

Innovative Transformation Path of Intangible Cultural Heritage Textile Techniques in Modern Cultural and Creative Product Design

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ABSTRACT Intangible cultural heritage techniques face challenges in modern cultural and creative product design, including difficulties in translating craft language into mass producible solutions, high user cognitive barriers, insufficient supply chain stability, and unclear copyright ownership. As digital preservation and intelligent information management increasingly rely on advanced visualization, electromagnetic identification, and wireless interaction technologies, establishing computable and standardized representations of traditional crafts has become an important research direction. This paper proposes an innovative transformation pathway centered on the main line of “computability of craft elements—visualization of design semantics—controllability of the production chain.” Field investigations and expert interviews are first conducted to establish a craft database, from which key parameters such as patterns, structural organization, colors, materials, and processing techniques are systematically extracted. Quality Function Deployment (QFD) is then employed to translate user requirements into weighted design indicators. Based on these indicators, morphological syntax and parameterization rules are constructed to generate multiple design alternatives and verify their manufacturability. Subsequently, small batch trial production is integrated with Life Cycle Assessment (LCA) and cost accounting to optimize materials and processes. Finally, user testing and A/B comparisons are performed to iteratively refine the design while establishing standardized identification and authorization procedures. Experimental results demonstrate that three product lines and twelve prototypes are successfully developed, achieving a prototype pass rate of 83.3%, a 28.4% reduction in average working time per piece, a 19.6% reduction in unit cost, an increase in user satisfaction from 3.62/5 to 4.41/5, and a 31.5% improvement in repurchase intention. In addition, copyright registration and authorization templates for eight pattern elements are completed, providing a practical framework for digital cultural heritage management and intelligent information interoperability.

INDEX TERMS intangible cultural heritage techniques, cultural and creative design, parametric translation, electromagnetic identification, digital heritage management

I. RESEARCH BACKGROUND AND PROBLEM DEFINITION

A. RESEARCH SUBJECTS AND APPLICATION SCENARIOS

This study focuses on the process element units of intangible cultural heritage techniques that can be extracted and recombined in product development. These include pattern composition rules, fabric structure, color matching logic, material characteristics and dyeing finishing properties, process paths, and quality judgment points, which can be used to establish reusable design and production descriptions [1,2].

The application scenarios target the modern cultural and creative product system: clothing accessories (scarves, bags,

jewelry), home furnishings (cushions, wall hangings), gifts and stationery, exhibition derivatives, and city souvenir products. The design task is not only to replicate the form but also to transform technical information into specifications, process routes, and storytelling to support mass production, new product launches through channels, and continuous iteration.

B. KEY CHALLENGES

There is a semantic gap between technological expression and industrial manufacturing. Many techniques rely on the experience of masters and apprentices and oral instruction, lacking parametric descriptions, which makes it difficult to quantify pattern reproduction, control color differences, and

ensure hand feel stability, thereby lengthening the sampling cycle.

User recognition is insufficient. The value of craftsmanship often remains at the level of superficial visual similarity, making it difficult to form a perceptible selling point; price explanation and repurchase motivation are weak [3,4].

Supply chain coordination is difficult. The combination of small batch, multi product production and manual processes increases the risks associated with material batches, equipment compatibility, and delivery time management, and reduces cost controllability.

Copyright and licensing mechanisms are weak. The boundaries between pattern elements, process adaptation, and brand use are unclear, leading to disputes over infringement and revenue distribution, which affects the depth of cooperation and long term development [5,6].

II. RESEARCH OBJECTIVES AND OVERALL APPROACH

A. OVERALL OBJECTIVES

Mass Production Capability: Transform the craft from artwork level handcraft into a system combining process specifications, quality standards, and alternative processes. Clarify the material list, key process parameters, inspection indicators, and tolerance ranges to reduce the probability of prototyping and rework.

Understandable: Translate the source of the pattern, process characteristics, tactile feel, and use value into an information structure that users can perceive, forming an understandable selling point and a consistent brand narrative. Support a unified expression of online text, images, short videos, and exhibition explanations [7,8].

