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Research on the Representation Intensity of Cultural Genes of Longquan Celadon Ewers in the Song Dynasty Based on Analytic Hierarchy Process - Entropy Weight Method (AHP-EWM)

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Abstract

This research aims to address the issues of weakened cultural attributes and ambiguous gene-screening criteria in the digital preservation of traditional handicraft intangible cultural heritage. Focusing on Longquan celadon ewers from the Song Dynasty, it proposes a quantitative screening framework for evaluating the representation intensity of cultural genes. Based on the tripartite cultural structure of "material-behavior-spirit", 23 gene elements–such as shape, glaze color, and craftsmanship were analyzed to construct a three-layer gene map. Through two rounds of anonymous expert consultations using the Delphi method (with the recovery rate increasing from 76.47% to 90%), 18 high-representation potential factors are screened out. Subsequently, the AHP-EWM was adopted to calculate comprehensive weights (CR $\leq$ 0.1), balancing subjective and objective deviations. Results indicate that the material layer carries the highest weight (0.494), among which the Plum Green glaze (0.541) and Bulbous-bellied shape (0.470) exhibit outstanding representation intensity. In the behavioral layer, decorative techniques (0.653) is predominant, while in the spiritual layer, auspicious culture (0.789) emerges as the key gene. This method provides an objective and operable framework for screening cultural genes in intangible cultural heritage, addressing the lack of quantitative evaluation of cultural attributes.

keywords: Cultural representation intensity, AHP-entropy weighting, Delphi method,Longquan celadon ewer,Digital preservation

1. Introduction

On 17 October 2003, UNESCO promulgated the Convention for the Protection of Intangible Cultural Heritage (ICH). Since its adoption, a total of 676 elements have been inscribed on the Intangible Cultural Heritage (ICH) Lists, covering 5 regions and 140 countries worldwide. Comprising diverse forms of non-material cultural expression, ICH embodies the human living heritage and represents the core values of cultural diversity. In the digital era, technological innovation has become an indispensable force for the sustainable development of cultural heritage[1, 2] . The advancement of digital technologies–such as 3D modeling, process documentation, and virtual reconstruction–has significantly expanded the possibilities for preservation and dissemination.

China currently holds 44 elements on UNESCO's World ICH lists, accounting for approximately 6% of the global total, with more than one-quarter belonging to the category of traditional handicrafts. Nevertheless, deficiencies remain in safeguarding this crucial

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category, particularly in identifying indicators with high cultural representational strength and in applying these insights to subsequent digital preservation efforts. Existing studies are often confined to isolated cultural or technical perspectives, lacking interdisciplinary integration: cultural researchers tend to lack operational frameworks for transmission, while technical practitioners often overlook the cultural logic underlying heritage artifacts. Consequently, maintaining the cultural integrity of heritage throughout the digitalization process has become a pressing challenge in contemporary ICH preservation.

Longquan celadon originated in the mid-Northern Song Dynasty, flourished during the Southern Song and the early Ming Dynasty, and declined in the early Qing Dynasty, with a production history spanning nearly a millennium [3]. Looking back at history, due to rapid economic and cultural development, as well as the increasing diversity of recreational activities in the Song Dynasty, porcelain became more widely used than in any previous dynasty. Longquan celadon of this period was exported to Asia, Africa, Europe and other regions through maritime trade routes, contributing to the prosperity of global commerce. At present, the Longquan celadon industry remains a key pillar of the local economy. As of 2024, its added value reached approximately 822 million yuan, with an average annual growth rate of 10.6%. The industry sustains over 4,600 business entities and employs more than 20,000 workers, accounting for 7.3% of Longquan City's GDP. However, this impressive industrial scale stands in sharp contrast to the low efficiency of heritage preservation efforts and the imbalance between investment input and output conversion. The core issue lies in the insufficient integration of cultural inheritors and technical practitioners, resulting in fragmented and singular protection models.

Therefore, it is imperative to accurately identify the core cultural genes of Longquan celadon and construct a collaborative framework for "cultural value excavation - technical tool adaptation". Such a framework is crucial not only for solving the dual problems of intangible cultural heritage protection and industrial upgrading of Longquan celadon, but also for creating a sustainable pathway for the future development of Longquan celadon.

Established in 2022, the Ancient Ceramic Gene Bank in Jingdezhen, has developed a comprehensive knowledge system by extracting and digitizing multidimensional information from ceramic fragments. This initiative provides robust data support and empirical references for the study and innovation of traditional crafts. Building upon the foundational data of the Gene Bank, the present research constructs an analytical framework encompassing gene map construction, quantitative screening, and weight calculation.

Within this framework, a hierarchical model of "material-behavior-spiritual culture" is employed to address the challenges of weakened cultural attributes and ambiguous gene identification in Song Dynasty Longquan celadon ewers. The study seeks to establish a scientific method for accurately screening high cultural representation intensity factors, thereby providing objective cultural attribute support for the digital preservation and revitalization of Longquan celadon.

2. Theoretical Foundations

2.1. The Concept of Longquan Celadon Ewers

The ewer–historically referred to as Zhuzi (pouring vessel), Zhuhu (pouring pot), or Bianti (flat-handled vessel)–is a container primarily used for holding and serving wine, typically crafted from ceramics or metal. The form of the Longquan celadon ewer can be traced back to the "chicken-head pot" (jishou hu) of the Three Kingdoms and Eastern Jin dynasties[4].

During the Song Dynasty, scholar-officials greatly admired the Confucian ideal of the junzi ("gentleman") whose character was described as "gentle and virtuous like jade." This cultural value, emphasizing refinement and purity, fostered an aesthetic preference for the jade-like translucency of Longquan celadon glazes. As a result, ewers became popular wine-pouring vessels at banquets, symbolizing elegance and moral virtue. Driven by both practical needs and technological innovation, their forms diversified over time, making the ewer one of the most iconic vessel types produced by Longquan kilns.

Given this historical and cultural context, the present study focuses on the Longquan celadon ewer as the primary research object for exploring cultural gene representation.

3. Methodology

This study begins with the application of the Delphi method, which integrates the expertise and evaluative judgments of multiple experts in Longquan celadon research. The process forms a reliable evaluation basis and lays the methodological groundwork for the subsequent construction of a multi-level cultural gene assessment system.

To ensure the scientific validity of indicator weighting, a comprehensive strategy combining the Analytic Hierarchy Process and the entropy-weight method is subsequently employed. This integrated strategy balances expert judgment and objective data evidence, thus enhancing the rigor and credibility of the final weight allocation.

