefore, specifies the sample boundary, expert composition, and judgement procedure, with consistency metrics serving as quality-control thresholds

Building on the preceding reasoning, the present study concentrates on the following three fundamental questions:

RQ1: What cultural gene elements of Sanjiang Dong embroidery in Guangxi can be systematically identified and organised to build an indicator system for design translation?

RQ2: How can AHP be applied to derive the relative weights of cultural gene elements and convert expert judgements into verifiable prioritisation evidence?

RQ3: How can executable design translation rules be constructed from weighted evidence while ensuring verifiability and semantic legitimacy through audit trails, consistency checks, and controlled generation validation?

This study examines the traditional costume system of Dong women in the core "Sanxingpo" area of Sanjiang, Guangxi, with analysis restricted to auxiliary garments and accessories (e.g., belts, chest pouches, and shoulder-strap covers) to ensure comparability in motifs and craft logic. The study extracts visual–semantic elements, applies semi-quantitative prioritisation, and formulates design translation rules, excluding material testing, industrial production, and supply-chain issues. Methodologically, AHP is used to derive consistency-checked expert priorities that inform decisions on element preservation and adaptive reconfiguration, rather than measuring consumer preferences.

This study makes three contributions. First, it proposes a case-bounded workflow linking cultural genealogy, AHP weighting, and rule construction. Second, it develops a quantitative weighting matrix and a structured rule repository for Sanjiang Dong embroidery. Third, it shows how these results can support more traceable design translation in controlled digital generation.

LITERATURE REVIEW

The 'Descriptive Exhaustiveness' and 'Insufficient Design Translation' in Traditional Embroidery Research

The study of traditional embroidery and ethnographic textiles often requires a substantial amount of descriptive information. Such studies examine aspects like theme in embroidery, colour schemes, methods of execution, knowledge transfer methods, and the meaning of the embroidery. Such studies consistently provide profound insights and local knowledge [8]. However, in cases of objectives like 'design translation' and 'system reuse' methods, there are some limitations to existing processes. First, there is a notable lack of focus on summarising stories, and a challenge arises in formulating parametric models and rules to apply to design systems [9]. Second, there is a notable lack of focus on transitioning from two-dimensional scans to active, configurable, and verifiable workflows, which hinders the reuse and validation of designs [10].

Currently, there has been a shift from static archiving to mechanical translation. He and Gao (2025) encourage the digital processing of traditional patterns to achieve "structural analysis – rule system integration." They observe that once patterns are vectorised and disassembled structurally, these patterns should be integrated into rule-based interactive systems to develop reusable frameworks [1].

Cultural Memes as Design Replicators

Recent visual studies of ICH reveal a distinct trend towards structuralization, with researchers employing biological metaphors such as cultural memes and cultural or design genes. This approach transforms traditional patterns from descriptive objects into decomposable and comparable units, making them suitable for digital modeling and redesign. Building on Dawkins's definition of memes as 'units of cultural transmission or imitation,' subsequent research has expanded this concept to address variation and context dependency in digital media, thereby supporting the unitisation of transmissible traditional visual elements [5]. In ICH research, this methodology typically involves extracting key visual elements, organizing them into structured maps, and utilizing quantitative tools such as multi-criteria decision analysis (MCDA) or AHP to translate abstract semantics into prioritized design evidence. This process integrates structure, colour, and meaning into a unified decision framework [5].

Despite these advances, two key limitations persist in the translation of verifiable design. First, most structuring efforts prioritise visible visual features but insufficiently model craft logic, material constraints, and operational processes. Rule-based generative theories suggest that effective redesign necessitates rules that describe the generation of forms, rather than solely their appearance. Second, while AHP is frequently employed to derive weight hierarchies, the outcomes often remain at the recommendation stage and are not translated into executable rule sets, which restricts system integration. Additionally, digital heritage research warns that digitisation may prioritise visual replication over semantic validity, resulting in semantic dilution if explicit evidence anchors and constraints are lacking. In this context, cultural memes provide a theoretically grounded approach to decomposing cultural complexity into actionable units, supporting a rigorous translation chain: genealogical organization, AHP consistency gating, and rule repository implementation. This process clarifies which elements must be preserved, which may be adapted, and which remain contextually constrained.

The Three-Layer Genealogical Structure of Sanjiang Dong Embroidery

Recent research in ICH and design has shifted beyond two-dimensional, ornament-focused interpretations by emphasising that cultural content encompasses not only visible forms but also practices, values, and belief systems that are not directly measurable. This approach, often termed "layered cultural understanding," is widely recognised and defines culture as both material and spiritual, with values accessed indirectly through documented behaviours and practices [11]. In alignment with UNESCO's interpretation of ICH, the essence of heritage is found in the transmission of knowledge and skills rather than in external carriers. Consequently, when pattern research is applied to design translation, relying solely on formal resemblance risks omitting underlying mechanisms and may result in semantic misinterpretation [12].

Accordingly, layered modelling is used to connect form, mechanism, and meaning. Research in material culture and craft indicates that analyses focused solely on finished aesthetics cannot explain the emergence or perceived correctness of forms. In contrast, computational design research demonstrates that reusable generation and controlled variation require explicit articulation of generative rules, which allows forms to be traced to their underlying mechanisms.

Building upon these research advancements, this study proposes a three-layer genealogical framework of cultural memes—'material-behaviour-spirit'—as a bridging structure from form to mechanism to semantics. It is crucial to emphasise that this tripartite division constitutes an analytical distinction rather than a fragmentation of cultural substance. Figure 1 illustrates this genealogical construction pathway.

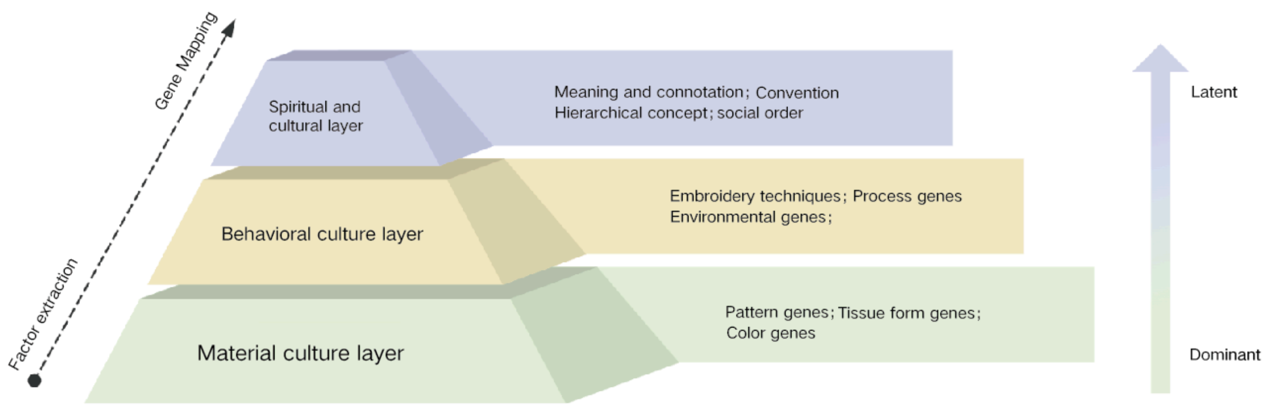


Figure 1. The Three-Layer Genealogical Framework of Sanjiang Dong Embroidery Cultural Memes

In the present framework, the behavioural layer is treated as a mediating layer rather than a statistically dominant one. Its function is to connect visible form with cultural meaning by regulating craft procedures, usage conventions, and contextually appropriate transformation. A lower AHP weight for this layer, therefore, does not imply irrelevance; rather, it indicates that experts regarded behavioural factors as less directly identity-bearing than material and symbolic factors in pairwise prioritisation. Even so, the behavioural layer remains necessary for determining how motifs may be legitimately combined, adapted, and translated in design practice. In this sense, the behavioural layer operates as a procedural and interpretive bridge within the translation chain, even though it does not rank highest in the weighting structure.

Three levels function in conjunction for two purposes: first, facilitating easy visual comparisons (material layer), while the second purpose is to establish the boundaries of the rules in the remaining layers (behavioural/spiritual layers), hence enhancing the cultural appropriateness of design interpretation.

