electronics

MDPI

Article

AI-Assisted Inheritance of Qinghua Porcelain Cultural Genes and Sustainable Design Using Low-Rank Adaptation and Stable Diffusion

Qian Bao, Jiajia Zhao *, Ziqi Liu and Na Liang

Major of Design, Department of Design, Graduate School, Hanyang University, Seoul 04763, Republic of Korea; baoqian@hanyang.ac.kr (Q.B.); liuziqi647@hanyang.ac.kr (Z.L.); liangna@hanyang.ac.kr (N.L.)
* Correspondence: zhaojia31531@hanyang.ac.kr

Abstract: Blue-and-white porcelain, as a representative of traditional Chinese craftsmanship, embodies rich cultural genes and possesses significant research value. Against the backdrop of the generative AI era, this study aims to optimize the creative processes of blue-and-white porcelain to enhance the efficiency and accuracy of complex artistic innovations. Traditional methods of crafting blue-and-white porcelain encounter challenges in accurately and efficiently constructing intricate patterns. This research employs grounded theory in conjunction with the KANO-AHP hybrid model to classify and quantify the core esthetic features of blue-and-white porcelain, thereby establishing a multidimensional esthetic feature library of its patterns. Subsequently, leveraging the Stable Diffusion platform and utilizing Low-Rank Adaptation (LoRA) technology, a generative artificial intelligence (AIGC)-assisted workflow was proposed, capable of accurately restoring and innovating blue-and-white porcelain patterns. This workflow enhances the efficiency and precision of pattern innovation while maintaining consistency with the original artistic style. Finally, by integrating principles of sustainable design, this study explores new pathways for digital innovation in blue-and-white porcelain design, offering viable solutions for the contemporary reinvention of traditional crafts. The results indicate that AIGC technology effectively facilitates the integration of traditional and modern design approaches. It not only empowers the inheritance and continuation of the cultural genes of blue-and-white porcelain but also introduces new ideas and possibilities for the sustainable development of traditional craftsmanship.

Keywords: AIGC; blue-and-white porcelain cultural genes; sustainable design; grounded theory; KANO model; Analytic Hierarchy Process (AHP); LoRA; stable diffusion

Academic Editor: George A. Tsihrintzis

Received: 15 January 2025
Revised: 11 February 2025
Accepted: 11 February 2025
Published: 13 February 2025

Citation: Bao, Q.; Zhao, J.; Liu, Z.; Liang, N. AI-Assisted Inheritance of Qinghua Porcelain Cultural Genes and Sustainable Design Using Low-Rank Adaptation and Stable Diffusion. *Electronics* **2025**, *14*, 725. https://doi.org/10.3390/electronics14040725

1. Introduction

With the rapid advancement of artificial intelligence (AI) technology, artificial intelligence-generated content (AIGC) has demonstrated a profound impact in the fields of creativity and design [1]. AIGC can not only generate diverse forms of artistic content, such as images, audio, videos, and 3D models, based on textual descriptions [2] but also simulate human esthetic and creative processes, providing novel sources of inspiration for design practices [3]. In recent years, the focus of design research has gradually shifted from the technical feasibility of AIGC to deeper explorations of cultural heritage and value creation. Increasing attention is being given to how AIGC technology can effectively enable the preservation and innovation of traditional culture within modern design [4,5]. Against this backdrop, leveraging AIGC technology to preserve the cultural heritage of traditional arts and crafts while meeting contemporary demands for ecological and sustainable design has emerged as a significant and worthwhile research direction.

As a quintessential representation of traditional Chinese arts and crafts, blue-and-white porcelain embodies profound cultural heritage and distinctive esthetic characteristics [6]. Its blue-and-white patterns, harmonious integration of natural and humanistic motifs, and the philosophical concept of "unity between heaven and humanity" not only capture the essence of Eastern traditional esthetics but also align seamlessly with contemporary design principles emphasizing ecology and sustainability [7]. However, existing research primarily focuses on the identification [8], preservation [9], and restoration [10] of traditional blue-and-white porcelain craftsmanship. While some scholars have explored the integration of traditional patterns with modern design languages through AIGC technology [11–13], there remains a lack of a systematic theoretical framework and practical pathway. Specifically, there is insufficient exploration of how AIGC technology can accurately capture the core esthetic genes of blue-and-white porcelain, innovate artistic creative methods, and achieve the organic integration of sustainable design principles at the levels of materials, craftsmanship, and product lifecycle. In other words, there remains a gap in research on how to preserve the unique esthetic characteristics of blue-and-white porcelain while seamlessly integrating them into the modern design context in the era of artificial intelligence.

The design community currently faces the dual challenge of preserving cultural identity and heritage in design while meeting modern society's demands for sustainability and innovation [14]. On the one hand, the production of blue-and-white porcelain is highly complex, involving intricate craftsmanship, the application of cobalt blue pigments, and high-temperature firing, making it difficult to perfectly replicate and preserve its exquisite techniques in modern large-scale production [8]. Over time, the transmission of blue-and-white porcelain craftsmanship has faced significant challenges [15]. On the other hand, in the context of the era of sustainable development, modern design places greater emphasis on sustainability and the environmental impact of production processes [16]. Moreover, in the innovative design process of blue-and-white porcelain, designers need to integrate emerging technologies such as artificial intelligence and 3D printing [17] to overcome the limitations of traditional porcelain creation and explore new design methods and pathways. To overcome the limitations of traditional porcelain creation and explore new design methods and pathways, how modern technology, particularly AIGC, can be utilized in the new era to bridge the gap between tradition and modernity, as well as esthetics and sustainability, has become a topic deserving of in-depth exploration [18].

Therefore, this study takes the inheritance of the cultural genes of blue-and-white porcelain as the research entry point and conducts an in-depth exploration of the following three core questions:

Q1: What are the core esthetic characteristics of blue-and-white porcelain, and how can AIGC technology accurately reproduce these features?

Q2: How can AIGC technology assist designers in preserving and inheriting the core esthetic characteristics of blue-and-white porcelain in modern ceramic creation?

Q3: How can AIGC technology drive innovation in the creation methods and pathways of blue-and-white porcelain while guiding its design and production toward a more ecological and sustainable future?

This study not only aims to preserve and inherit the esthetic characteristics of Chinese blue-and-white porcelain but also seeks to explore sustainable and innovative design approaches for cultural heritage through AIGC technology. This novel approach has the potential to transform design practices and offer new perspectives for the advancement of design theory. Furthermore, this study aspires to encourage the design community to break free from traditional constraints and adopt advanced technological tools and cutting-edge design theories with a more open mindset, thereby fostering continuous innovation and sustainable development in porcelain design.

2. Literature Review

This section will review the current research status related to AIGC technology, the esthetic features of blue-and-white porcelain, cultural gene inheritance, and sustainable design, providing theoretical support for this study.

2.1. AICG Technology Overview

AIGC refers to content generated using advanced generative artificial intelligence (GAI) technologies, rather than being created by human authors. It has the capability to automatically produce a substantial volume of content within a short period [19]. In 2014, Generative Adversarial Networks (GANs) [20] were introduced, representing a significant milestone in the field. Concurrently, variational autoencoders (VAEs) [21] and Diffusion Generative Models [22] were also developed, demonstrating remarkable results across various applications. Currently, artificial intelligence-generated content (AIGC) has garnered widespread societal attention in domains such as chatbots, virtual agents, art, music, and education [19].

In the field of design, AIGC technology is increasingly applied, bringing significant innovation and transformation, particularly in creative generation, automated design, and esthetic reproduction. In a comparative study of AIGC and traditional creative generation methods, Lin et al. [23] found that AIGC methods excel in enhancing creativity quality, originality, and refinement, providing a novel research perspective for design creativity generation. H.Y et al. [24] pointed out that the application of AIGC technology in automated design is transforming traditional design processes, with its efficiency and adaptability offering unprecedented possibilities for the creative industry. Liu et al. [25] explored the application of AIGC technology in reproducing the esthetics of Song Dynasty lacquerware and demonstrated its remarkable potential in traditional esthetic representation and design innovation. The integration of the generated artistic styles with traditional cultural esthetics offers a new paradigm for the design field. Related studies highlight the capabilities of AIGC in creative generation and design innovation.

However, despite the significant potential of AIGC technology in the design field, it also faces limitations and challenges. On the one hand, H.T. Le-Nguyen's research [26] highlights that AI's understanding of cultural connotations and esthetic characteristics remains limited, making it difficult to generate works with profound cultural depth. Meanwhile, Garcia, M. B. [27] comprehensively analyzed the challenges posed by generative artificial intelligence in the field of art, ranging from issues of authenticity and intellectual property to ethical dilemmas and its impact on traditional artistic practices. On the other hand, generative AI lacks originality and human esthetic judgment, which may result in a deficiency of uniqueness and emotional resonance, thereby posing a challenge to the role of human designers [28]. Furthermore, as AIGC technology becomes more widespread, Cao et al. pointed out that it may raise significant societal concerns, including biases in generated content, ethical issues such as deepfakes, and challenges related to copyright, privacy, and data security [19]. All these issues require ongoing research and resolution.

2.2. Esthetic Characteristics of Blue-and-White Porcelain

Blue-and-white porcelain originated in China and is renowned for its intricate designs and the harmonious contrast between cobalt blue oxide and the white porcelain body [29]. Liu, H. et al. pointed out in their study that blue-and-white porcelain, as a significant carrier of cultural heritage along the Maritime Silk Road, embodies the profound connotations of cultural integration between the East and the West [30]. Robert Finlay's study indicates that patterns and motifs are the core elements of the esthetic characteristics of blue-and-white porcelain, serving as key means of shaping the visual identity and esthetic value of these artifacts [31]. In their study on the influence of Ming dynasty blue-and-white porcelain patterns on contemporary visual art, Ying Xu et al. unanimously concluded that these patterns not only convey esthetic pleasure but also reflect social identity, cultural symbolism, and the spirit of the times [32].

The patterns of blue-and-white porcelain encompass flowers, birds, fish, insects, landscapes, figures, auspicious symbols, and religious and philosophical themes [33]. Clunas's research indicates that blue-and-white porcelain is not merely an art form but also an essential cultural carrier of Chinese heritage, imbued with rich historical and humanistic connotations [34]. Christian Fischer et al. proposed that in addition to patterns and colors, the organic integration of form and craftsmanship also constitutes a crucial dimension of the esthetic characteristics of blue-and-white porcelain [35]. In her research on the dissemination of Chinese ceramics, Ting, Vivian Wing Yan, pointed out that the production process of blue-and-white porcelain involves multiple stages, including molding, painting, glazing, and firing, with each stage reflecting the artisans' exceptional craftsmanship [36]. However, with the acceleration of modernization, although the esthetics of blue-and-white porcelain possess enduring appeal, significant challenges remain in terms of esthetic reproduction and dynamic cultural transmission. Zhang and Yan suggested that utilizing modern technological tools to facilitate the inheritance and innovation of blue-and-white porcelain esthetics has become a focal point of research interest [37]. Therefore, there is still a lack of clear consensus and systematic elaboration in academia regarding the balance between the esthetic characteristics and functional attributes of blue-and-white porcelain, as well as the relationship between craftsmanship details and the cultural esthetic preferences of different eras. This gap provides theoretical space for future research to explore the inheritance of cultural genes and sustainable innovation pathways for blue and white porcelain.

2.3. Cultural Gene Inheritance

In his 1976 book *The Selfish Gene*, Richard Dawkins introduced the concept of the "meme" or cultural gene [38]. Memes, as units of cultural transmission, play a significant role in the dissemination of cultural information and ideas, akin to genes in biological evolution. They facilitate the spread of social memory and cultural ideas through various media, impacting cultural inheritance and communication [39]. Research by Cannizzaro, S and Joel West suggests that cultural genes are essentially rooted in semiotics, indicating that they carry symbolic meanings that can be decoded and interpreted by individuals [40,41]. In her book *The Meme Machine*, Blackmore, S. emphasizes that the transmission of cultural genes relies on imitation and learning, ensuring the continuation and development of cultural elements within a group [42].

In the field of design, Cao, J. proposed that the inheritance of cultural genes is reflected in the extraction, reorganization, and innovative application of traditional cultural elements [43]. However, traditional craft inheritance mainly relies on oral transmission and hands-on teaching, which hinders the effective dissemination of cultural genes [44]. Nevertheless, the rise of digital technology has provided new avenues for the inheritance and innovation of cultural genes. For example, Lihua Han et al. stated in their research that digital technology enhances the extraction and storage of cultural genes, enabling the creation of genetic databases that facilitate cultural innovation applications [45]. Additionally, Laurent Debailleux et al. explored innovative applications of cultural heritage using virtual reality technology, providing more vivid demonstrations and immersive experiences of traditional culture [46]. However, S. Tiribelli pointed out in their research that maintaining cultural authenticity and avoiding the misinterpretation or fragmented representation of cultural elements during AI integration remains a critical area requiring further investigation [47]. Furthermore, Florin Gîrbacia's research revealed that the automated extraction, training, and application of cultural genes using AIGC technology face limitations in model comprehension and data quality [48].

In summary, cultural gene inheritance, as a mechanism for the continuation of cultural information, empowered by AIGC technology, can open up new pathways for the inheritance and innovation of blue-and-white porcelain cultural genes in contemporary society. This exploration not only contributes to strengthening cultural identity but also provides significant theoretical and technical support for the integration of traditional craftsmanship with modern design.

2.4. Sustainable Design Research

Sustainable design is a theoretical and methodological framework whose principles aim to achieve sustainability by reducing resource consumption, minimizing environmental impact, and extending product lifespan [49]. With the intensification of environmental issues, sustainable design has become a critical research paradigm. Based on the principle of ecological balance, sustainable design strategies aim to minimize negative environmental impacts [50]. Thackara, J. proposed that in practice, sustainable design not only focuses on the use of materials and energy but also emphasizes cultural and social identity sustainability [51]. The study by Chapman and Gant [52] suggests that integrating traditional culture into modern design is considered an effective approach to achieving cultural sustainability. Researchers such as Fuad-Luke have pointed out that this integration can not only enrich the meaning of design but also promote cultural inheritance and innovation [53]. For example, Walker, S's research indicates that incorporating traditional patterns and symbols into products can enhance their cultural value and market competitiveness [54]. With the development of AIGC technology, exploring the application of generative AI large language models in sustainable cultural heritage design has become a new research focus. Verganti, R. et al. [18] proposed that AI can be used to optimize design processes, improve resource utilization efficiency, and promote user engagement. However, Obreja, D. M. et al. [55] pointed out in their research on cultural sustainability that AI-related applications remain relatively underexplored and require further investigation.

In summary, the application of AIGC technology to empower the inheritance and sustainable design of the esthetic cultural genes of blue-and-white porcelain remains in its early exploratory stages. Our study represents a significant step in preserving the esthetics of blue-and-white porcelain. By deeply exploring the dual potential of AIGC technology, we aim to enhance design efficiency, streamline the creative process, and address existing technological challenges. This research is expected to provide new insights into the sustainable development of the intangible cultural heritage design field.

3. Design Research and Methods

This section will provide a detailed introduction to the mixed methodology employed in this study, including grounded theory, the KANO model, and the AHP (Analytic Hierarchy Process) method, as well as how these research methods are applied to both the qualitative and quantitative analysis of the esthetic features of blue-and-white porcelain.

