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Research on the Digital Interpretation and Design of Lingnan Xiangyunsha Intangible Cultural Heritage Technique Empowered by AIGC

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Abstract: Based on the theory of image narrative, this study focuses on the three value dimensions of the national intangible cultural heritage project, the Xiangyunsha dyeing and finishing technique: ecological foundation, artistic features, and cultural circulation. It constructs a triple semantic narrative axis of "natural symbiosis - craftsmanship - maritime trade" and explores the multimodal digital display design process in a virtual reality (VR) environment. By using AIGC-assisted image generation, 3D modeling, and immersive interaction design, a digital display system for ecological narrative space, craftsmanship narrative content, and trade narrative scenarios is constructed. This dynamic image narrative in a virtual reality environment not only effectively restores the complete process and cultural context of the Xiangyunsha intangible cultural heritage technique but also enhances users' immersive experience and emotional connection to the intangible cultural heritage value, improving the cross-temporal and spatial dissemination power and public recognition of the intangible cultural heritage value. The "image narrative + AIGC generation + VR immersion" digital display design proposed in this study provides an operational and extensible design framework for the digital revitalization of intangible cultural heritage and has theoretical and practical significance for promoting the innovative dissemination and cultural value reconstruction of intangible cultural heritage.

Keywords: Xiangyunsha; Intangible cultural heritage; Image narrative; Virtual reality; Digital display design

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Introduction

Under the backdrop of the vigorous promotion of the "Digital China" strategy by the state, the digital protection, dissemination and innovative expression of intangible cultural heritage are experiencing unprecedented development opportunities. The "Overall Layout Plan for Digital China Construction" released in 2023 explicitly states that it is necessary to "accelerate the digital layout of the cultural industry and innovate cultural expression methods", emphasizing the empowerment of cultural inheritance through digital technology and the creative transformation and innovative development of intangible cultural heritage projects. Meanwhile, relevant departments such as the Ministry of Culture and Tourism have successively issued policy documents such as the "14th Five-Year Plan for Cultural and Tourism Development" and the "Notice on Promoting the Digitalization of Intangible Cultural Heritage", providing policy support and direction for the digital revitalization of intangible cultural heritage.

As a representative national-level intangible cultural heritage project in the Lingnan region, the "three washes, nine boils and eighteen sunnings" dyeing and finishing technique of Xiangyunsha has a long production cycle and complex procedures, facing difficulties such as being difficult for the public to understand and insufficient inheritance capacity. In recent years, the academic community has conducted multi-dimensional discussions on the intangible cultural heritage (ICH) inheritance and digital protection of Xiangyunsha. Wen Xia and others have conducted sys-

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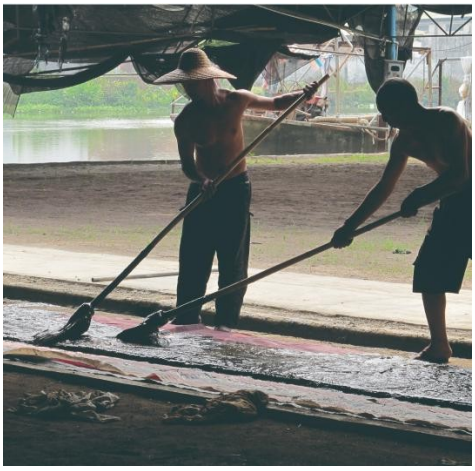


Figure 1 | The "GuoWU" process of Xiangyunsha

Figure 2 | Scene of Xiangyunsha fabric being dried in the sun

tematic research on the digital protection of Xiangyunsha dyeing and finishing techniques. Through field investigations and sample tests, they have established a relatively complete data foundation and visualized process flow, providing a model support for the systematic recording of complex process flows[1]. Bao Lei, from the perspective of sustainable development, emphasizes that Xiangyunsha, as an ICH fabric with an environmental protection concept, its design innovation not only helps cultural inheritance but also promotes its entry into the international fashion context[2].

However, current research still generally focuses on the establishment of digital archives and the analysis of cultural values. Studies on the specific application of image narration in the dissemination of intangible cultural heritage are relatively weak, and there is insufficient exploration of multimodal narration and interaction mechanisms in virtual reality environments. Especially in the dynamic reproduction of the complexity of the Xiangyunsha dyeing and finishing process and the construction of narrative structures, there is a lack of systematic and operational display models.Therefore, this study focuses on the ecological basis, artistic features and cultural circulation value elements of the Xiangyunsha dyeing and finishing technique, and constructs a narrative axis of "natural symbiosis - craftsmanship - maritime silk trade". Then, it uses AIGC to assist in image generation and reproduces the narrative semantics through 3D modeling, and builds an immersive digital display system with the help of virtual reality technology. Through the public experience evaluation of its usability, it realizes the emotional connection between the public and the value of intangible cultural heritage. Thus, it breaks the geographical restrictions to achieve cloud sharing, expands the coverage of the dissemination of Xiangyunsha intangible cultural heritage techniques, and aims to comprehensively demonstrate the narrative attributes of the living inheritance of intangible cultural heritage and provide a demonstrative solution for digital display design.