Table 1. Glossary of Terms Related to Longquan Celadon

Name	Legend	Explanation	Reference
The celadon Ewer		Its basic form was established in the Tang Dynasty. Evolved from the chicken-head ewer, it consists of a body, a spout, and a handle, capable of holding and pouring liquids, and combining practicality with aesthetic value. Its shape varied across different dynasties.	Cited from Sotheby's Chinese Works of Art Catalogue, Lot 534
"Chicken-head pot" (Jishou Hu)		It was popular from the Wei, Jin to the Sui dynasties, adorned with a chicken-head ornament. In the early stage, the chicken head was solid; later, it became hollow and functioned as a spout. The chicken tail evolved into a curved handle, making it the predecessor of the ewer.	Cited from Page 18 of "Illustrated Catalogue of Chinese Celadon" by Yu Jiaming
Wine injector		A wine pourer is a container used for storing and serving wine. It typically takes the form of a pot, such as an ewer or a handled pot, and is often used together with a wine-warming bowl.	Painted by Zhao Ji, Northern Song Dynasty; Collection of the National Palace Museum, Taipei
"When I think of the noble man, he is as gentle as jade."		"This jade ewer of the Qing Dynasty has a smooth shape and subtle patterns, just as the Book of Songs says, 'When I think of the noble man, he is as gentle as jade' — a combination of 'jade virtue' and craftsmanship."	—
"Zhuzi", "Zhuhu", "Bianti"		These three terms all refer to the ewer by different names in distinct historical periods. During the Tang Dynasty, it was called "Zhuzi" (literally "pouring vessel"), so named for its function of pouring water. "Zhuhu" was a synonym for it. The name "Bianti" (literally "flat handled vessel") emerged in the mid-Tang Dynasty as an alternative name for the ewer to avoid taboo.	—

3.1. Overview of the Delphi Method

The Delphi Method is a systematic prediction and judgment approach designed to achieve expert consensus through multiple rounds of anonymous questionnaires and feedback statistics. It is widely employed to synthesize expert knowledge and minimize bias in decision-making processes.

Specifically, previous studies have demonstrated the effectiveness of this method in various cultural and design contexts. For example, Shimin Pan constructed an index system for evaluating AIGC-generated Zisha (purple sand) pottery design schemes through two rounds of Delphi expert consultations, laying the foundation for AHP weight allocation and practical application in this field[5] . Similarly, scholars like Sara R Benson used this method in cross-national research on the legal protection of traditional cultural expressions (TCEs) of indigenous peoples, identifying six core protection elements and proposing a hierarchical protection mechanism, providing theoretical support for relevant international negotiations [6].

Building on these precedents, the present study applies the Delphi Method to systematically collect and refine professional opinions from Longquan celadon expert groups, form structured evaluation indicators, and provide a basis for subsequent AHP and entropy weight method analyses. The specific implementation process is as follows.

1. **Formulating Expert Selection Criteria:** In terms of selection criteria, focusing on the technological characteristics, cultural connotations, and digital preservation needs of Song Dynasty Longquan celadon ewers, it is specified that the criteria should cover four major fields—intangible cultural heritage inheritance, application implementation, digital technology, and cultural theory—to ensure field relevance. Meanwhile, experts are required to have participated in celadon-related research projects to guarantee professional qualifications.

2. **Consultation Quality Assessment:** For consultation quality assessment, it is carried out from four dimensions: expert enthusiasm, authority, opinion concentration, and expert opinion coordination. Authority (C_r) is comprehensively calculated from the expert's "judgment basis coefficient (C_a)" and "familiarity coefficient". (C_a) is the expert's self-evaluated score for the judgment basis, while the familiarity coefficient reflects the expert's familiarity with Song Dynasty Longquan celadon ewers. The calculation of authority (C_r) is as follows[7].

$$C_r = \frac{C_a + C_s}{2} \tag{1}$$

The concentration of opinions (M) is measured by the arithmetic mean of experts' "importance scores" for each indicator, where: represents the rank sum of the j-th indicator, k represents the number of experts, n represents the number of factors, and the calculation of opinion concentration is as follows.

$$M = \frac{\sum_{i=1}^{k} x_{ij}}{k} \tag{2}$$

The coordination degree of opinions includes the coefficient of variation (CV) and Kendall's coefficient of concordance (W), which jointly test the consistency of expert opinions and serve as the core quantitative basis for indicator screening. The coefficient of variation (CV) reflects the degree of dispersion of scores: the smaller the CV, the more coordinated the opinions. Kendall's coefficient of concordance (W) is used to test the overall consistency of scores given by k experts for n indicators. Ranging from 0 to 1, the value closer to 1 indicates higher consistency, expressed as follows.

$$W = \frac{12\sum_{j=1}^{n} R_j^2 - 3k^2 n(n+1)^2}{k^2(n^3 - n)} \tag{3}$$

The coefficient of variation (CV) reflects the degree of dispersion of scores. The smaller the CV, the more coordinated the opinions. The calculation is as follows.

$$CV = \frac{SD}{M} \tag{4}$$

3. **Delphi Method Application and Results Analysis:** The first round focuses on basic screening, retaining indicators based on the mean importance (M ≥ 3.30) and coefficient of variation (CV ≤ 0.25). Subsequent rounds strengthen consensus, requiring stable or improved M, CV ≤ 0.25, an authority coefficient (Cr ≥ 0.80), and a significant Kendall's W coefficient ($p < 0.05$).

4. **Establishment of the Final Indicator Framework:** After multiple rounds of anonymous feedback and quantitative indicator screening, agreement is achieved on all indicators, ultimately developing an evaluation system that reflects the "craft-culture" traits of Longquan celadon ewers.

3.2. Overview of the AHP

The AHP, proposed by Saaty in the 1970s, is a systematic and hierarchical multi-criteria decision analysis method[8]. Relying on rigorous mathematical foundations, this approach achieves quantitative evaluation through pairwise comparisons of factors, effectively reducing subjective biases and being widely applied in the field of cultural heritage assessment. Scholars like Min Li used AHP to determine the weights of narrative design indicators and combined with the TOPSIS method to screen the optimal narrative themes, providing a basis for narrative design of intangible cultural heritage handicraft products[9]. Jiahang Chen and others constructed an application model for thousand-porcelain intangible cultural heritage elements in furniture design through AHP. By calculating the weights of the criterion layer, they clarified the importance of key factors such as cultural symbols to guide specific design practices[10].

Given the varying degrees of influence of cultural genes on the cultural recognizability of Song Dynasty Longquan celadon ewers, this study introduces AHP to scientifically determine the weights of each indicator and quantify their relative importance. The specific steps are as follows.