3.1. Design Research Framework

The study was guided by the double diamond model, a systematic research methodology designed to optimize the research process. This model was employed to explore the potential of AIGC technology in the inheritance of cultural genes and sustainable innovative design of blue and white porcelain. The double diamond model [56] facilitates research across the two stages of "Discovery" and "Validation" to ensure the comprehensiveness and reliability of our research outcomes. The research process framework was developed based on the double diamond model, as shown in Figure 1.

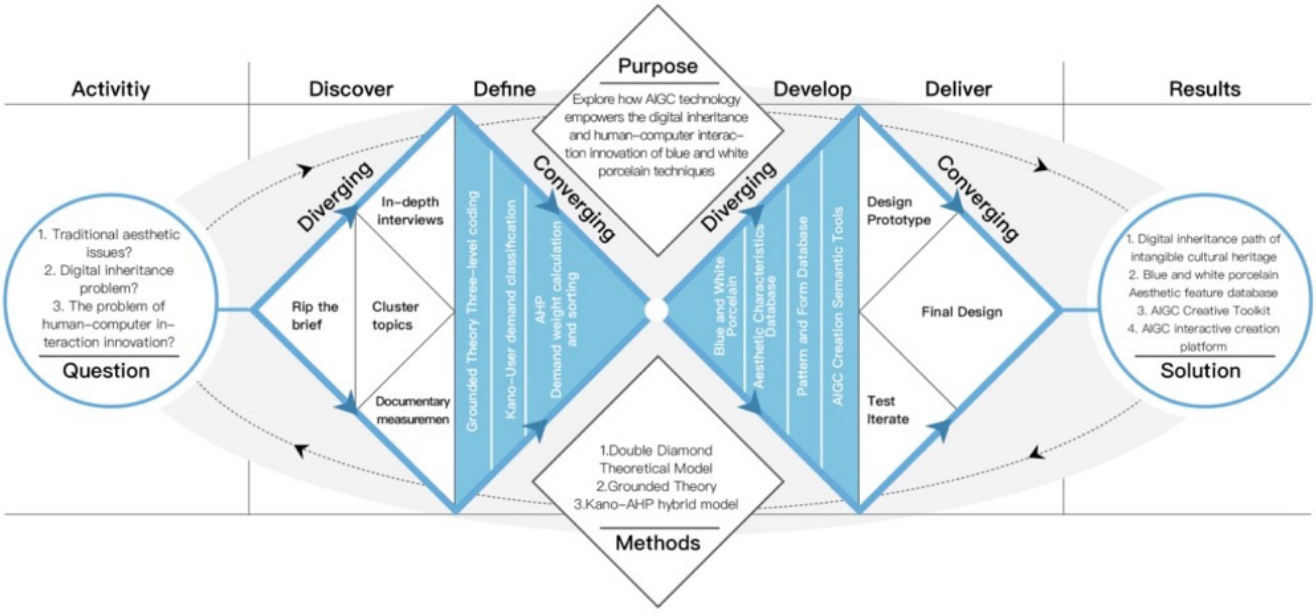

Figure 1. Design research framework based on the double diamond model.

In the first phase, "Discovery", bibliometric methods were systematically employed to summarize the morphological and pattern characteristics of blue-and-white porcelain. Additionally, in-depth interviews were conducted to gather insights from porcelain craft inheritors, design experts, and users regarding the esthetic features and deeper cultural meanings embedded in blue-and-white porcelain.

In the second phase, "Definition", emphasis was placed on constructing a multidimensional esthetic feature library for blue-and-white porcelain within the double diamond model. User interview data were analyzed through three-stage coding based on grounded theory, combined with Kano model surveys involving positive and negative questions. The Better–Worse quadrant coefficient analysis was used to classify esthetic features into basic, performance, attractive, and indifferent categories, followed by a quantitative analysis of key factors influencing these features. Subsequently, the Analytic Hierarchy Process (AHP) was applied to prioritize the core esthetic elements of blue-and-white porcelain, establishing a multidimensional esthetic feature library. This library provides scientific data support and theoretical foundations for the inheritance and sustainable design of blue-and-white porcelain's cultural genes.

In the third phase, "Development", the Stable Diffusion (SD) model was combined with Low-Rank Adaptation (LoRA) technology on the Stable Diffusion platform. The diffusion model was trained using a dataset of blue-and-white porcelain's esthetic features, establishing an innovative design workflow capable of accurately replicating the esthetic characteristics of blue-and-white porcelain.

Finally, the "Delivery" phase encompassed design practice, comprehensive user evaluation, and a synthesis of research findings and discussions. This phase involved a critical review and analysis of the entire research process, integrating sustainable design principles to develop an innovative design pathway for blue-and-white porcelain. Furthermore, in-depth discussions were conducted on the research outcomes, offering optimization suggestions and identifying future research directions.

3.2. Research Methods

Grounded Theory: This study employed the grounded theory method to systematically identify and refine the esthetic characteristics of blue-and-white porcelain. Grounded theory, established as a qualitative research method by Glaser and Strauss in the late 1960s and early 1970s, is based on the core principle of deriving theoretical frameworks directly from empirical data through constant comparative analysis and theoretical sampling, rather than predefining theoretical assumptions [57,58]. At the operational level, data collection and analysis in grounded theory are conducted through iterative cycles. The first phase, open coding, involves researchers analyzing the initial textual or visual data line by line without predefined theoretical frameworks, identifying concepts, attributes, and dimensions [58,59]. Next is the axial coding phase, where the concepts identified in the previous stage are linked to core phenomena, exploring causal relationships, conditions, interactions, and outcomes among various concepts [60]. Finally, during the selective coding phase, the core categories identified earlier are further integrated and refined to construct a theoretical framework explaining the research phenomenon [61]. Theoretical sampling is a critical strategy in grounded theory, where new data samples are purposefully collected based on the preliminary concepts or categories to further develop and refine the theory [62]. Throughout this process, data collection and analysis alternate as researchers continuously examine the data until theoretical saturation is reached, meaning no new concepts or relationships emerge from additional data [63].

In this study, the esthetic characteristics of blue-and-white porcelain were coded and sampled using a dynamic, iterative, and complementary process to ensure that the resulting esthetic framework achieved theoretical saturation and explanatory power. In summary, by employing the three-stage coding process of grounded theory (open coding, axial coding, and selective coding) along with the strategy of theoretical sampling, this study systematically explored and conceptualized the esthetic characteristics of blue-and-white porcelain from a qualitative perspective, thereby establishing a solid theoretical and data foundation for the subsequent application of the KANO-AHP hybrid model and AIGC technology.

KANO Model: The Kano model, developed by Professor Noriaki Kano of the Tokyo Institute of Technology in the 1980s, is an empirical method designed to analyze and understand the relationship between user needs and satisfaction [64]. The core concept of the Kano model lies in categorizing user needs based on their impact on user satisfaction, thereby providing guidance for product design, quality improvement, and user experience optimization [65]. The Kano model classifies product or service features according to trends in user satisfaction through user surveys or interviews. When product attributes meet specific needs, they result in increased user satisfaction; however, failure to address these needs appropriately may lead to dissatisfaction. Based on this logic, the Kano model categorizes user needs into five types [66]: must-be requirements, one-dimensional requirements, attractive requirements, indifferent requirements, and reverse requirements. By clearly distinguishing these five types of needs, the Kano model not only provides a reference for prioritizing product features and formulating improvement strategies but also enables design teams to effectively identify key characteristics and innovation points in product development and cultural heritage preservation [67].

In this study, the application of the Kano model provided a rational basis for the classification, weight ranking, and user demand positioning of the esthetic elements of blue-and-white porcelain, aligning traditional craftsmanship's esthetic features with modern user needs and further clarifying the relative importance of each characteristic. By integrating qualitative and quantitative analysis, this approach laid a solid data foundation for the subsequent application of AIGC technology in the digital innovation and design of cultural heritage.

Analytic Hierarchy Process (AHP): This study employed the Analytic Hierarchy Process (AHP) method to conduct a quantitative analysis and ranking of the importance of the esthetic characteristics of blue-and-white porcelain. The AHP, a multi-criteria decision-making analysis tool, was introduced by American operations researcher Thomas L. Saaty in the early 1970s. It has been widely applied in fields such as management, economics, environmental assessment, and public policy [68]. Its core advantage lies in decomposing complex decision-making problems into a clear hierarchical structure and systematically using pairwise comparisons and weight calculations to quantitatively evaluate the relative importance of elements at different levels [69,70].

In this study, the application of the Analytic Hierarchy Process (AHP) enabled a rigorous quantitative ranking of the key elements of the esthetic characteristics of blue-and-white porcelain, providing a scientific data foundation for subsequent Diffusion Model training based on the blue-and-white porcelain esthetic feature dataset and for developing innovative design pathways for blue-and-white porcelain.

4. Specific Experimental Process

This section will present the core processes and results of this study, focusing on the application of AIGC technology in blue-and-white porcelain design and revealing its potential in both the reproduction of traditional esthetics and modern innovative design.

4.1. Construction of a Multidimensional Esthetic Feature Library for Blue-and-White Porcelain Based on Grounded Theory and the KANO-AHP Hybrid Model

4.1.1. Coding of Esthetic Elements of Blue-and-White Porcelain Based on Grounded Theory

Due to the diversity and complex system of blue-and-white porcelain, its patterns not only embody a rich historical and cultural connotation but also reflect the essence of traditional Chinese esthetic craftsmanship. However, current research primarily focuses on the historical development or preservation of blue-and-white porcelain craftsmanship [71], while the scientific analysis and systematic exploration of its patterns as core esthetic elements remain insufficient, particularly regarding the integration of its cultural genes with modern design needs. Therefore, this study selected the patterns of blue-and-white porcelain as its core research subject.

(a) Data collection and collation stage

During the data collection phase, we conducted a systematic literature search to thoroughly investigate the esthetic characteristics of blue-and-white porcelain and their deeper significance. First, we used the CNKI (China National Knowledge Infrastructure) and Web of Science databases to search for relevant literature using the keyword "blue-and-white porcelain". Next, we identified key articles in the field based on citation and download metrics. Additionally, we employed the bibliometric analysis tool VOSviewer to annotate and analyze core literature. Subsequently, the research team carried out a meticulous selection process. An expert panel consisting of five university professors specializing in blue-and-white porcelain art research and intangible cultural heritage inheritors of blue-and-white porcelain developed a semi-structured interview outline on the esthetic characteristics of blue-and-white porcelain patterns. Specific details are shown in Table 1.

Table 1. Outline of semi-structured interview questions.

S/N	Semi-Structured Interview Questions
1	Which elements of the blue-and-white porcelain patterns do you think best reflect their aesthetic characteristics?
2	How do you think the blue-and-white porcelain patterns reflect the aesthetic aspirations of traditional Chinese culture?
3	What unique qualities do you think the colors of blue-and-white porcelain patterns possess? What aesthetic effects do they bring?
4	What principles do you think are generally followed in the layout and composition of blue-and-white porcelain patterns?
5	Which craftsmanship details do you think best capture the aesthetic essence of blue-and-white porcelain patterns?
6	What suggestions do you have for the inheritance and innovation of the aesthetic characteristics of blue-and-white porcelain patterns?

Grounded theory requires an in-depth analysis of raw data to summarize the underlying patterns and connections, ensuring that selected interviewees are representative and not influenced by external factors [72]. To obtain the latest insights into the esthetic characteristics of blue-and-white porcelain patterns, specific inclusion criteria were established to screen interview participants, including (a) holding a master's degree or above in disciplines related to ceramic art design or traditional craftsmanship, (b) specializing in areas such as ceramic design, art history, traditional craftsmanship, or interdisciplinary research, and (c) professionals with over three years of experience in ceramic craftsmanship, production, or research, including blue-and-white porcelain artisans, university educators in ceramic art design, doctoral candidates researching blue-and-white porcelain, or researchers involved in porcelain culture preservation or innovative entrepreneurship projects. For detailed statistics on participant information, see Table 2.

Table 2. Semi-structured interview demographics (n = 15).

Participants	Research Field	Age	Education Level	Workplace	Employment Qualifications	Location
P1	Ceramic Art Design	30	Ph.D.	Doctoral Student, China Academy of Art	Over 9 years of experience in ceramic art design	Hangzhou, China
P2	Ceramic Art Design	32	Ph.D.	Chinese Academy of Arts	Over 6 years of experience in ceramic art design	Beijing, China
P3	Digital Cultural Heritage Research	38	Ph.D.	School of Art, Renmin University of China	12 years of design experience, 5 years as an instructor	Beijing, China
P4	Blue and White Porcelain Craft	31	Master	Independent Studio	Inheritor of blue and white porcelain intangible heritage	Jingdezhen, China
P5	Contemporary Ceramic Creation Research	35	Ph.D.	China Ceramic Art Research Center	Over 8 years of experience in ceramic art design	Beijing, China
P6	Ceramic Art Design	25	Master	Jingdezhen Ceramic University	Over 5 years of experience in ceramic art design	Jingdezhen, China
P7	Cultural Heritage Digital Transmission and Preservation	37	Post-Doctorate	Tongji University School of Creativity	7 years of design experience, 2 years as a researcher	Shanghai, China

Table 2. *Cont.*

Participants	Research Field	Age	Education Level	Workplace	Employment Qualifications	Location
P8	Ancient Ceramic Art Research	45	Ph.D.	Senior Designer of Ceramic Products	Inheritor of blue-and-white porcelain intangible heritage	Jingdezhen, China
P9	AIGC and Intangible Cultural Heritage Innovation Design	35	Ph.D.	Doctoral Student, Hanyang University	5 years of experience in ceramic art research	Seoul, Republic of Korea
P10	Ancient Ceramic Research	41	Ph.D.	Intangible Cultural Heritage Research Institute	Inheritor of blue-and-white porcelain craftsmanship	Beijing, China
P11	Blue-and-White Porcelain Craftsmanship	33	Master	Independent Studio	Inheritor of blue-and-white porcelain intangible heritage	Jingdezhen, China
P12	AIGC and Intangible Cultural Heritage Sustainable Design	28	Ph.D.	Doctoral Student, Hanyang University	3 years of experience in intangible cultural heritage design	Seoul, Republic of Korea
P13	Blue-and-White Porcelain Craftsmanship Research	24	Master	Independent Studio	Inheritor of blue-and-white porcelain intangible heritage	Chaozhou, China
P14	Digital Transformation of Intangible Cultural Heritage	28	Master	Research Assistant, Tongji University	Over 5 years of design experience, 1 year as a research assistant	Shanghai, China
P15	Ceramic Craft Research and Modern Ceramic Art Exploration	36	Master	University Lecturer	Over 8 years of ceramic design experience, 5 years as a lecturer	Wuhan, China

(b) Semantic encoding stage

From 10 September 2024 to 25 October 2024, formal interviews were conducted with 15 participants. This sample size is considered typical in phenomenological research, which emphasizes depth and quality over quantity [73]. This study employed a combination of online (via Tencent Meeting) and offline methods to conduct semi-structured interviews. The duration of the interviews ranged from 35 to 80 min, with an average duration of approximately 55 min. All interviews were audio-recorded and transcribed verbatim. The researchers employed Braun and Clarke's six-phase thematic analysis method [74] and utilized the qualitative analysis software NVivo 14.0 to code the interview data. To ensure the objectivity and validity of the analysis, three researchers independently conducted the analysis and cross-validated the results.

