A Study on the Design Translation of Majiayao Polychrome Pottery Water Sports Equipment Integrating Affective Engineering and AI-Generated Content

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Abstract: This study aims to explore systematic pathways for generative AI (AIGC) to empower innovative digital design in cultural heritage preservation. Taking Majiayao painted pottery culture as the research subject, it integrates affective engineering with AIGC technology to construct a design translation framework spanning from cultural element perception to cultural and creative product generation. First, a database of painted pottery patterns was constructed, and core sensory factors were extracted. Second, the LoRA model was used to fine-tune Stable Diffusion, enabling precise control over the painted pottery style. Third, the Analytic Hierarchy Process (AHP) was employed to quantify user preference weights for cultural and product characteristics, mapping these to prompt parameters in the AIGC generation process. Ultimately, this approach generated the "Pottery Pattern Rhythm - Water-Inspired Elegance" series of aquatic sports equipment designs, including competitive swimwear, kayaks, and surfboards. User acceptance was validated through fuzzy comprehensive evaluation. This research provides a reference paradigm with both theoretical value and practical significance for the living inheritance and innovative transformation of intangible cultural heritage.

Keywords: Affective Engineering; AIGC; Majiayao Culture; Water Sports Equipment; LoRA Model; Design Translation

1. Introduction: Challenges and Opportunities in the Digital Era for Gansu's Cultural Heritage

As a significant cradle of the Yellow River civilization, Gansu possesses a rich repository of historical and cultural heritage. Among these, Majiayao painted pottery is renowned for its profound patterns and rich cultural connotations. In recent years, Gansu Province has placed high importance on the innovative transformation of cultural resources, emphasizing development through protection and inheritance through innovation. However, traditional cultural and creative product development often falls into dilemmas such as "formal resemblance without spiritual connection" and "disruption of cultural context," urgently necessitating the exploration of new design paradigms that integrate cultural essence, modern aesthetics, and functional suitability. The rise of technologies like Artificial Intelligence Generated Content (AIGC) provides new possibilities for the digital interpretation and creative translation of cultural heritage.

Historical and cultural heritage, serving as both the material carrier and living witness of China's outstanding traditional culture, is not only a precious legacy bequeathed by history but also the physical encapsulation of national memory [1]. Current design practices often encounter two major difficulties when translating static, ancient artifacts into products that align with modern aesthetics and functions. First, the translation process excessively relies on designers' personal experience and intuition, lacking systematic methodological support, leading to the dilution or misinterpretation of cultural genes during iteration. Second, while AIGC technology enhances generation efficiency, its "black-box" nature and randomness introduce uncertainty regarding the cultural accuracy and emotional resonance of the generated outcomes.

Majiayao painted pottery, as a typical relic of the late Neolithic period, features patterns that are not simple imitations of nature but rather "significant forms" carrying the ancestors' worldview and consciousness of life. Patterns such as spirals, grid patterns, and frog motifs, through visual principles like repetition, symmetry, and rhythm, constructed a primitive aesthetic system, providing rich symbolic resources for modern design. "Generative Artificial Intelligence (Generative AI) and its derivative, AI-Generated Content (AIGC), demonstrate immense potential in the fields of content creation and cultural communication" [2]. AIGC, trained on large-scale datasets, can generate content with various styles and characteristics, thereby producing creative and unique design works [3].

By integrating Kansei Engineering and AIGC, this study constructs a rational design framework aimed at bridging the semantic gap between Majiayao painted pottery culture and contemporary products. Kansei Engineering serves as the "translator," quantifying users' emotional needs, while AIGC acts as the "executor," enabling efficient solution generation. Their synergy provides a computable, guidable, and evaluable innovative paradigm for the living inheritance of intangible cultural heritage.