1. **The establishment of a paired comparison judgement matrix:** The establishment of a paired comparison judgement matrix is the first step in the process. In the matrix of Equation (5), a_{ij} represents the relative importance of a_i relative to a_j. If the former is more important, then $a_{ij} > 1$; if both are equally important, then $a_{ij} = 1$.

$$A = (a_{ij})_{n\times m} = \begin{bmatrix} a_{11} & a_{12} & \cdots & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & \cdots & a_{2n} \\ \cdots & \cdots & a_{ij} & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & \cdots & a_{nm} \end{bmatrix} \quad (5)$$

2. **Calculate the weights for each indicator:** In Equation (6), (7), and (8), denotes the jth score for the ith indicator, denotes the weight for the ith indicator, and denotes the normalised weight.

$$\overline{a_{ij}} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (i, j = 1, 2, \cdots, n) \quad (6)$$

$$\overline{w_i} = \sum_{j=1}^{n} \overline{a_{ij}} \quad (i, j = 1, 2, \cdots, n) \quad (7)$$

$$w_i = \overline{w_i} / \sum_{i=1}^{n} \overline{w_i} \quad (i = 1, 2, \cdots, n) \quad (8)$$

3. **The calculation of the maximum eigenvalue:** The maximum eigenvalue for the judgment matrix, as defined in Equation (9), involves the following parameters: n, which is the order of the matrix; A, the judgment matrix itself; and w, the weight of the ith indicator.

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(Aw)_i}{w_i} \quad (9)$$

4. **The matrix consistency check:** The matrix consistency check is conducted using Equations (10) and (11), where CI, CR, and RI are the consistency index, consistency ratio, and random consistency index, respectively. For the results to be scientifically valid, the condition CR ≤ 0.1 must hold for every judgment matrix[11].

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (10)$$

$$CR = \frac{CI}{RI} \quad (11)$$

3.3. The intervention of entropy weight method

In the field of intangible cultural heritage, the entropy-weight method has been widely adopted to reduce subjective bias and enhance the objectivity of multi-criteria evaluations.

For instance, Hu et al. employed a fuzzy Analytic Hierarchy Process (F-AHP) combined with the entropy-weight method to determine indicator weights that reflect user perception, thereby extracting key morphological features of Han-Dynasty terracotta figurines that balance cultural significance and audience recognition[12]. Likewise, Chunmei Hu et al. combined AHP, the entropy weight method, and the cloud model to assess mural deterioration: AHP integrated experts' hierarchical cognition of mural deterioration, the entropy weight method objectively corrected weights to reduce deviations, and the cloud model analyzed deterioration sensitivity, achieving multi-dimensional assessment of mural health and providing theoretical support for mural protection[13].

However, the evaluation results of the Analytic Hierarchy Process (AHP) may contain deviations caused by human subjectivity. To overcome this limitation, the entropy weight method is introduced and a combined approach of AHP and entropy weight method is adopted to determine comprehensive weights, thereby improving the accuracy of weight determination. Its basic principle is as follows: as an objective weighting method, the entropy weight method is often used to evaluate the values of uncertain factors in research objects. It quantifies uncertainty specifically to achieve quantitative analysis. In comprehensive evaluation, the greater the degree of disorder of an indicator, the smaller its entropy value, indicating more information provided and a greater role in comprehensive evaluation, and vice versa.

Therefore, in the specific analysis of the cultural recognizability of Longquan celadon ewers, the entropy weight of each indicator can be calculated using entropy based on the variation degree of each indicator's value [14]. The main calculation steps of the objective weighting method based on the entropy weight method are as follows.

1. **Normalise the original data:** In Equation (12), y_{ij} denotes the normalised value of the i-th sample for the j-th indicator. x_{ij} represents the original observed value of the i-th sample for the j-th indicator.

$$y_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \quad (12)$$

2. **Calculate the entropy of each indicator:** In Equation (13), M_j represents the entropy value of the jth evaluation indicator, where m denotes

the total number of samples participating in the evaluation. In the equation, f_{ij} denotes the feature weight of the ith object under the jth indicator. The traditional entropy weighting method is defined as $f_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}}$, with the convention that $f_{ij} = 0$ implies $f_{ij} \ln f_{ij} = 0$. This method has certain limitations; therefore, this study employs Equation (14) for calculation [15]:

$$M_j = -\frac{1}{\ln m} \sum_{i=1}^{m} f_{ij} \ln f_{ij} \tag{13}$$

$$f_{ij} = \frac{(y_{ij} + 1)}{\sum_{i=1}^{m} (y_{ij} + 1)} \tag{14}$$

3. **Calculate the weights for each indicator:** In Equation (15), M_j denotes the entropy of the jth indicator, v_j denotes the weight of the jth indicator, and n denotes the number of indicators.

$$v_j = \frac{1 - M_j}{n - \sum_{j=1}^{n} M_j} \tag{15}$$

3.4. The Integration of the Entropy Weight Method and AHP

To synthesise the strengths of both methodologies, this study combines the Analytic Hierarchy Process (AHP) with the Entropy Weighting Method to determine the weights for the cultural gene evaluation indicators of the Song Dynasty Longquan celadon ewer. Assuming the weights obtained by AHP and Entropy Weighting are w_j and v_j respectively, the combined weight is calculated as per Equation (16) [16]:

$$\lambda_j = \frac{w_j v_j}{\sum_{j=1}^{n} w_j v_j} \tag{16}$$

4. Construction of the Cultural Gene Map

4.1. The Concept of Meme

Memetics is a theoretical framework based on Darwin's theory of evolution, aiming to explain the laws of cultural evolution from an evolutionary perspective [16]. Originating in 1976, the theory was proposed by British biologist Richard Dawkins, who introduced the term "meme" as a cultural analogy to the "gene" in biology, later abbreviated as "meme" [17]. In 1998, "meme" was officially included in The Oxford English Dictionary, defined as "the basic unit of culture, transmitted by non-genetic means, especially imitation". Although contemporary studies in memetics generally follow this paradigm, its theoretical boundaries and methodological framework remain open to further refinement. Since the 1980s, Chinese scholars have developed localized interpretations of this concept, introducing the notion of "cultural genes" as an analogy to biological genes. Three main academic communities have since emerged in China: (1) philosophy and theory scholars like Wang Dong [18], who define cultural genes as fundamental factors influencing cultural inheritance and evolution; (2) ethnology and cultural anthropology scholars such as Bai Guixi [19], who proposed a "six-element" model of cultural genes based on ethnic crafts, analyzing genotypes and phenotypes while establishing classification principles; Wu Qiulin[20] argues that cultural genes reflect humanity's deep "cultural nature", offering new paths for cultural anthropology; (3) cultural history scholars like Liu Zhihui et al. [21], who interpret cultural genes' theoretical significance through traditional cultural genealogy. These diverse definitions collectively enrich the theoretical connotation of "cultural genes", providing multi-dimensional theoretical support for constructing the cultural gene mapping framework of Longquan celadon.