Multi-criteria Decision-making and AHP

In the field of ethnic costume studies, the significance of patterns is typically evaluated using designers' experiential intuition or qualitative cultural interpretation [13]. However, embroidery design translation necessitates the simultaneous consideration of several mutually constraining objectives, including cultural recognisability, formal aesthetics, craft feasibility, semantic stability, and market adaptability. This complexity renders single-metric comparison impractical. Consequently, the literature often employs MCDA. Within MCDA, AHP is widely applied for evaluating traditional patterns and prioritising design elements due to its capacity for hierarchical decomposition and consistency testing. While AHP does not eliminate subjectivity, it formalises expert judgement through pairwise comparisons and consistency metrics, such as CR, thereby enhancing transparency and auditability in decisions involving multiple coexisting factors without unified metrics. Recent applications of AHP can be categorised into three main orientations: assigning weights to the relative importance of patterns, colours, and compositional factors [14]; integrating AHP with cultural stratification models, such as explicit/implicit or form/meaning frameworks, to jointly assess visual features and cultural semantics [15]; and employing FAHP or cross-validating with other MCDA methods to improve robustness and interpretability [16]. MCDA methods to enhance robustness and interpretability [17].

Nevertheless, significant structural gaps persist. AHP is frequently utilised solely as a weight-generation tool, with insufficient explanation regarding how these weights inform operational design decisions, such as determining which elements must be retained, which may be modified, and which should be excluded. Additionally, judgment matrices, consistency indices, and evaluation procedures are often inadequately reported, thereby reducing verifiability and limiting cross-study comparability. In the present study, the three-tier cultural memetic lineage of "material–behaviour–spirit" is aligned with the hierarchical logic of AHP. Consistent with Saaty's (1980) approach, the memetic spectrum is mapped onto an AHP decision hierarchy (see Figure 2), transforming dispersed cultural descriptions into a structured Evaluation Index System that facilitates subsequent mathematical operations and algorithmic constraints [18].

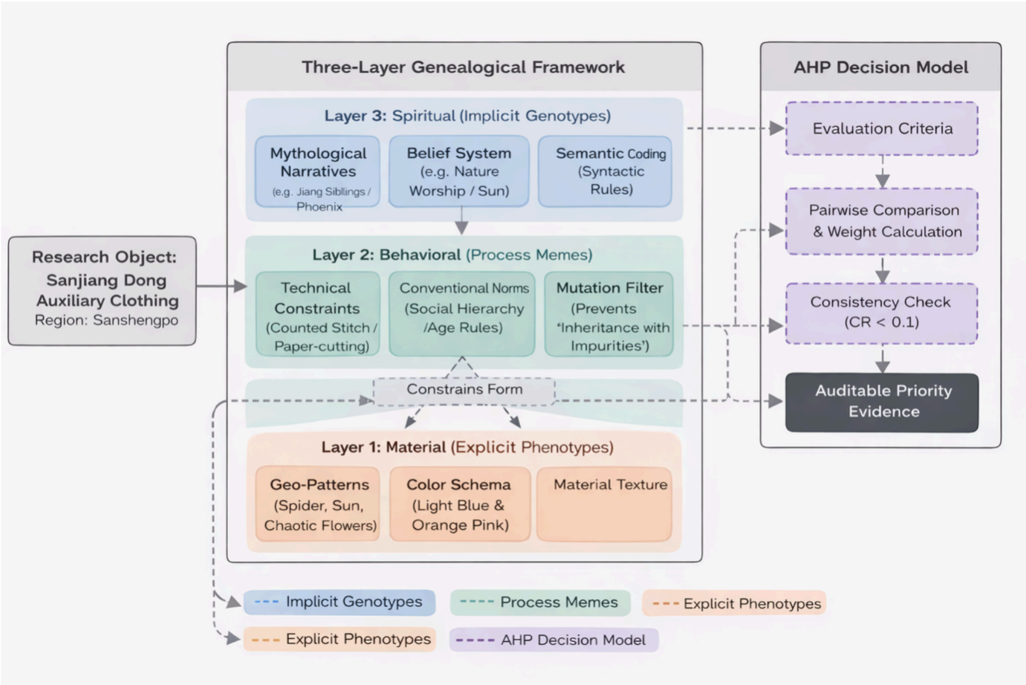


Figure 2. The hierarchical decomposition structure of the Sanjiang Dong embroidery evaluation model

Therefore, within the framework of this study, the methodological significance of AHP lies not in 'digitising culture', but in establishing an interpretable and verifiable prioritisation mechanism for design translation. This mechanism not only addresses design research's demands for transparency and reproducibility, but also lays the methodological groundwork for the subsequent section's progression from "weights" to 'rule libraries' – enabling the parametric and interface-based expression of design decisions.

GENERATIVE AI IN CULTURAL HERITAGE: FROM PASSIVE DIGITISATION TO ACTIVE REGENERATION

Recent advances in artificial intelligence are moving ICH research beyond passive digitisation toward active regeneration. Related concerns about culturally misaligned outputs have also been discussed in AI research, particularly in culturally sensitive evaluation of language-based systems[19]. In heritage design, however, the problem appears in a different form: outputs may reproduce visual resemblance while disregarding cultural structure, craft logic, or semantic boundaries, thereby producing culturally misleading results rather than legitimate reinterpretation [20]. In this study, cultural hallucination is defined as an output that violates the evidence-based rule set derived from Sanjiang Dong embroidery samples. This includes structural inconsistency in motif skeletons, composition, or protected colour relations; semantic misplacement of symbols associated with blessing, protection, or ancestral memory; and contextually inappropriate use of taboo or restricted elements. By contrast, creative variation refers to modifications that remain within the adjustable range of the rule repository, including limited changes in density, negative space, secondary colour proportion, or auxiliary decorative detail. The distinction is important because it separates culturally bounded variation from invalid generation. Within this framework, AHP is not introduced to eliminate variation, but to determine which elements should remain as hard constraints, which may operate as soft constraints, and which must be excluded in controlled generation.

Existing mitigation strategies generally fall into three broad categories: model-side control, rule-based translation, and knowledge structuring. Each improves controllability to some degree, but none by itself fully explains how cultural evidence should be prioritised when multiple design constraints compete. Decisions about what must be preserved, what may be adapted, and what should be filtered out, therefore, often remain dependent on empirical judgement. The present study addresses this gap by positioning AHP as an intermediate prioritisation layer between cultural analysis and generative execution. High-priority elements are translated into mandatory retention rules, medium-priority elements into bounded adjustment rules, and taboo-related or semantically incompatible elements into exclusion rules. Generative AI is thus treated not as an autonomous interpreter of heritage, but as a rule-governed execution environment for controlled design translation. The resulting chain—meme extraction, genealogical structuring, AHP prioritisation, and rule-based generation—offers a clearer basis for traceable cultural regeneration.

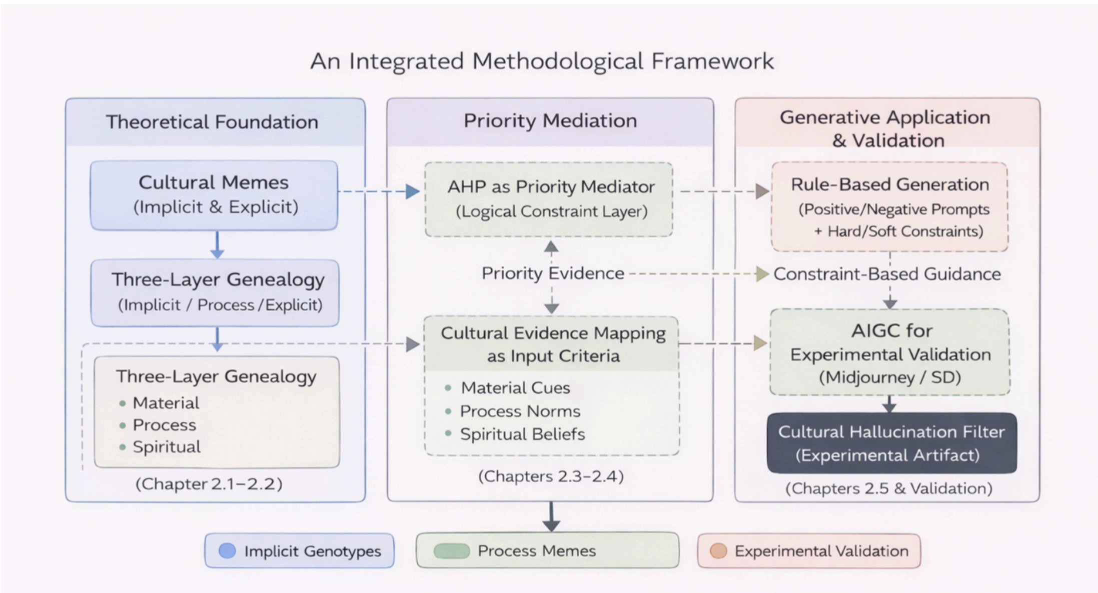


Figure 3. AHP-Guided Conceptual Framework for Generative Design

In summary, this study combines cultural meme theory, three-tier genealogy modelling, AHP, and generative AI into a closed-loop translation chain: “meme → genealogy → priority evidence → rule-based generation.” This approach enables reusable and verifiable digital design translation, preserves cultural legitimacy and interpretability, and establishes a foundation for the subsequent methodological and empirical sections.