During the open coding phase, 108 initial concepts (a1–a108) and 31 categories (A1–A31) were identified. In the axial coding phase, a total of seven main categories (B1–B9) and three dimensions (C1–C3) were obtained, as detailed in Table 3.

Table 3. Results of open and axial coding based on grounded theory.

Dimension	Main Category	Sub-Category	Initial Concepts
C1. Visual Features	B1. Patterns	A1. Plant Patterns	a1. Lotus pattern; a2. Peony pattern; a3. Chrysanthemum pattern; a4. Plum blossom pattern; a5. Pine bamboo plum; a6. Grape pattern; a7. Lotus leaf pattern; a8. Bamboo pattern; a9. Pine tree pattern
		A2. Animal Patterns	a10. Dragon pattern; a11. Phoenix pattern; a12. Qilin pattern; a13. Lion pattern; a14. Fish pattern; a15. Butterfly pattern; a16. Crane pattern; a17. Cicada pattern
		A3. Geometric Patterns	a18. Return pattern; a19. Thunder pattern; a20. Cloud pattern; a21. Scroll grass pattern; a22. Eight treasure pattern; a23. Ruyi pattern
		A4. Character pattern	a24. Lady pattern; a25. Children's play pattern; a26. Fisherman plowing and reading pattern; a27. Mythological figures
		A5. Landscape Patterns	a28. Mountain and water pattern; a29. Jiangnan scenery; a30. Boatman singing pattern
		A6. Artifact Patterns	a31. Museum pattern; a32. Jade spring bottle; a33. Longevity bottle
		A7. Text Patterns	a34. Blessing, Prosperity, Longevity, Happiness patterns; a35. Poetry patterns; a36. Auspicious patterns; a37.Greetings
		A8. Religious Patterns	a38. Buddha pattern; a39. Bodhi pattern; a40. Daoist symbols; a41. Dharma device patterns
		A9. Traditional Auspicious Symbols	a42. Eight Immortals crossing the sea; a43. Longevity peach pattern; a44. Fish leaping over the dragon gate; a45. Prosperity surplus pattern
	B2. Color	A10. Hue	a46. Blue and white hue; a47. Cyan hue; a48. Classic blue; a49. Deep blue; a50. Light blue
		A11. Layering	a51. Rich layers; a52. Depth and variation; a53. Color stacking
		A12. Contrast	a54. Blue-white contrast; a55. Bright–dark contrast; a56. Detail-to-whole contrast
		A13. Transparency	a57. Semi-transparency; a58. Gradient; a59. Lightness; a60. Fluidity; a61. Negative space
	B3. Composition	A14. Symmetry	a62. Vertical symmetry; a63. Horizontal symmetry; a64. Mirrored symmetry
		A15. Balance	a65. Balanced distribution; a66. Lightweight balance; a67. Negative space balance
		A16. Centralized Layout	a68. Centralized composition; a69. Edge composition
		A17. Scattered Layout	a70. Scattered distribution; a71. Irregular arrangement; a72. Spatial penetration
	B4. Form	A18. Line Fluidity	a73. Fluidity; a74. Softness and harmony
		A19. Pattern Simplification	a75. Abstraction; a76. Generalization; a77. Conciseness
		A20. Structural Features	a78. Circular shapes; a79. Square shapes
		A21. Spatial Perception	a80. 3D perception; a81. Depth perception

Table 3. *Cont.*

Dimension	Main Category	Sub-Category	Initial Concepts
C2. Craft Characteristics	B5. Techniques	A22. Handmade Painting	a82. Uniqueness; a83. Detailed brushwork; a84. Random creativity
		A23. Engraving and Filling	a85. Line engraving; a86. Fine filling; a87. Engraving techniques
		A24. Underglaze Coloring Techniques	a88. Underglaze penetration; a89. Layered dyeing; a90. Color harmony
		A25. Gradient Effects	a91. Gradient variations; a92. Temperature control; a93. Natural texture
C3. Cultural Connotations	B6. Cultural	A26. Religion And Philosophy	a94. Buddhist imagery; a95. Taoist symbols; a96. Confucian thought
		A27. Symbolic Meanings	a97. Symbols of power; a98. Symbols of peace; a99. Symbols of unity
		A28. Historical Culture	a100. Mythology; a101. Literary sentiments
	B7. Themes	A29. Nature Themes	a102. Flora and fauna; a103. Landscapes; a104. Seasonal changes
		A30. Mythological Legends	a105. Eight Immortals Crossing the Sea; a106. Dragon legends
		A31. Life Scenes	a107. Fishing and farming; a108. Children's play

(c) Theoretical saturation test

The research process of grounded theory is essentially an iterative cycle of deriving new concepts from raw data, conducting theoretical sampling, and categorizing and attributing data. Researchers conduct in-depth analyses on each piece of data, gradually extracting new concepts and categories, and continuously supplementing and refining data collection based on these preliminary findings. This process continues until no new concepts or categories emerge during data analysis, ultimately leading to the construction of a saturated and explanatory theoretical model [75].

In this study, all original statements from the interview data of 12 experts were sequentially segmented and organized. Through three levels of coding (open coding, axial coding, and selective coding), 108 initial concepts were extracted. By the time the coding reached the 12th expert, it was observed that all original concepts could be classified into the already coded categories, and no new concepts or classifications emerged, indicating that the conditions for constructing a complete theoretical model had been met. However, to enhance the completeness, rigor, and scientific validity of the study, the interview data from the remaining three experts were also coded. As no new concepts or categories emerged from this process, it was confirmed that the theoretical research had reached a high level of saturation at this stage.

4.1.2. Classification of Esthetic Elements of Blue-and-White Porcelain Patterns Based on KANO Model

The KANO model analyzes original user needs by setting both positive and negative questions, thereby identifying the relationship between different requirements and user satisfaction.

The research process is divided into the following four stages.

Firstly, in terms of questionnaire design, this study preliminarily constructed a dual-factor KANO questionnaire framework based on the results of open and axial coding derived from grounded theory. The framework aims to clarify the categorical attribution and importance of various esthetic demand elements in the design of blue-and-white porcelain [76]. To enhance the operability of the questionnaire and the willingness of respondents to participate, this study employed a five-point Likert scale for scoring, where scores ranging from 1 to 5 represent varying degrees of importance from "completely unimportant" to "very important" [77]. Compared to higher-order scales, the five-point scale is widely applied in questionnaire studies due to its moderate difficulty. It not only provides sufficient differentiation but also effectively reduces respondents' cognitive load or fatigue caused by an excessive number of options [78].

In the specific implementation process, respondents were required to evaluate each demand element from two dimensions: the positive dimension (the degree of satisfaction increases when the demand is met) and the negative dimension (the degree of satisfaction decreases when the demand is not met). Specific details are shown in Table 4. The dual scoring method for the positive and negative dimensions not only integrates the classification results of the KANO model with the quantitative evaluation of the importance of elements by users but also provides a more detailed empirical foundation for subsequent AHP analysis and the formulation of sustainable design strategies.

Table 4. Kano questionnaire format for collecting esthetic characteristics of blue-and-white porcelain patterns.

User Needs	Question	Favorite	Necessary	Indifferent	Reluctant	Disgusting
The core aesthetic features of blue and white porcelain patterns	What is your attitude if you have this aesthetic feature?	☐	☐	☐	☐	☐
	What would your attitude be without this aesthetic feature?	☐	☐	☐	☐	☐

Secondly, to ensure the reliability of the data, this study adopted a combination of online and offline survey distribution methods. The offline survey was conducted between 29 October and 8 November 2024 at two locations: Jingdezhen Ceramic University and the Tao Xi Chuan Market. The research team distributed closed-ended questionnaires to local residents, visitors, and blue-and-white porcelain craftsmen through face-to-face communication. A total of 325 questionnaires were distributed, and 287 valid responses were collected, with 132 questionnaires returned from Jingdezhen Ceramic University and 155 from the Tao Xi Chuan Market. In the online portion, the survey primarily targeted professional groups, including inheritors of the intangible cultural heritage of blue-and-white porcelain, ceramic designers, and product designers. A total of 200 questionnaires were distributed, with 189 valid responses collected. Through the combination of online and offline surveys, this study covered a diverse range of participants in the blue-and-white porcelain field, providing representative and reliable empirical data for subsequent analysis.

Thirdly, reliability and validity analyses were conducted based on the data collected from the user survey, with the detailed results shown in Table 5. After merging the online and offline data, SPSS 26.0 software was used to comprehensively assess the reliability of the data. First, the reliability of the data was tested using Cronbach's α coefficient to assess the overall stability of the scale [79]. The results showed that the overall Cronbach's α value was 0.775, which is above the 0.7 standard, indicating that the questionnaire has high internal consistency and reliability. Subsequently, validity testing was conducted to further evaluate the consistency between the data and the theoretical model. Based on a six-dimensional evaluation index system, the KMO and Bartlett's test of sphericity were used to validate the structural validity of the questionnaire. The analysis revealed a KMO value of 0.817 (greater than 0.7) and Bartlett's test p-value of 0.000 (with a significance level less than 0.05), indicating that the null hypothesis was significantly rejected, which demonstrates that the structural validity of the questionnaire is good. These results prove that the data collection was sufficient and representative, providing a solid foundation for analysis in multifactorial contexts, and further enhancing the reliability and validity of the research findings.

Table 5. KMO and Bartlett test.

KMO Value	0.817	
Bartlett's test of sphericity	Approximate Chi-Square	8619.00
	DF Value	276.00
	p-Value	0.000

Finally, a statistical analysis was conducted on the percentage of demand types for each indicator in the classified evaluation index system. The most frequently occurring demand element for each indicator was identified as the final type for that indicator, as detailed in Table 6. The demand elements were statistically evenly distributed among the attractive elements (A), must-be elements (M), expected elements (O), indifferent elements (I), and reverse elements (R). The overall reliability of the data is high, and the design of the evaluation indicators is reasonable.

Table 6. Results of the user demand questionnaire on the esthetic characteristics of blue-and-white porcelain patterns.

Number	Percentage (%)						Type	SI	DSI
	(M)	(O)	(A)	(I)	(R)	(Q)			
A1. Plant Patterns	14.27%	21.61%	51.76%	12.09%	0.73%	0%	M	35.86%	−73.74%
A2. Animal Patterns	17.09%	26.13%	46.23%	10.55%	0%	0%	M	43.22%	−72.36%
A3. Geometric Patterns	15.58%	26.13%	40.20%	18.09%	0%	0%	M	41.71%	−66.33%
A4. Figure Patterns	45.73%	20.60%	17.09%	16.58%	0%	0%	A	66.33%	−37.69%
A5. Landscape Patterns	39.20%	29.65%	16.08%	14.07%	1.01%	0%	A	69.54%	−46.19%
A6. Artifact Patterns	21.61%	13.57%	19.10%	45.73%	0%	0%	I	35.18%	−32.66%
A7. Text Patterns	19.10%	13.07%	26.13%	41.71%	0%	0%	I	32.16%	−39.20%
A8. Religious Patterns	27.14%	10.05%	16.58%	46.23%	0%	0%	I	37.19%	−26.63%
A9. Traditional Auspicious Symbols	22.11%	21.11%	37.19%	19.60%	0%	0%	M	43.22%	−58.29%
A10. Hue	23.62%	44.72%	15.08%	16.58%	0%	0%	O	68.34%	−59.80%
A11. Layering	23.62%	37.69%	20.10%	18.09%	0.50%	0%	O	61.62%	−58.08%
A12. Contrast	41.81%	22.11%	18.12%	17.59%	0.37%	0%	A	64.14%	−40.40%
A13. Transparency	20.60%	21.11%	20.10%	38.19%	2.08%	0%	I	41.71%	−41.21%
A14. Symmetry	21.11%	37.69%	31.66%	9.55%	0%	0%	O	58.79%	−69.35%

Table 6. *Cont.*

Number	Percentage (%)						Type	SI	DSI
	(M)	(O)	(A)	(I)	(R)	(Q)			
A15. Balance	41.21%	20.10%	19.60%	18.09%	1.01%	0%	A	61.93%	−40.10%
A16. Centralized Layout	15.58%	24.12%	14.57%	45.23%	0.50%	0%	I	39.90%	−38.89%
A17. Scattered Layout	13.07%	26.13%	20.60%	39.53%	0.67%	0%	I	39.39%	−46.97%
A18. Line Fluidity	20.10%	36.68%	29.65%	13.57%	0%	0%	O	56.78%	−66.33%
A19. Pattern Simplification	11.56%	25.43%	23.62%	38.19%	1.21%	0%	I	37.24%	−49.49%
A20. Structural Features	22.11%	46.23%	20.60%	11.06%	0%	0%	O	68.34%	−66.67%
A21. Spatial Perception	18.59%	21.11%	17.59%	42.71%	0%	0%	I	39.70%	−38.69%
A22. Handmade Painting	15.08%	42.95%	29.15%	12.06%	0.77%	0%	O	58.38%	−72.59%
A23. Engraving and Filling	28.64%	15.58%	20.60%	34.17%	1.01%	0%	I	44.67%	−36.55%
A24. Underglaze Coloring Techniques	36.18%	12.06%	10.05%	41.71%	0%	0%	I	48.24%	−22.11%
A25. Gradient Effects	45.23%	19.60%	11.56%	23.62%	0%	0%	A	64.82%	−31.16%
A26. Religion and Philosophy	33.17%	10.58%	14.57%	41.31%	0.37%	0%	I	43.94%	−25.25%
A27. Symbolic Meanings	19.60%	29.15%	34.67%	16.58%	0%	0%	M	48.74%	−63.82%
A28. Historical Culture	39.20%	16.08%	16.08%	28.64%	0%	0%	A	55.28%	−32.16%
A29. Nature Themes	52.26%	20.69%	12.06%	14.57%	0.41%	0%	A	73.23%	−32.83%
A30. Mythological Legends	28.67%	14.07%	16.08%	41.18%	0%	0%	I	42.71%	−29.15%
A31.Life Scenes	11.56%	26.13%	20.10%	42.21%	0%	0%	I	37.69%	−46.23%

As shown in Table 6, the Kano model classification table was used to compare the survey results and determine the proportion of each functional requirement attribute. Based on the analysis results, the satisfaction influence coefficient (SI, positive effect) and dissatisfaction influence coefficient (DSI, negative effect) for each indicator were calculated based on the following proportions:

$$SI = (A + O)/(A + O + M + I)$$

$$DSI = -1 \times (O + M)/(A + O + M + I)$$

The positive–negative coefficient represents the sensitivity of the indicator to user satisfaction. A larger calculated SI value indicates higher user satisfaction with the requirement, while a smaller DSI value indicates lower user dissatisfaction with the requirement. A detailed analysis is shown in Figure 2.