The Inheritance and Digital Exhibition of The Intangible Cutural Heritage Value of Xiangyunsha

Value elements of intangible cultural heritage skills

As a distinctive intangible cultural heritage of the textile category in the Lingnan region, Xiangyunsha showcases the integrated heritage value of its ecological foundation, fabric artistry, and cultural circulation through the dyeing and finishing technique of "three washes, nine boils, and eighteen sunnings". This dyeing and finishing technique adheres to the traditional Chinese philosophy of "harmony between man and nature", and is produced in the "mulberry pond and fish pond" ecological environment where the people of Lingnan coexist in harmony with nature. The entire production process is highly dependent on natural resources and climatic conditions, demonstrating the artisans' profound understanding of the synergy between time rhythms, environmental changes, and artificial manufacturing. The core "blackening" process (**Figure 1**) uses specific river mud and the juice of the Ipomoea batatas plant to create a natural oxidation reaction, giving the fabric a unique two-sided color and lustrous texture after multiple sunnings, forming an eco-friendly natural dyeing and finishing system. The sunning process follows the natural solar terms and time rhythms, reflecting the traditional artisans' precise perception and adaptation to environmental factors such as sunlight intensity and wind direction (**Figure 2**). This not only avoids the ecological damage caused by chemical dyes but also endows Xiangyunsha with the cultural connotation of "acting in accordance with the times and going with the flow".

The Xiangyunsha fabric presents a visual style rich in the aesthetic qualities of the East. Its color is low-key and steady. The common brown and black tones on the silk surface emit a soft luster, forming an understated and reserved aesthetic

Figure 3 | The "simple and elegant beauty" of Xiangyunsha

connotation, conveying the pursuit of "simple and elegant beauty" [3] (**Figure 3**). This color language stems from the admiration of the beauty of natural materials and is distinct from the bright and intense color tones of modern industrial dyeing and finishing. It not only retains the practicality of the fabric but also demonstrates fluidity and a sense of ceremony in its structural cutting and wearing experience, still possessing a strong artistic appeal in the contemporary design context.

As an important commodity on the Maritime Silk Road, the production technology of Xiangyunsha has been constantly updated and passed down throughout history. From being a tribute to the imperial court in the Qing Dynasty to an export specialty in the Guangzhou-Foshan region in modern times, the production of Xiangyunsha not only shaped a regional handicraft ecosystem but also witnessed the commercial exchanges and cultural intercommunication in the Lingnan region. During its cross-regional dissemination, Xiangyunsha was not only sold far to Southeast Asia, Europe and America, but also adapted to the aesthetic and functional demands of different markets[4]. For instance, to cater to the humid climate and the clothing preferences of the Chinese community in Southeast Asia, local innovations were made in the fabric patterns and color treatments; while for the European and American markets, more emphasis was placed on its eco-friendly and natural dyeing concepts, in line with the international consumers' concern for sustainable fashion. This cultural circulation mechanism of local production, global circulation and aesthetic adaptation makes Xiangyunsha both local and international, constituting a typical model of cultural hybrid craftsmanship.

Since being included in the National List of Intangible Cultural Heritage Representative Items in 2008, the Xiangyunsha dyeing and finishing technique has received institutional protection and the promotion of diverse dissemination, becoming an important symbol of Lingnan cultural identity. With the empowerment of digital and virtual reality technologies, it has presented new paths of dissemination and possibilities for dynamic inheritance.

The image narrative attributes of intangible cultural heritage skills

In recent years, image narrative has gradually become a hot topic in the research of digital and cultural communication as an important path for the digital revitalization of intangible cultural heritage (ICH). Current research mainly focuses on three aspects: First, by leveraging technologies such as virtual reality (VR) and augmented reality (AR), multimodal narrative systems integrating images, sounds, interactions, and texts are constructed to enhance immersive experiences and user engagement, transforming ICH from "static display" to "experiential communication". Second, attention is paid to the recording and dissemination effects of digital images of ICH, analyzing the influence of image elements such as frame rate, change frequency, and gradient rhythm on audience perception and cultural understanding. Third, from the perspective of cultural memory construction and emotional connection, it explores how image narrative can strengthen the cultural expression and sense of identity of ICH, and enhance the depth of ICH dissemination and public participation through interactive digital media. These studies collectively indicate that image narrative is not only a medium for the visual expression of ICH but also an important driving force for the semantic extension and dynamic inheritance of its culture.

