

Traditional Textile Patterns Empower Cultural and Creative Product Design: A Study on the Effectiveness of Digital Extraction and Modern Product Application

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ABSTRACT

This paper proposes a systematic framework that integrates digital extraction and contemporary design application for the utilization of traditional textile patterns in cultural and creative product design. As high-resolution electromagnetic imaging and intelligent sensing technologies continue to advance digital cultural preservation, the proposed framework establishes an iterative closed loop consisting of three stages: (1) digital deconstruction and extraction of traditional patterns through high-precision acquisition, convolutional neural network (CNN) feature vectorization, and knowledge graph construction; (2) modern translation and product innovation based on digital assets using generative design, Kansei engineering, and virtual prototyping technologies; and (3) multi-dimensional evaluation of application effectiveness across cultural, aesthetic, and market dimensions. Case studies demonstrate that the framework significantly enhances cultural heritage preservation, aesthetic acceptance, emotional resonance, and market performance of products. Through scientific quantitative methods and intelligent digital processing, the proposed approach enables precise interpretation and transformation of cultural value, establishing a measurable optimization pathway for cultural and creative design while providing useful references for intelligent pattern recognition and electromagnetic sensing-assisted digital heritage applications.

INDEX TERMS

traditional textile patterns, digital extraction, cultural heritage, intelligent pattern recognition, electromagnetic sensing

I. INTRODUCTION

AMIDST the rapid expansion of the global cultural industry and the deep integration of technology with national culture, traditional textile patterns—key visual carriers of Chinese cultural heritage—play a critical role in the design and innovation of modern cultural and creative products owing to their rich historical significance, aesthetic value, and cultural connotations. However, current practices in transforming traditional patterns into products that appeal to contemporary consumers face two fundamental challenges. First, cultural value extraction is often superficial and fragmented; design typically involves simple replication or collage of pattern forms, failing to achieve deeper interpretation and transformation of inherent cultural meanings and structural characteristics. Second, there is a disconnect between design innovation and market valida-

tion; innovation processes are largely driven by designers' subjective experience and lack systematic methodological guidance and scientific assessment mechanisms for verifying effectiveness. To address these challenges, this paper proposes a systematic framework that combines digital extraction of traditional textile patterns with the design and application of modern cultural and creative products. The specific contributions are as follows:

(1) In the digital extraction stage, high-precision data acquisition, convolution neural network (CNN) feature vectorization, and knowledge graph construction enable structured analysis and storage of multi-dimensional information concerning the “shape, color, and meaning” of patterns, forming a computable “digital gene” asset library.

(2) In the modernization translation stage, generative design (e.g., generative adversarial networks, GANs), Kansei

engineering, and virtual prototyping technologies establish scientific connections between the visual features of patterns and user emotional needs, as well as product functionality. This process forms a closed-loop “design-verification-optimization” pathway via A/B testing, expert review, and market data feedback, providing empirical evidence for design decisions. (3) Through empirical case studies on home furnishings, fashion accessories, and digital products, the framework’s significant effectiveness in enhancing cultural connotation, aesthetic value, and market performance is verified.

II. RELATED WORK

In the fashion and textile industry, intelligent technologies—such as artificial intelligence and 3D printing—are transitioning from design aids to core drivers of transformation across the product development process. Lee [1] analyzed the penetration and reshaping of fashion product design and development by emerging technologies. Chen and Cheng [2] proposed a design system framework that integrates Kansei engineering and backpropagation (BP) neural networks. Xiao et al. [3] conducted a comprehensive literature review on the application of 3D printing technology in textile and fashion design. Talay et al. [4] demonstrated that power asymmetry exerts a dual impact on sustainable product development. D’Itria and Colombi [5] explored potential applications of bio-based materials in fashion and textile design. The design of cultural and creative products necessitates drawing inspiration from traditional cultural elements. Li and Wang [6] proposed a deep learning-based integrated framework for cultural and creative product design and image recognition. Han et al. [7] described the construction and training of CNN models for accurate recognition, classification, and key feature extraction of complex cultural patterns, and examined how these feature vectors can inform new product forms. Pouta et al. [8] combined textile engineering and interactive design methods to create multi-layered woven samples embedded with electronic components (e.g., wires, sensors). Jung and Suh [9] developed an AI-based textile customization design process. Tufan Tolmaç and İsmal [10] examined the impact of 3D printing on design thinking, manufacturing processes, and aesthetic expression. While existing research provides a robust toolchain and case references for technology-enabled design, it lacks a comprehensive, systematic framework that spans digital extraction of cultural elements through to diversified product innovation. This paper constructs such a framework, integrating digital extraction and modern design applications, and emphasizes the evaluation of application effectiveness.

