

From Cultural Genes to Digital Regeneration: An AHP-Based Study on the Creative Transformation of Liaonan Shadow Puppetry Cultural Heritage

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Abstract

Intangible cultural heritage (ICH) safeguarding increasingly requires methods that connect cultural interpretation with contemporary forms of participation rather than reproducing heritage as isolated visual symbols. This study develops an integrated Cultural Gene-AHP-Digital Regeneration framework for the creative transformation of Liaonan shadow puppetry. Cultural resources were coded into material, behavioral, and spiritual gene layers, and an Analytic Hierarchy Process (AHP) model was used to evaluate their relative priorities and corresponding design-transformation factors. Eighty questionnaires were distributed and 53 valid responses were obtained. At the criterion level, spiritual cultural genes received the highest weight (0.4041), followed by behavioral (0.3191) and material genes (0.2768). At the global level, carving technique (0.1828), performance manipulation (0.1363), cultural spirit (0.1313), and folk belief (0.1113) emerged as the four most influential cultural factors. These results were translated into an AIGC-assisted, human-screened digital regeneration workflow and examined through a practice-based case: an interactive night lamp for parent-child storytelling. The case is treated as methodological validation rather than a commercial proposal, demonstrating how weighted cultural factors can be traced into form, interaction, narrative, and visual generation decisions. The study contributes a reproducible decision structure for moving from cultural interpretation to design action while retaining human review of culturally sensitive AI-generated content. It also identifies limitations related to sample composition, fieldwork documentation, and the absence of longitudinal user evaluation.

Keywords: Liaonan Shadow Puppetry, Intangible Cultural Heritage, Cultural Gene, Analytic Hierarchy Process (AHP), Creative Transformation, Digital Regeneration

1 Introduction

A. Research Background and Inheritance Dilemma

The safeguarding of intangible cultural heritage has shifted from an object-centered logic of preservation toward the maintenance of living practices, knowledge transmission, participation, and cultural meaning. The 2003 UNESCO Convention defines ICH as practices, representations, expressions, knowledge, and skills that communities recognize as part of their heritage, emphasizing recreation and intergenerational transmission rather than static conservation[1]. Chinese shadow puppetry, inscribed on UNESCO's Representative List in 2011, illustrates this living character particularly clearly: carving, manipulation, music, oral narrative, local ritual, and performance knowledge operate together as an integrated cultural practice[2]. Such a perspective makes the question of creative transformation more complex than simply extracting recognizable motifs for contemporary products.

Liaonan shadow puppetry, situated in southern Liaoning, combines carved shadow figures, translucent materials, color conventions, performance manipulation, narrative repertoires, folk beliefs, and local aesthetic values. The source study identifies a contemporary dilemma familiar across many ICH practices: visual symbols can be circulated quickly, yet the behavioral and spiritual dimensions that make those symbols meaningful are more difficult to transfer into everyday contexts. Heritage scholarship has repeatedly cautioned that safeguarding is not equivalent to freezing a practice in an idealized past. Rather, heritage is continuously produced through selection, interpretation, performance, and social use[3-5]. Therefore, a design-oriented regeneration strategy must preserve traceability to cultural meaning while allowing adaptation to new media and audiences.

Existing shadow-puppetry design research in China has expanded rapidly, including work on digital activation, cultural-gene mapping, AI-assisted visual design, and knowledge-graph analysis[6-8]. However, many applications still begin with a predefined product carrier or a set of visually salient symbols. This can lead to a weak connection between cultural interpretation and design decisions: a designer may know which motif is distinctive but not why one cultural element should receive priority over another, how an embodied performance action can be translated into interaction, or how generated images should be evaluated for cultural acceptability. These problems are especially relevant when generative artificial intelligence is introduced, because high visual productivity can amplify decontextualization as easily as it can accelerate ideation.

B. Literature Review and Research Gap

Three bodies of work are particularly relevant. First, cultural-gene approaches treat culture as a patterned system whose relatively stable elements can be identified, coded, and recombined. The metaphor is historically related to Dawkins's discussion of cultural transmission[9], but in design research it is better understood as an operational device for organizing cultural information rather than as a literal biological theory. Botz-Bornstein's discussion of genes, memes, and the Chinese concept of *wen* further highlights the importance of pattern, transformation, and re-creation in cross-cultural interpretations of the

gene metaphor[10]. Chinese design studies have used cultural-gene analysis to structure the visual, technical, behavioral, and symbolic attributes of ICH[11-14].

Second, AHP offers a transparent way to convert qualitative judgments into relative priorities through hierarchical decomposition, pairwise comparison, and consistency testing[15-16]. Recent design studies have combined cultural-gene analysis with AHP to prioritize heritage factors and reduce purely intuitive selection[17-18]. Yet AHP results are often treated as an endpoint - a ranking table - rather than being explicitly connected to downstream design operations. Third, digital heritage research shows that virtual, augmented, mixed-reality, 3D, and interactive systems can extend documentation, interpretation, and participation[19-20]. Participatory digital making can also move digital heritage beyond display toward active reproduction and creative engagement[21]. Generative AI adds another layer of possibility, but it also raises questions of human agency, authenticity, evidence, and accountability[22].

Accordingly, this study addresses three gaps. The first is a structural gap between cultural interpretation and quantitative priority setting: cultural-gene coding and AHP are often applied separately or with limited explanation of how one informs the other. The second is a translation gap between weighted results and design action: the path from a high-weight cultural factor to a concrete choice of form, interaction, or narrative is frequently implicit. The third is a governance gap in AIGC-assisted heritage creation: generative outputs require cultural constraints and human screening rather than being treated as authoritative reconstructions. The present study therefore reframes the original product-design work as a heritage-regeneration method in which the product case functions only as a practice-based test of the proposed analytical pathway.