Reproducible: Establish a modular element library and a rule based generation mechanism to enable expansion into different product categories under the same set of rules. Accumulate transferable documents in team collaboration to support stable replication across batches and factories.

Comprehensive Constraints: Establish trade-off principles among cultural expression, cost, delivery time, environmental protection, and compliance to form an actionable basis for decision making, rather than relying on personal experience and judgment.

B. PATH FRAMEWORK

The process elements can be calculated: the pattern, structure, color, material, and process are broken down into parameters and rules (size, repeating unit, density, yarn specification, dyeing formula, working time, etc.), and an element-parameter-constraint table is established to facilitate the evaluation of cost and manufacturability [9,10].

Design semantic visualization: Map process logic to design language and user language, outputting visual specifications (pattern genealogy diagram, structural diagram, color and material swatches, tactile/durable/easy-to-clean experience labels, etc.), so that design decisions and dissemination content share a common chain of evidence.

Production chain controllability: Expand design documents into executable production packages (BOM, process routes, inspection points, risk lists, and alternatives), use small batch trial production and data collection to correct parameters, and form stable delivery standards.

Closed-loop mechanism: User feedback, quality data, and cost data are used together to update parameters in subsequent rounds, driving continuous iteration and large-scale expansion of the product line.

III. METHOD AND PROCESS DESIGN

A. TECHNOLOGICAL DATA DIGITIZATION AND ELEMENT EXTRACTION

Fieldwork focuses on process tracking, requiring the recording of equipment conditions, tool status, and the impact of environmental factors on color differences and moisture content. This creates a chain of notes:

“action–tool–result”. Interviews employ a semi structured framework, focusing on the basis for process decisions.

Sample fabrics, semi finished products, and dyed samples are collected simultaneously, along with batch, operator, timing, and shooting scale information. Key steps are supplemented with short videos to facilitate review of technique details and comparison with quantitative data.

The database structure adopts the format: feature entry – parameter field – evidence attachment – applicable boundary. The pattern entry includes vectorized graphics, forming rules, meaning labels, and applicable scales.

The organizational structure section includes weave diagrams, density ranges, and descriptions of feel and drape.

The color entry records the formula, color chart reference, color fastness, and color difference tolerance.

Material entries record composition, suppliers, alternatives, and price fluctuation ranges [11,12].

The process entry records the process route, key inspection points, time breakdown, yield, and causes of defects.

Each record is linked to a photo, sample fabric number, measurement table, and interview excerpt, supporting retrieval, reuse, and traceability.

B. MAPPING DEMAND TO METRICS

Demand collection should reflect real constraints rather than abstract preferences. The sample covers target buyers and users, and the channels include e commerce review texts, offline experience interviews, and small focus groups. Statistically, the target buyers are mainly in the 25–40 age group, with women accounting for approximately 63% and men for 37%. Their educational background is predominantly undergraduate or higher, and their occupations include creative design, education, and professional technical positions. This group generally has a middle to high income level and a high level of aesthetic engagement, making rational consumption decisions and focusing on cost effectiveness. The interview questions revolve around purchase motivation, pain points, reasons for abandonment, acceptable price range, and cultural information understanding methods, guiding

respondents to make rational comparisons and judgments on samples in terms of touch, color, weight, size, and affordability.

The corpus is transcribed into coded tags, summarized by frequency and intensity, and original evidence is preserved for high disagreement needs for subsequent A/B testing verification [13,14].

The indicator system adopts a three level hierarchical structure. Level 1 represents user value dimensions, including experience, functionality, cultural value, price, and sustainability. Level 2 consists of measurable indicators, such as wear resistance, color fastness, storage capacity, and information interpretability. Level 3 specifies the corresponding testing and evaluation methods, including measurement tools, sample size, pass–fail thresholds, and tolerance ranges. The weights consist of user side importance (questionnaire scores and interview emphasis) and enterprise side constraint weights (cost, delivery time, production capacity, compliance risks). After weight calculation, target values and minimum thresholds are formed, and these thresholds are written into the sampling acceptance form to avoid rework due to inconsistencies in standards later on.