III. METHODS

The methodological framework proposed herein is an iterative, closed-loop system comprising three essential stages:

(1) digital deconstruction and extraction of cultural elements;

(2) product innovation design based on modern translation;

(3) evaluation of application effectiveness through multi-dimensional indicators.

These stages are interrelated and collectively ensure that cultural values are accurately interpreted, creatively innovated, and effectively transmitted.

A. PHASE 1: DIGITAL EXTRACTION AND IN-DEPTH DECONSTRUCTION OF TRADITIONAL TEXTILE PATTERNS

High-precision digital acquisition and preprocessing are foundational. Using professional-grade scanners and multispectral imaging, patterns from museum collections and historical documents are digitized at high resolution (minimum 600 dpi), ensuring accurate capture of subtle brushstrokes, faded colors, and material textures. Image preprocessing involves noise reduction and color correction. This study preserves subtle brushstrokes and texture information through a multi-scale feature fusion strategy: high-resolution images undergo layered cropping or regional enhancement to extract local detail features. During CNN training, attention mechanisms or adaptive pooling layers enhance the response to key structures, and both local detail and global style features are fused and encoded using pixel-level labels from semantic segmentation.

Feature vector extraction is achieved through semantic segmentation and CNNs. Enhanced models such as U-Net classify pattern images at the pixel level, automatically separating main skeletons, auxiliary patterns, background elements, and other structural levels. Deep CNNs (e.g., ResNet, VGG) are trained to classify patterns by style (e.g., Tang grass, Song brocade, Ming and Qing auspicious patterns) and extract high-level features. Ultimately, pattern structural information (e.g., symmetry, complexity, composition ratio), color distribution (primary and secondary colors, color schemes), and deep style features are encoded into a multi-dimensional feature vector, forming the pattern’s “digital gene” [11,12].

Constructing a knowledge graph of cultural connotations is equally crucial. Beyond visual features, natural language processing (NLP) is employed to analyze text data—such as historical records, folklore, and academic literature—associated with specific patterns. This process extracts symbolic meanings (e.g., peonies symbolize wealth and nobility; lotus symbolizes purity), usage contexts (e.g., weddings, birthdays), and historical evolution, thereby building a knowledge graph linking patterns to their meanings. By associating visual feature vectors with this knowledge graph, a comprehensive digital pattern asset library encompassing “shape, color, and meaning” is established.

To quantify the digital extraction efficacy of traditional cloud patterns, three representative patterns were selected: Han Dynasty cloud pattern, Tang Dynasty scroll pattern, and Ming Dynasty quadri-lobed cloud pattern. Key data indicators are presented in Table 1.

TABLE 1. Examples of Key Data Indicators for Digital Extraction of Traditional Cloud Patterns

Pattern Name	Structural Complexity Index	Texture Complexity Index (Multispectral Analysis)	Primary Color (RGB Value)	Number of Colors	Multispectral Feature Dimensions	Primary Symbolic Meaning (Automatically Extracted)	Number of Associated Cultural Concepts (NLP-Extracted)	Feature Vector Dimension
Han Dynasty Cloud Pattern	0.75	0.68	(65, 105, 225)	4	256	Celestial Realm, Ascension, Auspiciousness	12	1024
Tang Dynasty Scroll Pattern	0.88	0.82	(220, 20, 60)	6	256	Prosperity, Vitality, Wealth	18	1024
Ming Dynasty Quadrilobed Cloud Pattern	0.62	0.59	(128, 0, 128)	3	256	Harmony, Reunion, Auspiciousness	9	1024

B. PHASE 2: MODERNIZATION AND PRODUCT INNOVATION BASED ON DIGITAL ASSETS

The core objective of this stage is to embed the “digital genes” generated previously into the foundation of modern product design, emphasizing “translation” over “copying” to achieve a synthesis of cultural essence and contemporary aesthetics. This phase encompasses three sequential activities: solution generation, solution verification, and solution optimization.