C. Research Objectives and Questions

The objective is to construct and test an integrated method that links cultural-gene deconstruction, AHP-based prioritization, design translation, and AIGC-assisted regeneration. Four research questions guide the study: RQ1, how can the cultural resources of Liaonan shadow puppetry be organized into a structured material-behavior-spirit gene spectrum? RQ2, which cultural genes and design-transformation factors receive higher relative priorities under the AHP evaluation? RQ3, how can weighted cultural priorities be converted into traceable strategies for contemporary digital regeneration without reducing heritage to decorative symbol extraction? RQ4, how can an AIGC-assisted design case be used to validate the internal logic of the framework while retaining human cultural review?

D. Contributions and Structure

The study makes three contributions. First, it proposes a Cultural Gene-AHP-Digital Regeneration framework that treats cultural genes as a coding mechanism, AHP as a decision-support mechanism, and AIGC as an assistive generation mechanism under human control. Second, it provides an empirical priority structure for Liaonan shadow puppetry, showing that behavioral and spiritual factors are not secondary to visible form and that carving technique, performance manipulation, cultural spirit, and folk belief are central to the transformation process. Third, it demonstrates a traceable gene-to-strategy

mapping through a practice-based interactive storytelling case, thereby shifting evaluation from whether an object merely looks traditional to whether its form, interaction, and narrative can be explained through the preceding cultural analysis.

The remainder of the article introduces the theoretical foundations, explains the research design and AHP procedure, reports the cultural-gene and weight results, presents the regeneration strategy and case validation, and discusses theoretical implications, practical implications, limitations, and future work. The overall research framework is presented in Fig. 1.

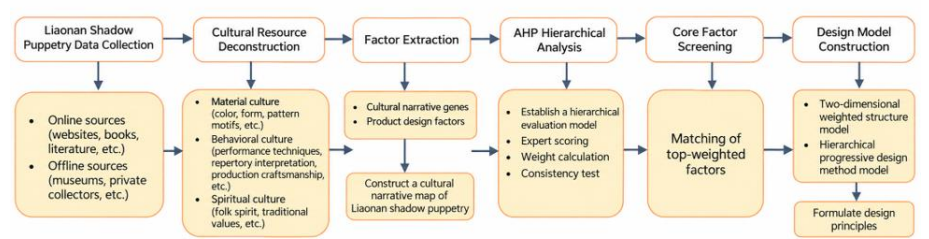


Fig. 1 Research Framework and Process

2 Theoretical Foundation and Literature Review

A. Cultural Gene Theory and ICH Creative Transformation

The term cultural gene is used here as a methodological metaphor for relatively stable and recognizable units of cultural information. Its conceptual ancestry can be traced to the idea that cultural information is transmitted, varied, and selected[9], while subsequent discussions have emphasized that cultural patterns are not copied mechanically but are reconfigured through interpretation[10]. For heritage design, the usefulness of the metaphor lies in decomposition and traceability: a complex tradition can be divided into observable forms, embodied actions, and value-laden meanings, and later design decisions can be linked back to those coded sources.

This operational interpretation is compatible with the living-heritage orientation of the UNESCO Convention. A heritage element does not exist only in a material artifact; it is continually recreated through communities, practices, knowledge, and social settings[1]. Kirshenblatt-Gimblett describes intangible heritage as a form of metacultural production in which practices become objects of reflection and representation[3], while Kurin stresses that safeguarding must remain connected to practitioners and social contexts[4]. Smith similarly conceptualizes heritage as a cultural process of meaning-making rather than an inherent property of things[5]. Together, these perspectives suggest that creative transformation should preserve relationships among material carriers, performed actions, and cultural meanings instead of isolating visual signs.

Previous Chinese design research has demonstrated the practical value of cultural-gene classification in woodblock New Year pictures, regional crafts, performance traditions, and shadow puppetry[11-14,23]. However, an analytical risk remains: once cultural elements are coded, they can appear equivalent even when their significance differs. A gene spectrum therefore

needs a priority mechanism. In this study, the material-behavior-spirit structure is not intended as an ontological claim that all ICH can be reduced to three layers. It is an analytical scaffold derived from the source study, used to maintain connections between visible features, embodied practices, and value systems during subsequent evaluation.

B. AHP in Cultural Heritage Evaluation and Design Decision

The Analytic Hierarchy Process, developed by Saaty, supports multicriteria decision-making by decomposing a complex goal into hierarchical criteria and asking evaluators to make pairwise comparisons[15-16]. The method is useful when decisions combine measurable and non-measurable dimensions, as is common in cultural heritage. AHP does not eliminate subjectivity; rather, it makes judgments explicit, produces relative weights, and tests whether the pattern of comparisons is acceptably consistent. This transparency is important for design research because it exposes which cultural elements are prioritized and how strongly those priorities depend on a particular respondent group.

Applications in Chinese cultural and creative design have used AHP to identify core cultural factors, combine expert knowledge with user-oriented evaluation, and reduce arbitrary selection[17-18]. The present study extends this use in two ways. First, the hierarchy includes both cultural-gene indicators and design-transformation indicators, allowing the analysis to distinguish cultural importance from preferred modes of contemporary expression. Second, the weight results are not treated as direct prescriptions. A higher weight indicates relative priority within the judgment model, not a license to erase lower-weight factors or a universal statement about heritage value. The weights are therefore used as decision cues within a broader interpretive process.