METHODOLOGY

A closed-loop framework—Meme Extraction → AHP Quantification → Generative Execution—links unstructured field evidence to auditable design outputs.

Phase 1 (Data acquisition & pre-processing): Fieldwork (May–Oct 2024) at the Sanjiang Dong Museum and Tsinghua Embroidery Workshop used typological sampling of “auxiliary clothing” (belts, chest pouches, shoulder-strap covers) to capture intact pattern “DNA” and social norms. A curated set of 20 core samples was used as a rule-construction dataset rather than as an exhaustive representation of Sanjiang Dong embroidery. The final sample was selected to maximise typological clarity, motif recognisability, and cross-category comparability under controlled analytical conditions.

(see table 1).

Table 1. Sampling scope, period, sites, and screening criteria for the visual dataset

Sampling scope	Sampling Period	Sampling sites	Screening criteria	Initial N	Final N
Women’s waist belts; women’s dudou (chest bibs); shoulder-strap covers	3 May 2024 – 2 Oct 2024	Sanjiang Dong Ethnic Museum; Qinghua Embroidery Workshop, Sanjiang Dong Autonomous County	(1) Images are clear and complete.(2) Samples are typical/representative within the same category.(3) Motifs, colour, and compositional features are sufficiently salient for analysis.	100	20

Selection & Framework: Samples were screened by visual integrity, typological representativeness, and discernible craftsmanship traces. Using Saaty’s hierarchy theory, criteria were structured into three tiers: Material (patterns/colours), Behaviour (craftsmanship/conventions), and Spiritual (mythology/taboos).

Phase 2 (AHP quantification): A mixed panel of 30 experts conducted the AHP evaluation to balance cultural authenticity, interpretive depth, and design applicability. The panel included Dong embroidery practitioners, intangible cultural heritage scholars, and design-related university teachers. All participants had substantial field, research, or teaching experience and met predefined eligibility requirements. Pairwise comparisons were completed using Saaty’s 1–9 scale, and the resulting matrices were processed in SPSSAU. The decision hierarchy was organised into three levels: the target layer, the 3r, and the factor layer. To improve rating consistency, each criterion was supported by a definition sheet and sample references. Group judgments were aggregated by geometric mean, and all matrices were checked against the consistency threshold of $CR < 0.10$. Any matrix failing this standard was returned for conflict review and revision. The final outputs included judgment matrices, weight vectors, CI/CR values, and a log of divergent items.

Table 2. Expert panel composition for AHP evaluation

Expert group	n	Inclusion basis
Dong embroidery inheritors/practitioners	10	≥5 years of practice; representative works or transmission experience
ICH / ethnic art scholars	10	Relevant research outputs or project experience
Design-related university teachers	10	Mid-level title or above; relevant publications or projects

Note. The panel was intentionally balanced between local practice knowledge, heritage interpretation, and design translation expertise.

Phase 3 (Dual-Path Generation & Validation): The AHP results were not applied as direct numerical controls over image generation. Instead, they were converted into a three-level rule framework for generative governance. High-priority elements were defined as mandatory retention rules, medium-priority elements as bounded adjustment rules, and taboo-related or semantically incompatible elements as exclusion rules. Under this mapping, the material layer primarily constrained visible form, the behavioural layer regulated craft-consistent transformation and feasible combinations, and the spiritual layer constrained semantic legitimacy through symbol selection, context restriction, and prohibited pairings.

Controlled generation was implemented through ChatGPT and Midjourney as execution environments rather than transparent generative engines. This phase was therefore designed to examine the applicability of the rule set in guided generation, not to claim direct access to the models' internal decision logic—experimental prompts encoded both fixed and variable items derived from the rule repository. Fixed items included motif skeleton, key colour relations, and output specifications; variable items included symbolic descriptors, stylistic wording, density, and negative space. A control condition retained only subject and general style cues. Outputs were then assessed against the rule base for structural consistency, colour consistency, and semantic legitimacy. Each criterion was screened in pass/fail form to distinguish acceptable variation from evidence-breaking output, including taboo or context-inappropriate combinations. For reproducibility, each prompt package was logged with tool configuration, reference set, prompt version, fixed and variable items, run controls, and screening decisions, and the documentation was aligned with Table 20. The versioned rule repository was also exported in JSON format to support downstream reuse and later comparison across generation runs. In this design, traceability resided in the explicit rule repository, prompt log, and post hoc screening criteria rather than in the internal transparency of the commercial models themselves.

RESULTS AND ANALYSIS

Evidence and Data Overview: From Field Visuals to Computable Factor Repositories

The methodological approach in this study follows the MRS framework, encompassing data collection, cleaning, structuring, and quantification. Primary data were collected through fieldwork footage taken between May and October 2024 at the Sanjiang Dong Museum and the Tsinghua Embroidery Workshop. The research specifically examines auxiliary garments and accessories within the traditional Dong women's attire system, including back straps, chest pouches, and belts, to enhance the representativeness and codability of samples in terms of motif themes, craft processes, and symbolic significance. After image cleaning, boundary cropping, and integrity screening, 20 core vector samples were extracted and standardised from the raw footage. These samples function as unified input units for subsequent visual factor extraction and weight evaluation.

The findings are presented by decomposing cultural information into three genealogical layers: material, behavioural, and spiritual. Additionally, six operational gene categories are identified, including patterns, colour, composition, craftsmanship, environment, and symbolism. This approach establishes a traceable and auditable evidence structure, which serves as an input interface for quantifying multi-criteria decisions.

Structured Extraction of Cultural Gene Structure

Visual content analysis and structured extraction reveal that the 'design-translatable information' of Sanjiang Dong embroidery constitutes a composite system formed by visual morphology, production practices, and high-context semantics, rather than a single patterned graphic. To enhance the reusability of these findings, the extracted elements are categorised into six gene groups, encompassing both dominant and latent genes. A corresponding factor entry library (D1…Dn) has been established to provide clear evaluation boundaries for pairwise comparisons within AHP.

Extraction of Dominant Genes in Dong Embroidery Culture:

(a) Pattern Genes

Motif archetypes in Dong embroidery exhibit stable typological lineages, including animal, plant, and totemic motifs. Each archetype maintains fixed correspondences with garment placement and semantic function.

This study adopts 'repeatably identifiable motif types' as the analytical unit at the pattern level, translating them into codifiable variable entries. By synthesising field imagery and textual materials, pattern genes are consolidated into three core categories: animal motifs, plant motifs, and totemic motifs. These categories are distinguished by their semantic functions, morphological identification points, and combinatorial rules, serving as unified entry points for defining graph nodes and connecting edges. Table 3 summarises representative factors, minimal identifying characteristics, and typical co-occurrence relationships for each category.

Table 3. Key-feature extraction and graph encoding for Pattern Genes

Pattern subcategory	Representative factors (examples)	Core semantic function	Minimum identificatory features	Common co-occurrence / combination rules
Animal motifs	Fish; Butterfly; Bird	Symbolic expressions grounded in the natural environment and everyday life; in recurrent themes, they convey meanings such as purity/protection, affection and fertility blessings, and guardianship/migration guidance.	Fish: main body axis + fin/tail feature points. Butterfly: bilateral-symmetry skeleton + antennae/ wing-edge features; often an abstract fusion that appears "butterfly-like yet not strictly butterfly, flower-like yet not strictly flower." Bird: flattened/planar abstraction highlighting beak/ wing/claw feature points while downplaying species distinctions.	Fish motifs frequently co-occur with water/flow (running-water) patterns; butterfly motifs frequently co-occur with floral/grass motifs (the "butterflies playing with flowers" theme); bird motifs often function as a symbolic "primary motif" node within the graph.
Plant motifs	Banyan-tree motif; flower-and-leaf motifs	Underpinned by animistic beliefs and agrarian experience; convey blessings for life continuity/growth, and use botanical order as a metaphor for the natural–cosmic order and lived ethics.	Banyan: trunk/branch skeleton + dense foliage (often a centralized layout). Flower/leaf motifs: two-way continuous repeats or scroll/ vine structures + stylised forms + colours not constrained by natural prototypes.	Banyan motifs often combine with a central sun motif in "encircling/guarding" compositions; floral/grass motifs commonly combine with butterfly/bird motifs (symbolic image structures); plant motifs may also serve as filler/linking layers nested within border bands.
Totemic / worship motifs	Sun motif; Dragon–Phoenix motif; Chaos-flower motif	Centred on ancestor spirits (e.g., Sasui Grandmother / "Sa") and celestial power; totem embroidery on garments functions as a protective, wish-making practice, oriented toward stability, peace, and spiritual order.	Sun: circular sun unit + outer halo ring (often outlined in white thread) + serialised arrangements (commonly 9 or 11 units).	Sun motifs often appear as multi-unit serial combinations and are semantically bound to "light/divine protection → children's safety and healthy growth."