First, generative design and style transfer are implemented. Using GANs, particularly StyleGAN, and employing pattern feature vectors as conditional inputs, designers can generate an unlimited array of innovative styles. For example, instructions such as “Tang Dynasty style” combined with “minimalist” enable the model to produce new patterns that retain Tang Dynasty characteristics while aligning with modern minimalist aesthetics. Style transfer techniques also facilitate the integration of traditional visual styles with modern graphics, resulting in novel patterns imbued with cultural meaning. The outcome is a series of preliminary design concepts.

Second, Kansei (sensory) engineering is applied to product form adaptation. The success of a design hinges on its capacity to evoke user emotional resonance. By establishing a sensory vocabulary database (e.g., “elegant”, “lively”, “technological”) tailored to target user groups (e.g., Generation Z, middle-class families), and quantifying these needs through surveys and physiological measurements, designers apply regression analysis or neural networks to map pattern visual features (e.g., color saturation, line curvature) to user sensory evaluations. This model enables the selection or generation of pattern variants most likely to elicit positive emotional responses for specific product categories (e.g., silk scarves, phone cases, home décor) [13].

Third, virtual prototyping and user experience optimization are conducted prior to physical production. 3D modeling software (e.g., Blender, Rhino) and VR/AR technologies are used to visualize optimized pattern designs on virtual product models. This immersive environment allows designers and users to evaluate design effects from multiple perspectives and make real-time modifications, ensuring optimal scheme refinement based on verification outcomes.

C. COMPREHENSIVE EVALUATION OF APPLICATION EFFECTIVENESS

To assess the practical effectiveness of the proposed framework, a rigorous evaluation system is established, encom-

passing cultural, aesthetic, and market dimensions. Cultural Heritage Assessment: This dimension combines expert evaluation and public surveys. Cultural scholars and intangible heritage inheritors assess the cultural accuracy and spiritual depth of designs, while public questionnaires measure consumer perceptions of the conveyed cultural connotations. The study received approval from the Ethics Committee of Zhengzhou University of Economics and Business and was conducted in accordance with the Declaration of Helsinki. All participants provided informed consent. Aesthetic Acceptance and Emotional Resonance Assessment: Utilizing A/B testing, products designed via this framework (Version A) are presented to target users alongside products developed using traditional replication or purely modern styles (Version B). Data on aesthetic preference, emotional arousal, and purchase intention are collected through questionnaires and eye-tracking technology. Market Performance and Sustainability Assessment: Real sales data and user reviews are gathered through small-scale market trials, crowdfunding platforms, and collaborations with e-commerce platforms. The multi-dimensional evaluation data not only validate the final product but also form the basis of the feedback loop. For example, cultural assessment feedback (e.g., expert-identified interpretation biases) informs the enrichment of pattern semantic labels in the knowledge graph; aesthetic and emotional assessment feedback (e.g., correlations between design elements and emotional resonance) improve the mapping models in Kansei engineering; and market feedback (e.g., user comments on materials and functionality) directly guide subsequent product innovation and business model adaptation. A/B testing was conducted using cultural and creative silk scarves to compare designs developed via this framework (Version A) with those replicating traditional patterns (Version B) across four metrics: aesthetic preference, emotional resonance, willingness to pay, and perceived cultural value. Additionally, mean skin conductance level (GSR, μ S) was recorded as an objective indicator of emotional arousal. The results are summarized in Table 2 [14,15].