C. Digital Regeneration and AIGC in ICH

Digital regeneration is used in this article to describe more than digital preservation. Digitization can document and archive heritage resources, while regeneration concerns the re-entry of cultural knowledge into new practices, interfaces, narratives, and participatory situations. Reviews of cultural heritage technologies show that virtual, augmented, mixed-reality, 3D modeling, and motion-capture systems have broadened access and interpretation[19-20]. More recent human-computer interaction research argues that digital making can contribute to living transmission when participants actively reproduce and reinterpret craft processes rather than only viewing digital representations[21].

AIGC can support this regenerative process by rapidly externalizing alternative visual and narrative interpretations. In the source study, AIGC was used to assist character exploration, form ideation, and scenario visualization rather than to replace cultural analysis. This role is consistent with concerns raised in current heritage research: generative systems can create persuasive images without evidentiary grounding, and therefore human agency, documentation, and cultural accountability remain essential[22]. Recent Chinese studies similarly explore AI-assisted activation of shadow puppetry and cultural-gene-based generation[24-27]. The methodological principle adopted here is consequently 'generate broadly, screen culturally, integrate selectively.' AIGC functions downstream of cultural coding and weighting, not upstream as a source of heritage facts.

D. Analytical Framework of This Study

The analytical framework links four layers. The first layer deconstructs Liaonan shadow puppetry into material, behavioral, and spiritual cultural genes. The second layer evaluates the relative importance of these genes and corresponding design-transformation indicators with AHP. The third layer identifies a smaller set of core factors by considering both local and global weights. The fourth layer converts those factors into prompts, visual constraints, interaction rules, and narrative principles for AIGC-assisted regeneration, followed by human cultural screening and practice-based validation. This sequencing creates an auditable chain from source interpretation to design outcome. The analytical framework is illustrated in Fig. 2.

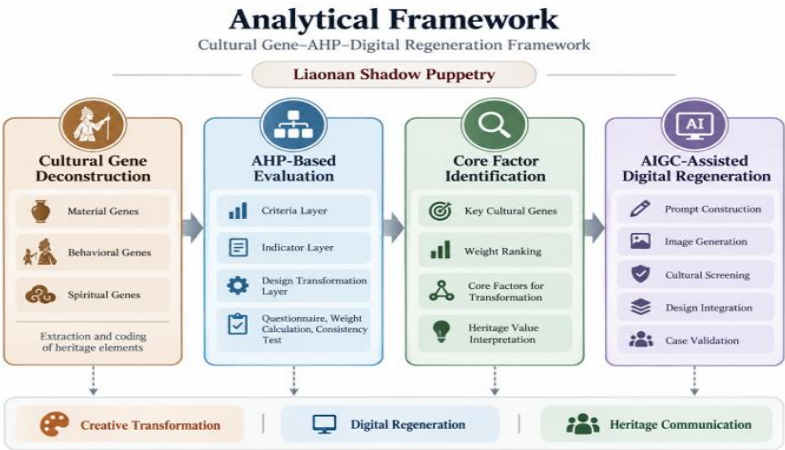


Fig. 2 Analytical Framework of Cultural Gene-AHP-Digital Regeneration

3 Research Design and Methodology

A. Case Selection: Liaonan Shadow Puppetry

Liaonan shadow puppetry was selected because it combines tangible craft characteristics with performative and symbolic dimensions in a form that makes cross-layer translation observable. Shadow figures provide material evidence through silhouette, head shapes, costumes, patterns, tools, color, and semi-translucent surfaces. Performance depends on carving technique, manipulation, light, screen relations, musical or narrative coordination, and embodied knowledge. The spiritual layer contains folk beliefs, moral narratives, symbolic meanings, and regional cultural memory. This combination allows the study to test whether a design method can retain links among artifact, action, and meaning rather than privileging one layer.

B. Research Process and Data Sources

The study combined literature review, field investigation, image and material organization, case analysis, questionnaire evaluation, AHP calculation, and design-based validation. The cultural dataset was assembled from published scholarship on Liaonan and Chinese shadow puppetry, visual

records of shadow figures and performance-related objects, and contextual materials collected in the original study. These materials were coded into the three cultural layers before the AHP model was constructed. The original manuscript does not report the dates, number, or exact locations of individual fieldwork sessions; therefore, field observations are treated here as qualitative contextual evidence rather than as a statistically sampled ethnographic dataset. This limitation is addressed again in Section 6.3.

The quantitative stage distributed 80 questionnaires and obtained 53 valid responses. The valid sample comprised 42 design students, three teachers from different design fields, five specialists in cultural and creative design research, and three Liaonan shadow-puppetry enthusiasts. The distribution is therefore strongly design-oriented. This composition is useful for evaluating translation into design but cannot be interpreted as representative of all heritage communities or general users. The study consequently reports AHP results as sample-specific priority judgments and avoids treating them as universal cultural rankings.

C. Cultural Gene Deconstruction and Coding

Cultural resources were coded into three criterion categories. Material cultural genes include color, head-shape or head-carving features, decorative patterns, material and craft processes, and performance props. Behavioral cultural genes include carving techniques and performance manipulation. Spiritual cultural genes include pattern connotations, color symbolism, folk belief, and cultural spirit. Codes C_{11} - C_{15} , C_{21} - C_{22} , and C_{31} - C_{34} were assigned to these indicators respectively. The classification was derived from the source study's systematic organization of Liaonan shadow-puppetry resources and its emphasis on the relation between visible form, production or performance behavior, and underlying meaning.