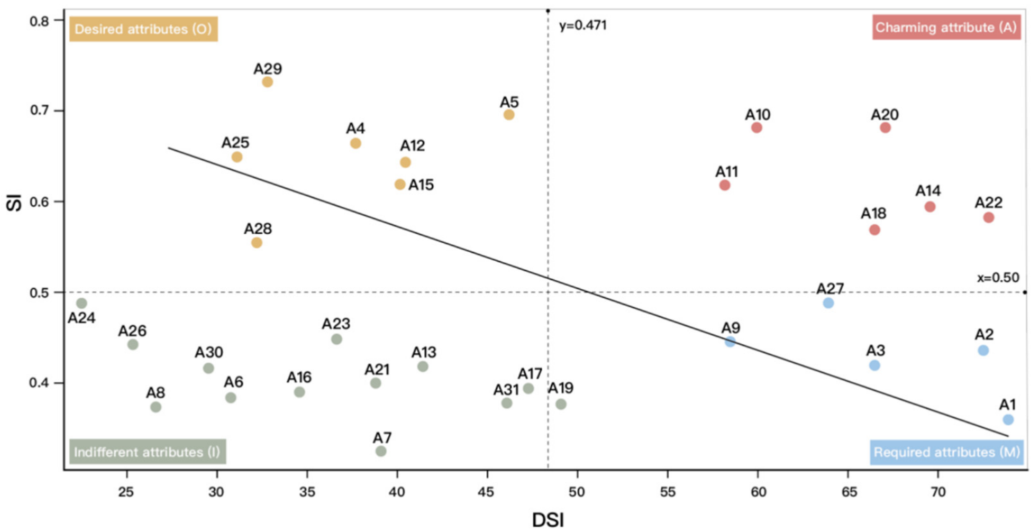

Figure 2. Better–Worse quadrant scatter plot.

4.1.3. Weight Ranking of Core Esthetic Characteristics of Blue-and-White Porcelain Patterns Based on the Analytic Hierarchy Process

In the previous stage of research, the Kano model was used to classify the esthetic characteristics of blue-and-white porcelain patterns, identifying different types of impacts on user satisfaction (e.g., attractive, must-be, and one-dimensional attributes). However, the classification results of the Kano model alone are insufficient to comprehensively quantify the specific importance of each esthetic element. Therefore, to further analyze the relative weights and priorities of different esthetic characteristics, this study introduces the Analytic Hierarchy Process to systematically and quantitatively rank the key esthetic features of blue-and-white porcelain patterns.

The Analytic Hierarchy Process systematically evaluates the relative importance of each element by constructing a hierarchical model, conducting pairwise comparisons, and integrating expert judgment matrices. The AHP not only addresses the limitations of the Kano model's qualitative analysis but also provides a scientific basis for optimizing strategies in innovative designs of blue-and-white porcelain.

Step 1: Construction of the judgment matrix

Based on the results of grounded theory estimation and Kano model analysis, ten experts in product design, porcelain design, and visual design were invited to conduct pairwise comparisons of the key esthetic characteristics of blue-and-white porcelain. Judgment matrix A was constructed in the following form:

$$A = \left(a_{ij}\right)_{n\times n} \tag{1}$$

In the formula, a_{ij} is the ratio of the relative importance of two factors compared with indicator i and indicator j, and $a_{ij} > 0$, $a_{ii} = 1$, $a_{ij} = \frac{1}{a_{ij}}$, $(i, j = 1, 2, 3, \ldots, n)$.

Step 2: Determine the indicator weights ω and calculate the maximum characteristic root of the matrix λ_{max}.

First, regularize the columns in judgment matrix A:

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} (i, j = 1, 2, 3, \ldots, n) \tag{2}$$

Second, add the regularized matrices and sum by rows:

$$c_i = \sum_{j=1}^{n} b_{ij} (i, j = 1, 2, 3, \ldots, n) \tag{3}$$

Again, regularize the processing vector $C = (c_1, c_2, \ldots, c_n)$:

$$\omega_i = \frac{c_i}{\sum_{i=1}^{n} c_i}(i = 1,2,3,\ldots,n) \tag{4}$$

Obtain the corresponding weight of each indicator $\omega_i(i = 1,2,3,\ldots,n)$.

Finally, solve for the largest characteristic root λ_{max}:

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(PW)_i}{nW_i}(i,j = 1,2,3,\ldots,n). \tag{5}$$

where $(PW)_i$ is the i-th component of the vector PW, and n is the order.

Step 3: Consistency testing. First, identify the consistency indicators:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{6}$$

Solve for the consistency ratio based on the table of values of judgment matrix RI:

$$CR = \frac{CI}{RI} \tag{7}$$

When $CR < 0.1$, the consistency test passes, and the weights are valid.

As shown in Figure 3, based on the Kano model, the classification of the esthetic characteristics of blue-and-white porcelain patterns organizes the essential elements (M), performance elements (O), and attractive elements (A) into a hierarchical structural model. This model consists of a goal layer, guidance layer, and indicator layer.

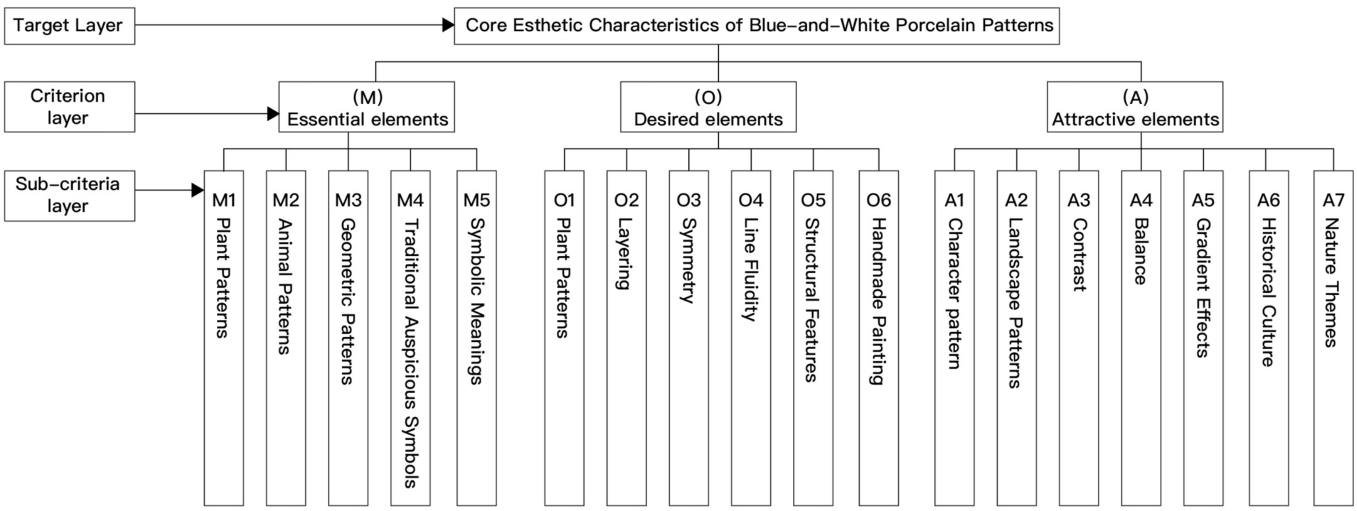

Figure 3. Esthetic features of blue-and-white porcelain pattern hierarchical analysis model.

Based on the Analytic Hierarchy Process (AHP), the judgment matrix for the user demand criteria layer of the esthetic characteristics of blue-and-white porcelain patterns was first constructed, as shown in Table 7. The weight values of each indicator were calculated using Formulas (2)–(4). Then, the maximum eigenvalue was calculated using Formula (5), resulting in λ_{max} = 3.0387. With Formulas (6) and (7), the consistency ratio (ICR) was determined as 0.0372 < 0.1, indicating that the judgment matrix is consistent. The sub-criteria layer judgment matrix was calculated in the same way to obtain the weight values of each indicator, as shown in Table 8. These weight values were normalized to derive comprehensive weights, which were then prioritized (Figure 4).

Table 7. Criterion-level judgment matrix.

Index	Must-Be Needs (M)	One-Dimensional Needs (O)	Attractive Needs (A)	Weighted Value	I_{CR}
The must-be needs (M)	1	3	5	0.6334	0.0372
The one-dimensional needs (O)	1/3	1	3	0.2605	
The attractive needs (A)	1/5	1/3	1	0.1062	

Table 8. Sub-criterion-level judgment matrix.

Primary Index	Secondary Index	Judgment Matrix							Weight	I_{CR}
The must-be needs (M)	M1. Plant Patterns	1	3	5	1	2			0.3128	0.0818
	M2. Animal Patterns	1/3	1	1/2	1/3	1/3	/		0.0786	
	M3. Geometric Patterns	1/5	2	1	1/3	1/5			0.0887	
	M4. Traditional Auspicious Symbols	1	3	3	1	3			0.3158	
	M5. Symbolic Meanings	1/2	3	5	1/3	1			0.3048	
The one-dimensional needs (O)	O1. Hue	1	1/3	2	1/5	1/2	1/5		0.0773	0.0884
	O2. Layering	3	1	2	1	1/3	2		0.169	
	O3. Symmetry	1/2	1/2	1	1/3	1/5	1/3	/	0.0578	
	O4. Line Fluidity	5	1	3	1	1/2	2		0.2093	
	O5. Structural Features	2	3	5	2	1	3		0.2342	
	O6. Handmade Painting	5	1/2	3	1/2	1/3	1		0.1504	
The attractive needs (A)	A1. Character pattern	1	1/2	5	2	1/5	1/4	1/3	0.091	0.0948
	A2. Landscape Patterns	2	1	3	2	1/3	1/2	1/3	0.1085	
	A3. Contrast	1/5	1/3	1	1/5	1/4	1/5	1/3	0.0377	
	A4. Balance	1/2	1/2	5	1	1/2	1/2	1/2	0.0974	
	A5. Gradient Effects	5	3	4	2	1	3	3	0.2121	
	A6. Historical Culture	4	2	5	2	1/3	1	2	0.1053	
	A7. Nature Themes	1	1/2	5	2	1/5	1/4	1/3	0.158	

As shown in Figure 4, data analysis reveals that users place the highest importance on cultural connotations and traditional elements among the esthetic features of blue-and-white porcelain. Specifically, traditional auspicious symbols (weight: 0.3158), botanical patterns (weight: 0.3128), and symbolic meanings (weight: 0.3048) play a significant role in conveying cultural value. Additionally, visual and craftsmanship features such as structural characteristics (weight: 0.2342), kiln variation effects (weight: 0.2121), and line smoothness (weight: 0.2093) also hold significant importance, indicating a high level of user attention to product appearance and craftsmanship details. This suggests that blue-and-white porcelain design needs to strike a balance between cultural heritage and visual esthetics to meet core user needs.

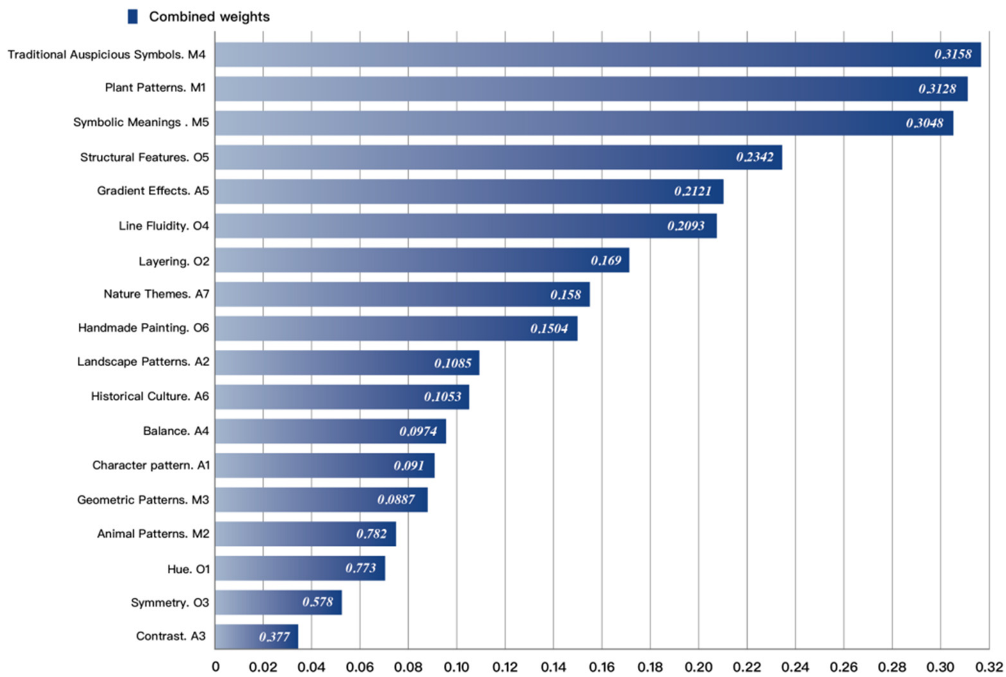

Figure 4. Weight sorting of esthetic features of blue-and-white porcelain patterns based on AHP.

In comparison, traditional artistic elements such as landscape patterns, historical culture, geometric patterns, and animal motifs have relatively lower importance (all with weights below 0.11). Design features such as tonal gradation, symmetry, and contrast exert even more limited influence (all with weights below 0.08). These results provide clear priority guidance for blue-and-white porcelain design, emphasizing a focus on cultural symbols, visual forms, and craftsmanship optimization, while appropriately simplifying lower-priority features. This study offers valuable reference points for designers in formulating strategies for the modernization and internationalization of innovative blue-and-white porcelain design.

4.1.4. Construction of a Multidimensional Esthetic Feature Library of Blue-and White-Porcelain Patterns

This study, based on an in-depth understanding and systematic analysis of the esthetic characteristics of blue-and-white porcelain, constructed an esthetic feature library for blue-and-white porcelain patterns. The research team extracted esthetic elements through the three-level coding of grounded theory, classified esthetic needs using the KANO model, and prioritized esthetic feature elements using the Analytic Hierarchy Process (AHP), forming a scientifically rigorous analytical framework. Based on the AHP analysis results, this study selected the top 10 elements by weight to construct the esthetic feature dimensions of blue-and-white porcelain, specifically including the following: M4. Traditional Auspicious Symbols, M1. Botanical Patterns, M5. Symbolic Meanings, O5. Structural Features, A5. Kiln Variation Effects, O4. Line Smoothness, O2. Layering, A7. Natural Themes, O6. Handmade Painting, and A2. Landscape Patterns. These core dimensions not only reflect the traditional cultural genes of blue-and-white porcelain but also highlight its significant esthetic value in modern design.

The construction of the feature library relies on a multidimensional esthetic feature theoretical model, with each dimension containing sub-models that meticulously document their attributes and logical relationships. The key attributes of these dimensions are supplemented and validated using high-quality physical data and image resources. To enhance the completeness and authority of the feature library, the research team extracted pattern data from blue-and-white porcelain artifacts spanning different historical periods and regions. They also collaborated with the China Pattern Online Museum to collect 375 high-resolution blue-and-white porcelain pattern images, as shown in Figure 5. These data resources not only encompass the diversity of blue-and-white porcelain esthetic characteristics but also provide a solid foundation for innovative design and sustainable cultural heritage preservation.