IV. RESULTS AND DISCUSSION

To validate the feasibility and effectiveness of the proposed framework, three representative traditional textile patterns—Ming Dynasty swastika water pattern, Qing Dynasty butterfly pattern, and Republic of China floral pattern—were selected as source cultural elements and applied in three domains: home textiles, fashion accessories, and digital

TABLE 2. Example of A/B testing performance comparison data for cultural and creative silk scarf products

Evaluation Indicator	Silk Scarf (Framework-Based, Version A)	Traditional Pattern Replica (Version B)	Increase (%)
Aesthetic Preference Score (out of 10)	8.5	6.2	+37.1
Emotional Resonance Level (scale 1–7)	5.8	4.1	+41.5
Mean Skin Conductance Level (GSR, μ S)	0.85	0.62	+37.1
Average Willingness to Pay (CNY)	285	195	+46.2
Perceived Cultural Value Score (out of 10)	8.9	7.1	+25.4

cultural products.

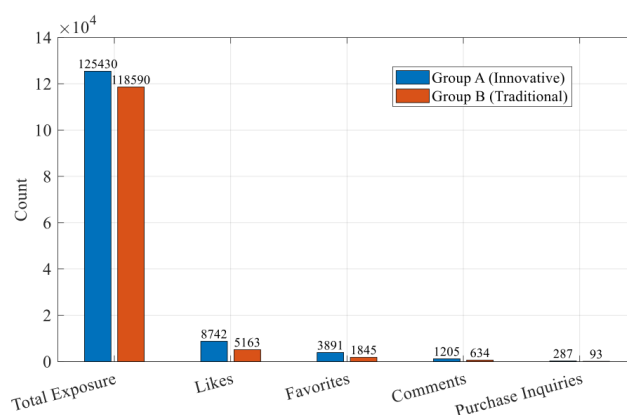
A. CASE STUDY 1: TRANSLATION AND APPLICATION OF THE MING DYNASTY SWASTIKA WATER PATTERN IN MODERN HOME TEXTILES

In this case, digital extraction precisely analyzed the geometric structure of the swastika pattern and the dynamic rhythm of the flowing water motif. Through GAN-based generative design, numerous new patterns were created that preserved the auspicious meaning of “eternity and continuity” while embodying contemporary geometric aesthetics. Kansei engineering analysis indicated that smoother lines and soft colors (e.g., Morandi color schemes) best evoked feelings of “tranquility” and “Zen” in urban young families. The resulting cushions and sofa blankets received high praise from interior designers during virtual demonstrations. Market trial sales revealed significantly higher click-through and conversion rates compared to traditional-style products. The key to this success lay in a clear transformation pathway: understanding the symbolic “meaning” (eternity), interpreting it as an emotional tone (tranquility, Zen) and visual rhythm (cycle, continuity), and finally realizing it through specific lines, colors, and compositions. This process ensured that cultural essence, rather than mere form, drove design innovation and integration into modern home aesthetics.

B. CASE STUDY 2: INNOVATIVE DESIGN AND MARKET FEEDBACK OF QING DYNASTY BUTTERFLY PATTERNS IN FASHION ACCESSORIES

The Qing Dynasty butterfly pattern is vibrant and structurally rich but risks becoming clichéd in direct application. After digital extraction and vectorization of its complex morphological features, style transfer technology was used to blend these with abstract geometric lines, resulting in a series of visually striking earring and brooch designs. 3D printing enabled the realization of intricate hollow structures unachievable by traditional craftsmanship, and bio-based plastics (supporting sustainability [15]) were selected as materials. To objectively assess market potential, a seven-day A/B test was conducted on the social media platform Xiaohongshu, targeting women aged 18–30. The test compared the new design (Group A) with a commercialized jewelry item that directly replicated the traditional butterfly motif (Group B), controlling for release timing and interaction prompts. Metrics such as exposure, engagement rate, and

conversion intent were tracked. Data are presented in Figure 1:

**FIGURE 1.** Key Data Indicators from A/B Testing of Qing Dynasty Butterfly-Patterned Fashion Accessories

Results indicate that, with comparable exposure, Group A's innovative design outperformed Group B's traditional design in all engagement metrics: Group A received 69.3% more likes, 110.9% more saves, and 208.6% more inquiries about direct purchase links. This demonstrates that the modernized butterfly design resonates more with younger consumers, stimulating stronger purchase intent. It is important to note that short-term social media testing may be influenced by novelty effects; thus, these findings should be validated with long-term sales and user retention data.