A second set of indicators describes design transformation rather than heritage content itself. Material transformation indicators comprise color matching (D_{11}), form aesthetics (D_{12}), pattern decoration (D_{13}), and material selection (D_{14}). Behavioral transformation indicators comprise functional effect (D_{21}), interactive experience (D_{22}), scenario design (D_{23}), and emotional experience (D_{24}). Spiritual transformation indicators comprise symbolic features (D_{31}), cultural communication (D_{32}), symbolic concepts (D_{33}), and aesthetic awareness (D_{34}). Separating cultural genes from design indicators reduces a common analytical ambiguity: the cultural importance of an element and the preferred mode of expressing it are related but not identical questions.

D. AHP Model Construction and Questionnaire Design

The AHP hierarchy contains a target layer, three cultural criteria, 11 cultural-gene indicators, and 12 design-transformation indicators. Respondents compared elements pairwise using Saaty's nine-level scale, in which 1 indicates equal importance and 3, 5, 7, and 9 indicate progressively stronger preferences; 2, 4, 6, and 8 are intermediate judgments, and reciprocal values are used for reverse comparisons[15-16]. The AHP model is shown in Fig. 3, and the nine-level scale is presented in Table 1.

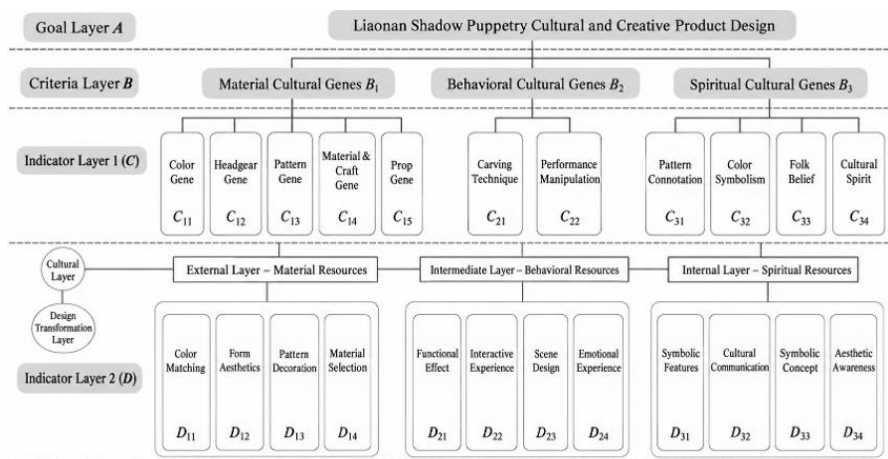


Fig. 3 AHP Hierarchical Evaluation Model

Table 1 Nine-Level Scale

Relative Importance of Factor i Compared with Factor j	Scale
Factor i is equally important as factor j	1
Factor i is moderately more important than factor j	3
Factor i is strongly more important than factor j	5
Factor i is very strongly more important than factor j	7
Factor i is extremely more important than factor j	9
Intermediate values between the above judgments	2, 4, 6, 8
When the two factors are compared in the reverse order, the reciprocal of the original comparison value is used	Reciprocal

E. Consistency Test and Weight Calculation

For each judgment matrix, the priority vector was normalized to obtain the relative weights. The relative weight is calculated using Formula (1).

$$\omega_i = \frac{v_i}{\sum_{i=1}^m v_i} \quad (1)$$

The maximum eigenvalue was then estimated to support the consistency calculation. The maximum eigenvalue is calculated using Formula (2).

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^n \frac{|A\omega|_i}{\omega_i} \quad (2)$$

The consistency index is defined as $C_I = \frac{(\lambda_{max}-n)}{(n-1)}$, and the consistency ratio compares C_I with the random consistency index R_I . The consistency ratio is calculated using Formula (3). A matrix was considered acceptable when $C_R < 0.10$, following the conventional AHP criterion [15-16].

$$C_R = \frac{C_I}{R_I} \quad (3)$$

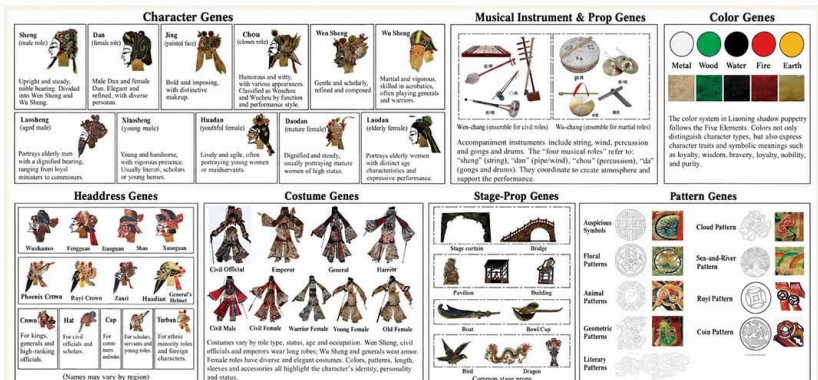
4 Cultural Gene Deconstruction and Weight Evaluation