As a result, cultural information at the pattern level is condensed into an auditable 'category-factor-identification point-co-occurrence rule' structure. This structure provides a stable and consistent variable framework for converting expert judgments into priority weightings and compiling them into design translation rules. The specific pattern gene extraction table is presented below.

Animal motifs in Sanjiang Dong embroidery display significant diversity, with common patterns such as butterflies, fish, crabs, and golden pheasants. The development of these motifs is closely tied to the natural environment and lifestyle of Dong-inhabited regions. The butterfly motif (D_1), a prevalent animal pattern, is often rendered abstractly and symbolises the continuity of life and the fulfilment of love. The fish motif (D_2) signifies purity and frequently appears alongside flowing water patterns in garment embroidery. The golden pheasant motif (D_3) is symbolically significant as the earthly incarnation of the phoenix. It is depicted in a stylized, two-dimensional form that emphasizes the bird's beak, wings, claws, and tail, while minimizing specific species variations, thereby embodying a universal sense of hope (see Table 4).

Plant motifs, including banyan tree patterns and floral-leaf designs, represent a prominent category of natural symbolism in Dong embroidery. Rooted in agricultural practices and the animistic belief that all entities possess spirits, these motifs reflect a cultural acknowledgment of natural order and the intrinsic value of life. The banyan tree motif(D_4) demonstrates notable regional variation. In the infant slings of Yangxi Township in Sanjiang, for example, the design incorporates a robust trunk as the central structure, surrounded by luxuriant branches and foliage that encircle a sun motif. This arrangement produces a stable, centralized composition that symbolizes the holistic unity of natural life and cosmic order.

Floral-leaf motifs(D_5) commonly decorate garment fronts, sleeve edges, and utilitarian textiles. These motifs are often integrated with animal patterns, such as butterflies and birds, to represent the nurturing and proliferation of life. The designs typically utilize two-dimensional continuous or scroll-work compositions, marked by stylized forms and unrestricted coloration that enhance the decorative qualities of folk art(see Table 5)..

In summary, botanical motifs transform natural observations into enduring cultural symbols through highly abstracted forms, thereby reflecting the Dong people's worldview and system of values.

Totem Worship Motifs: The embroidery of the Sanjiang Dong people is deeply rooted in animistic beliefs and polytheistic worship. Revered entities such as the Matriarch Sa Sui, the sun, moon, stars, clouds, thunder, and lightning are imbued with mystical power. These objects of veneration are transformed into totems and embroidered onto garments to invoke stability and peace in both daily life and the spiritual realm. Dragon motifs (D_7) and phoenix motifs (D_8) symbolize favorable weather and auspiciousness, adorning belts and flowing ribbons in stylized forms. The chaos pattern (D_9), derived from the golden-spotted giant spider, is regarded as the earthly incarnation of Grandmother Sa and represents protection against evil spirits, as well as the blessing of fertility. The sun motif (D_{10}) is among the most representative decorative motifs in Sanjiang Dong embroidery, symbolising the blessings of light and divine power. Dong women embroider this mythical image onto children's back carriers, thereby intertwining ancestral legends with daily life. This practice expresses profound reverence for ancestral spirits and embodies heartfelt wishes for the safe growth of infants and the continuity of life(see table 6).

Table 4. Animal Motif Gene Extraction in the Sanjiang Area

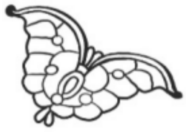
Type	Sample (illustration)	Line-art extraction	Interpretation
Animal motifs	Butterfly motif (D_1) 		Symbolises blessings for life continuity and harmonious love; commonly used on shoulder-strap covers.
Animal motifs	Fish motif (D_2) 		Symbolises purity and the rice–fish symbiosis; commonly used on women's *dudou* (chest bibs) and shoulder-strap covers.
Animal motifs	Golden rooster motif (D_3) 		Symbolises hope; commonly used on women's *dudou* (chest bibs) and aprons/waist coverings.

Table 5. Plant Motif Gene Extraction in the Sanjiang Area

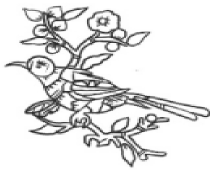
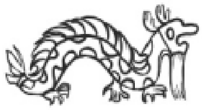
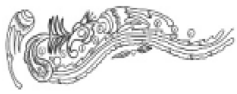
Type	Sample (illustration)	Line-art extraction	Interpretation
Plant motifs	Banyan motif (D_4) 		Literally "dragon tree"; symbolises renewal and growth; commonly used on children's back-carrier straps.
Plant motifs	Flower–leaf and bird motif (D_5) 		Symbolises reproduction and fertility; commonly used on shoulder-strap covers.
Plant motifs	Butterfly–floral motif (D_6) 		Symbolises love and happiness, reflecting Dong people's aspirations for a better life; commonly used on hem ribbons/streamers.

Table 6. Totemic/Worship Motif Gene Extraction in the Sanjiang Area

Type	Sample (illustration)	Line-art extraction	Interpretation
Totemic/worship motifs	Dragon motif (D_7) 		Symbolises favourable weather and auspiciousness; commonly used on belt decorations.
Totemic/worship motifs	Phoenix motif (D_8) 		Refers to the myth of the phoenix bird bringing grain seeds to Jiangliang and Jiangmei, symbolising hope for life; commonly used on ribbons/streamers.
Totemic/worship motifs	Chaos-flower motif (D_9) 		Symbolises Sa Grandmother; wards off evil and conveys blessings for many children and good fortune; commonly used on back-carrier straps.
Totemic/worship motifs	Sun motif (D_{10}) 		Symbolises mysterious protective power and reverence for life; commonly used on shoulder-strap covers.

(b) Colour Genes

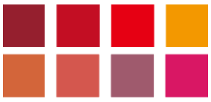
Colour Genes define Sanjiang Dong embroidery colour as a stable, rule-based configuration within the hue–value–chroma space, transforming descriptive colour use into computable variables for spectral databases and generative design constraints.

Images are standardised (background removal, format unification) and exported as PNG-8 indexed colours to extract representative palettes. Approximate colour aggregation and adjustable proximity parameters reduce pattern and lighting noise, yielding verifiable and comparable colour entries.

Results show a hue system centred on red, green, and blue, with hierarchical rhythm structured by lightness and saturation. Two interacting groups are identified: cool tones (indigo/blue/green/purple) conveying calmness and depth, and warm tones (red/magenta/pink/yellow/orange) expressing vivid affect. Their co-presence establishes visual order through contrast and harmony.

For application, colour genes are operationalised as colour-derivation genes and colour-pairing genes.

Table 7. Extraction of Colour Genes in Sanjiang Dong Embroidery

Colour gene	Colour derivatives	Colour extraction	Semantic tendency	Adjustable range
Red–yellow palette (D_{11})	Pure red, magenta, dark red, fuchsia, rose pink, orange-red, crimson.		Intense, vivid affective expression	Allow slight-to-moderate shifts in lightness/saturation within the same hue family; keep reds as the dominant or focal colour; avoid replacing the red family with cool hues as the main palette.
Blue–green palette (D_{12})	Sea blue, sky blue, cyan, royal blue, mint green, pale blue.		Calm, steady, profound	Allow within-image brightness variation to accommodate composition; suitable as background/base or a secondary subject palette; avoid over-brightening that collapses depth and layering.
Purple palette (D_{13})	Wine purple, deep purple, light purple (lavender).		Noble, restrained	Use as an auxiliary/transition colour between warm and cool hues; control area proportion (small-to-medium) to prevent undue dominance; avoid mixing with too many unrelated colours.
Grey/neutral palette (D_{14})	Black, brown, dark grey, light grey.		Soft, restrained	Use for contours, separators, backgrounds, and contrast control; adjust brightness only slightly to maintain readability; avoid turning neutrals into the thematic dominant colour.