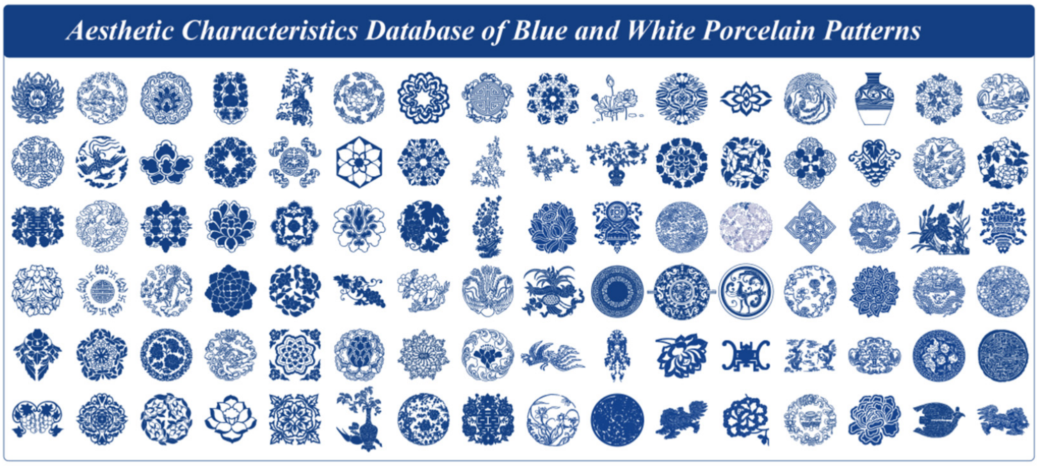

Figure 5. Blue-and-white porcelain pattern esthetic feature dataset based on hybrid research model.

This esthetic feature library was used as the raw sample data for AIGC experimental training. By inputting filtered and structured high-quality data into the AIGC model, the core esthetic characteristics of blue-and-white porcelain patterns can be efficiently reproduced, enabling innovative designs based on these features. In subsequent experiments, AIGC technology, through deep learning of the feature library, can not only accurately reproduce the traditional esthetic patterns of blue-and-white porcelain but also generate innovative patterns with a modern design sensibility.

4.2. Blue-and-White Porcelain LoRA Model Training

In the study of cultural gene inheritance and innovative design of blue-and-white porcelain patterns, Generative Adversarial Networks (GANs) offer an unprecedented method for automatically generating high-quality pattern images. This study utilized the esthetic feature library of blue-and-white porcelain patterns as the data foundation and trained a Stable Diffusion (SD) deep learning model. Stable Diffusion is a powerful image generation tool that can run locally for free. Currently, multiple online services allow users to access different versions of SD, such as DreamStudio (https://dreamstudio.ai/ accessed on 10 February 2025), Stable Diffusion Online (https://stablediffusionweb.com/ accessed on 10 February 2025), Hugging Face (Stable Diffusion 2-1-stabilityai Hugging Face Space), and Stable Diffusion WebUI (GitHub—AUTOMATIC1111/stablediffusion-webui) [80]. In the digital and innovative research of blue-and-white porcelain patterns, we used the Stable Diffusion WebUI interface to generate the required research images.

As shown in Figure 6, the LoRA model training was supported with Kohya_ss (v24.1.7), a community-developed comprehensive toolkit for training, fine-tuning, and optimizing large-scale language models (LLM) and diffusion models [81]. A total of 375 complete blue-and-white porcelain pattern examples from the esthetic feature library were selected to train the LoRA model in Kohya_ss. All image dimensions were standardized to 512 $\times$ 512 pixels to ensure clarity, and data augmentation techniques such as random rotation, scaling, and horizontal flipping were applied to enhance the model's learning performance. Subsequently, the 375 high-quality blue-and-white porcelain patterns were annotated with descriptive text labels for each image. In using the Stable Diffusion text-to-image generation model, constructing the "Prompt" is a crucial step. This study employed the BLIP (Bootstrapping Language-Image Pre-training) captioning tool, which is integrated into the Kohya framework. During LoRA model training, the model can generally recognize and generate the visible external features of blue-and-white porcelain patterns, such as tonal depth, line smoothness, geometric pattern arrangements, and detailed overall form representation. However, these features are primarily reflected on the visual level, while capturing and reproducing the deeper cultural connotations, artistic symbolism, and specific stylistic elements of blue-and-white porcelain remain relatively insufficient.

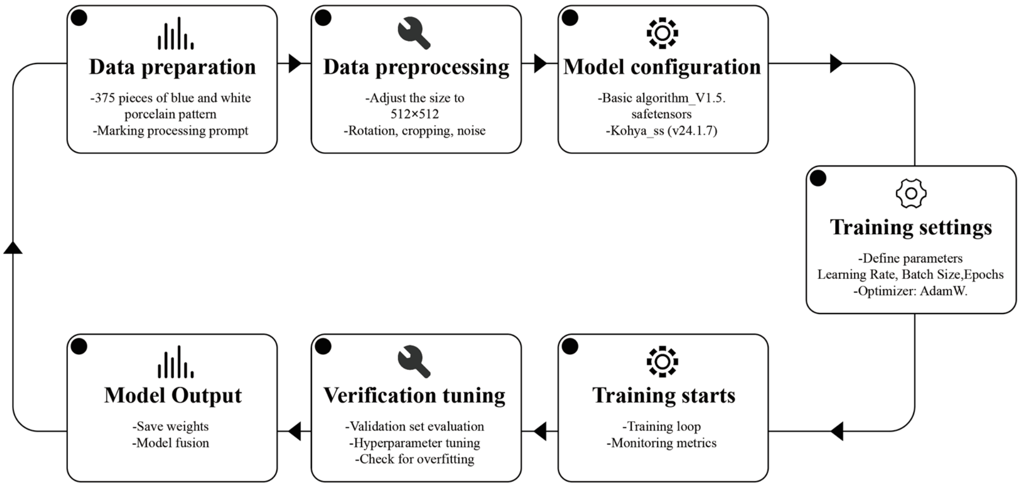

Figure 6. LoRA training research process.

Therefore, during the training of the LoRA model, dynamic adjustments to the training data were required, as shown in Tables 9 and 10. Training parameters were optimized based on the morphological and detailed characteristics of blue-and-white porcelain patterns. The batch size was set to 4, with a checkpoint saved every 10 epochs out of 100 epochs. The clip_skip parameter was set to 2 to enhance detail capture during the image generation process, achieving a balance between detail retention and model diversity performance. To save memory, the precision was set to fp16, and the learning rate was set to 0.0001, ensuring stable and efficient training [82]. The objective of this study was to verify style training. Minimal manual adjustments were made to the annotations, and the term "blue-and-white porcelain" was added as a prompt to guide the model without disrupting its learning process.

Table 9. Lora training parameters (1).

Dataset Size	Resolution	Batch Size	Max Epochs	Save Everyn Epochs	Network Dim	Network Alpha	Clip Skip	LR	UNet LR
275	512 × 512	2	8	2	64	2	2	0.0001	0.0001

Table 10. Lora training parameters (2).

Text Encoder	LR LR Scheduler	LR Restat Cycles	Persistent Dataloader Workers	Noise Offset	LoCon Conv Dim	Conv Alpha	Approx. Training Time
0.0001	cosine_ with_ restarts	1	2	0.1	4	0.1	1

4.3. Blue-and-White Porcelain Pattern Innovation Design Workflow

This study developed an innovative design workflow for blue-and-white porcelain patterns based on artificial intelligence-generated content (AIGC), as shown in Figure 7. It integrates the Stable Diffusion (SD) model, Low-Rank Adaptation (LoRA) technology, and optimized text generation guidance, offering an efficient and flexible solution for the digital inheritance and modern innovative design of blue-and-white porcelain patterns. Through this workflow, designers can rapidly simulate and evaluate innovative blue-and-white porcelain design Plan without relying on physical resources, promoting the innovative application of traditional craftsmanship in the digital era.

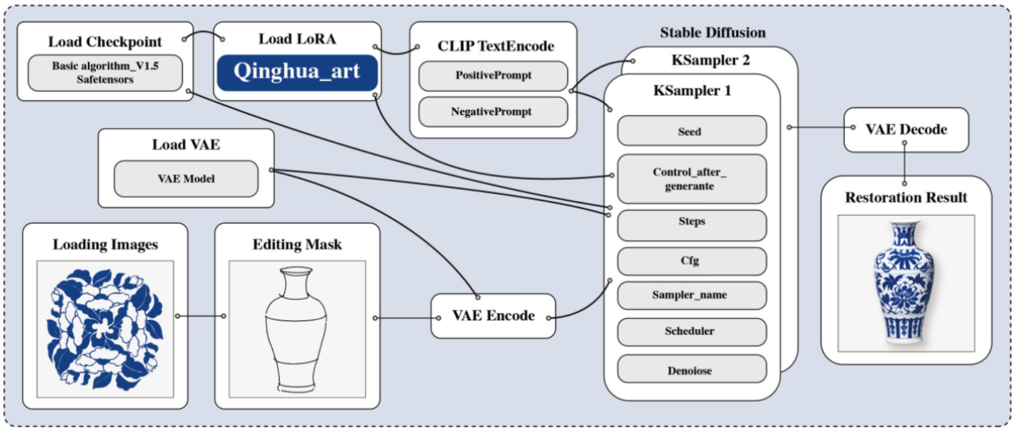

Figure 7. Blue-and-white porcelain innovative design workflow based on Comfy UI.

First, the workflow adopts a Stable Diffusion model suitable for generating blue-and-white porcelain patterns, such as the version "dreamshaper_8inpainting", and activates the visual autoencoder (VAE) model "vae-ft-mse-840000-ema-ptrimed" to enhance the precision and diversity of the generated images. Additionally, the specially trained LoRA model "Qinghua_art" was loaded, with the LoRA intensity parameter set between 0.9 and 1.0 to balance the requirements between generating complex details and overall performance. This configuration significantly enhances the model's ability to recognize and generate blue-and-white porcelain pattern features. The core of image generation lies in the design and optimization of prompts. This study used the CLIP text encoder to guide the generation process, with forward prompts specifying design requirements, such as "The image showcases a blue-and-white porcelain piece featuring lotus patterns, smooth lines, and a classic form, presented as a high-resolution photographic artwork". Meanwhile, reverse prompts were used to exclude unwanted features, such as "low resolution, noise, watermarks, or inappropriate content", ensuring the precision and high quality of the generated images. Experiments revealed that overly complex prompts might lead to overfitting or deviations in model outputs. Therefore, prompt design must strike a balance between simplicity and detailed description, accurately expressing pattern design requirements while avoiding excessive constraints on the model's generative flexibility.

To optimize the generation results, the workflow employs a dual-sampler (KSampler) configuration to control randomness and consistency during the generation process. KSampler (1): The step range was set between 60 and 100, the Classifier-Free Guidance (cfg) value was 8.0, the denoising strength was 0.92, the sampler adopted the Denoising Diffusion Probability Model (DPM++ 2M), and the scheduler was configured using Karras. KSampler (2): The step count was reduced to 20, the cfg value was lowered to between 4 and 7, and the denoising strength was adjusted to between 0.2 and 0.3 to quickly generate pattern samples for preliminary evaluation.

The dual-sampler configuration enables blue-and-white porcelain pattern designs of varying complexity to achieve a dynamic balance between detail and overall performance. Experimental results show that simple patterns typically meet design requirements in a single generation, while complex patterns require 5 to 8 iterations to achieve optimal results.

4.4. Developing Innovative Design Pathways for Blue-and-White Porcelain by Integrating Sustainable Design Theory

In recent years, the continuous intensification of global resource consumption and environmental pressure has made it imperative for the design field to integrate sustainable development principles into the innovative design of traditional cultural arts [83]. The digitization of traditional cultural genes and the rise of artificial intelligence-generated content (AIGC) technology have opened up new possibilities for the sustainable and innovative design of cultural heritage [84].

The core objective of this study was to explore specific methods for integrating sustainable design principles with blue-and-white porcelain creation. Through generative artificial intelligence (AIGC) technology, particularly the LoRA model on the Stable Diffusion platform, efficient virtual reproduction and simulation of diverse blue-and-white porcelain design Plan can be achieved. Designers can rapidly generate and evaluate multiple blue-and-white porcelain design Plan without consuming physical resources, significantly reducing the carbon footprint of the design process. This approach not only effectively preserves and reproduces the core esthetic elements of blue-and-white porcelain but also innovatively adjusts its functionality and form to meet the diverse needs of modern living environments, providing a new pathway for the digital inheritance and sustainable design of blue-and-white porcelain esthetic characteristics.

4.4.1. Application of Sustainable Design Theory

In the current global context, characterized by climate change and the depletion of natural resources, sustainability has become a core issue in the field of design [14]. This trend has prompted designers to reconsider and redefine the standards of "high-quality design" to balance environmental, social, and economic benefits [14]. Tracy Bhamra's concept of "Design for Sustainable Behaviour" (DfSB) provides an important methodology for achieving this goal. DfSB aims to actively guide and influence consumer behavior through carefully considered product design, reducing negative environmental and social impacts. This concept goes beyond the traditional definition of design, focusing not only on product appearance and functionality but also on the role of design in shaping user behavior and habits.

Sustainable design strategies within the DfSB framework primarily include several key aspects, aiming to guide user behavior and reduce environmental and social impacts through optimized product design:

- Behavioral Constraints: Design the physical characteristics of products to make it easier for users to adopt sustainable behaviors during usage.
- Behavioral Promotion: The design can encourage users to adopt more sustainable behaviors.
- Information Communication: Provide clear information and guidance on sustainable usage within the product, helping users understand the environmental impact of their behavior and raising their environmental awareness.
- User Participation: Encourage users to participate in the product design process, allowing them to customize products based on their needs and habits, thereby improving efficiency and sustainability.

- Habit Formation: Make sustainable behaviors more convenient and automated through design, helping users form new and more sustainable usage habits.
- Contextual Design: Consider the user's usage context and design products suitable for specific environments and cultural backgrounds to better meet user needs and promote sustainable behavior.
- Feedback Mechanism: Incorporate feedback mechanisms into product design, enabling users to understand the impact of their usage behavior in real time.

These principles are interrelated and collectively form the foundational framework of sustainable design. Based on DfSB theory, this study integrates its principles with the esthetic characteristics of blue-and-white porcelain, exploring innovative pathways for the fusion of traditional craftsmanship and modern sustainable design. This study not only advances the digitalization and modernization of cultural heritage design practices but also provides theoretical and practical references for the application of sustainable behavior design in the field of traditional arts.

4.4.2. Sustainable Innovative Design Process for Blue-and-White Porcelain Esthetic Characteristics

As an artistic medium integrating traditional cultural elements with modern esthetics, blue-and-white porcelain has become a significant research area for cultural heritage preservation and sustainable design innovation. Based on the principles of sustainable development, this study utilized generative artificial intelligence (generative AI) tools to construct a sustainable innovative design model for blue-and-white porcelain, exploring a novel pathway for its modernization (as shown in Figure 8). The innovative design process comprises five core stages: "Design Object Research", "User Needs Analysis", "Large Model Training", "Concept Design and Creative Development", and "Sustainable Design Integration". With environmental responsibility as its core orientation and user needs as the design center, this study aimed to achieve an organic integration of traditional esthetic elements with innovative design. It not only provides an operational framework for the modernization of blue-and-white porcelain creation but also offers theoretical support for cross-disciplinary research in cultural heritage and sustainable design.