2. Research Pathway: A "Kansei Engineering + AIGC" Synergistic Driver for a New Design Paradigm

2.1 Application of Kansei Engineering in Design

"Kansei Engineering is a method for translating users' emotional needs into product design elements" [4]. As one of the important methods for product emotional design [5], it analyzes users' emotional information through quantitative methods to establish the mapping relationship between users' emotional needs and product design [6]. However, "how to precisely measure users' vague emotional imagery, determine the relative weights of vocabulary, and accurately quantify the complex mapping model between users' emotional imagery vocabulary and design object elements are the research problems and difficulties in the Kansei Engineering operation process" [7]. Therefore, Kansei Engineering requires advanced psychological measurement tools to more accurately capture users' momentary emotional reactions when encountering design objects, thereby obtaining more detailed and accurate emotional imagery data. On the other hand, mathematical methods such as fuzzy mathematics and Analytic Hierarchy Process (AHP) are employed to judge and quantify the relative weights of users' emotional imagery vocabulary, constructing a relatively scientific and reasonable complex mapping model. Simultaneously, combined with big data technology, the analysis and mining of large amounts of user feedback and product data can further optimize the application effect of Kansei Engineering in design. This enables it to better translate users' emotional needs into actual product design elements, providing strong support for emotional design. Specifically, big data technology can collect diverse emotional feedback from different user groups when encountering design objects, covering multiple dimensions such as age, gender, region, and cultural background. Through in-depth mining of these vast datasets, patterns and trends of user emotional needs hidden within can be discovered, such as differences in emotional resonance triggered by specific design elements among different user groups. Based on these analytical results, designers can more precisely adjust and optimize design elements, ensuring that products meet the emotional needs of a broader user base, thereby enhancing the level of emotional design and market competitiveness of products.

2.2 Artificial Intelligence Generated Content (AIGC)

Since November 2022, the chatbot model ChatGPT, launched by OpenAI, has swept the internet and rapidly iterated. With its natural language output, cross-modal content generation, rapid response capability, and rich applicability across scenarios, it has sparked a new competition in the field of artificial intelligence [8]. In fact, ChatGPT, like AI painting, AI writing, and AI programming, belongs to the category of AIGC (AI-Generated Content) applications [9]. In February 2024, OpenAI's Sora model achieved for the first time the direct generation of high-quality video content from simple text prompts, marking a leap in AIGC technology from static text generation to dynamic video generation [10]. At the beginning of 2025, the release of DeepSeek further promoted innovation in AIGC technology within the field of multimodal content generation. Artificial intelligence is driving content creation from traditional Professional-Generated Content (PGC) and User-Generated Content (UGC) towards AI-Generated Content (AIGC) [11]. Compared to traditional design processes, AI technology has already demonstrated significant advantages in enhancing designers' creative stimulation [12]. The rapid development of Generative AI is enabling "cost-reduction and efficiency-improvement" applications across many fields [13]. Designers can input specific design requirements and corresponding constraints into AI generation tools such as Midjourney, Stable Diffusion, Kling, and Doubao to guide the AI model to quickly and efficiently generate multiple solutions. Song Yu et al. [14]. trained an AIGC cultural and creative model capable of redrawing traditional ink painting features, guiding it to generate Chinese aesthetic images through input "prompts"

2.3 Design Process

Within the framework of Kansei Engineering, representative samples of Majiayao painted pottery were selected as research stimuli. The KJ method was used to collect and summarize users' emotional imagery vocabulary for painted pottery in the context of modern design. The obtained vocabulary was used to construct a Semantic Differential (SD) scale. User evaluation data were collected and imported into SPSS software for reliability testing and Principal Component Analysis (PCA) to extract representative core emotional factors.

Next, the Fuzzy Analytic Hierarchy Process (FAHP) was employed, inviting design experts and target users to conduct pairwise comparisons of various representative emotional imagery terms, constructing fuzzy complementary judgment matrices. The relative weights of emotional factors in each criterion layer were calculated to establish the key dimensions and priorities of users' emotional needs.

Subsequently, morphological analysis was used to deconstruct the visual composition of Majiayao painted pottery, breaking it down into basic design elements such as patterns, colors, and vessel forms, thereby establishing a structured cultural gene database. Simultaneously, the forms, functions, and usage scenarios of water sports equipment (e.g., swimwear, kayaks, surfboards) were analyzed.

Building on this, the Quality Function Deployment (QFD) House of Quality was used to construct a mapping relationship model between emotional imagery vocabulary and water sports equipment design elements. Key design features significantly influencing users' emotional perception were identified. Guided by these findings, designers created rough prototypes meeting the input requirements for AIGC.