4.2. The Construction Framework

Building on these theoretical foundations, the selection and classification of cultural genes for Longquan celadon ewers adopt the framework proposed by Bai Guixi, which outlines a five-element relationship of shape, decoration, technique, institutional system, and connotation. This framework subdivides into eight parallel levels: "vessel shape, glaze color, human agency, and the living attributes of culture, etc", cultural genes are dynamic–capable of replication, recombination, and inheritance–thus requiring factors to be viewed as a community [22]. A cultural gene map serves to visualize cultural resources in logical order, revealing relational and evolutionary patterns[23]. Based on Longquan celadon's attributes, this study employs a "material-behavior-spiritual culture" hierarchical division, proposing a construction path through a "three-layer integrated" perspective [24].(See Figture 1).

4.3. Construction of the Material Culture Layer Gene Pedigree Map

Vessel Shape Gene. The main shapes of Song Dynasty Longquan celadon ewers can be divided into three categories: bionic-shaped ewer (D1), cylindrical ewer (D2), and bulbous-bellied ewer (D3) [25]. Specifically, the bionic-shaped ewer draws inspiration from natural plant morphologies–such as gourds, pumpkins, and pears–incorporating organic silhouettes into ceramic design. The cylindrical ewer features a tubular body with its maximum diameter located at the shoulder, tapering gently toward the base; the bulbous-bellied ewer (D3) features a bulging abdomen, approximately spherical or oblate, with a full contour. Given the

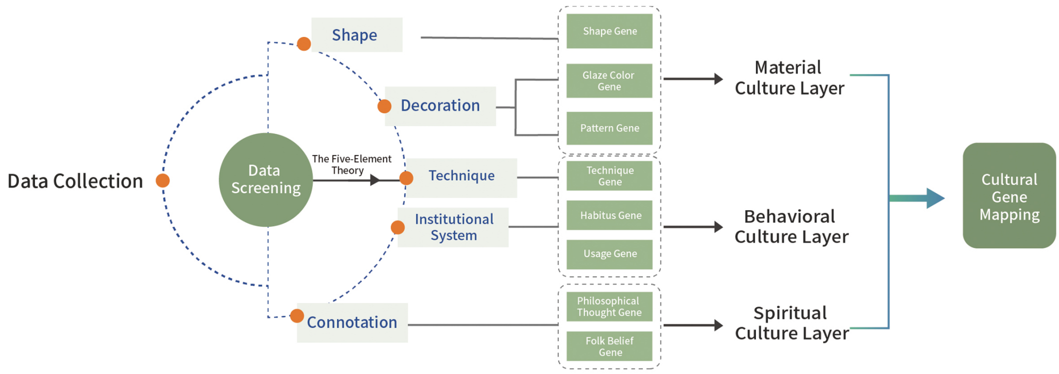

Figure 1. Construction Path of Cultural Gene Map

distinct morphological variations among these three types, the present study conducts digital contour extraction and comparative modeling to quantitatively characterize their formal differentiation.(See Figture 2).

Glaze Color Gene. The chromatic concept of Longquan celadon was profoundly shaped by cultural ideals, spiritual symbolism, and natural aesthetics.

Given that the early Song Dynasty glazes were primarily lime-based, the predominant hues included light blue and bluish-yellow. To objectively quantify these traditional glaze colors, the CMYK color values were extracted and converted into numerical visualizations, enabling accurate digital reconstruction of historical tones.

During the Song period, both artisans and literati named distinct glaze types according to their optical characteristics. By the mid-to-late Southern Song Dynasty, the Longquan kilns had developed iconic glazes such as pea green, celestial blue and plum green, which elevated celadon aesthetics to the ideal realm of "jade-like beauty." [26] At this stage, black-bodied celadon typically displayed tones such as celestial blue (D5) and prawn shell cyan-dark cyan (D8), whereas white-bodied celadon was dominated by pea green (D4), powder blue (D6), and plum green (D7).(See Figture 3).

Decoration Genes. The Patterns on Longquan Kiln celadon are visual symbolic images where ancient people transformed natural objects onto porcelain surfaces, using celadon as a carrier to express the principles of nature and cultural interests. In the Northern Song Dynasty, ewers were large in size, with decorations mainly featuring geometric pattern and incised flowers, often separated by melon ribs. Examples of geometric pattern included water ripples and cloud patterns, while incised flower patterns included lotus petal patterns and banana leaf patterns, with comb patterns carved on the petals to set off the main patterns. In the early Southern Song Dynasty, production scale continued that of the Northern Song period, but in the late period, influenced by the southward migration of the Song court and aesthetic changes, ewers were gradually replaced by vases and burners. Patterns simplified from complex to simple, with lotus and lotus leaves becoming the mainstream. Thus, the patterns on Song Dynasty Longquan celadon can be divided into two categories: plant pattern (D11) and geometric pattern (D12).(See Figture 4)

4.4. Construction of Behavioral Culture Layer Gene Pedigree Map

Craftsmanship Gene. The forming craftsmanship (D13) of Longquan celadon include wheel throwing, hand building, carving-inlay, and mold making. Its decorative craftsmanship (D14) are categorized into craftsmanship and glazing: in craftsmanship, the early Northern Song Dynasty was dominated by fine-line incising combined with carving, while the mid-late period focused on incising-carving. The Southern Song Dynasty saw the prevalence of three-dimensional modeling and relief-style "exposed-rein" decoration [27]. Multiple glazing was commonly adopted, with 3-5 repeated glazing and drying processes forming a thick jade-like glaze layer [28]. The inheritance and development of key processes–glaze preparation, glazing, biscuit firing, and glaze firing–have established Longquan celadon's technical system, profoundly influencing subsequent ceramic production.

Conventional Gene. Convention genes are the behavioral patterns and core norms of craftsmen that are materialized through artifacts. The Song Dynasty kiln workers' focus on porcelain production led to ritual customs such as the "Three Offerings Ceremony", "Worshipping Kiln Gods" and "Burial of Kiln Amulets" (D15). Through these rituals, they expressed awe and offered prayers for porcelain production [29]. The drinking practice of "warming wine to keep warm" (D16) promoted the evolution of celadon shapes.