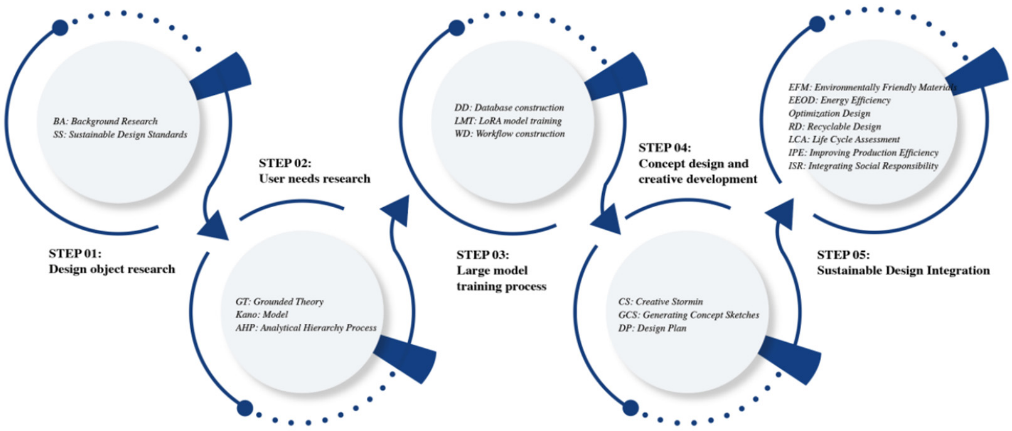

Figure 8. The innovative design process of blue-and-white porcelain.

STEP 01: Research on Design Objects

This phase serves as the foundation of the entire design process, aiming to deeply understand the historical background of blue-and-white porcelain culture and its potential application in modern sustainable design. Through a systematic study of the historical evolution and cultural value of blue-and-white porcelain, its unique status and significance in traditional Chinese craftsmanship are clarified. This research focuses on the key characteristics of blue-and-white porcelain patterns, including traditional auspicious symbols, botanical motifs, and their symbolic meanings, with a comprehensive analysis of their cultural connotations. Additionally, by dynamically evaluating modern living environments and consumer needs, this study explored how to balance traditional craftsmanship with contemporary esthetics, laying a solid theoretical and practical foundation for innovative design in blue-and-white porcelain.

STEP 02: User need research

The user need research aimed to deeply understand the preferences, behavior patterns, and specific requirements of target users regarding blue-and-white porcelain pattern design. This stage integrates grounded theory, the KANO model, and the AHP analytical method to ensure the scientific rigor and systematic nature of the user need research, providing data support and theoretical foundations for subsequent design development.

In the user need research, grounded theory was employed as the theoretical foundation for constructing the cultural genetic characteristics of blue-and-white porcelain. Through open coding, user feedback related to blue-and-white porcelain pattern design was extracted from interviews and questionnaires, identifying key concepts such as cultural heritage, esthetic preferences, and modern application needs. Subsequently, axial coding was used to clarify the causal relationships between core concepts and various factors, followed by selective coding to integrate all categories, thereby constructing a comprehensive user needs framework for blue-and-white porcelain. This process not only ensured the comprehensiveness and depth of user feedback but also provided a solid foundation for the quantitative analysis of user needs.

The KANO model was employed in this study to classify and interpret user need types, analyzing the specific impacts of different needs on user satisfaction. Basic needs encompass the cultural reproduction of traditional blue-and-white porcelain patterns, such as botanical motifs and geometric symbols, where the fulfillment of these needs directly affects users' fundamental expectations. Performance needs are proportional to users' satisfaction with functionality and esthetic value, such as tonal gradation and symmetry in design. Excitement needs emphasize the integration of modern innovative designs with traditional elements, and fulfilling these needs can significantly enhance users' sense of surprise and satisfaction with their experience. The application of the KANO model not only clearly delineated the types of user needs but also provided a basis for further prioritization of these needs.

The Analytic Hierarchy Process was utilized to quantitatively analyze the importance of user needs by constructing a hierarchical structure model. First, a hierarchical model comprising the goal layer, criterion layer, and sub-criterion layer was established. Experts were then invited to conduct pairwise comparisons and assign scores to the demand elements, with consistency checks performed to ensure the logical soundness and reliability of the data. Finally, the weight distribution of each demand feature was determined, providing scientific guidance for prioritizing critical elements in the innovative design of blue-and-white porcelain. The application of this method enabled the design Plan to precisely align with user needs while achieving a dynamic balance between cultural heritage and modern innovation.

STEP 03: Large-model training process

This study utilized a multidimensional esthetic feature library of blue-and-white porcelain to select 375 high-quality pattern images. After data cleaning, standardization (512×512 pixels), and data augmentation (rotation, scaling, and flipping), descriptive texts were generated using the BLIP tool. These were manually refined to form a high-quality prompt label set, providing precise semantic support for model training. LoRA model training was conducted based on the Stable Diffusion framework, utilizing the "Kohya_ss" tool to optimize the specialized "qinghua_art" model. Parameter settings such as a learning rate of 0.0001 and Clip Skip set to 2 enhanced the model's ability to recognize and generate patterns. Parameter tuning enabled the model to achieve a balance between detail capture and overall style expression, demonstrating excellent performance in tone, lines, and form. It is also recommended to introduce multimodal data to better capture the deeper cultural connotations and artistic features of blue-and-white porcelain.

To ensure the efficiency and controllability of the training and generation processes, this study introduced the visualization workflow tool ComfyUI, which enabled full-process management from data loading and model training to image generation through modular configuration. With the aid of well-designed forward and backward prompts, the model precisely focused on the core esthetic features of blue-and-white porcelain while filtering out irrelevant elements, thereby reducing the risk of overfitting. Additionally, the dual KSampler configuration balanced the detail and speed of image generation, with complex patterns requiring five to eight iterations to achieve optimal results, while simple patterns typically met requirements in a single iteration. The flexibility of ComfyUI not only supported the rapid experimentation and optimization of design Plan but also dynamically adjusted parameters and strategies through real-time feedback, improving model training efficiency and the quality of the final outputs.

STEP 04: Concept design and creative development

This research phase focuses on exploring the integration of esthetic elements of blue-and-white porcelain with modern design innovation. The research team conducted in-depth brainstorming sessions to stimulate diverse design thinking, resulting in the preliminary development of several sets of creative concept sketches. Subsequently, these creative outputs were imported into the Comfy UI workflow for iteration and optimization, maximizing the potential of computer-aided design to validate and refine the feasibility of the proposals. Through continuous refinement and meticulous improvement, innovative design solutions were ultimately developed that integrate the classical esthetic qualities of blue-and-white porcelain with modern esthetic requirements.

Therefore, the integration of Stable Diffusion and LoRA technologies has significantly enhanced the creative process, enabling both the precise reproduction and innovation of blue-and-white porcelain patterns. Drawing on the research by Wong, M. F et al. [85] on AI-assisted programming and the evaluation of large language models trained on code via the OpenAI Codex, the authenticity of traditional blue-and-white porcelain artistic styles has been preserved while also fostering the generation of novel and innovative designs.

To better evaluate the practical effectiveness of sustainable innovative design concepts for blue-and-white porcelain, the research team, based on the framework of innovative design theory, selected the most representative elements of blue-and-white porcelain as research objects. These included the Yuan Dynasty blue-and-white "fish and algae" patterned platter, the blue-and-white "cloud and dragon" patterned elephant ear vase, and the blue-and-white "entwined peony with cloud shoulder pattern" lidded plum vase. Using generative AI tools, we created two sets of blue-and-white porcelain conceptual design Plan, referred to as Plan A and Plan B (see Figure 9). Plan A utilized esthetic feature prompts for blue-and-white porcelain, the LoRA low-rank model, and ControlNet technology. In contrast, Plan B was generated based solely on simple prompts related to blue-and-white porcelain.

To ensure the academic rigor and practical value of the research findings, we invited three types of evaluators to assess the design proposals: one inheritor of the intangible cultural heritage of blue-and-white porcelain, three professors specializing in art and design, and ten doctoral students specializing in ceramic and product design. The evaluation process focused on multiple dimensions, including the esthetic characteristics of blue-and-white porcelain patterns, cultural heritage transmission, innovation, functionality, sustainability, technical controllability, user satisfaction, and market adaptability. A systematic and comprehensive analysis was conducted (see Tables 11 and 12 for details).

Figure 9. AIGC conceptual design plans for blue-and-white porcelain: Plan A and Plan B.

Table 11. Comparative evaluation of Plan A and Plan B across multiple dimensions.

No.	Evaluation Dimension	Average Score of Plan A	Average Score of Plan B
1	Can the aesthetic characteristics of blue-and-white porcelain patterns be accurately reproduced?	4.31	3.91
2	Can the historical and cultural connotations of blue-and-white porcelain be effectively inherited?	3.78	3.54
3	Can innovation be demonstrated?	4.28	3.87
4	How does it perform in terms of functionality?	3.15	2.98
5	Is it integrated with sustainable design principles?	3.24	3.19
6	Is the technical implementation and controllability of AIGC technology effective?	4.07	3.15
7	How is user satisfaction with the AI-generated design Plan?	4.51	3.77
8	Does the AI-generated design Plan have strong market adaptability?	3.98	3.22

Table 12. Expert preference assessment for design plan A and plan B.

Description	Choice	Frequency	Percentage
From the perspective of inheritance of aesthetic characteristics and sustainable design of blue-and-white porcelain, which design do you think better represents the aesthetic characteristics of blue-and-white porcelain?	Plan A	9	64.2%
	Plan B	5	35.7%
From the perspective of contemporary porcelain aesthetics, which design do you prefer?	Plan A	11	78.5%
	Plan B	4	28.5%

From the perspective of the cultural gene inheritance and sustainable design of blue-and-white porcelain, Plan A better expresses the esthetic characteristics of blue-and-white porcelain patterns, accounting for 64.2%. From the perspective of contemporary porcelain esthetics, Plan A is also more favored, accounting for 78.5%. Although Plan B scored lower in both dimensions, a significant portion of respondents still believed that its design reflects certain esthetic characteristics of blue-and-white porcelain and contemporary design esthetics, accounting for 35.7% and 28.5%, respectively.

Comprehensive evaluation results show that Plan A excels in appearance design and thematic alignment. In particular, it successfully showcases the dynamic beauty of classic blue-and-white porcelain elements such as the "Fish and Algae Pattern" and the "Cloud and Dragon Pattern", achieving a high level of visual alignment with the esthetic characteristics of Yuan Dynasty blue-and-white porcelain patterns. In contrast, Plan B shows obvious shortcomings in reproducing the esthetic characteristics of blue-and-white porcelain patterns. The generated images have lower alignment with the preset theme, and the control over shapes and patterns is relatively weak. This indicates that, under current technical conditions, Plan A demonstrates a more mature performance in cultural inheritance and innovation. Meanwhile, Plan B requires further optimization to improve the accuracy of reproducing the esthetic characteristics of blue-and-white porcelain and to enhance the overall cultural connotation of the works. Looking ahead, we will build upon the technological and methodological advantages of Plan A to develop creation strategies that better align with the esthetic characteristics of blue-and-white porcelain.

STEP 05: Integration of Sustainable Design

In the innovative design practice of blue-and-white porcelain, deeply integrating sustainable principles into the design process is a key step in achieving cultural heritage preservation and fulfilling modern responsibilities. This study approached sustainable design through six key directions—environmentally friendly materials (EFMs), Energy-Efficient Optimized Design (EEOD), Recyclable Design (RD), Life Cycle Assessment (LCA), Improved Production Efficiency (IPE), and Integration of Social Responsibility (ISR)—providing systematic strategic support for sustainable blue-and-white porcelain design.

First, selecting low-carbon, renewable, and biodegradable raw materials, while considering their environmental impact throughout their lifecycle, serves as the foundation for achieving sustainable design in blue-and-white porcelain. In environmentally replacing or modifying traditional materials such as clay and glaze, the excessive consumption of natural resources during production can be significantly reduced while improving the environmental friendliness of the final product [50]. Second, introducing energy-saving technologies and process optimization strategies in blue-and-white porcelain production is essential for reducing energy consumption and greenhouse gas emissions, effectively improving energy efficiency throughout the production process [86]. Third, ensuring that blue-and-white porcelain products can be efficiently recycled and reused after their service life ends is crucial. With the improvement of structural design and connection methods, products can be easily disassembled, sorted, and reused after damage or retirement, thereby reducing the environmental burden caused by ceramic waste [87]. Fourth, conducting a quantitative environmental impact analysis throughout the lifecycle of blue-and-white porcelain products, from raw material acquisition, production, transportation, and usage to final disposal, helps identify high-environmental-burden stages and propose optimization strategies [88]. Through Life Cycle Assessment (LCA), the environmental impact of each design decision can be precisely evaluated, providing scientific support for improvement strategies and ensuring the ecological competitiveness of blue-and-white porcelain in the global market. Fifth, optimizing manufacturing processes and supply chain management reduces energy and material consumption at intermediate stages, enhances economic benefits for enterprises, and promotes green manufacturing practices [89]. Finally, reinforcing social responsibility in design combines environmental protection principles with cultural dissemination, guiding consumers to recognize the environmental and cultural value. By emphasizing environmental protection, cultural heritage, and community engagement in product design, packaging, and marketing strategies, consumer environmental awareness can be enhanced, encouraging green consumption and establishing a strong brand image for blue-and-white porcelain in international markets [53].

5. Results and Discussion

This section will provide an in-depth analysis of the research results, exploring the application of AIGC technology in blue-and-white porcelain creation and its impact on cultural heritage preservation. This study is grounded in grounded theory and the Kano-AHP hybrid model, combined with AIGC image generation technology. Using blue-and-white porcelain as the research subject, this study systematically and scientifically explored the esthetic characteristics of porcelain patterns, constructed a multidimensional esthetic feature database for blue-and-white porcelain patterns, and applied AIGC technology to preserve traditional esthetics while promoting the effectiveness of innovative and sustainable design methods.

Research Outcome 1: Esthetic Element Dataset of Blue-and-White Porcelain Patterns Based on Grounded Theory and the KANO-AHP Hybrid Model

This study establishes an esthetic element dataset of blue-and-white porcelain patterns. Based on grounded theory, the KANO-AHP hybrid model qualitatively collects and quantitatively analyzes the esthetic characteristics of blue-and-white porcelain patterns. The dataset comprehensively describes the design elements of blue-and-white porcelain patterns from multiple perspectives, including cultural inheritance, esthetic value, functionality, and specific patterns. These raw data can serve as precise original samples for training large generative AI models, significantly enhancing AI training efficiency. Through the blue-and-white porcelain pattern database, generative AI (Stable Diffusion ComfyUI) can accurately replicate the esthetic characteristics of blue-and-white porcelain patterns and initiate innovative designs based on these features. Furthermore, the establishment of the blue-and-white porcelain pattern database provides valuable resources for designers and researchers, assisting them in creating new designs or replicating traditional blue-and-white porcelain.

Research Outcome 2: Utilizing AIGC Technology to Construct a Blue-and-White Porcelain Design Workflow and Reproduce Traditional Esthetics

By developing a dedicated AIGC design workflow for blue-and-white porcelain patterns, this study achieves the digital reproduction of traditional blue-and-white porcelain esthetics in modern design. The workflow integrates the Stable Diffusion model, LoRA technology, and optimized text prompts, effectively addressing the challenge of preserving traditional blue-and-white porcelain esthetics in a modern design context. Its core lies in leveraging structured esthetic feature data and efficient model training methods to ensure the generated works accurately reproduce the detailed features and esthetic connotations of blue-and-white porcelain patterns. This workflow ensures that the generated results meet design requirements while maintaining high artistic quality and traditional esthetic characteristics through well-structured text prompts and dual large language model configurations. Designers can utilize this tool to quickly capture the essence of blue-and-white porcelain patterns while integrating modern design concepts, endowing their works with a contemporary feel and diversity. This method not only enhances the efficiency of blue-and-white porcelain design innovation but also improves the adaptability of traditional craftsmanship, providing technological support for the inheritance and innovation of traditional blue-and-white porcelain culture.