Finally, the rough prototypes and the weighted emotional imagery vocabulary were input as "prompts" into an AIGC generative tool (e.g., Midjourney). Combined with the LoRA fine-tuned painted pottery style model and the water sports product morphology model, multiple rounds of iterative generation were conducted, outputting a series of water sports equipment design solutions. User evaluation was then used to verify whether these solutions met the target users' emotional needs and functional expectations.

3. Design Practice: Majiayao Pattern Water Sports Series

3.1 Collection of Majiayao Painted Pottery Samples

Given the abundance and wide distribution of Majiayao painted pottery, the research team formulated a detailed collection plan to ensure comprehensiveness and accuracy. On one hand, visits were made to institutions such as the Gansu Provincial Museum and archaeological research organizations to photograph high-resolution images of Majiayao painted pottery and record detailed dimensions, decorative characteristics, and other information. On the other hand, advanced digital technologies, including 3D scanning and high-definition photography, were utilized to digitally process the painted pottery samples, establishing a digital sample library of Majiayao painted pottery. Fifteen pieces (5 each from Majiayao, Banshan, and Machang types) were selected as experimental samples (Table 1), covering typical patterns such as water wave patterns, spiral patterns, and dance figures.

3.2 Cultural Gene Analysis and Digital Archiving

This study systematically collected 128 typical Majiayao painted pottery samples from institutions including the Gansu Provincial Museum, constructing a structured digital gene bank. Using morphological analysis, samples were deconstructed into three major gene groups: pattern, color, and vessel form. Each gene was annotated with spatiotemporal distribution and cultural significance, forming a machine-readable cultural semantic network (Table 2).

Table 1. Selected Experimental Samples

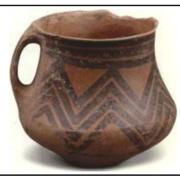
				
Majiayao Water Ripple Pattern	Majiayao Pointed-Base Spiral-Patterned Painted Pottery Vase	Majiayao Water-Patterned Double-Handled Vase	Majiayao Polychrome Pottery Basin with Dance Motifs	Majiayao-style Spiral-Patterned Painted Pottery Vase
				
Mid-Mountain Spiral-Patterned Polychrome Pottery Jar	Semi-mountain-shaped curved-tooth pattern painted pottery jar	Half-Mountain Gourd-Shaped Polychrome Pottery Vessel	Half-Mountain Diamond-Patterned Polychrome Pottery Bowl	Four-Circle Patterned Polychrome Pottery Vessel from Ban Shan
				
Machang Zigzag-Patterned Single-Handled Polychrome Pottery Jar	Machang Swirl-Patterned Polychrome Pottery Jar	Machang Polychrome Pottery Jar with Circular Patterns	Machang Pottery Jar with Wavy Decorations	Machang Variant Human-Patterned Polychrome Pottery Jar

Table 2. Analysis of Core Cultural Genes in Majiayao Culture Polychrome Pottery

Gene category	Core Elements	Visual characteristics	Cultural Symbolism
Cultural Genes	Swirl pattern, water ripple pattern, frog pattern	Continuous, cyclical, dynamic	Life's Continuity, Nature's Rhythm
Color Gene	Terracotta Red (C:30 M:100 Y:100 K:10), Jet Black	Striking contrast, rustic and substantial	Primordial vitality, mystique
Form Gene	Bowls, pots, pitchers, vases	Full, symmetrical, stable	Practicality and Ritual

3.3 Quantitative Extraction of User Emotional Imagery

Initial imagery vocabulary was collected through literature review and expert interviews, and categorized using the KJ method, ultimately filtering out 12 representative pairs of emotional imagery terms (e.g., "ancient-modern," "mysterious-bright," "flowing-static"). Based on these, a 7-level Semantic Differential scale was created, and 15 representative painted pottery sample images were selected as stimuli. Questionnaires were distributed to the target user group (N=182, including designers, cultural enthusiasts, and general consumers), with 172 valid responses collected. SPSS 26.0 was used for Exploratory Factor Analysis (EFA). The KMO value was 0.783, and Bartlett's test of sphericity was significant ($\chi^2 = 687.32$, df=66, $p < .001$), indicating the data were suitable for factor analysis. Principal Component Analysis with Varimax rotation extracted three common factors, with a cumulative variance contribution rate of 76.8% (Table 3).