As shown in Table 6, the colour structure of Sanjiang Dong embroidery exhibits ethnic stability with rich intra-ethnic gradation. The warm colour spectrum, centred on the red-yellow group, conveys high arousal, benedictory sentiments, and festive expressions. The cool colour spectrum, formed by the blue-green group, establishes a stable and profound visual foundation. Purple tones predominantly serve as semantic markers of solemnity and restraint. Neutral hues such as grey, black, and brown are employed for boundary control and overall tonal equilibrium. Within this structure, the 'adjustable range' refers to subtle modifications within the same colour group's brightness and saturation, as well as proportional control of neutral colours in contouring, separation, and shadowing. This method prevents stylistic drift and loss of cultural distinctiveness that may result from cross-group substitutions.

Table 8. Extraction of Colour-Pairing Genes in Sanjiang Dong Embroidery

Pairing gene	Typical combination	Sample (illustration)	Colour extraction	Structural characteristics	Semantic / aesthetic orientation
High warm–cool contrast pairing	Red/Purple paired with Blue (D_{15})			Strong warm–cool contrast; high visual impact	Festival-like tension; explicit sense of hierarchy. Bright and festive style.
Soft-contrast and unified pairing	Light Blue paired with Orange and Pink (D_{16})			Soft hues; restrained contrast; overall coordinated unity	Fresh, light, and harmonious tonality. Bright and refreshing style.
Neutral harmony and restrained pairing	Black paired with Light Grey (D_{17})			Balanced warm–cool impression; subtle and restrained	Rustic, understated, and refined style.

As summarized in Table 8, the codification of recurring colour schemes within the samples utilizes the framework of 'pairing gene—typical combination—structural characteristics—semantic/aesthetic orientation'. This table demonstrates that colour pairing is not simply the stacking of colour blocks. Instead, it forms a repeatable visual order through the interplay of contrast intensity, primary-secondary hierarchy, and neutral tones. Analysis of the samples indicates that the overall colour style can be categorised into three relatively stable types:

Bright and Cheerful: Defined by high saturation and lightness, this type features vivid colours and strong contrasts to produce a powerful visual impact.

Bright and Refined: Characterised by medium-low saturation and higher lightness, with restrained contrasts and overall harmonious Rustic and Elegant: Primarily defined by low brightness and low saturation, this type is often complemented by solid colours or small areas of contrasting accents, resulting in a restrained and understated aesthetic.stThe coexistence of these three types allows Sanjiang Dong embroidery to retain its ethnic characteristics while achieving significant visual flexibility. This diversity also establishes a foundation for a 'controllable variation space' in subsequent digital translation.

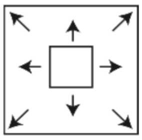
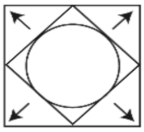
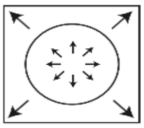
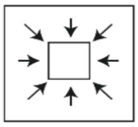
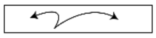
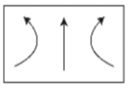
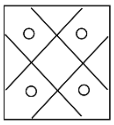
From a material and craftsmanship perspective, traditional Dong embroidery threads are primarily dyed with plant or mineral pigments, resulting in colours derived from natural phenomena. These pigments exhibit exceptional stability and durability, as evidenced by century-old embroidered pieces that retain vivid hues. Therefore, the chromatic gene represents not only a formal visual choice but also the material manifestation of the 'nature-life-aesthetics' relationship on the garment's surface. This relationship forms one of the cultural foundations supporting the long-term stability of juxtaposed warm and cool hues.

(c) Composition Genes

Composition genes characterise the spatial organisation rules of Sanjiang Dong embroidery patterns within a two-dimensional plane. Their analysis focuses on compositional skeletons that are reproducible across samples, rather than the subject matter or colour effects of individual motifs. Based on how patterns adapt to their carriers, this study categorises compositional forms into two systems: Suitable Patterns and Continuous Patterns. Suitable patterns predominantly feature on visual focal points, such as chest panels, shoulder strap covers, and aprons, emphasising centralised focus and symbolic representation. Continuous patterns are frequently employed along borders and decorative bands, stressing rhythmic continuity and boundary control. Analysis of samples reveals that high-frequency skeletons within the suitable pattern system include symmetrical, centripetal, centrifugal, balanced, and grid-like types. Symmetrical patterns establish stable order through axial symmetry. Centripetal patterns enhance focal concentration and compactness. Centrifugal patterns generate outward momentum through radial expansion. Balanced patterns display a harmonious distribution of elements. Grid patterns offer high stability and serve as order markers through compartmentalised division. The continuous pattern system is characterised by zigzag and scattered-dot types. Zigzag patterns emphasise linear rhythm and boundary demarcation, while scattered-dot patterns produce a light-hearted peripheral visual effect through open rhythmic sequences. Collectively, these types form the compositional gene pool of Sanjiang Dong embroidery, illustrating the systematic division of visual functions between central and peripheral zones.

The compositional genes are presented using a structured approach comprising type, sample illustration, skeleton diagram, and functional interpretation (see Table 8). This method codifies compositional types into input units, thereby establishing a structural foundation for pattern recombination, layout constraints, and the expression of visual information.

Table 9. Extraction of Composition Genes in Sanjiang Dong Embroidery

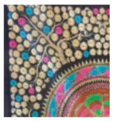
Type	Sample (illustration)	Colour extraction	Interpretation
Centrifugal composition (D_{18})	  	  	Visual expansion outward; strong sense of motion/dynamism.
Centripetal composition (D_{19})			Strong focal convergence; compact and stable overall structure.
Balanced composition (D_{20})	 	 	Regular, coordinated, and visually harmonious.
Symmetrical composition (D_{21})			Balanced and coordinated visual effect through symmetry.
"Well-grid" composition (D_{22})			Stable structure; symbolically associated with well (water-well) culture.
Zigzag composition (D_{23})			Primarily decorative in effect.
Scattered-dot composition (D_{24})			Lively and free; dispersed rhythmic distribution.

Extraction of Implicit Genes in Dong Embroidery Culture:

Craft/Process GenesCraft genes refer to the stable, reproducible technical structures of Sanjiang Dong embroidery at the behaviour-operation level, primarily manifested as implicit knowledge, including procedural sequences, critical actions, and effect control. To convert experiential techniques into analyzable items, the analysis focuses on the widely applied and structurally clear paper-cut appliqué embroidery, extracting its main process in a structured format.

These techniques, as the behavioural-cultural layer of Sanjiang Dong embroidery, have evolved through continuous replication and adaptation over extended periods, resulting in relatively stable operational sequences and technical systems. Techniques commonly used in the Sanjiang Dong region include paper-cut appliqué embroidery, flat embroidery, lock stitch embroidery, and raised embroidery. Paper-cut appliqué embroidery is the representative technique of the region. Building on flat embroidery, it involves covering the surface of paper-cut patterns with embroidery thread, integrating the design with the fabric. This process produces a rich, smooth decorative effect with distinct layers. Lock stitching is applied along pattern outlines, using continuous lock stitches to reinforce the structure and make the borders more distinct and stable. Pick-up embroidery, often found on collars and sleeve edges, uses a method of picking up threads from both warp and weft to create geometric or continuous decorative patterns, resulting in a strong sense of rhythm and orderly beauty(see Table 10).

Table 10. Technique-Gene Extraction for Sanjiang Dong Embroidery

Stitch technique	Paper-cut embroidery (D_{25})	Satin stitch / flat embroidery (D_{26})	Chain/locking stitch (D_{27})	Counted-thread embroidery (*tiaohua*) (D_{28})
Sample (illustration)				
Key characteristics	Embroidery executed on the basis of paper-cut motifs.	A basic stitch widely used for large-area coverage.	Continuous locking stitches used to reinforce the structural integrity of motifs.	Motifs formed by picking warp–weft threads (counted-thread method).

Environmental Genes

Environmental genes are defined as the latent conditions that are established and perpetuated within the natural ecology, social activity, and cultural context of Sanjiang Dong embroidery. Rather than appearing as isolated decorative motifs, these genes influence the embroidery system by guiding subject selection, colour orientation, and usage scenarios. At the natural level, the region's mountainous water networks and humid climate have fostered a coexistence of rice cultivation and fishing, which is reflected in the frequent depiction of aquatic imagery, such as fish, ripples, and crabs, as well as botanical imagery, including banyan trees, flowers, and grasses. Additionally, the reliance on traditional plant and mineral dyes has resulted in a colour palette dominated by red, blue, and green, marked by a balance of contrasting warm and cool tones that achieve overall visual harmony.