A. Cultural Gene Spectrum of Liaonan Shadow Puppetry

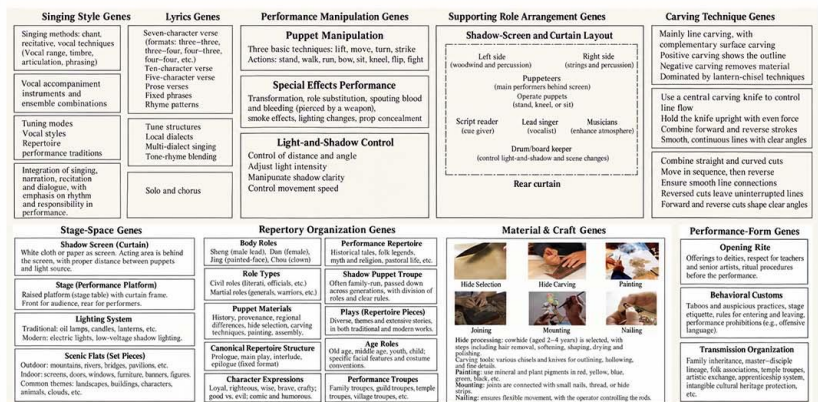
The gene spectrum organizes Liaonan shadow puppetry as an interdependent cultural system. At the material level, shadow-figure profiles, head shapes, costume patterns, mineral-like color conventions, translucent skin-like material qualities, carving tools, screens, lighting-related objects, and other props form the visible and tactile basis of the practice. These features are culturally meaningful because they are produced through particular techniques and are read in performance rather than in isolation. The source study notes, for example, that head-shape conventions can encode role distinctions, while the combination of positive and negative carving affects line, light transmission, and visual rhythm.

At the behavioral level, two clusters are especially important: carving technique and performance manipulation. Carving is not only a production method but a visible record of hand skill, line control, and material knowledge. Performance manipulation transforms static figures into narrative actors through rod control, movement, lighting, and coordination with storytelling. At the spiritual level, pattern and color meanings connect to folk beliefs, moral ideas, auspicious symbolism, collective memory, and cultural spirit. The three layers therefore form a nested rather than sequential relation: material features make actions visible, actions activate narrative and social participation, and spiritual meanings guide interpretation. The cultural gene spectrum is presented in Fig. 4.

Material Cultural Genes of Liaonan Shadow Puppetry



Behavioral Cultural Genes of Liaonan Shadow Puppetry



Spiritual Cultural Genes of Liaonan Shadow Puppetry

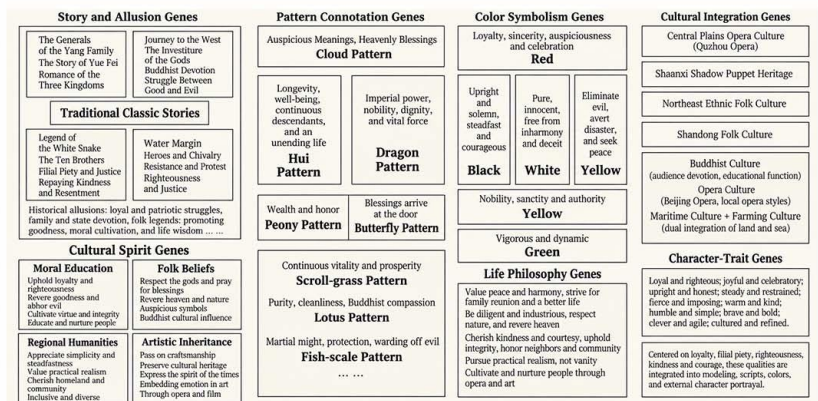


Fig. 4 Cultural Gene Spectrum of Liaonan Shadow Puppetry

B. Criterion-Level Weight Results

All judgment matrices met the $C_R < 0.10$ consistency criterion. At the criterion level, spiritual cultural genes obtained the highest weight ($B_3 = 0.4041$), followed by behavioral cultural genes ($B_2 = 0.3191$) and material cultural genes ($B_1 = 0.2768$), with $C_R = 0.0014$. The result is important because it reverses a

common design tendency to begin with what is most immediately visible. Within this respondent sample, values, beliefs, and cultural meanings were considered more important than direct material replication, while embodied practice occupied an intermediate but substantial position.

Within the material layer, props received the highest local weight ($C_{15} = 0.2292$), followed by material and craft ($C_{14} = 0.2158$), patterns ($C_{13} = 0.2082$), color ($C_{11} = 0.1966$), and head-shape/head carving ($C_{12} = 0.1501$); $C_R = 0.0127$. Within the behavioral layer, carving technique ($C_{21} = 0.5730$) exceeded performance manipulation ($C_{22} = 0.4270$); $C_R = 0.0000$. Within the spiritual layer, cultural spirit ($C_{34} = 0.3250$) and folk belief ($C_{33} = 0.2755$) ranked above pattern connotation ($C_{31} = 0.2103$) and color symbolism ($C_{32} = 0.1892$); $C_R = 0.0072$. The criterion-level and indicator-level weights are shown in Table 2.

Table 2 Criteria and Indicator Layer Weights

<i>B</i>	<i>B</i> ₁	<i>B</i> ₂	<i>B</i> ₃	Weight
<i>B</i> ₁	1	0. 8334	0. 7129	0. 2768
<i>B</i> ₂	1. 1999	1	0. 7587	0. 3191
<i>B</i> ₃	1. 4027	1. 3181	1	0. 4041

Note: *B*₁ = Material Culture; *B*₂ = Behavioral Culture; *B*₃ = Spiritual Culture. $C_R = 0.0014$, satisfying the consistency requirement.

C. Indicator-Level and Design Transformation Weight Results

The design-transformation results reveal a different pattern because they measure preferred forms of contemporary expression rather than cultural significance. In the material transformation layer, material selection received the highest local weight ($D_{14} = 0.3106$), followed by pattern decoration ($D_{13} = 0.2446$), color matching ($D_{11} = 0.2382$), and form aesthetics ($D_{12} = 0.2066$); $C_R = 0.0063$. In the behavioral transformation layer, emotional experience ranked first ($D_{24} = 0.2758$), followed by scenario design ($D_{23} = 0.2636$), functional effect ($D_{21} = 0.2474$), and interactive experience ($D_{22} = 0.2133$); $C_R = 0.0077$. In the spiritual transformation layer, aesthetic awareness received the highest weight ($D_{34} = 0.3007$), followed by symbolic concepts ($D_{33} = 0.2624$), symbolic features ($D_{31} = 0.2378$), and cultural communication ($D_{32} = 0.1991$); $C_R = 0.0056$.