Table 3. Factor Analysis Results for Sensory Imagery

Sensory Imagery Pairs	Component 1 Historical Depth	Component 2 Dynamic Vitality	Component 3 Visual Impact
Rustic-Modern	0.891	0.124	0.203
Mysterious - Bright	0.845	0.256	0.158
Heavy-Light	0.812	0.301	0.109
Flowing-Still	0.154	0.925	0.138
Strong-Weak	0.287	0.872	0.225
Complex-Minimalist	0.332	0.301	0.835
Brilliant – Subtle	0.198	0.187	0.806
Variance Contribution Rate(%)	38.2	24.3	14.3

3.4 AIGC Model Training and Prompt Engineering

To achieve precise generation of the painted pottery style, this study adopted a dual-LoRA parallel training strategy.

<lora:majiayao_style:1.2> professional photo of an athlete in competitive swimwear, <majiayao vortex patterns:0.9>, <majaoyao water patterns:0.7>, dynamic and powerful, red and black color scheme on beige background, <lora:swimwear_morphology:0.8> --ar 3:4 --style raw

Painted Pottery Style LoRA Model: The organized painted pottery pattern dataset served as the training set, input into Stable Diffusion WebUI. Booru Dataset Tag Manager was used for precise tagging, with tags including trigger words (e.g., majiayao), pattern types, and emotional factor descriptors.

4. Design Practice and Outcome Validation

4.1 AIGC Generation Process and Iterative Optimization

Based on the completed cultural gene analysis and quantitative extraction of user emotional imagery, this study, following the pre-established design translation pathway, implemented systematic process control and iterative optimization for the AIGC generation.

First, based on the pattern, color, and vessel form genes from the cultural gene database, the core visual elements of Majiayao painted pottery (e.g., vortex patterns, water wave patterns, reddish-brown and ink-black color schemes) were extracted as the content foundation for AIGC generation (Figure 1).

Second, combined with the user emotional factor weights determined by AHP, a prompt word system with semantic hierarchy and weight structure was constructed. Initial prompts focused on basic cultural elements, e.g., "An athlete in synchronized swimming, with swimwear designed incorporating painted pottery spiral patterns." Although the generation results at this stage preliminarily reflected cultural characteristics, they remained relatively vague in terms of semantic accuracy and emotional expression.

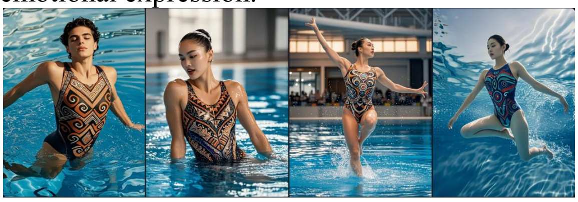


Figure 1. Initial Generation Results

To further improve generation quality, the study introduced the pre-trained dual-LoRA models—the Painted Pottery Style LoRA and the Water Sports Equipment Morphology LoRA—to exert dual control over style and structure during generation. Simultaneously, based on the emotional factor weights from AHP, prompts were weighted and optimized, enhancing emphasis on high-weight emotional words like "dynamic" and "powerful." An example of an optimized prompt is as follows:

<lora:majiayao_style:1.2> An athlete wearing swimwear, the pattern on the clothing primarily features Majiayao painted pottery spiral patterns, the colors are mainly reddish-brown and ink-black approximating Majiayao painted pottery, embodying dynamic vitality and a sense of historical weight.

Generation results at this stage showed significant improvement in pattern accuracy, color fidelity, and emotional imagery conveyance (Figure 2).

Finally, through multiple rounds of "prompt evolution" and fine-tuning of LoRA model weights, the generated schemes achieved a high degree of alignment among cultural semantics, visual expression, and user emotional needs, forming ideal outputs that met the design objectives (Figure 2).