C. SCHEME GENERATION AND MANUFACTURABILITY VERIFICATION

Rule construction begins with what to retain: preserving the identifying features of the technique, such as the typical pattern skeleton, the tactile characteristics of the organization, and specific color contrast relationships. These are then written into operable generation rules: the addition, deletion, rotation, mirroring, and splicing of unit patterns; borders, white space, and rhythm control; primary and secondary color relationships and a forbidden list; material replacement and target tactile ranges [15,16]. The parameterization part defines the range and step size; for example, the repetition pitch can be discretely taken within a certain range, and the density is graded within the range allowed by the device. The rules and parameters together form a generative, interpretable, and traceable scheme family.

After multiple solutions are generated, they enter a rapid screening process based on hard constraints from the process and equipment. The verification table includes: whether the minimum line width and minimum stitch pitch/weft density can be achieved; whether the color falls within a reproducible formula range; whether key graphics suffer recognition loss after scaling; whether any new high-risk manual steps are added to the process flow; and risk assessments for wrinkles and color fading during packaging and transportation.

For solutions that pass verification, a rough cost calculation and delivery time estimate are added to form a candidate solution pool. For those that fail, the reasons for failure are recorded and added back to the database as a basis for rule revision, rather than a one time rejection.

D. SMALL-BATCH TRIAL PRODUCTION AND COMPREHENSIVE OPTIMIZATION

Small batch trial production does not aim for a perfect, one time result. Each sample is linked to production batch information (raw material batch number, operator, equipment parameters, environmental records, and time breakdown). Quality recovery uses defect coding (color difference, uneven stitching, pilling, shrinkage, deformation, pattern misalignment, edge wear, etc.) to record the location, frequency, and possible causes of occurrence.

Feedback is simultaneously collected from the production side, the problem list is sorted by severity and probability of occurrence, and the next round of parameter adjustment and process revision is initiated.

The scope of Life Cycle Assessment (LCA) covers raw material acquisition, production and processing, transportation and packaging, use, maintenance, and disposal, thereby identifying environmental hotspots where improvement efforts can be most effectively directed. Cost accounting adopts the decomposition method, breaking down materials and other items to the individual level, and incorporating yield as a key multiplier into the estimation [17].

Optimization decisions follow a dual threshold: a reduction in ecological impact should not come at the cost of a significant decline in yield, and a reduction in cost should not sacrifice core identification features.

Optional strategies include replacing suppliers or fiber ratios with more stable ones, adjusting dyeing formulas to reduce color differences, and using more maintainable structures to reduce the burden during the usage phase.

E. USER TESTING AND ITERATIVE FINALIZATION

The testing procedure adopted a scenario based task and real time feedback approach, setting up reading tests such as touch comparison to reduce the bias caused by purely verbal evaluations. The A/B comparison controlled the number of variables to ensure that the differences were explainable. Each subject completed the same task and gave a score and reason.

The data records include overall preference selection, key indicator scores, dwell and touch duration, accuracy of retelling cultural information, and follow up questions for discrepancies to determine whether they are aesthetic differences or insufficient understanding of information.

Iterative decision making is driven by both threshold constraints and gain objectives. The threshold constraints stem from the quality and manufacturing dimensions, requiring that color difference control, shrinkage rate, color fastness, assembly strength, production yield, and time efficiency all meet the baseline.

Gain targets come from the user and market dimensions and need to achieve the preset improvement of indicators such as brand recognition and gift suitability. The final standard is consolidated into a production package integrating components, including the bill of materials, process routes, key parameter control ranges, quality inspection nodes and

sampling ratios, packaging specifications, information labeling requirements, and after sales maintenance guidelines.

F. INTELLECTUAL PROPERTY AND STANDARDIZED DELIVERY

The identification system transforms craft information into identifiable communication components (craft name, process highlights, material source, place of origin, and participant information) presented in a unified format, adaptable to hangtags, packaging, websites, and exhibition labels. Narrative guidelines emphasize evidence based expression: the source and meaning of patterns reference database entry numbers, and process descriptions correspond to flowcharts and inspection points, avoiding exaggeration and vague descriptions.

Visual consistency rules are established to ensure that the product series presents a stable brand identity across different channels, and directly reusable text templates are provided for sales pitches and content production.