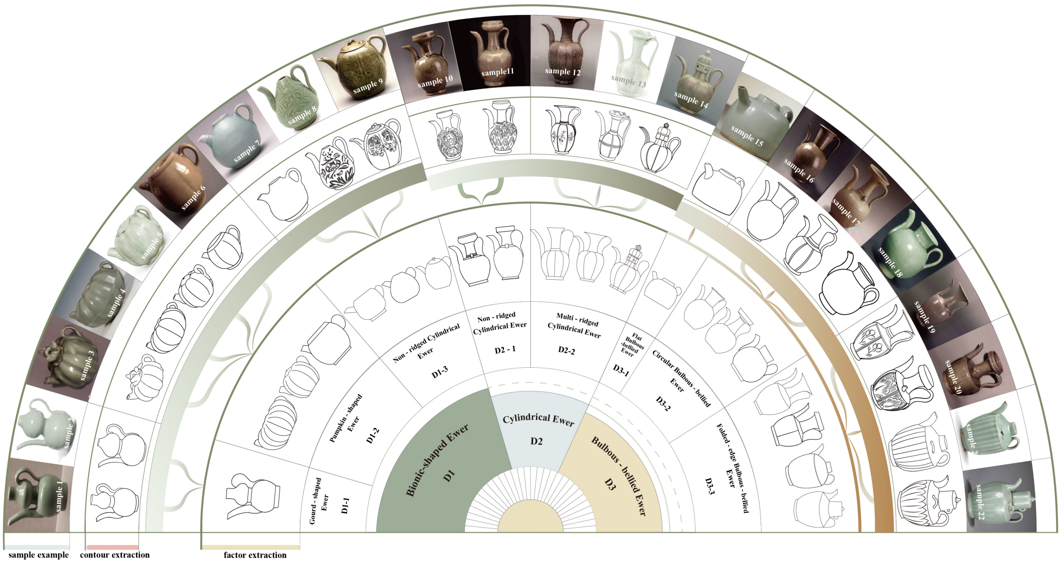

Figure 2. Gene Map of Shapes for Longquan Celadon Ewers of the Song Dynasty

It made the practical functions blend with cultural connotations.

Usage Gene. Longquan celadon's usage genes derive from diverse applications and cultural meanings, classified into daily life utensil (D17) and ritual furnishing (D18). The former were widely used in daily life, teahouses, taverns, and imperial banquets; the latter served in cultural venues and traditional rituals, together shaping its rich usage gene system.

4.5. Construction of the Spiritual and Cultural Layer Gene Pedigree Map

Philosophical Thought Gene. The philosophical thought genes of ewers are mainly composed of jade virtue spirit (D19), Wu-wei thought (Non-interference) (D20), and nature-oriented concept (D21). In the Southern Song Dynasty, the decline of national power triggered a shift in social mentality, and the style of celadon tended to be clear and graceful, reflecting the Taoist concept of "purity and inaction" . Glaze colors such as powder blue and plum green, with their jade-like luster, became the material carriers of the Confucian "jade virtue" spirit, embodying the Song people's admiration for noble character. The bionic shapes of melon-bellied and pear-shaped ewers not only imitate the external forms of natural objects but also condense their inner vitality, integrating natural images and vital energy into the utensil shapes, which is a concentrated expression of natural philosophy.

Belief and Custom Gene. The Belief and Custom Gene is the core cultural essence rooted in folk beliefs and customs, with intergenerational inheritance, profoundly influencing the beliefs, behaviors, and values of specific groups. The Folk Belief & Custom Gene of Song Dynasty Longquan celadon ewers are mainly reflected in two aspects: auspicious culture (D22) and kiln god worship (D23). Against the backdrop of the rise of commodity economy and civic culture, ewers conveyed rich auspicious meanings through gourd shapes, lotus decorations, and glaze colors such as powder blue and plum green. Meanwhile, with the prevalence of Taoism and the Five Elements thought in the Song Dynasty, kiln worship rituals and religious symbols were integrated into the ewer-making process, reflecting craftsmen's awe of kiln transformation and driven by policies, making celadon ewers an important medium connecting humans and deities.

5. Results Discussion

5.1. Construction and Optimization of Ewer Evaluation Index System

Based on the theoretical framework of the ewer cultural gene map, this study constructs a multi-level evaluation structure model, including 1 target layer (A), 3 comprehensive layers (B1–B3), 8 evaluation layers (C1–C8), and 23 factor-layer indicators (D1–D23). To improve the accuracy and representativeness of the evaluation system, the Delphi expert consultation method was used to carry out two rounds of screening for the factor-layer indicators.

In the first round of expert consultation, 17 questionnaires were distributed, and 13 valid questionnaires were recovered, with a valid recovery rate of 76.47%. The statistical results of importance scores showed that the average score of each indicator ranged from 2.85