Figure 2. Secondary Generation Results

4.2 Series Design Presentation

Based on the aforementioned generation process, this study ultimately output the "Pottery Pattern Rhythm – Water-Inspired Elegance" series of water sports equipment designs, covering competitive swimwear, kayaks, surfboards, sailboats, and matching equipment. Each scheme strictly adhered to the results of the cultural gene analysis and integrated user emotional imagery factors. The specific design logic is as follows:

Competitive Swimwear Design: Using Majiayao painted pottery vortex and water wave patterns as the core pattern genes, they organically extend along the lines of human muscles and movement flow. The color gene employs the contrast between reddish-brown and beige, embodying "primitive vitality." In terms of emotional imagery, emphasis is placed on "dynamic vitality" and "visual impact." AIGC was used to simulate pattern layout to optimize competitive performance (Figure 3).

Figure 3. Competition Swimsuit

Kayak Design: Majiayao zigzag patterns were modularized and vectorized, adapted to the kayak's streamlined structure. Patterns are distributed longitudinally along the hull, enhancing visual dynamics and reflecting the fusion of "historical weight" and "dynamic vitality." (Figure 4)

Figure 4. Kayak

Surfboard Design:The vortex pattern serves as the visual core, with the rotational dynamics of the pattern strengthening the product's sporty characteristics. Gradient color treatment achieves a natural transition from reddish-brown to beige, ensuring cultural recognizability while conforming to modern aesthetics (Figure 5).

Accessory Design: Swimming goggles, swim caps, and other accessories feature water ripple patterns as border accents in their details, maintaining the series' consistency and integrity (Figure 6).

4.3 Scheme Evaluation

To validate the effectiveness of the generated schemes, target users (N=50) were invited to conduct a fuzzy comprehensive evaluation of the final designs. An evaluation system was established containing three primary indicators—Cultural Identifiability, Aesthetic Expressiveness, Functional Adaptability—and nine secondary indicators. Results showed the series achieved a comprehensive score of 8.73 out of 10, with excellent performance across all dimensions. Specifically: Cultural Identifiability scored 8.82 (Cultural Uniqueness 9.1, Semantic Accuracy 8.5); Aesthetic Expressiveness scored 8.91 (Visual Impact 9.2, Formal Beauty 8.6); Functional Adaptability scored 8.35 (Fit with Product Form 8.4, No Impact on Core Function 8.3). The evaluation results confirm the effectiveness of this translation pathway in enhancing the quality and user acceptance of intangible cultural heritage creative designs.

Figure 5. Surfboard

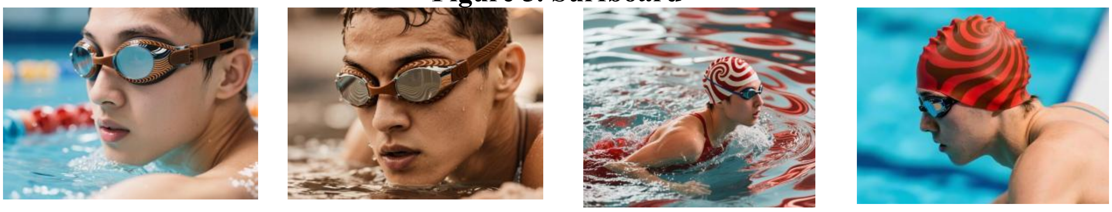


Figure 6. Supporting Equipment

5. Conclusion and Outlook

The "Kansei Engineering–AIGC" synergistic-driven model constructed in this study provides a scientific and systematic innovation pathway for the product translation of painted pottery cultural heritage. By quantifying users' emotional needs and integrating them into the AIGC generation process, precise inheritance and modern expression of cultural genes have been achieved. This model not only improves design efficiency but also demonstrates significant advantages across multiple dimensions including cultural identifiability, aesthetic expressiveness, and functional adaptability, providing strong support for the creative transformation and innovative development of cultural heritage. Future research could further explore the adaptability of this model across different types of cultural heritage and design translation strategies in cross-cultural contexts, aiming to promote the globalization process of living heritage inheritance. However, this study has certain limitations, particularly in translating higher-level connotations such as cultural "artistic conception." Future work will explore the application of multimodal large models in dynamic cultural narratives and attempt to construct cross-cultural design translation evaluation standards, thereby further stimulating the innovative vitality of cultural heritage in the digital age.

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