After combining local weights with the criterion weights, the highest global design-factor weights were aesthetic awareness (0.1215), symbolic concepts (0.1060), symbolic features (0.0961), emotional experience (0.0880), material

selection (0.0860), and scenario design (0.0841). These results suggest that the contemporary transformation of Liaonan shadow puppetry should not be evaluated only through visual fidelity. Respondents placed substantial emphasis on whether the regenerated form feels aesthetically coherent, communicates symbolic meaning, creates emotional connection, and functions within a recognizable scenario. The design transformation weights are presented in Table 3.

Table 3 Design Transformation Layer Weights

C_1	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	Weight
C_{11}	1	1.7687	0.7671	0.8675	0.8073	0.1966
C_{12}	0.5654	1	0.6635	0.7908	0.8242	0.1501
C_{13}	1.3036	1.5071	1	0.7757	0.8497	0.2082
C_{14}	1.1528	1.2646	1.2892	1	0.8322	0.2158
C_{15}	1.2386	1.2132	1.1769	1.2016	1	0.2292

Note: C_{11} = Color Genes; C_{12} = Headpiece Genes; C_{13} = Pattern Genes; C_{14} = Material and Craftsmanship Genes; C_{15} = Prop Genes. $C_R = 0.0127$, satisfying the consistency requirement.

D. Core Cultural Genes and Heritage Value Interpretation

Global weights were used to identify a compact set of high-priority cultural factors for the practice case. Carving technique ranked first among cultural genes (C_{21} global weight = 0.1828), followed by performance manipulation (C_{22} = 0.1363), cultural spirit (C_{34} = 0.1313), and folk belief (C_{33} = 0.1113). The next group consisted of pattern connotation (0.0850), color symbolism (0.0765), props (0.0634), material and craft (0.0597), patterns (0.0576), color (0.0544), and head-shape/head carving (0.0415). The important point is not simply that the top four factors are numerically larger. Their distribution indicates that the most influential content spans behavioral and spiritual layers, so a transformation that only reproduces silhouettes or colors would fail to engage the strongest priorities identified by the model.

The core-factor mapping therefore translates carving technique into line, perforation, and light-transmission rules; performance manipulation into modular switching, projection, sequencing, and participatory storytelling; cultural spirit into age-appropriate moral narrative and emotional framing; and folk belief into carefully screened symbolic references rather than literal transplantation of ritual signs. Lower-weight material factors remain necessary

as supporting constraints that preserve recognizability. In this way, AHP guides attention without collapsing the heritage system into a four-item checklist. The mapping between core factors and design strategies is shown in Table 4.

Table 4 Core Factors and Design Mapping

C_2	C_{21}	C_{22}	Weight
C_{21}	1	1.3418	0.5730
C_{22}	0.7453	1	0.4270

Note: C_{21} = Carving Techniques; C_{22} = Performance Manipulation. $C_R = 0.0000$, satisfying the consistency requirement.

5 Creative Transformation Strategy and Digital Practice

A. Transformation Framework: Material-Behavior-Spirit

The transformation strategy follows a material-behavior-spirit logic, but the three layers operate reciprocally. The material layer asks which visible and tactile properties make the regenerated object legible as an interpretation of Liaonan shadow puppetry. The behavioral layer asks how carving and manipulation can become contemporary forms of participation rather than being represented only as images. The spiritual layer asks what values and cultural meanings are communicated through narrative, symbolism, and the use situation. Each design move should therefore answer two questions: which cultural code does it derive from, and which transformation indicator does it satisfy?

At the material level, the method prioritizes translucency, carved or perforated line qualities, modular shadow-figure components, and selective color references rather than literal replication of historical artifacts. Material selection received the highest local weight in the material transformation layer, so the case uses semi-translucent surfaces and light-dependent visual effects to evoke the perceptual logic of shadow play. At the behavioral level, emotional experience and scenario design ranked above purely technical interaction, suggesting that participation should be organized around a meaningful social context. The case therefore adopts parent-child storytelling rather than interaction for its own sake. At the spiritual level, aesthetic awareness and symbolic concepts guide the simplification of traditional forms so that contemporary legibility does not erase cultural meaning.

B. Digital Regeneration Path with AIGC

The AIGC-assisted workflow begins with cultural constraints rather than open-ended prompting. First, high-priority genes are translated into a

structured prompt vocabulary that records visual form, material quality, carving logic, performance relations, narrative themes, and prohibited distortions. Second, generative tools are used to produce multiple visual alternatives. Third, outputs are screened against the cultural-gene spectrum: forms that introduce unsupported costume details, misleading regional features, incoherent carving logic, or excessive commercial stylization are rejected or revised. Fourth, accepted outputs are integrated with interaction and scenario requirements. Finally, the design case is evaluated for traceability: each major decision must be explainable through the preceding cultural and AHP analysis.

This workflow treats generative images as provisional design material rather than heritage evidence. The original study did not record the exact AIGC model, software version, seed, or full prompt history; therefore, the present method is intentionally described at the process level and does not claim reproducibility of individual generated images. This is a methodological limitation, but it also clarifies the transferable contribution: the framework can be implemented with different generation systems so long as the cultural constraint set, human screening criteria, and decision trace are documented. The AIGC-assisted digital regeneration workflow is shown in Fig. 5.