Despite this, current ICH image narratives still face many challenges in practical application, especially in the systematic recording and visual representation of skill processes. ICH skills are mostly passed down through oral instruction and demonstration between masters and apprentices, lacking systematic digital archiving and process tracking mechanisms.

Figure 4 | Synergistic space of nature and agricultural activities in Mulberry-fish pond systems

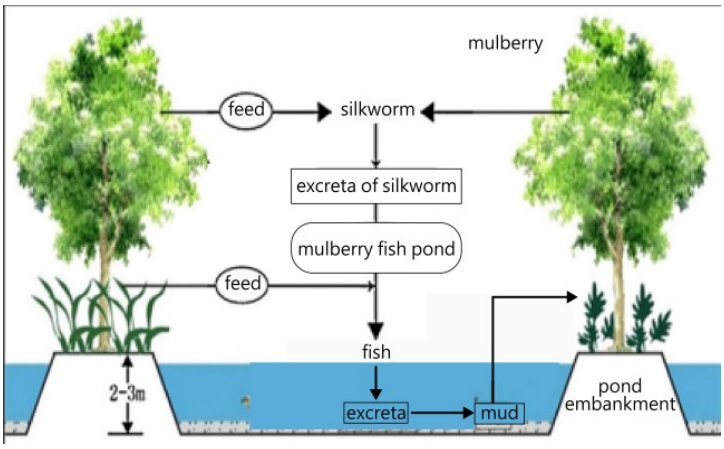


Figure 5 | Ecological closed loop of mulberry fish ponds

As a result, image materials often remain as fragmented static records, making it difficult to support a complete and coherent narrative construction. For instance, the dyeing and finishing process of Xiangyunsha fabric is highly complex and dependent on natural conditions. Its key steps, such as the "blackening" process, involve the natural reaction of plant dyes and specific soils, which are difficult to standardize and reproduce in image modeling and visual expression, thereby affecting the visual interpretation of its deep cultural connotations.

Digital presentation methods of intangible cultural heritage images

In the contemporary context where the digital dissemination of intangible cultural heritage is continuously deepening, the display of intangible cultural heritage presents diversified paths combining offline museums, craft workshops, and online museum APPs. This breaks through the closed nature and participation threshold of previous localized display spaces and expands the breadth and depth of intangible cultural heritage dissemination. Existing research mostly focuses on technical implementation paths such as 3D modeling, virtual display, and interactive experience, promoting the visual preservation and online dissemination of intangible cultural heritage information[5]. Some scholars have attempted experimental research from directions such as immersive narrative and digital person interpretation[6], but there are still deficiencies in cultural semantic refinement, visual narrative design, and the mechanism of audience emotional resonance.

The current mainstream online platforms for intangible cultural heritage display still mainly present single-directional museum models and craft introductions, lacking cross-temporal, all-process, and multi-dimensional image narrative support, making it difficult to fully mobilize the sensory and emotional participation of the audience. Taking Xiangyunsha as an example, this type of intangible cultural heritage has a relatively monochromatic color, a complex technical process, and lacks systematic image records, and its audience is highly regional. Due to these characteristics, there are technical bottlenecks in technical restoration, making it difficult to effectively attract young audiences in the digital context. This situation further restricts the visual depth of digital reconstruction and the operational space for cross-media dissemination of this type of intangible cultural heritage, and urgently requires the construction of an innovative image narrative mechanism that integrates semantic understanding and emotional connection.

The Narrative Axis of Xiangyunsha Intangible Cultural Heritage Skills

The narrative space of natural symbiosis

The dyeing and finishing process of Xiangyunsha is not only a highly complex manual procedure but is also deeply rooted in the unique ecological environment and agricultural system of the Lingnan region, especially the traditional agricultural ecological model of "mulberry pond fish farming" (**Figure 4**), which provides a stable material foundation and philosophical support for the production of Xiangyunsha[7]. This system forms a self-sufficient and circular ecological space through the coordinated cycle among mulberry tree planting, silkworm breeding, silk weaving, and fish pond farming, embodying the ecological consciousness of "harmony between man and nature" in the Lingnan region at the practical level.