The rights confirmation process covers three lines: material registration, adaptation records, and finished product archiving. Original patterns and sample fabrics are registered with registration numbers; each modification is recorded, including the version and responsible person; and the finished product's corresponding design drawings, production packages, and promotional materials are archived together. The authorization template clearly defines the scope of authorization (category, channel, duration, region), attribution method, restrictions on secondary creation, sample confirmation mechanism, quality and public opinion responsibility, revenue distribution, and auditing standards. For external collaborations, a compliance checklist is added, including prohibited elements, sensitive expression avoidance, and review points, making the authorization executable, traceable, and extensible.

IV. RESULTS AND EFFECTIVENESS EXHIBITION

A. OUTPUT SCALE

Three product lines were established, and twelve prototypes were developed and archived, covering three typical consumer scenarios: wearable accessories, home furnishings, and gift stationery. Each product line includes four prototypes, differentiated by a shared set of technical elements: pattern units are adapted to various carriers such as scarves, bags, cushions, and ornaments at different scales and repeat intervals; color schemes are grouped into low saturation everyday styles and high contrast festive styles; and materials are configured within three target ranges: skin friendly, wear resistant, and easy to care for. Each of the twelve prototypes is provided with a production package and version number, including a BOM list, process route, key parameter ranges, quality inspection points, and a defect comparison table. Prototype samples and measurement data are entered into a database to support subsequent replication and series expansion.

Prototype review records are simultaneously archived as element category adaptation entries for easy cross category migration and reuse.

B. MANUFACTURING AND COST INDICATORS

Prototype scope: Twelve prototypes entered small batch trial production, with three units of each prototype produced according to the same process package to cover operator differences and batch fluctuations.

Pass rate determination: Key quality inspection points are used as thresholds (dimensional tolerance, color difference tolerance, appearance defect level, structural strength/durability). Failure to meet any threshold is considered a failure. Retesting records the reasons for failure but is not count as a first round pass.

Work time measurement: Time is calculated for each product according to the process (material preparation, weaving/processing, finishing, assembly, quality inspection, and packaging), and non-process time such as waiting and downtime is excluded. The average value is used as the work time per piece.

Cost accounting: Unit cost = materials + labor (calculated by working hours) + wastage + quality inspection/packaging allocation. Using the baseline prototype (unparalleled and uncalibrated versions) as a control group, the changes in the optimized version are compared. Table 1 shows the test indicators:

TABLE 1. Test Indicators

Indicator Item	Judgment/Caliber	Data Source	Result
Prototype pass rate	Number of first round qualified prototypes / 12	Quality Inspection Record Form	83.3%
Average work time per piece (min/piece)	Average time taken per process	Work Hour Breakdown Sheet	↓28.4%
Unit cost (RMB/piece)	Materials + Labor + Losses + Allocation	Cost Accounting Sheet	↓19.6%
Rework rate	Number of returned parts / Total number of parts	Defect Coding Table	Decrease (synchronous recording)
Yield	Number of qualified pieces / Total number of pieces	Small-batch trial production statistics	Increase (synchronous recording)

Based on the above indicators, the first round of testing achieved a pass rate of 83.3%. The failed prototypes were mainly due to two types of defects: color difference and edge details. This verified the boundary of the effect of calculable process elements – controllable production chain on stable delivery. That is, parameters and inspection points can significantly reduce structural problems, but stronger batch control is still needed for dyeing and finishing fluctuations.

The average unit time decreased by 28.4%, mainly due to the rerouting of process routes and the solidification of key parameter ranges, which reduced repeated machine adjustments and rework, corresponding to mass production in the summary. The unit cost decreased by 19.6%, which was contributed by the reduction in time, the reduction in losses, and the substitution of materials, without sacrificing identification features (the pass rate remained at a high level), supporting the replicable serial expansion.

C. USER AND MARKET FEEDBACK METRICS

Before the test, two rounds of same-scenario evaluations were conducted with the target customer group.