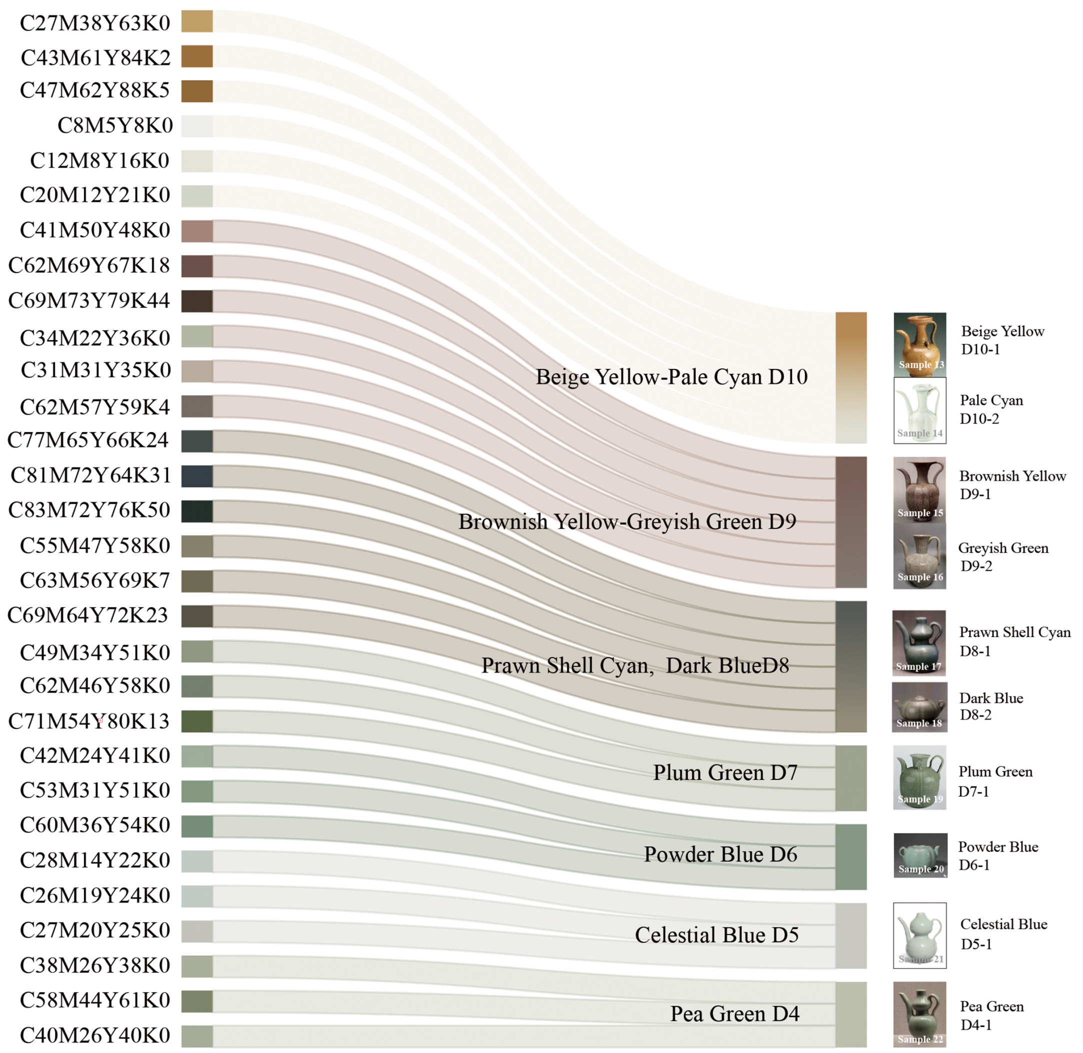

Figure 3. Glaze Color Gene Map of Song Dynasty Longquan Celadon Ewers

Table 2. Gene Pedigree Map of the Behavioral Culture Layers for Song Dynasty Longquan Celadon Ewers

Gene Type	Factor Name	Explanatory Description
Craftsmanship Gene	Forming Craftsmanship D13	Wheel Throwing, Hand-pinching, Carving and Assembling
Craftsmanship Gene	Decorative Craftsmanship D14	Sgraffito, Carving, Pinching, Exposed Body Texture, Repeated Biscuit Firing and Layered Glazing
Conventional Gene	Ritual Custom D15	Triple Offering Ceremony, Kiln God Worship, Burying Ritual Objects for Kiln Consecration
Conventional Gene	Drinking habit D16	warming wine to ward off the cold
Usage Gene	Daily life utensil D17	Vessels for routine drinking (water, wine, tea), Commercial service in tea and wine houses, Imperial banquet ware
Usage Gene	Ritual furnishing D18	Utilization at Elite Literary Gatherings, Ritual Vessels for Sacrificial Ceremonies

[redacted] [redacted] [redacted]

Figure 4. Decoration Gene Map of Song Dynasty Longquan Celadon Ewers

Table 3. Spiritual Culture Layer Map of Song Dynasty Longquan Celadon Ewers

Gene Type	**Factor Name**	**Reasons for Formation**
philosophical thought gene	Jade virtue Spirit D19	The "Jade Virtue Spirit" is a moral system in traditional Chinese culture that analogizes the virtues of a gentleman to jade, encompassing such virtues as benevolence wisdom, righteousness, and propriety, and originating from Confucian and Taoist thoughts.
philosophical thought gene	Wu-wei Thought D20	Sgraffito, Carving, Pinching, Exposed Body Texture, Repeated Biscuit Firing and Layered Glazing
philosophical thought gene	Nature-Oriented Concept D21	Triple Offering Ceremony, Kiln God Worship, Burying Ritual Objects for Kiln Consecration
Folk Belief Gene	Folk auspicious culture D22	The bionic forms of Song Dynasty Zhihu (ewers) reflect the Shengsheng philosophy; their mimicry of nature is an act of reverence that embodies the principle of learning from and harmonizing with the natural world.
Folk Belief Gene	Kiln God Worship D23	The crafting of the Zhihu was associated with the Jiyao (kiln-offering) ceremony. The subtly carved elements on the ware represented a belief in the Kiln God (Yaoshen), intended to pray for protection and success in the technically uncertain firing.

to 4.85, and the coefficient of variation (CV) ranged from 0.056 to 0.258. According to the preset screening criteria ($M \geq 3.30$, $CV \leq 0.25$), 5 indicators did not meet the requirements. Experts also proposed that glaze color gene entries such as "prawn shell cyan-dark blue (D8)", "brownish yellow-greyish green (D9)",

and "beige yellow-pale cyan (D10)" had weak cultural representativeness and suggested deleting them. This study adopted this opinion, optimized the factor layer, and reduced the number of indicators to 18. In the second round of consultation, 10 questionnaires were distributed, 9 were effectively recovered, and the recovery rate reached 90%. The second-round evaluation covered 29 indicators, with an average importance score ranging from 3.33 to 4.89, and the CVs were all lower than 0.25, all meeting the screening criteria. The Kendall's coefficient of concordance was 0.217 ($p < 0.05$), indicating that the consistency of expert opinions reached a statistically significant level. Although the score of the "ritual furnishing (D18)" indicator fluctuated slightly in the two consultations, the overall expert coordination degree was significantly improved compared with the first round.

Through two rounds of Delphi expert consultation, the final evaluation system includes 3 comprehensive layers, 8 evaluation layers, and 15 factor-layer indicators, forming a clear-structured and high-consensus evaluation framework for the "craft-culture" characteristics of Longquan celadon ewers, laying a solid empirical foundation for the subsequent Analytic Hierarchy Process (AHP).(See Figture 5)

5.2. Weight Calculation of Ewer Cultural Factors

Comparison of Three-Layer Weights. This study uses the AHP-EWM to analyze questionnaire data to determine the relative importance of cultural gene indicators. Based on expert scoring, the weight vector sets of each cultural layer are obtained by integrating average values (Table 4). All indicators passed the consistency test (Table 5), indicating that the judgment matrix has acceptable reliability.