At the socio-cultural level, the spatial organisation of villages and family-based craft transmission mechanisms ensures the continuity of patterns and techniques. The Sa-sui belief system and ancestor spirit worship establish a high-context semantic framework, allowing symbolic motifs such as spider and sun patterns to serve as blessings, protective charms, and life-sustaining elements on everyday items, including baby carriers and garment decorations. In summary, environmental genes constitute the contextual foundation for the Dong embroidery lexicon and rule set, offering boundaries and interpretative grounding for subsequent gene extraction and visual translation (see Table 11).

Table 11. Extraction of Activity–Environment Genes in Sanjiang Dong Embroidery

Environment gene	Environmental prototype (data source)	Feature description	Functional orientation
Natural environment (D_{29})		Mountain–water settlements and agro–fishery production landscapes	Provides ecological constraints on motifs and colour usage (e.g., water/plant imagery and tendencies toward warm–cool palette selection).
Semi-open environment (D_{30})		Public interaction spaces such as covered bridges and ancient paths	Supports social interaction and display contexts; strengthens visual demands for decorative bands and boundary-oriented compositions.
Humanistic/cultural environment (D_{31})		Ritual/collective activity spaces such as drum towers (e.g., singing/dancing, *lusheng* performances)	Provides a high-context semantic framework, stabilising the use of symbolic motifs and their identity-/blessing-oriented functions.

Implied-Meaning Genes

Implied-meaning genes denote the stable narrative sources, belief frameworks, and value orientations that underlie Dong embroidery motifs. These genes establish semantic boundaries for motif combinations and their usage contexts. This conceptual layer extends beyond mere aesthetic appeal or decoration; it consolidates collective memory and worldviews into visual symbols, thereby transforming embroidery into a cultural system of meaning that can be repeatedly referenced and recalled. Drawing on textual materials and field interviews, implied-meaning genes are categorised into three sources: legendary narratives, belief systems, and value concepts (see Table 12).

Table 12. Extraction of Semantic (Implied-Meaning) Genes in Sanjiang Dong Embroidery

Gene source	Representative carriers	Implied-meaning factor	Interpretation
Legends and folk narratives	Phoenix-bird motif; Wild-goose motif; Spider motif; Frog motif	Auspiciousness and good fortune (D_{32})	Mythic narratives (e.g., the phoenix bird) are translated into recognisable motif prototypes to commemorate group history and convey auspicious blessings.
Legends and folk narratives	Phoenix-bird motif; Wild-goose motif; Spider motif; Frog motif	Ancestral commemoration (D_{33})	Commemorates the phoenix bird bringing grain seeds to ancestors and the assistance received during migration; also commemorates Sa Grandmother, expressing aspirations for reproduction and flourishing lineage.
Belief and worship	Dragon motif; Bat motif; Sun motif	Many offspring and abundant blessings (D_{34})	Invokes fertility, prosperity, and familial flourishing through protective sacred symbols.
Belief and worship	Dragon motif; Bat motif; Sun motif	Warding off misfortune and overcoming hardship (D_{35})	Prays for favourable weather and timely harvests; seeks mysterious/sacred protection for children's growth and safety.
Values and life ideals	Butterfly motif; Fish motif; Floral motifs	Praise of love (D_{36})	Expresses positive ideals of romantic love, harmony, and marital happiness through symbolic motif pairing.
Values and life ideals	Butterfly motif; Fish motif; Floral motifs	Reverence for nature (D_{37})	Reflects an animistic worldview ("all things have spirit") and conveys wishes for thriving populations and enduring lineage.

Within legendary narratives, mythical motifs such as the phoenix are rendered as recognisable pattern archetypes. These motifs commemorate group histories and migratory experiences, facilitating a continual retelling of narratives through embroidery on clothing and utilitarian objects. In the context of belief and worship, symbolic systems, including sun motifs, cloud patterns, and dragon-snake imagery, convey meanings of protection, exorcism, and tranquility. These symbols are also integrated with ancestor spirit worship, establishing specific themes as visual indicators of life guardianship and cultural order. In terms of value systems, motifs such as fish, agricultural imagery, and botanical patterns, including trees and flowers, collectively articulate ethical aspirations for fertility, abundance, industrious harvests, longevity, prosperity, and harmonious coexistence between humanity and nature. Collectively, this symbolic genetic code confers semantic legitimacy upon the pattern system, ensuring that digital translation and generative reorganisation preserve cultural coherence at the level of meaning rather than relying solely on formal resemblance.

AHP-Based Evaluation Model and Importance Assessment of Cultural Genes in Sanjiang Dong Embroidery

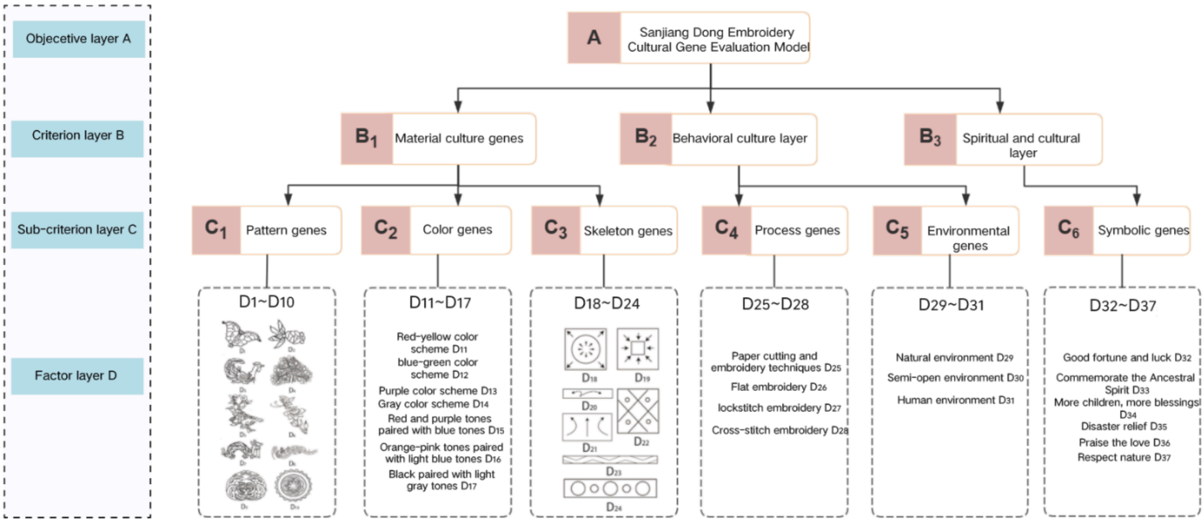


Figure 4. Cultural Gene Evaluation Model for Sanjiang Dong Embroidery

A comparative analysis of the quantitative findings from this study and those of Wang et al. on Song Brocade reveals substantial cultural heterogeneity. According to Wang's data, as an official court craft, the 'material layer (visual style)' of Song Brocade exhibited absolute dominance, reflecting the constraints imposed by the strict visual standardization requirements of official systems, such as the Yingzao Fashi.

In contrast, the data from this study indicate that the combined weight of the 'material layer (technical logic)' and 'spiritual layer (semantic metaphor)' in Sanjiang Dong embroidery reaches 85.8% (material layer: 0.521; spiritual layer: 0.337; behavioural layer: 0.142). This pronounced difference has significant sociological implications. For non-literate Dong communities, embroidery serves not only as ornamentation but also as a 'cipher system' for sub-clan identification and for mediating sacred and profane communication. Therefore, preserving 'structural syntax' (for example, the centrally symmetrical solar motif framework) is more important in digital translation than simply replicating 'colour values'. This finding addresses the historical bias in digital design, which has emphasised colour and form over structure.

This study employed AHP to quantify judgments from an expert panel (n = 30). The judgement matrix was constructed using Saaty's 1–9 scale, with consistency ratio (CR) < 0.10 serving as the quality threshold. Results are as follows:

Relative weights for Layer A (Material, Behaviour, Spiritual) indicate that the material layer (B1) holds the highest priority, followed by the spiritual layer (B3), while the behavioural layer (B2) ranks lower. Consistency testing confirmed that the group's judgments possess acceptable coherence.