An A/B comparison was performed between the baseline prototype (unoptimized version) and the optimized prototype (parameterized + manufacturability verified). Participants completed tactile experience, appearance recognition, usage scenario simulation, and price range selection, and filled out a 5 point scale for satisfaction and repurchase intention (intention multiple choice questions were quantified as proportions). The questionnaire was used with the same criteria and the same presentation order, but randomized to reduce guidance bias. Table 2 shows the test results:

TABLE 2. Test Results

Index	Baseline Prototype	Optimized Prototype
Overall satisfaction (/5)	3.62	4.41
Increase in satisfaction	—	+ 0.79
Repeat purchase intention (%)	Reference value	+ 31.5%
Appearance recognition score (/5)	3.55	4.30
Tactile comfort rating (/5)	3.48	4.36
Price acceptance (percentage matching target price range)	Below target	Closer to the goal

The results indicate that the satisfaction rate increased from 3.62 to 4.41, an increase of 0.79, indicating that the optimization not only improved the manufacturing indicators but was also significantly perceived by users.

The improvements are concentrated on tactile comfort and appearance recognition, allowing users to understand the value of patterns and materials more quickly. The 31.5% increase in repurchase intention reflects a better match between experience and price expectations, enhancing market conversion potential.

Price acceptability moved closer to the target price range, indicating that perceived value was maintained while costs decreased, thereby enabling scalable and replicable production. To further solidify the results, follow up surveys should be conducted on divergent samples, and positioning remains a key obstacle affecting repeat purchases.

D. COPYRIGHT AND LICENSING RESULTS

Copyright registration was completed for eight pattern elements. Registration was organized into independently usable pattern units and combination rules, covering both the digital organization of original patterns and adapted versions created without altering core identifying features. Each registration included a source evidence package containing field collection records, sample fabric photos, vectorized files, version iteration logs, and application examples, ensuring a clear and traceable ownership chain. Simultaneously, an authorization template and reusable mechanism were developed: the scope of authorization, attribution method, boundaries of secondary creation, quality and

public opinion responsibility, review nodes, and revenue distribution criteria were written into the terms. The process of material registration—adaptation record—finished product archiving—external authorization was standardized to support rapid access and risk control in cross category and cross batch collaborations. Table 3 summarizes the results of the copyright registration and authorization mechanism.

TABLE 3. Summary of the Achievements of the Copyright Registration and Licensing Mechanism

Achievements	Quantity/Status	Key Content	Reusable Output
Pattern element copyright registration	8 items completed	Unit pattern + combination rules + version number	List of Authorizable Patterns
Source evidence package	8 sets complete	Data acquisition records / fabric samples / vector files / iteration logs	Property rights confirmation document template
Authorization template	1 set completed	Scope / Term / Geography / Authorization / Benefits / Liability	Contract Terms Library
Proofreading and stamping process	1 set online	Proofreading points, avoidance of sensitive expressions, and use of seals	Approval Form
Archiving and retrieval mechanism	1 set established	Encoding rules, version management, application scenario tags	Database retrieval fields

This achievement corresponds to the reproducible aspect set in the abstract: the pattern assets can be used in a standardized manner; it corresponds to the understandable aspect: the evidence package and narrative materials can be directly used for external explanation; and it corresponds to the mass producible aspect:

the authorization and review process reduces cooperation friction and rework costs.

V. CONCLUSIONS AND APPLICATION RECOMMENDATIONS

This study establishes a traceable database through field research and element extraction, converting patterns, structures, colors, materials, and processes into calculable parameters and constraints. Quality

Function Deployment (QFD) compresses user language into verifiable indicators and weights, reducing repetitive aesthetic debates. A controllable solution space is created through morphological syntax and parametric generation. Unmanufacturable solutions are pre-selected using hard constraints on equipment and processes. Small-batch trial production recovers defects and cycle time data. LCA and cost accounting drive process and material optimization. A/B testing confirms changes in perceived value and purchase intention, resulting in executable standardization and production packages. This method establishes a data loop and standardized delivery interface between cultural expression and industry constraints, suitable for continuous operation in serial expansion, cross factory replication, and brand dissemination.

AUTHOR CONTRIBUTIONS

Ge Zhang designed, collected and analyzed the data, and drafted the manuscript. Ge Zhang conducted the study,

critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Ge Zhang participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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