Furthermore, through the AIGC design workflow for blue-and-white porcelain, this study further explores pathways for integrating tradition with modernity, promoting the regeneration and expansion of blue-and-white porcelain culture in the context of the new era. This integration model not only enhances the cultural value of modern design but also provides methodological support for the sustainable development of traditional craftsmanship innovation.

Research Outcome 3: Research Pathway and Sustainable Design Innovation

AIGC technology provides an innovative pathway for cultural gene inheritance and sustainable design. This study focuses on the inheritance of blue-and-white porcelain cultural genes and sustainable design, constructing a novel research model based on AIGC technology, combined with grounded theory and the KANO-AHP hybrid model for empirical research. This research focuses on integrating traditional blue-and-white porcelain elements with modern esthetics while strictly adhering to sustainable development principles, thereby forming a novel sustainable design pathway.

The entire design process was divided into five stages. First, an in-depth study of the design object was conducted using grounded theory to extract the core cultural genes and esthetic elements of blue-and-white porcelain. Second, the KANO-AHP hybrid model was employed to analyze user requirements and clarify the design direction. Next, during the conceptual design and creative development phase, an AIGC-based cultural gene inheritance database and design workflow were constructed, significantly shortening creation time and iteration cycles. Subsequently, sustainable design principles were integrated into the design process to enhance environmental compatibility, ultimately achieving intelligent design and production.

As shown in Table 13, compared to traditional blue-and-white porcelain design pathways, the sustainable innovative design model proposed in this study achieves significant improvements in multiple aspects, including design concepts, material selection, design tools, design processes, production processes, user participation, environmental impact, and sustainable innovation design. This systematic study validates the application value of AIGC technology in the inheritance of blue-and-white porcelain cultural genes and sustainable design, providing a referential theoretical framework and practical methodology for integrating traditional culture with modern technology.

In this study, the application of AI technology, particularly generative AI based on Stable Diffusion and LoRA, to the creation of blue-and-white porcelain was explored. Additionally, its impact on traditional craftsmanship and modern porcelain production was analyzed. This study found that modern porcelain production can leverage generative AI-assisted design to rapidly generate multiple design options, significantly enhancing creative efficiency and customization capabilities. In contrast, traditional blue-and-white porcelain production relies on hand-drawing and artisans' expertise, placing greater emphasis on brushstroke details and the uniqueness of craftsmanship. Rather than being in opposition, these two approaches complement each other in esthetic expression and production processes. Furthermore, in terms of creative approach, generative AI can rapidly produce multiple design variations, offering diverse inspiration for artisans and designers, whereas traditional craftsmanship prioritizes personalized techniques and esthetic expertise accumulated over time. Additionally, in the production process, modern creators can utilize AI to quickly test different styles, color combinations, and layout designs. However, artisans are still required to complete crucial steps such as firing and glazing, preserving the esthetic essence of traditional craftsmanship. Finally, in terms of creativity and heritage, this human–machine collaboration model enables the harmonious integration of traditional craftsmanship and modern technology. It not only ensures the preservation of the classic essence of blue-and-white porcelain but also facilitates its innovative expression in new markets and contexts. Consequently, modern porcelain creators and traditional artisans form a collaborative relationship, with generative AI empowering creativity and artisans ensuring the flawless execution of quality during production. Together, they contribute to the continuous transmission and evolution of blue-and-white porcelain craftsmanship.

At the same time, to assess the role of AIGC in the preservation and transmission of cultural heritage, future studies will aim to develop multidimensional metrics to evaluate the effectiveness of technological interventions. The first metric is Esthetic Fidelity, which measures the degree of similarity between AI-generated patterns and traditional handmade designs in terms of form, lines, and colors, thus evaluating their ability to restore the "cultural gene" of blue-and-white porcelain. The second metric is Adoption Rate, which assesses how many designers and intangible cultural heritage practitioners are willing to incorporate AI-assisted tools into their creative processes. Surveys and interviews will be conducted to gather feedback on aspects such as efficiency and inspiration. Lastly, Public Engagement will be evaluated based on the attention, interaction, or sales data of AI-assisted blue-and-white porcelain works on public media, exhibitions, or new media platforms in order to gauge public acceptance of digital heritage transmission forms.

Table 13. Comparative analysis of traditional blue-and-white porcelain creation and AIGC sustainable innovative design model.

Comparison Dimensions	Traditional Blue-and-White Porcelain Design Model	AIGC Sustainable Innovative Design Model for Blue-and-White Porcelain
Design Concept	Emphasizes the inheritance of historical and cultural symbols and traditional esthetic values, with limited consideration for sustainability.	Through the integration of AIGC technology into the design process, this approach blends blue-and-white porcelain elements with contemporary esthetics, emphasizing cultural diversity and sustainable development.
Material Selection	Heavily relies on traditional materials, with insufficient attention to low-carbon and environmental standards.	Systematically evaluates the ecological footprint of materials, prioritizing low-carbon, recyclable, and environmentally friendly materials to reduce carbon emissions during production.
Design Tools	Depends on traditional methods such as hand-drawing and manual modeling, resulting in longer design cycles.	Utilizes large-scale model training and AIGC tools to achieve data-driven and intelligent design, accelerating creative generation and improving design efficiency.
Design Process	The design process is primarily led by master craftsmen, with inadequate research on user needs and a lack of data-driven strategies.	Adopts a systematic and phased design workflow, including in-depth object research, user demand analysis, large-scale model training, conceptual innovation development, and integration of sustainable solutions, emphasizing data-driven approaches aligned with user needs.
Production Process	Production relies mostly on manual craftsmanship, characterized by lengthy, time-consuming processes and high resource consumption.	Implements partial or fully automated and intelligent workflows, optimizing manufacturing steps, improving production efficiency, and reducing resource input.
User Participation	Limited user feedback channels result in insufficient user engagement in the design process.	Applies grounded theory and the KANO-AHP model to analyze user requirements, directly integrating user feedback and preferences into the design process, enhancing user engagement and interactivity.
Environmental Impact	Lacks systematic environmental assessments, with inadequate control over resource consumption and pollution reduction.	Adheres to carbon neutrality principles, adopting strategies such as reduction, reuse, recycling, repair, and redesign to optimize design and manufacturing processes, minimizing environmental impact.
Innovation and Sustainable Design	Innovation is limited, with an emphasis on craftsmanship inheritance while neglecting sustainable development requirements.	Deeply integrates design with sustainability principles, leveraging data analysis and technological iteration to drive the parallel evolution of digitalization and green innovation in blue-and-white porcelain design.

Furthermore, the integration of AIGC with traditional porcelain creation processes has had a profound impact on the industry. First, generative AI has significantly shortened the design cycle during the pattern generation and porcelain creation stages. Secondly, it effectively reduces trial-and-error costs. Although there is an initial investment in model training, once a mature dataset and workflow are established, the marginal cost of subsequent generation and optimization becomes relatively low, thereby reducing research and development risks. Additionally, the potential impact on the labor structure is notable.

While AI does not replace the critical firing and detailed finishing processes performed by artisans, it fosters the emergence of new roles such as cultural heritage digital designers and data/model developers, promoting the diversification of the industry. Overall, the application of AIGC in porcelain creation and production can significantly enhance creative efficiency, enrich esthetic expressions, and expand the industry's value chain, bringing new vitality and opportunities to the development of the blue-and-white porcelain industry.

Finally, the application of AIGC technology in traditional craftsmanship also faces several challenges. Firstly, in terms of data and technological barriers, a large number of high-quality pattern images, technical equipment, and professionals are required. Collaboration with museums and intangible cultural heritage preservation organizations is essential to establish a comprehensive database. Secondly, regarding cultural authenticity and esthetic bias, the training process of generative AI models may result in the misapplication or "collage" of traditional elements. To prevent cultural elements from being misrepresented, a "human–machine collaboration" model must be adopted, involving experts and artisans in reviewing and selecting the generated results. Furthermore, the acceptance of new technology by traditional artisans is a concern. Older artisans may be skeptical or unfamiliar with new technologies. Workshops and demonstration projects should be conducted to allow them to experience firsthand how AI can assist in creativity and improve efficiency, while emphasizing the irreplaceability of traditional craftsmanship. Lastly, regarding intellectual property, when external data are used for model training, legal authorization must be ensured to protect the rights of original creators. Additionally, proper attribution or explanations of pattern sources should be provided in the final products to respect cultural property rights.

Overall, AIGC not only offers enhanced creativity and efficiency for blue-and-white porcelain creation but also introduces new possibilities for cultural heritage preservation. However, it also faces a series of challenges, including data issues, cultural authenticity, artisan acceptance, and copyright concerns. By systematically integrating AI technology with cultural heritage, it is believed that harmonious coexistence with traditional craftsmanship can be achieved in the future, promoting the innovation and transmission of blue-and-white porcelain culture.

6. Conclusions

This study, through the application of AIGC technology, achieved the integration of traditional cultural genes with modern digital innovation, providing a practical and feasible solution for the digital transmission and preservation of cultural heritage, while promoting the sustainable development of blue-and-white porcelain creation. By combining AIGC technology with the cultural genes of blue-and-white porcelain, this study employed the three-level coding method based on grounded theory to extract the multidimensional esthetic characteristics of blue-and-white porcelain, encompassing three core dimensions: visual characteristics, craftsmanship features, and cultural meanings. Through the KANO-AHP hybrid research model, key elements within the esthetic features of blue-and-white porcelain were identified, and a multidimensional esthetic feature dataset of blue-and-white porcelain was successfully constructed, providing significant reference for the accurate transmission of traditional blue-and-white porcelain esthetic elements in contemporary design.

Additionally, the study developed an AIGC-assisted design workflow based on Stable Diffusion and LoRA technologies and, through training on the blue-and-white porcelain esthetic feature database, successfully achieved the efficient reproduction and innovative design of blue-and-white porcelain patterns. AIGC technology not only enhanced design efficiency and expanded creative boundaries but also demonstrated significant advantages in the precise reproduction of traditional esthetic features and their integration with modern design.

The primary contribution of this study lies in the effective integration of AIGC technology with the cultural genes of blue-and-white porcelain, providing an efficient and sustainable solution for the digital transmission and innovation of cultural heritage and promoting the sustainable development of blue-and-white porcelain creation. Furthermore, the constructed blue-and-white porcelain esthetic feature database provides designers with an accessible pathway to traditional patterns, enriching the cultural diversity and esthetic depth of creative products.

Nevertheless, AIGC technology still presents certain limitations, such as insufficient or biased training data, which may lead to discrepancies between generated patterns and the fine details of traditional craftsmanship. This could pose challenges during the actual production process. Future research could further optimize AIGC models to improve the accuracy and diversity of pattern generation and explore ways to integrate these models more closely with traditional craftsmanship processes, thereby enhancing the effectiveness of the technology in cultural heritage preservation.

Author Contributions: Conceptualization, Q.B.; methodology, Q.B.; software, J.Z.; validation, J.Z.; formal analysis, Q.B.; investigation, N.L.; resources, N.L.; data curation, Q.B.; writing—original draft preparation, Q.B.; writing—review and editing, Q.B.; visualization, Q.B.; supervision, J.Z., Z.L. and N.L.; project administration, Q.B.; funding acquisition, Q.B., J.Z., Z.L. and N.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets used during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Fui-Hoon Nah, F.; Zheng, R.; Cai, J.; Siau, K.; Chen, L. Generative AI and ChatGPT: Applications, challenges, and AI-human collaboration. *J. Inf. Technol. Case Appl. Res.* **2023**, *25*, 277–304. [CrossRef]
2. Jin, J.; Yang, M.; Hu, H.; Guo, X.; Luo, J.; Liu, Y. Empowering design innovation using AI-generated content. *J. Engi-Neering Des.* **2024**, *36*, 1–18. [CrossRef]
3. Fan, X.; Wu, Z.; Yu, C.; Rao, F.; Shi, W.; Tu, T. ContextCam: Bridging Context Awareness with Creative Human-AI Image Co-Creation. In Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems, Honolulu, HI, USA, 11–16 May 2024; Association for Computing Machinery (ACM): New York, NY, USA, 2024; Article 157. pp. 1–17.
4. Stoean, R.; Bacanin, N.; Stoean, C.; Ionescu, L. Bridging the past and present: AI-driven 3D restoration of degraded artefacts for museum digital display. *J. Cult. Herit.* **2024**, *69*, 18–26. [CrossRef]
5. Park, C.-W.; Kim, H.-K.; Lee, J.-H. Research on Digital Cultural Heritage Expansion Using AI Technology. In Proceedings of the 2024 Fifteenth International Conference on Ubiquitous and Future Networks (ICUFN), Budapest, Hungary, 2–5 July 2024; IEEE: New York, NY, USA, 2024; pp. 516–519.
6. Ao, J.; Li, W.; Ji, S.; Chen, S. Maritime silk road heritage: Quantitative typological analysis of qing dynasty export porcelain bowls from Guangzhou from the perspective of social factors. *Herit. Sci.* **2023**, *11*, 263. [CrossRef]
7. Wei, L.; Zhu, D.; Chen, Y. Exploration on the Design Genes of Folk Blue and White Porcelain Decorations. In Proceedings of the International Conference on Art Design and Digital Technology (ADDT 2022), Nanjing, China, 16–18 September 2022; Azman, A.B., Kamarudin, N., Ji, Y., Eds.; European Alliance for Innovation (EAI): Gent, Belgium, 2022; p. 91.
8. Li, J.; Yang, Y.; Zou, D.; Wu, L.; Wu, Q.; Lin, Z.; Li, Q. Recognition of Yuan blue and white porcelain produced in Jingdezhen based on graph anomaly detection combining portable X-ray fluorescence spectrometry. *Herit. Sci.* **2024**, *12*, 79. [CrossRef]
9. Zheng, Q.; Zhu, B.; Cai, Q.; Li, J.; Fang, C.; Wu, N. Extraction method of Yuan blue and white porcelain pattern based on multi-scale Retinex and histogram multi-peak threshold segmentation. *Herit. Sci.* **2024**, *12*, 211. [CrossRef]