Table 13. Pairwise Comparison Matrix and Weights for Level A

A	B1 (Material)	B2 (Behaviour)	B3 (Spiritual)
B1 (Material)	1.000	3.842	2.316
B2 (Behaviour)	0.260	1.000	0.412
B3 (Spiritual)	0.432	2.427	1.000
Weight	0.521	0.142	0.337
Weight share	52.10%	14.20%	33.70%

Table 14. Summary of Consistency Test Results for Level A

Maximum eigenvalue (λ_{max})	CI	CR	Consistency test result
3.041	0.020	0.034	Passed

These results demonstrate that, in the context of executable design translation, visually recognizable and structurally parameterizable material evidence serves as the primary input. At the same time, the connotations and symbolic meanings associated with the spiritual layer impose a substantial constraining influence, with a priority that significantly surpasses that of the behavioural layer. This lower ranking should be understood as reduced direct salience in priority weighting, not as the absence of a mediating role in the translation process. This hierarchy provides quantitative support for the subsequent classification of variables into three categories: mandatory retention, adjustable, and prohibited.

Weighting within Layer B (the Sub-Criteria Layer) reveals distinct priority structures in both the Material Layer and the Behavioural Layer. In the Material Layer (B1), the Pattern Gene (C1) receives the highest weighting, followed by the Colour Gene (C2), and then the Structural Gene (C3). In the Behavioural Layer (B2), Craft Gene (C4) is weighted substantially higher than Environmental Gene (C5).

Table 15. Pairwise Comparison Matrices and Weights for Level B

B1	C1	C2	C3	B2	C4	C5
C1	1.000	2.714	4.128	C4	1.000	2.317
C2	0.368	1.000	2.306	C5	0.431	1.000
C3	0.242	0.434	1.000	/	/	/
Weight	0.587	0.262	0.151	Weight	0.698	0.302
Weight share	58.70%	26.20%	15.10%	Weight share	69.80%	30.20%

Table 16. Summary of Consistency Test Results for Level B

Level	Maximum eigenvalue (λ_{max})	CI	CR	Consistency test result
B1	3.028	0.014	0.024	Passed
B2	2.000	0.000	0.000	Passed

This outcome reveals two principal analytical insights. First, patterns represent the most fundamental visual identity markers and should be prioritized as hard constraints during the translation process. Second, craftsmanship, as the primary variable at the behavioral level, determines the feasibility of realizing patterns and compositions under actual production conditions, thus serving as a critical gatekeeping factor in implementable design.

C Layer (Factor Layer) Weighting and Consistency: Formation of the Core Factor Library. At the factor layer (D1…Dn), all sub-matrices passed consistency testing (CR < 0.10), which indicates statistically acceptable stability in the sequencing of factors within the six gene categories.

Table 17. Local Priorities (Single-Level Rankings) and Weights for Level C

Level C	Local rank	Weight	Level C	Local rank	Weight
D1	11	0.018	D22	7	0.032
D2	3	0.136	D23	5	0.101
D3	4	0.104	D24	6	0.071
D4	8	0.062	D25	1	0.285
D5	9	0.051	D26	4	0.189
D6	2	0.158	D27	2	0.280
D7	6	0.081	D28	3	0.246
D8	7	0.074	D29	3	0.243
D9	1	0.223	D30	1	0.414
D10	5	0.093	D31	2	0.343
D11	4	0.132	D32	1	0.264

Level C	Local rank	Weight	Level C	Local rank	Weight
D12	5	0.101	D33	2	0.217
D13	6	0.083	D34	3	0.187
D14	7	0.058	D35	4	0.151
D15	2	0.206	D36	6	0.071
D16	1	0.243	D37	5	0.110
D17	3	0.177			
D18	1	0.287			
D19	3	0.164			
D20	4	0.129			
D21	2	0.216			

Table 18. Summary of Consistency Test Results for Level C

Level	Maximum eigenvalue (λ_{max})	CI	CR	Consistency test result
C1	11.734	0.073	0.067	Passed
C2	7.291	0.048	0.036	Passed
C3	7.182	0.030	0.023	Passed
C4	8.407	0.058	0.051	Passed
C5	3.018	0.009	0.016	Passed
C6	6.347	0.069	0.056	Passed

Furthermore, the factor weighting vectors constitute a directly accessible core factor library for subsequent applications. Table 19presents the top three key factors for each gene category, ranked according to their internal weighting within that category, to facilitate rapid comprehension of the key rankings.

Table 19. Top-3 Key Factors within Each of the Six Gene Categories (Within-Category Weights)

Gene category	Top-3 factors (within-category weight)
C1 Pattern genes	D9 (0.223), D6 (0.158), D2 (0.136)
C2 Colour genes	D16 (0.243), D15 (0.206), D17 (0.177)
C3 Composition genes	D18 (0.287), D21 (0.216), D19 (0.164)
C4 Craft/technique genes	D25 (0.285), D27 (0.280), D28 (0.246)
C5 Environment genes	D30 (0.414), D31 (0.343), D29 (0.243)
C6 Semantic (implied-meaning) genes	D32 (0.264), D33 (0.217), D34 (0.187)

Collectively, these results establish the quantitative foundation for translating cultural evidence into actionable design variables. Within the spiritual domain, constraint strength was assigned by combining factor rank and semantic risk. D32–D34 were treated as hard semantic anchors, D35 as an exclusion-sensitive factor, and D36–D37 as bounded semantic guidance. Thus, the spiritual weight of 0.337 indicates the importance of this constraint domain, while practical control of generative output is implemented through factor-level rule assignment.

APPLICATION AND DISCUSSION

Application Scenarios and Validation Logic

The study employs the 'Sanjiang Dong Embroidery Pattern Silk Scarf Design' as a validation case, introducing generative tools to establish a dual-path mechanism.

(a) High-weight explicit genes, including patterns, composition, and colour, are used as visual constraint inputs to ensure structural and stylistic consistency.

(b) High-weight implicit genes, such as symbolism and semantic boundaries, serve as semantic constraint inputs to reinforce cultural legitimacy and alignment of meaning.

Both pathways are integrated within a unified input package, which generates an audit trail using standardised logging fields, including input package ID, reference image collection, prompt version, iteration round, and selection or exclusion rationale. This approach ensures process traceability and verifiability (see Figure 5).

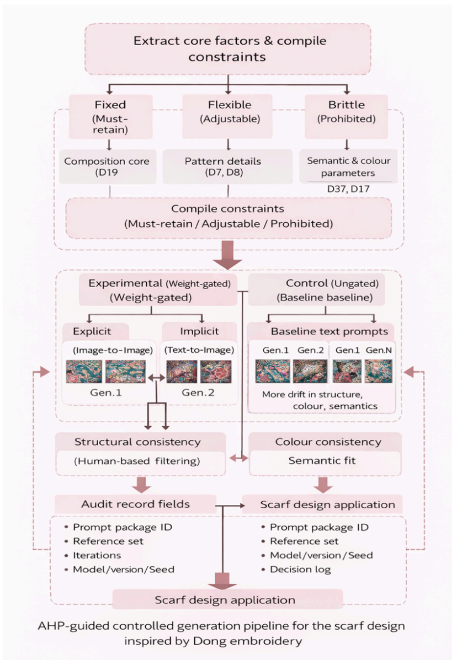


Figure 5. AHP-Guided Controlled Generation and Audit-Trail Validation Pipeline for Sanjiang Dong-Embroidery–Inspired Scarf Design

Application Results

Comparative analysis indicates that weight-driven controlled generation substantially improves output quality in three principal dimensions:

(a) Structural Consistency: The experimental group demonstrated increased stability in maintaining compositional types, such as symmetrical or centrifugal arrangements, which reduced layout drift and minimized loss of focus on the primary subject.

(b) Colour Consistency: The experimental group more consistently preserved established colour scheme logic, thereby avoiding discordant combinations that conflict with relevant cultural contexts.

(c) Semantic Alignment: In generating content with high-context semantics, such as symbolism, blessings, or protection, the experimental group produced fewer instances of 'visually plausible yet culturally invalid' mismatches. These results suggest that the effective and controllable generation of cultural semantics requires explicit boundary conditions and arbitration pathways, rather than relying solely on visual similarity.

The experiment also identifies a common risk associated with generative tools: systems that prioritize stylistic realism are susceptible to inferential bias, in which 'visibility substitutes for explainability' and semantic validity is assumed based on visual resemblance. To mitigate this, ambiguous samples are arbitrated during the screening phase using a 'semantic legitimacy priority' principle. Cases that cannot be resolved are recorded in a bias repository for retrospective attribution analysis. The resulting data is then used to expand constraint entries and semantic evidence, enabling the rule repository to evolve iteratively rather than remain static.