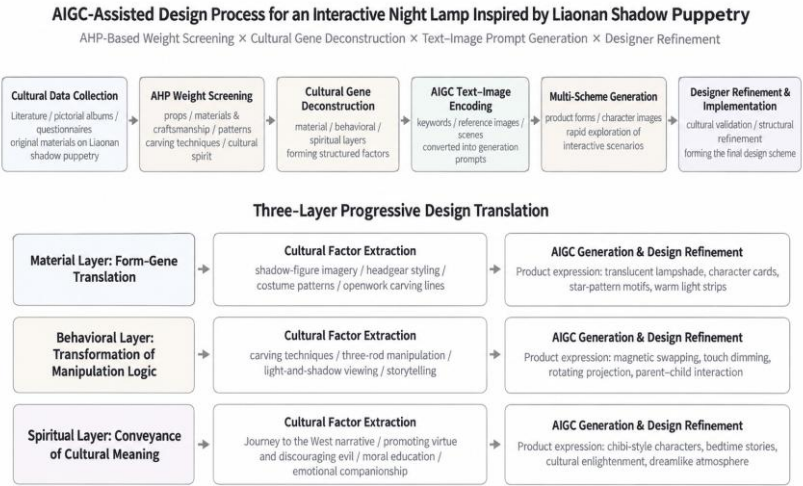


Fig. 5 AIGC-Assisted Digital Regeneration Workflow

C. Case Validation: An Interactive Night Lamp for Parent-Child Storytelling

This case is not intended as a commercial product proposal, but as a practice-based validation of the proposed framework. The interactive night lamp, named 'Yingqi Tongmeng Lamp' in the source study, was selected because a light-based carrier can directly engage shadow puppetry's dependence on silhouette, translucency, projection, and staged narrative. The parent-child storytelling context also creates a social situation in which performance manipulation and cultural narrative can be translated into participation. The design is therefore assessed primarily by whether its decisions can be traced to weighted genes and transformation factors, not by market potential, manufacturing cost, or product specifications.

D. Material Layer

The material layer translates the visual logic of shadow puppetry into a simplified contemporary system. Character cards retain silhouette-based recognition, perforated decorative lines, and references to traditional costume patterns. The source study emphasizes a red-black-gold palette, translucent or leather-like textures, and the interplay of positive and negative carving. In the revised framework, these features are treated as optional but culturally grounded constraints rather than as fixed brand colors. Their role is to preserve the relation between material, carving, and light. The lamp's transparent cover and projected layers create overlapping shadows, allowing the heritage reference to emerge through optical behavior instead of through surface ornament alone.

A child-oriented visual simplification was applied to reduce the density of traditional details while retaining recognizable line and pattern structures. This is a form of controlled abstraction: proportions, contours, and expressions may be simplified, but the design avoids replacing Liaonan shadow-puppetry characteristics with generic cartoon styling. Material selection is especially relevant because D_{14} received the highest local weight within the material transformation layer. Semi-translucent surfaces and cutout cards therefore become a bridge between the historical perceptual principle of backlit shadow figures and a contemporary domestic storytelling setting.

E. Behavioral Layer

The behavioral layer responds directly to the two highest behavioral cultural genes: carving technique and performance manipulation. Traditional rod manipulation is not mechanically replicated. Instead, its underlying logic - selecting a figure, positioning it in relation to light and screen, changing scenes, and coordinating movement with narration - is translated into modular character and scene cards, magnetic or replaceable placement, projection, and story sequencing. This transformation preserves the performative relationship among actor, object, light, and narrative while adapting the physical actions to a child-accessible interface.

The interaction scenario is organized around co-narration. A child can select or replace characters and scenes while a parent guides the story, producing a small-scale participatory performance rather than passive viewing. The source scheme also includes touch-based light adjustment and multiple lighting or projection states. In the present interpretation, these functions are secondary to the narrative sequence: technology is useful insofar as it supports the transition from static cultural representation to active storytelling. This distinction reflects the AHP result in which emotional experience and scenario design received higher local weights than interactive experience alone.

F. Spiritual Layer

The spiritual layer converts abstract value content into an age-appropriate narrative structure. Cultural spirit and folk belief ranked third and fourth among the global cultural-gene weights, and the source study associates Liaonan shadow puppetry with moral education, auspicious symbolism, and culturally embedded narratives. The case uses Journey to the West characters because they are familiar to children and provide a flexible storytelling medium.

Importantly, Journey to the West is not treated as a uniquely Liaonan cultural gene. Its role is that of a cross-regional narrative carrier through which Liaonan visual and performative characteristics can be expressed.

Character generation was therefore constrained by shadow-puppetry conventions in head shapes, costume patterning, cutout line structure, props, and color logic. AIGC was used to explore both tradition-oriented and Q-version child-oriented characters, after which outputs were screened and adjusted. This process illustrates how generative variation can be subordinated to cultural criteria. The character designs are shown in Fig. 6 and Fig. 7.



Fig. 6 Journey to the West Character Design Influenced by Liaonan Shadow Puppetry



Fig. 7 Q-Version Character Design

G. Design Outcome and Cultural Adaptation

The final scheme integrates a translucent projection cover, illuminated base, replaceable character and scene modules, and touch-based light control. In the source proposal, a hemispherical form and layered projection effects create a dream-like domestic environment. For the present study, those formal details are secondary to the cultural adaptation logic. The outcome is considered successful as a framework test when four relationships remain visible: carving technique informs line and perforation; performance manipulation informs modular sequencing and projection; cultural spirit informs the moral and emotional structure of storytelling; and material genes support recognizability through translucency, pattern, and color.