In this system, the fertile alluvial plain is transformed into a good foundation for planting and breeding by building ponds with water diversion. Mulberry trees are planted on the pond banks, and the leaves are used for silkworm breeding. After the silkworms are harvested, the cocoons can be reeled to produce raw silk for Xiangyunsha production. Meanwhile, the silkworm droppings and mulberry leaf residues are returned to the soil, serving as natural fertilizers for the crops around the ponds, further enhancing soil

Figure 6 | Space for the weaving of Xiāngyúnsha

fertility. At the same time, the fish in the ponds purify the water during feeding, and their excrement and organic matter at the bottom of the ponds can also be used as fertilizers to nourish the mulberry fields, achieving an ecological closed loop of "fish nourishing mulberry, mulberry nourishing silkworm, silkworm producing silk, and silk weaving into cloth" (**Figure 5**). This forms a complex spatial image of mulberry fields, fish ponds, mulberry trees, and silkworms, reflecting the spatial logic and temporal rhythm of human and nature collaboration. Mulberry pond fish farming is not only an agricultural technology system but also an ecological wisdom that harmonizes production with nature, constituting the natural symbiotic narrative space for the generation of Xiangyunsha and conveying the narrative logic of natural changes, agricultural activities, and artificial weaving (**Figure 6**). It is an image-based representation of the cultural context of Xiangyunsha intangible cultural heritage "growing from the land"[8].

Narrative content of craftsmanship

The intangible cultural heritage of Xiangyunsha is renowned for its natural dyes and manual processes, whose complexity and rhythm form a highly expressive content section in the narrative of intangible cultural heritage images. This craftsmanship not only embodies the traditional textile wisdom of the Lingnan region but also constitutes the core narrative content of "craftsmanship".

The entire process begins with the "four water washes" of the tuberose (**Figure 7**). The craftsman needs to wash the tuberose four times to remove impurities and activate the dyeing activity, thereby forming a stable and usable dye solution. This dye solution is then used for the first immersion dyeing of the natural silk fabric, laying the color foundation for the entire process. After the first water wash following the immersion dyeing, the dye is evenly penetrated through water washing. Subsequently, the "sprinkling of tuberose water" (using the solution from the second water wash of the tuberose) and "color sweeping" processes are carried out, where a brush is used to evenly apply the dye solution to enhance the color consistency of the fabric. This series of processes needs to be repeated six times, with each round of sprinkling and sweeping followed by drying and "sealing with tuberose" (using the solution from the third water wash of the tuberose), forming a stable dye layer and enhancing the luster of the fabric. This combination of drying and sealing with tuberose also needs to be repeated six times. The subsequent "boiling of silk" process enhances the flexibility of the fabric and the fastness of the dye through high-temperature boiling. Then comes the "second sealing with tuberose", where the fabric is continuously sealed and dyed with the solution from the fourth water wash of the tuberose, and this process is repeated twelve times in combination with drying operations, gradually deepening the color layers and texture structure. This stage is a critical point for the construction of color and texture and is also an important manifestation of the craftsman's experience and control over the process. In the final finishing stage, the fabric needs to be boiled again to stabilize the fiber state, and the "blackening", "washing black", "third sealing with tuberose", and "sprinkling mist" processes are completed in sequence. In the blackening process, the fabric undergoes a natural reaction with iron-rich river mud, generating a unique black-brown color effect; the third sealing with tuberose still uses the solution from the fourth water wash to further consolidate the color and luster. Finally, through "sprinkling mist", the fineness and hand feel of the fabric are enhanced to produce the typical characteristics of Xiangyunsha[9].

The dyeing and finishing process of Xiangyunsha creates diverse images through the combination of tools, materials, manual techniques, and natural environments. It showcases the rhythm and stages of the process through unique workflow nodes, and forms dynamic interactions between micro-operation details and natural environmental conditions, demonstrating the deep understanding and aesthetic tendencies of traditional craftsmanship in collaborative creation with natural resources.