10. Ming, Y.; Me, R.C.; Chen, J.K.; Rahmat, R.W.O. A systematic review on virtual reality technology for ancient ceramic res-toration. *Appl. Sci.* **2023**, *13*, 8991. [CrossRef]
11. Wu, J.; Cai, Y.; Sun, T.; Ma, K.; Lu, C. Integrating AIGC with design: Dependence, application, and evolution—A systematic literature review. *J. Eng. Des.* **2024**, 1–39. [CrossRef]
12. Hu, Y. Research on the Design Method of Traditional Decorative Patterns of Ethnic Minorities under the Trend of AIGC. *J. Electron. Inf. Sci.* **2023**, *8*, 58–62.
13. Ma, W.; Chubotina, I. Regeneration of the design of weaving and embroidery patterns based on artificial intelligence tech-nologies. *Art Des.* **2024**, *3*, 65–74. [CrossRef]
14. Wang, Y.; Xi, Y.; Liu, X.; Gan, Y. Exploring the Dual Potential of Artificial Intelligence-Generated Content in the Esthetic Reproduction and Sustainable Innovative Design of Ming-Style Furniture. *Sustainability* **2024**, *16*, 5173. [CrossRef]
15. Jie, H.Y.; Halabi, K.N.M. Research on The Inheritance and Innovation of Blue and White Porcelain from The Perspective of Cultural and Creative Products. *Int. J. Acad. Res. Bus. Soc. Sci.* **2024**, *14*, 1577–1588. [CrossRef] [PubMed]
16. Schoenung, J.M.; Olivetti, E.A.; Editors, G. Sustainable development of materials: Broadening stakeholder engagement. *MRS Bull.* **2023**, *48*, 362–367. [CrossRef]
17. Zhu, Z.; Ng, D.W.H.; Park, H.S.; McAlpine, M.C. 3D-printed multifunctional materials enabled by artifi-cial-intelligence-assisted fabrication technologies. *Nat. Rev. Mater.* **2021**, *6*, 27–47. [CrossRef]
18. Verganti, R.; Vendraminelli, L.; Iansiti, M. Innovation and design in the age of artificial intelligence. *J. Prod. Innov. Manag.* **2020**, *37*, 212–227. [CrossRef]
19. Wang, X.; He, Z.; Peng, X. Artificial-Intelligence-Generated Content with Diffusion Models: A Literature Review. *Mathematics* **2024**, *12*, 977. [CrossRef]
20. Goodfellow, I.; Pouget-Abadie, J.; Mirza, M.; Xu, B.; Warde-Farley, D.; Ozair, S.; Courville, A.; Bengio, Y. Generative adver-sarial networks. *Commun. ACM* **2020**, *63*, 139–144. [CrossRef]
21. Cao, Y.; Li, S.; Liu, Y.; Yan, Z.; Dai, Y.; Yu, P.; Sun, L. A survey of ai-generated content (aigc). *ACM Comput. Surv.* **2024**, *57*, 1–38. [CrossRef]
22. Du, H.; Li, Z.; Niyato, D.; Kang, J.; Xiong, Z.; Huang, H.; Mao, S. Diffusion-based reinforcement learning for edge-enabled AI-generated content services. *IEEE Trans. Mob. Comput.* **2024**, *23*, 8902–8918. [CrossRef]
23. Lin, H.; Jiang, X.; Deng, X.; Bian, Z.; Fang, C.; Zhu, Y. Comparing AIGC and traditional idea generation methods: Evaluating their impact on creativity in the product design ideation phase. *Think. Ski. Creat.* **2024**, *54*, 101649. [CrossRef]
24. Yin, H.; Zhang, Z.; Liu, Y. The exploration of integrating the midjourney artificial intelligence generated content tool into design systems to direct designers towards future-oriented innovation. *Systems* **2023**, *11*, 566. [CrossRef]
25. Liu, X.; Xu, Y. Exploring the application path of AIGC technology in the styling design of traditional artifacts: A case study of Song dynasty lacquerware. In Proceedings of the Third International Conference on Electronics Technology and Artificial Intelligence (ETAI 2024), Guangzhou, China, 17–19 September 2024; SPIE: Bellingham, WA, USA, 2024; Volume 13286, pp. 377–387.
26. Le-Nguyen, H.-T. Ethical Dilemmas of AI Perspectives Towards Common Digital Art and Digital Crafting: AI Artistic View on Morality. In *Making Art With Generative AI Tools*; IGI Global: Hershey, PA, USA, 2024; pp. 226–257.
27. Garcia, M.B. The Paradox of Artificial Creativity: Challenges and Opportunities of Generative AI Artistry. *Creat. Res. J.* **2024**, 1–14. [CrossRef]
28. Yang, Q.; Steinfeld, A.; Rosé, C.; Zimmerman, J. Re-examining whether, why, and how human-AI interaction is uniquely difficult to design. In Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, Honolulu, HI, USA, 25–30 April 2020; Association for Computing Machinery (ACM): New York, NY, USA, 2020; pp. 1–13.
29. Fu, R. Application and Expression of White Painting in Yuan Blue and White Ceramic Painting. *Int. J. Educ. Humanit.* **2024**, *14*, 389–391. [CrossRef]
30. Liu, H.; Fu, C.; Li, W. Silk road heritage: The artistic representation of port trading culture in the images of characters in Qing Dynasty Guangzhou export paintings. *PLoS ONE* **2024**, *19*, e0308309. [CrossRef]
31. Finlay, R. *The Pilgrim Art: Cultures of Porcelain in World History*; University of California Press: Berkeley, CA, USA, 2010; pp. 1–352.
32. Xu, Y.; Puntien, P. Ming Dynasty Blue And White Motifs And Their Influence On Contemporary Painting And Visual Arts. *Mediterr. Archaeol. Archaeom.* **2024**, *24*, 86.
33. Medley, M. *The Chinese Potter: A Practical History of Chinese Ceramics*; Phaidon Press: New York, NY, USA, 1980; pp. 1–288.
34. Clunas, C. *Art in China*; Oxford University Press: Oxford, UK, 1997; pp. 1–248.
35. Fischer, C.; Hsieh, E. Export Chinese blue-and-white porcelain: Compositional analysis and sourcing using non-invasive portable XRF and reflectance spectroscopy. *J. Archaeol. Sci.* **2017**, *80*, 14–26. [CrossRef]
36. Ting, V.W.Y. *Communicating Chinese Ceramics: A Study of Material Culture Theory in Selected Museums in Britain*; University of Leicester (United Kingdom): Leicester, UK, 2008.
37. Zhang, H.; Yang, L. The innovation of traditional ceramic art in modern design. *J. Ceram. Art Des.* **2018**, *37*, 55–62.

38. Aaen-Stockdale, C. Selfish memes: An update of Richard Dawkins' bibliometric analysis of key papers in sociobiology. *Publications* **2017**, *5*, 12. [CrossRef]
39. Lane, J.E. Meme Theory. In *The Routledge Handbook of Evolutionary Approaches to Religion*; Lane, J.E., Ed.; Routledge: London, UK; New York, NY, USA, 2022; pp. 1–8.
40. Cannizzaro, S. Internet memes as internet signs: A semiotic view of digital culture. *Sign Syst. Stud.* **2016**, *44*, 562–586. [CrossRef]
41. West, J. The Selfish Meme: Dawkins, Peirce, Freud. *Semiotica* **2020**, *2020*, 199–213. [CrossRef]
42. Blackmore, S. *The Meme Machine*; Oxford University Press: Oxford, UK, 1999.
43. Cao, J. Innovative application of intangible cultural heritage elements of shadow play in digital field design. In Proceedings of the 2024 International Conference on Culture-Oriented Science & Technology (CoST), Beijing, China, 25–28 August 2024; IEEE: New York, NY, USA, 2024; pp. 137–140.
44. Chen, Z.; Hassan, A.B.; Ghazali, S.S. The Role of Community Education in China in the Transmission of Traditional Culture: A Systematic Literature Review. *Int. J. Acad. Res. Bus. Soc. Sci.* **2024**, *14*, 1–15. [CrossRef] [PubMed]
45. Han, L.; Wang, Y.; Wang, X. Research on the Extraction, Storage and Innovative Design Application of Cultural Relic Genes. In Proceedings of the 2023 International Conference on Culture-Oriented Science and Technology (CoST), Xi'an, China, 11–14 October 2023; pp. 386–390.
46. Debailleux, L.; Hismans, G.; Duroisin, N. Exploring cultural heritage using virtual reality. In Proceedings of the Digital Cultural Heritage: Final Conference of the Marie Skłodowska-Curie Initial Training Network for Digital Cultural Heritage, ITN-DCH 2017, Olimje, Slovenia, 23–25 May 2017; Springer: Berlin/Heidelberg, Germany, 2018; pp. 289–303.
47. Tiribelli, S.; Pansoni, S.; Frontoni, E.; Giovanola, B. Ethics of Artificial Intelligence for Cultural Heritage: Opportunities and Challenges. *IEEE Trans. Technol. Soc.* **2024**, *5*, 293–305. [CrossRef]
48. Gîrbacia, F. An Analysis of Research Trends for Using Artificial Intelligence in Cultural Heritage. *Electronics* **2024**, *13*, 3738. [CrossRef]
49. Margolin, V. Design for a sustainable world. *Des. Issues* **1998**, *14*, 83–92. [CrossRef]
50. Papanek, V. *The Green Imperative: Ecology and Ethics in Design and Architecture*; Thames and Hudson: London, UK, 1995.
51. Thackara, J. *In the Bubble: Designing in a Complex World*; MIT Press: Cambridge, MA, USA, 2005; pp. 1–352.
52. Chapman, J.; Gant, N. *Designers Visionaries and Other Stories: A Collection of Sustainable Design Essays*; Routledge: London, UK, 2007; pp. 1–144.
53. Fuad-Luke, A. *Design Activism: Beautiful Strangeness for a Sustainable World*; Routledge: London, UK, 2009; pp. 1–272.
54. Walker, S. *The Spirit of Design: Objects, Environment and Meaning*; Routledge: Oxfordshire, UK, 2011; pp. 187–190.
55. Obreja, D.M.; Rughiniș, R.; Rosner, D. Mapping the conceptual structure of innovation in artificial intelligence research: A bibliometric analysis and systematic literature review. *J. Innov. Knowl.* **2024**, *9*, 100465. [CrossRef]
56. Rugman, A.M.; D'cruz, J.R. The "double diamond" model of international competitiveness: The Canadian experience. *MIR Manag. Int. Rev.* **1993**, *33*, 17–39.
57. Glaser, B.G.; Strauss, A.L.; Strutzel, E. The Discovery of Grounded Theory; Strategies for Qualitative Research. *Nurs. Res.* **1968**, *17*, 364. [CrossRef]
58. Corbin, J.; Strauss, A. *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*; Sage Publications: Thousand Oaks, CA, USA, 2014.
59. Charmaz, K. *Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis*; Sage: Thousand Oaks, CA, USA, 2006.
60. Bryant, A.; Charmaz, K. Grounded theory in historical perspective: An epistemological account. In *The SAGE Handbook of Grounded Theory*; Sage Publications: Thousand Oaks, CA, USA, 2007; pp. 31–57.
61. Birks, M.; Mills, J. *Grounded Theory: A Practical Guide*; Sage: Thousand Oaks, CA, USA, 2015.
62. Suddaby, R. From the editors: What grounded theory is not. *Acad. Manag. J.* **2006**, *49*, 633–642. [CrossRef]
63. Bowen, G.A. Naturalistic inquiry and the saturation concept: A research note. *Qual. Res.* **2008**, *8*, 137–152. [CrossRef]
64. Kano, N.; Seraku, N.; Takahashi, F.; Tsuji, S. Attractive quality and must-be quality. *J. Jpn. Soc. Qual. Control* **1984**, *14*, 39–48.
65. Chen, C.-C.; Chuang, M.-C. Integrating the Kano model into a robust design approach to enhance customer satisfaction with product design. *Int. J. Prod. Econ.* **2008**, *114*, 667–681. [CrossRef]
66. Berger, C.; Blauth, R.; Boger, D.; Bolster, C.; Burchill, G.; DuMouchel, W. Kano's methods for understanding custom-er-defined quality. *Cent. Qual. Manag. J.* **1993**, *2*, 3–36.
67. Xu, Q.; Jiao, R.J.; Yang, X.; Helander, M.; Khalid, H.M.; Opperud, A. An analytical Kano model for customer need analysis. *Des. Stud.* **2009**, *30*, 87–110. [CrossRef]
68. Saaty, T.L. The analytic hierarchy process (AHP). *J. Oper. Res. Soc.* **1980**, *41*, 1073–1076.
69. Saaty, T.L. How to make a decision: The analytic hierarchy process. *Eur. J. Oper. Res.* **1990**, *48*, 9–26. [CrossRef]
70. Ishizaka, A.; Labib, A. Review of the main developments in the analytic hierarchy process. *Expert Syst. Appl.* **2011**, *38*, 14336–14345. [CrossRef]

71. Zhu, F.; Shao, J. Protection and symbolization innovation of manufacturing process of blue and white porcelain. *Appl. Mech. Mater.* **2012**, *192*, 430–434.
72. Belfrage, C.; Hauf, F. The gentle art of retroduction: Critical realism, cultural political economy and critical grounded theory. *Organ. Stud.* **2017**, *38*, 251–271. [CrossRef]
73. Starks, H.; Brown Trinidad, S. Choose your method: A comparison of phenomenology, discourse analysis, and grounded theory. *Qual. Health Res.* **2007**, *17*, 1372–1380. [CrossRef]
74. Braun, V.; Clarke, V. Using thematic analysis in psychology. *Qual. Res. Psychol.* **2006**, *3*, 77–101. [CrossRef]
75. Liu, Z.; Zhang, W. A qualitative analysis of Chinese higher education students' intentions and influencing factors in using ChatGPT: A grounded theory approach. *Sci. Rep.* **2024**, *14*, 18100.
76. Strauss, A.L. *The Discovery of Grounded Theory: Strategies for Qualitative Research*; Routledge: Oxfordshire, UK, 2017.
77. Allen, I.E.; Seaman, C.A. Likert scales and data analyses. *Qual. Prog.* **2007**, *40*, 64–65.
78. Hartley, J. Some thoughts on Likert-type scales. *Int. J. Clin. Health Psychol.* **2014**, *14*, 83–86. [CrossRef]
79. Hair, J.F.; Black, W.C.; Babin, B.J.; Anderson, R.E. *Multivariate Data Analysis*, 7th ed.; Pearson: Upper Saddle River, NJ, USA, 2009.
80. Rost, M.; Andreasson, S. Stable Walk: An interactive environment for exploring Stable Diffusion outputs. In Proceedings of the HAI-GEN 2023: 4th Workshop on Human-AI Co-Creation (Joint Proceedings of the ACM IUI Workshops 2023), Sydney, Australia, 27–31 March 2023; pp. 89–97.
81. Bmaltais. Kohya's GUI. Available online: https://github.com/bmaltais/kohya_ss (accessed on 10 October 2024).
82. Zhang, X. AI-Assisted Restoration of Yangshao Painted Pottery Using LoRA and Stable Diffusion. *Heritage* **2024**, *7*, 2571–9408. [CrossRef]
83. Tukker, A. Product services for a resource-efficient and circular economy–a review. *J. Clean. Prod.* **2015**, *97*, 76–91. [CrossRef]
84. Rasoolimanesh, S.M.; Seyfi, S.; Hall, C.M.; Hatamifar, P. Understanding memorable tourism experiences and behavioural intentions of heritage tourists. *J. Destin. Mark. Manag.* **2021**, *21*, 100621. [CrossRef]
85. Wong, M.F.; Guo, S.; Hang, C.N.; Ho, S.W.; Tan, C.W. Natural language generation and understanding of big code for AI-assisted programming: A review. *Entropy* **2023**, *25*, 888. [CrossRef]
86. Lu, Q.; Li, C. Comprehensive utilization of Chinese medicine residues for industry and environment protection: Turning waste into treasure. *J. Clean. Prod.* **2021**, *279*, 123856. [CrossRef]
87. Denyer, R. The Re-use and Recycle of Ceramic Materials. *Ceram. Int.* **2013**, *39*, 203–208.
88. Inghels, D.; Inghels, D. Quantification of the Environmental Impact. In *Introduction to Modeling Sustainable Development in Business Processes: Theory and Case Studies*; Springer: Berlin/Heidelberg, Germany, 2020.
89. Dangelico, R.M.; Pujari, D. Mainstreaming Green Product Innovation: Why and How Companies Integrate Environmental Sustainability. *J. Bus. Ethics* **2010**, *95*, 471–486. [CrossRef]