The case also illustrates the difference between adaptation and reconstruction. It does not claim to reproduce a historical Liaonan stage, an authentic ritual performance, or an authoritative image of a traditional character. Instead, it creates a contemporary interpretive interface informed by selected cultural features. This distinction is essential when AIGC is used in heritage contexts: generated content should be labeled and governed as interpretation, while documentary or historical claims require separate evidence. The final scheme is presented in Fig. 8.



Fig. 8 Final Scheme of the Interactive Night Lamp “Yingqi Tongmeng Lamp”

6 Discussion

A. Theoretical Implications

The first theoretical implication is that cultural-gene analysis becomes more useful when it is treated as a traceability structure rather than as a catalog of motifs. In the Liaonan case, the AHP results show that the strongest global weights belong to carving technique, performance manipulation, cultural spirit, and folk belief. Only two of these are directly visual. This supports broader heritage arguments that the significance of ICH lies in practices and meaning-making as well as in material manifestations. It also suggests that design studies using cultural genes should distinguish between visible recognizability and cultural centrality. A visually salient factor may be useful for identification but not necessarily the most important factor for living transmission.

The second implication concerns the role of AHP. The method does not objectively measure heritage value; it formalizes the judgments of a defined respondent group. This distinction is especially important in culturally sensitive research. The present study uses AHP as a decision-support device that makes priorities inspectable and testable for consistency, while interpretation remains necessary. By separating cultural indicators from design-transformation indicators, the model further avoids conflating the importance of a heritage element with the attractiveness of a particular design treatment. This separation can be adapted to other ICH contexts where researchers need to connect qualitative cultural analysis with explicit design decisions.

Third, the study positions AIGC within a human-governed sequence. Generative AI is most defensible when it follows cultural analysis and is constrained by an explicit evidence or interpretation base. This aligns with recent calls to preserve human agency and accountability in AI-mediated heritage work. The proposed workflow therefore does not treat prompt engineering as a substitute for cultural expertise. Instead, cultural-gene coding and AHP create a pre-generation constraint set, while human screening creates a post-generation control. This two-sided structure is a practical response to hallucination, stylistic homogenization, and unsupported cultural hybridization.

B. Practical Implications

For designers and cultural institutions, the framework provides a sequence for moving from dispersed heritage resources to an explainable regeneration concept. The first practical advantage is prioritization: when time or design space is limited, the weight structure indicates which factors deserve stronger attention. The second is cross-layer mapping: a carving technique can become a visual rule, a manipulation practice can become an interaction rule, and a cultural value can become a narrative rule. The third is documentation: if each generated or designed element is linked to a coded source and a transformation rationale, teams can review cultural appropriateness more systematically.

For AIGC-based practice, the framework suggests that cultural prompts should be built from verified attributes and should include negative constraints or rejection criteria. Design teams can maintain a prompt-and-review log that records which source feature motivated a generated element, why an output

was accepted or rejected, and what modifications were made manually. Such a log would be more valuable for heritage accountability than simply archiving final images. The framework is also compatible with participatory review: inheritors, local experts, educators, and target users can assess different layers rather than being asked to give a single undifferentiated judgment about whether a design 'looks cultural.'

C. Limitations and Future Research

Several limitations constrain the interpretation of the findings. First, the AHP sample is small and heavily concentrated among design students: 42 of the 53 valid respondents came from that group, while teachers, design-research specialists, and shadow-puppetry enthusiasts formed much smaller subgroups. The source study did not include a substantial sample of recognized inheritors, puppeteers, folk-culture scholars, parents, or children. The resulting weights therefore reflect a design-oriented respondent structure and should not be generalized to all stakeholder groups.

Second, the original research record does not provide sufficient methodological detail about fieldwork dates, sites, coding reliability, or the AIGC model and prompt parameters. Future studies should publish a codebook, document inter-coder agreement where multiple coders are used, archive prompt versions and model settings, and separate historically verified content from interpretive generation. Third, the night-lamp case is a practice-based demonstration rather than a user-validated intervention. Claims about learning, emotional attachment, usability, or long-term heritage transmission cannot be made from the present evidence. Future work should compare alternative carriers, conduct usability and cultural-comprehension studies with parents and children, and examine whether interaction improves retention of heritage knowledge over time.

Finally, future research should broaden participation in the weighting process and test whether priorities differ across stakeholder groups. A multi-group AHP or other multicriteria approach could compare inheritors, heritage researchers, designers, local residents, and target users. Longitudinal work could also investigate how digital regeneration affects cultural understanding after repeated use. Such extensions would turn the current framework from a design-decision prototype into a more robust model of participatory heritage regeneration.

7 Conclusion

This study reframed a Liaonan shadow-puppetry cultural-creative design project as a method for the creative transformation and digital regeneration of intangible cultural heritage. By integrating cultural-gene deconstruction with AHP and AIGC-assisted practice, it established a traceable pathway from cultural resources to design decisions. The AHP results placed spiritual cultural genes first at the criterion level (0.4041), followed by behavioral (0.3191) and material genes (0.2768), while carving technique, performance manipulation, cultural spirit, and folk belief formed the leading global cultural factors. These findings indicate that contemporary regeneration should address embodied practice and meaning rather than rely primarily on visual symbol extraction.

The interactive night-lamp case demonstrated how those priorities can inform material, interaction, and narrative choices under a human-screened

AIGC workflow. Its value lies in methodological validation rather than commercial product development. More broadly, the framework offers a structured way to connect qualitative heritage interpretation, explicit decision support, and generative design while preserving human responsibility for cultural accuracy. Future research should improve stakeholder diversity, documentation of field and coding procedures, reproducibility of AI-assisted generation, and longitudinal evaluation of heritage learning and participation.

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