Among the three layers of Song Dynasty ewer culture, the material culture layer (B1) has the highest weight of 0.494, indicating it serves as the core carrier of the overall cultural system. It not only provides a material foundation for spiritual and behavioral cultures but also aligns with the Song Dynasty's philosophical pursuit of harmony between utility and beauty in everyday artifacts. The weights of the behavioral culture layer (B2) and spiritual culture layer (B3) are similar, at 0.255 and 0.250 respectively, differing by only 0.005. This proximity indicates a strong interdependence between practice and ideology: spiritual culture is expressed through behavioral practices, while behavioral culture is guided by spiritual concepts.

Overall, the influence hierarchy among the three layers follows the pattern B1 > B2 > B3, collectively constructing an integrated cultural value system. These findings provide a quantitative and theoretically grounded basis for the digital extraction, evaluation, and preservation of key cultural genes in Longquan celadon.

Core Factor Ranking of Each Layer. In the material culture layer (B1), the ranking of weights reveals that the glaze color gene (C2) holds the highest value, followed by the vessel shape gene (C1) and the decoration gene (C3). This prominence of glaze color reflects the Song Dynasty aesthetic principle that "glaze color is the soul of celadon." Typical glaze colors such as plum green and powder blue have high representation intensity. In the vessel shape gene (C1), bulbous-belly ewers and bionic ewers are dominant. The former inherits the plump aesthetics of the Tang Dynasty, while the latter reflects the Song Dynasty's craftsmanship ideology of "making utensils to resemble images". In decoration genes, plant patterns are dominant, in line with the Song Dynasty's natural aesthetics and literati sustenance.

In the behavioral culture layer (B2), the hierarchy of importance is as follows: craftsmanship gene (C4), usage gene (C6), and conventional gene (C5). As the key to realizing cultural expression, craftsmanship genes are particularly influenced by decoration techniques. In conventional genes, ritual customs are more easily perceived due to their strong inheritance; in usage genes, ritual furnishings have higher weights, which are closely related to the revival of etiquette in the Song Dynasty and the cultural practice of the literati class symbolizing status with artifacts.

In the spiritual culture layer (B3), the belief and custom gene (C8) outweighs the philosophical thought gene (C7), indicating that folk beliefs such as auspicious culture are more perceptible and communicable than abstract philosophical ideals. In philosophical thought genes, the the jade virtue spirit (D14) is the core, reflecting that scholars use the jade-like texture of celadon to symbolize personality cultivation; in belief-custom genes, auspicious culture (D17) is absolutely dominant, because it fits the universal life vision and literati aesthetics, while the influence of kiln god worship (D18) is limited to the industry.

Based on the data of each layer, the key cultural genes that have the greatest impact on the decision-making objectives include: D3 (bulbous-bellied ewer), D4 (powder blue), D5 (plum green), D6 (plant pattern), D9 (decorative craftsmanship), D10 (ritual customs), D13 (ritual furnishing), D14 (jade virtue spirit), and D17 (auspicious culture).

These nine high-weight factors collectively embody the aesthetic, behavioral, and spiritual essence of Song Dynasty Longquan celadon culture, offering a data-supported foundation for future digital modeling and cultural gene visualization.

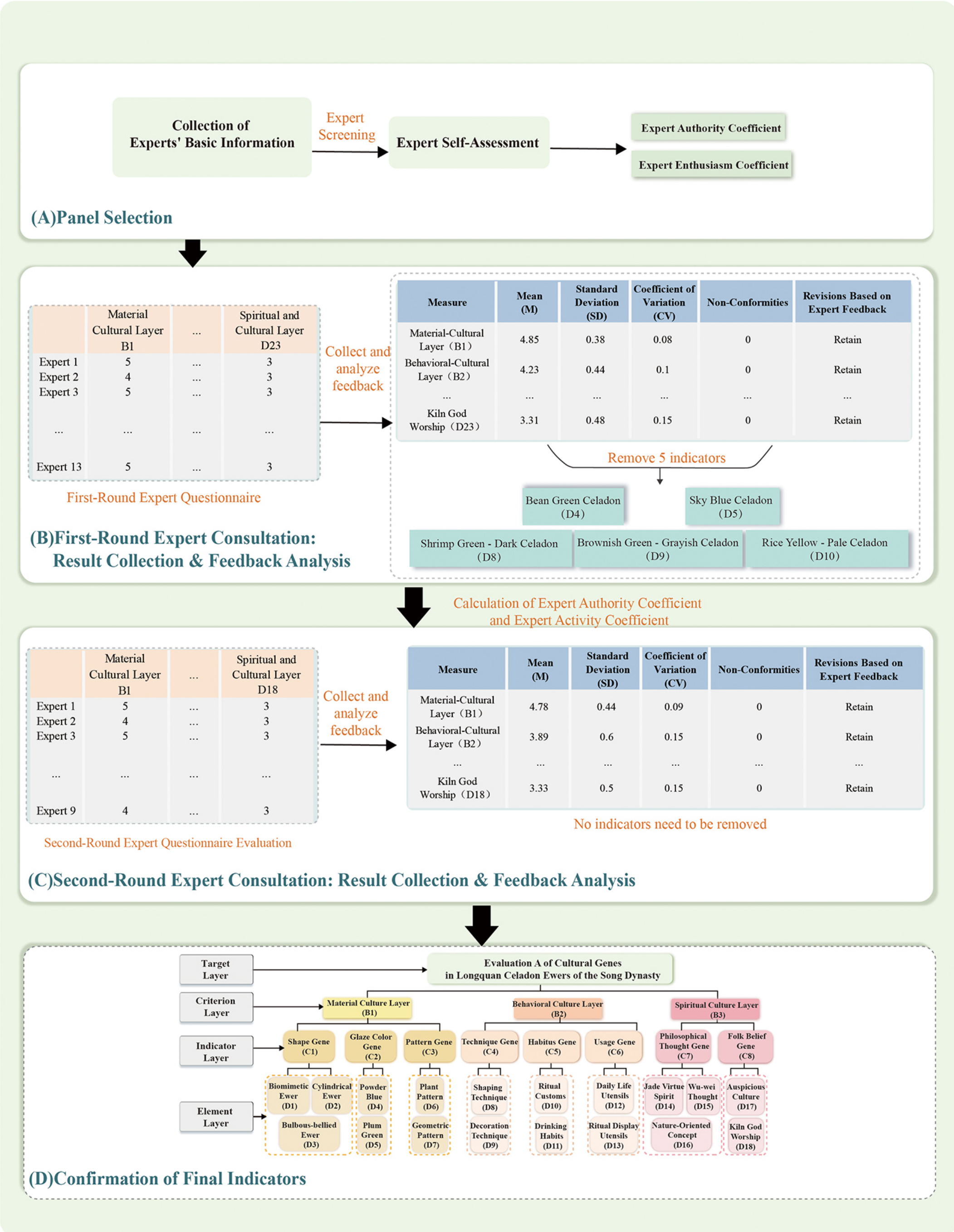

Figure 5. Delphi Method Research Framework (A)Panel Selection; (B)First-Round Expert Consultation: Result Collection & Feedback Analysis; (C)Second-Round Expert Consultation: Result Collection & Feedback Analysis; (D)Confirmation of Final Indicators

6. Conclusion

This study examined the representational strength of cultural genes in Song Dynasty Longquan celadon ewers through the combined application of the Delphi method and the AHP-entropy weighting method. By constructing a hierarchical evaluation framework grounded in the tripartite cultural model of material-behavior-spirit, and by conducting two rounds of expert consultation, the research objectively identified, screened, and quantified the core cultural factors that contribute most significantly to the heritage identity of Longquan celadon.