Table 20. Experimental Specification for the Controlled Comparison Study

Experimental group	Prompt package ID	Reference set ID	Prompt version	Fixed items	Variable items	Iteration range	Total outputs generated	Deviant samples	Final retained	Screening / exclusion rationale
Control Group A	PK-01	R7 (Dragon motif)	P-V1	Line-art skeleton; RGB palette constraints; output specifications	None	1–3	48	15	6	Style mismatch; failed to convey the intended implied meaning.
Experimental Group B	PK-01	R7 (Dragon motif)	P-V2	Line-art skeleton; RGB palette constraints; output specifications	Implied-meaning keywords; material/style terms; density and negative space	1–4	64	14	8	Insufficient negative space; overly dense/ornate decoration.

Case Evidence 1: This case study evaluates whether outputs achieve stable convergence in both structural and stylistic dimensions when high-weight dominant factors are fixed as reference image input packages. The experimental group employs pattern line art and compositional skeletons as image-to-image generation control inputs, while embedding semantic connotations and colour parameters in the text-to-image generation process to enable joint gating of form, semantics, and colour. The control group uses identical thematic and stylistic descriptions but omits weighting constraints to assess the attribution effect of the gating mechanism. Outputs are evaluated using three metrics: structural consistency, colour consistency, and semantic alignment. The rationale for screening and reasons for exclusion are documented for audit purposes.

Relevant factors include: Pattern D1, D3, D7; Composition D18; Symbolism D32 (Auspicious Fortune), D34 (Abundant Offspring and Blessings), D37 (Natural Symbiosis); and Colour D16 (RGB). Colour determination is based on the structure of the colour scheme and the principles of colour pairing. For example, pairing light blue with orange-pink indicates soft contrast and overall harmony, which defines whether colours fall within acceptable ranges.

Figure 6. Case Evidence 1: Weight-Gated Image-to-Image Control for Structural–Style Convergence in a Sanjiang Dong-Embroidery–Inspired Scarf Design

Case Study Evidence 2: This case examines whether the gating mechanism preserves consistent logic across different versions as pattern and symbolic factor combinations vary. The experimental group employs a uniform input strategy, including reference image structure locking, semantic label boundary definition, and colour parameter constraint orientation. This approach aims to stabilize the compositional type and color structure in generated outputs while preventing misalignment with high-context symbolism. Outputs are evaluated using three metrics, and deviant samples are retrospectively documented to ensure the scalability of the rule set rather than reliance on isolated successful instances.

Relevant factors include Pattern D4 and D9, Composition D18, Symbolism categories such as 'D33 Honouring Ancestral Spirits', 'D34 Prosperity Through Numerous Offspring', and 'D37 Reverence for Nature', and Colour D17 (RGB). The basis for colour determination is established, which summarizes colour families and details the pairing of genes. For example, 'red-purple paired with blue' indicates strong contrast, while 'black paired with light grey' indicates restrained harmony. These references are used to interpret compliant pairings across various stylistic orientations.

Figure 7. Case Evidence 2: Cross-Version Weight-Gated Generation with Pattern–Semantic Recombination and Colour-Pairing Compliance in Dong-Embroidery–Inspired Scarf Design

Methodological Increments from "Textual Induction" to "Executable Rules"

Translating cultural research findings into actionable design knowledge hinges not on adding more descriptions, but on establishing audit-capable, invocable, and iterable rule expressions. This study's discussion centres on AHP functioning not as an ‘interpretation tool for results,’ but as a ‘priority gating mechanism,’ translating expert judgment into variable structures that can enter the generation process.

Specifically, Layer A and Layer B weights answer ‘Which categories must be prioritised for retention’, while Layer C weights address ‘Which factors are most critical within the same category’. The resulting core factor library can be directly compiled into three rule categories:

Must-retain: High-weighting pattern/composition/symbolic factors with identity-defining functions, used to lock in cultural identity;

Adjustable: Colour and partial pattern detail factors permitting stylistic variation without compromising structural or semantic boundaries;

Prohibited: Combinations that may trigger semantic violations or identity mismatches, used to filter high-risk generation outcomes.

Methodologically, this research establishes and validates a transferable framework: AHP Weighted Evidence → Constrained Compilation (Gate Rules) → Dual-Path Controlled Generation → Tri-Indicator Audit Screening (Structure/Colour/Semantics) → Deviation Retrospection and Rule Refinement. Its value lies in providing a reusable ‘culture-computing’ interface, rather than offering a singular interpretation for individual motifs.

Contributions, Limitations, and Future Work

This study provides a verifiable incremental contribution to theory, methodology, and application. Theoretically, it operationalises the concept of “cultural identity” through a structured explanatory framework grounded in a material, behavioural, and spiritual genealogy, as well as six gene categories. This approach enables textile and apparel intangible cultural heritage (ICH) patterns to be defined as explicit variables rather than solely through narrative description. Methodologically, the integration of AHP into the cultural gene system, combined with consistency-threshold quality control, translates aesthetic and cultural judgments into auditable priority evidence that can directly inform rule compilation and facilitate cross-case reuse. In practical terms, using scarf design as a validation carrier, the study demonstrates that weight-driven constraint compilation enhances structural consistency and semantic fit, providing a viable pathway for ICH digitisation to progress from passive display to controlled regeneration.

Several limitations affect the interpretation of the findings. The visual dataset is restricted to a specific sampling window and sites, and relies on a limited set of core vector samples as unified input units. While this approach enhances replicability, it limits generalisability across different regions and artefact types.

An expert evaluation was conducted with a sample size of n = 30, which included consistency screening. Although matrix reliability is improved, the results may still be influenced by variations in expert experience and preference structures. Additionally, the generative validation addresses only the visual, semantic, and constraint chain, without considering engineering factors such as material properties, production costs, or supply chains. Consequently, the conclusions are primarily relevant to design knowledge representation and digital regeneration, rather than direct application in industrial production.

Future research should extend validation in three key directions. First, cross-region and cross-artefact comparative sampling should be expanded to assess the stability of A/B-level weight structures. Second, the introduction of multi-stakeholder evaluation and the use of measurable indicators, such as cultural recognition rates, semantic consistency scores, and misreading rates, should enhance the quantification of semantic legitimacy arbitration. Third, the rule base should be further formalised as version-controlled knowledge structures, such as ontologies, knowledge graphs, or constraint grammars, to support higher-level integration and reproducibility within digital design and interactive systems.

CONCLUSIONS

This study takes Sanjiang Dong embroidery as a case study, forming a closed-loop process from field evidence to actionable design knowledge centred on the objective of 'verifiable design translation'. At the identification and structuring level, the research organises six cultural factors (patterns, colours, composition, craftsmanship, environment, and symbolism) into a tripartite spectrum of 'material-behaviour-spiritual'. These are operationalised into a codifiable factor library, providing a unified framework for subsequent quantification and rule compilation. At the priority evidence level, AHP weighting results indicate the material layer holds the highest priority (0.521), followed by the spiritual layer (0.337), with the behavioural layer ranking relatively low (0.142). Consistency meets the threshold (CR = 0.034). At the sub-criteria level, patterns were identified as the foremost material element, whilst craftsmanship significantly outweighed environmental factors within behavioural considerations, substantiating the 'preserve/adjust' decision hierarchy.

At the translation implementation level, the study compiles weight evidence into 'mandatory retention —adjustable—prohibited' gating rules. Within controlled silk scarf generation scenarios, dual-path inputs—explicit structural constraints and implicit semantic boundaries—are employed in conjunction with audit field logging and consistency screening. This achieves traceable governance of generation deviation risks and semantic legitimacy constraints. Overall, this research advances embroidery studies from interpretive outcomes to executable, auditable, and iterable rule-based expressions, providing a verifiable pathway for the digital regeneration of textile- and clothing-based intangible cultural heritage. The present study should therefore be read as a bounded methodological demonstration rather than a comprehensive representational model of Sanjiang Dong embroidery. The 20 core samples support rule extraction and controlled generation testing under defined conditions, but they do not substitute for broader regional, historical, or artefact-level coverage. Subsequent work should further examine the transferability of the framework across regions, media, and application settings. Its extrapolation remains constrained by sample coverage, contextual differences, and the depth of engineering integration; subsequent validation of its transferability across regions and media is required.

Author Contributions

Conceptualization –ZHENG; methodology – ZHENG; formal analysis – ZHENG; investigation – ZHENG; resources –ZHENG and HUANG; writing-original draft preparation – ZHENG; writing-review and editing – ZHENG and HUANG; visualization – ZHENHG; supervision – HUANG. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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Human research subjects

This study involved human participants in the form of an expert panel (n = 30), who provided pairwise judgments for AHP weighting. Informed consent was obtained from all participants, and expert responses were recorded and analysed in an anonymised manner.

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