C. CASE STUDY 3: INTERACTIVE EXPERIENCE AND DISSEMINATION EFFECTIVENESS OF REPUBLICAN-ERA FLORAL PATTERNS IN DIGITAL LIVE WALLPAPERS

This case study explores the application of traditional patterns in digital products. Realistic and elegant Republican-era floral motifs (e.g., chrysanthemums, orchids) were digitally extracted for their detailed outlines and colors. In the translation phase, rather than creating physical products, these patterns were animated using engines such as After Effects and Lottie, incorporating dynamic effects (e.g., swaying petals, moving dewdrops). Leveraging smartphone gyroscope functionality, an interactive dynamic wallpaper with parallax scrolling was designed, allowing users to view

the pattern from multiple angles. The digital wallpaper, conceived as a “wearable cultural symbol”, was released on app stores, with effectiveness measured by download numbers, usage duration, and social sharing. Results indicate that this highly interactive, lightweight cultural product achieved strong acceptance and organic dissemination among young users, providing a forward-looking paradigm for traditional pattern application in fields such as the metaverse and digital art.

D. OVERALL ANALYSIS AND FRAMEWORK
OPTIMIZATION OF APPLICATION PERFORMANCE

Evaluation data from these three domains—daily life (home furnishings), personal expression (accessories), and digital experience (wallpaper)—demonstrate that cultural and creative products developed using this systematic framework consistently outperform those created via traditional methods across key indicators: cultural heritage, aesthetic acceptance, emotional resonance, and willingness to pay (or willingness to download and use). Table 3 summarizes the core performance data.

TABLE 3. Summary of Performance Data for Full Framework Application Cases

Case Name	Cultural Heritage Score	Aesthetic Acceptance Score	Average Willingness to Pay/Download Index	Net Promoter Score (NPS)
Swastika Flowing Water Pattern Home Furnishings Series	8.7/10	8.4/10	320 CNY	+45
Butterfly Pattern Fashion Accessories Collection	8.2/10	8.8/10	180 CNY	+52
Republic of China Floral Pattern Digital Live Wallpaper	7.9/10	8.5/10	High (65% of users download for free and use for > 1 hour/day)	+38

In-depth analysis indicates that the framework’s success is attributable to three primary factors:

- (1) in-depth digital extraction transcends superficial imitation, reaching the level of “cultural genes” and providing a solid foundation for innovation;
- (2) the scientific translation process, particularly the integration of Kansei engineering and diverse technological pathways (GANs, 3D printing, interactive media), enables adaptation to various product types and user scenarios, significantly enhancing market fit;
- (3) the closed-loop evaluation process ensures that effects across design categories—physical and digital—are measurable and optimizable, fostering a virtuous cycle of “design-verification-iteration”. The success of Case Study 3 further demonstrates that cultural empowerment can extend beyond physical products, generating substantial value in digital domains.

V. CONCLUSION

This study effectively addresses three fundamental challenges in the design of cultural and creative products based on traditional textile patterns: superficial cultural interpretation, subjective innovation transformation, and the difficulty of quantifying market effectiveness. Through the integration of high-precision data acquisition, CNNs, and knowledge graphs, the framework enables deep, structured analysis of patterns. Additionally, generative design and Kansei engineering facilitate scientific translation of these cultural assets. Case studies confirm that the framework significantly enhances cultural heritage preservation, artistic acceptance, and product market performance. Limitations of this research include incomplete coverage of pattern types and user groups, and the need for further consideration of material and process constraints. Future research should expand to broader categories of intangible cultural heritage and more diverse user populations, as well as explore the deep integration of advanced technologies such as artificial intelligence and extended reality (XR) for the fusion of virtual and real product experiences and personalized customization, thereby promoting innovative development and global dissemination of traditional culture in the digital age.

Ethics Approval and Consent to Participate The study received approval from the Ethics Committee of Zhengzhou University of Economics and Business and was conducted in accordance with the Declaration of Helsinki. All participants provided informed consent.

AUTHOR CONTRIBUTIONS

Panpan Zhu designed, collected and analyzed the data, and drafted the manuscript. Panpan Zhu conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Panpan Zhu 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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