The findings demonstrate that the material culture layer exerts the greatest influence (0.494), followed by

Table 4. Comprehensive Weight and Layered Weight Values Table of AHP-EWM Method

Target Layer	Other layers	AHP	Entropy Method	Combination
Evaluation A of Cultural Genes in Longquan Celadon Ewers of the Song Dynasty	Material Culture Layer (B1)	0.494	0.346	0.532
	Behavioral Culture Layer (B2)	0.255	0.316	0.251
	Spiritual Culture Layer (B3)	0.250	0.279	0.217
	Vessel Shape Gene (C1)	0.403	0.218	0.241
	Glaze Color Gene (C2)	0.437	0.549	0.657
	Decoration Gene (C3)	0.160	0.233	0.102
	Craftsmanship Gene (C4)	0.468	0.354	0.498
	Conventional Gene (C5)	0.292	0.223	0.194
	Usage Gene (C6)	0.240	0.423	0.308
	Philosophical Thought Gene (C7)	0.297	0.404	0.224
	Belief and Custom Gene (C8)	0.703	0.596	0.778
	Bionic-shaped Ewer (D1)	0.321	0.197	0.198
	Cylindrical Ewer (D2)	0.226	0.471	0.333
	Bulbous-bellied Ewer (D3)	0.453	0.332	0.470
	Powder Blue (D4)	0.483	0.476	0.459
	Plum Green (D5)	0.517	0.524	0.541
	Plant Pattern (D6)	0.613	0.523	0.635
	Geometric Pattern (D7)	0.387	0.477	0.365
	Forming Craftsmanship (D8)	0.408	0.354	0.347
	Decorative Craftsmanship (D9)	0.592	0.646	0.653
	Ritual Custom (D10)	0.591	0.532	0.625
	Drinking Habits (D11)	0.409	0.468	0.375
	Daily Life Utensils (D12)	0.456	0.465	0.415
	Ritual Furnishing (D13)	0.544	0.535	0.585
	Jade Virtue Spirit (D14)	0.561	0.280	0.493
	Wu-wei Thought (D15)	0.181	0.303	0.182
	Nature-Oriented Concept (D16)	0.258	0.417	0.325
	Auspicious Culture (D17)	0.789	0.558	0.789
	Kiln God Worship (D18)	0.211	0.442	0.211

Table 5. Consistency Test Table

Target Layer	RI	CR	Consistency Test Result	Layer
Evaluation A of Cultural Genes in Longquan Celadon Ewers of the Song Dynasty	0.52	0.083	Passed	Material Culture Layer (B1)
			Passed	Behavioral Culture Layer (B2)
			Passed	Spiritual Culture Layer (B3)
			Passed	Vessel Shape Gene (C1)
			Passed	Glaze Color Gene (C2)
			Passed	Decoration Gene (C3)
			Passed	Craftsmanship Gene (C4)
			Passed	Conventional Gene (C5)
			Passed	Usage Gene (C6)
			Passed	Philosophical Thought Gene (C7)
			Passed	Belief and Custom Gene (C8)

the behavioral and spiritual layers. Within the material layer, glaze color and vessel shape genes—particularly the plum green(D5) and bulbous-bellied ewer (D3)—emerged as the strongest carriers of cultural symbolism. In the behavioral dimension, decorative craftsmanship (D9) and ritual custom (D10) were central to expressing craftsmanship and social rituality. Within the spiritual layer, the jade virtue spirit (D14) and auspicious culture (D17) encapsulated the moral ideals and aesthetic aspirations of Song society.

Table 6. Ranking Table of High Representation Factors

Criterion Layer	Indicator Layer	Combination Weight	Element Layer	Combination Weight
Material Culture Layer (B1)	Glaze Color Gene (C2)	0.657	Plum Green (D5)	0.541
			Powder Blue (D4)	0.459
	Vessel Shape Gene (C1)	0.241	Bulbous-bellied Ewer (D3)	0.470
	Decoration Gene (C3)	0.102	Plant Pattern (D6)	0.635
Behavioral Culture Layer (B2)	Craftsmanship Gene (C4)	0.498	Decorative Craftsmanship (D9)	0.653
	Usage Gene (C6)	0.308	Ritual Display Utensils (D13)	0.585
	Conventional Gene (C5)	0.194	Ritual Customs (D10)	0.625
Spiritual Culture Layer (B3)	Belief and Custom Gene (C8)	0.778	Auspicious Culture (D17)	0.789
	Philosophical Thought Gene (C7)	0.224	Jade Virtue Spirit (D14)	0.493

Methodologically, this research establishes an integrative model that combines subjective expert knowledge and objective statistical weighting, offering a replicable approach for the quantitative assessment of intangible cultural heritage. It demonstrates that cultural gene representation can be scientifically measured and visualized, bridging qualitative interpretation with digital quantification.

In practical terms, the study provides a data-driven foundation for the digital preservation and creative transformation of traditional craftsmanship. The cultural gene weights derived here can inform heritage digitization, cultural design innovation, and interactive exhibition modeling, enabling more accurate cultural reconstruction in the digital domain.

Future research may further expand this framework by integrating multi-modal data (e.g., image recognition, 3D morphology, and text mining) to refine cross-cultural comparisons and enhance the dynamic simulation of cultural gene transmission.

In sum, this study not only deepens the understanding of Longquan celadon's cultural ontology but also contributes a methodological paradigm for the quantification and visualization of cultural genes within the broader field of intangible cultural heritage studies.

DECLARATIONS

Ethics approval and consent to participate

Not applicable.

Conflict of interest

No potential conflict of interest was reported by the authors.

Dataset to be available

All data generated or analyzed during this study are included in this published article.

Consent for publication

Not applicable.

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Authors' information

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