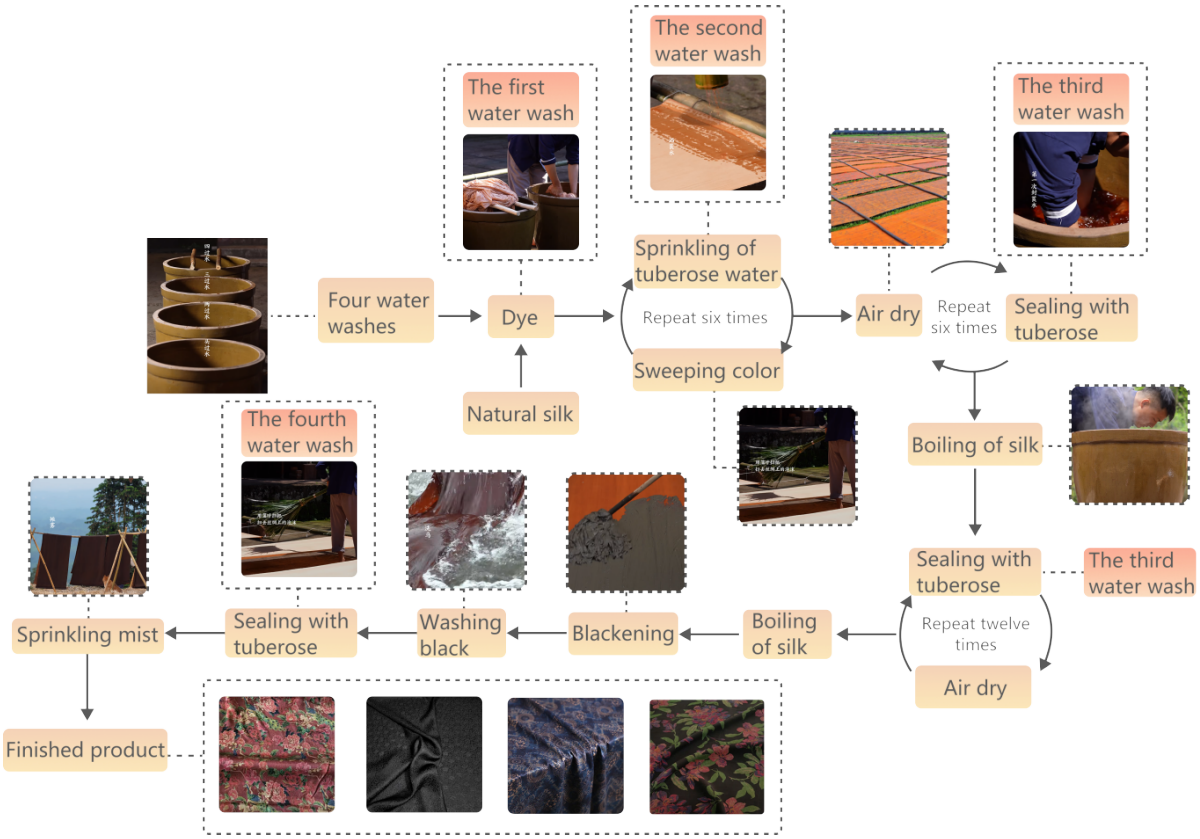


Figure 7 | Dyeing and finishing process technology procedures of Xiāngyúnsha

The narrative context of maritime silk road trade

The dyeing and finishing techniques, which integrate natural wisdom and ingenious craftsmanship, have created the Xiangyunsha handicrafts with a distinct Lingnan style. These products were circulated overseas along with the prosperity of the Maritime Silk Road[10]. As a specialty export product of the Guangzhou-Foshan region in the modern foreign trade system, Xiangyunsha gradually entered the international market through trade hubs such as the Thirteen Factories in Guangzhou since the Qing Dynasty, and was sold to Southeast Asia, the Indian Ocean coast, and some countries in Europe and America. Its unique fabric style, which is understated yet rich in texture, meets the aesthetic expectations of specific cultural consumer groups for oriental handicrafts, making it an important medium for the exchange of clothing and cultural imagination between China and the West.

Driven by trade flows, not only were large quantities of Xiangyunsha products exported through maritime networks, but the dyeing and finishing techniques behind them were also gradually recognized and absorbed by foreign regions. On the one hand, the craft workshops in the Guangzhou-Foshan area gradually formed a large-scale and specialized division of labor system, completing the production and export process of Xiangyunsha through the organizational structure of guilds, workshops, and ports. On the other hand, these technological knowledges influenced the surrounding regions through cultural exchanges, giving rise to the evolution and integration of dyeing and finishing techniques for Nanyang native cloth, demonstrating the cultural export capacity of traditional techniques as soft technologies. The cultural flow formed a narrative context where material representation and cultural expression are integrated, reflecting that Xiangyunsha is not only a representative of Lingnan regional culture but also a key node connecting local handicrafts with the global cultural market. Its early practice in the global dissemination of intangible cultural heritage provides historical references and cultural depth for today's digital display and international exchanges.

The ecological foundation of the Xiangyunsha dyeing and finishing techniques, the craftsmanship process that gives rise to artistic features, and the cultural circulation brought by the Maritime Silk Road trade have formed a narrative axis from narrative space to context integration of "natural symbiosis - craftsmanship - Maritime Silk Road trade"(Figure 8), comprehensively embodying the ecological, technical, and cultural values of Xiangyunsha dyeing and finishing techniques.

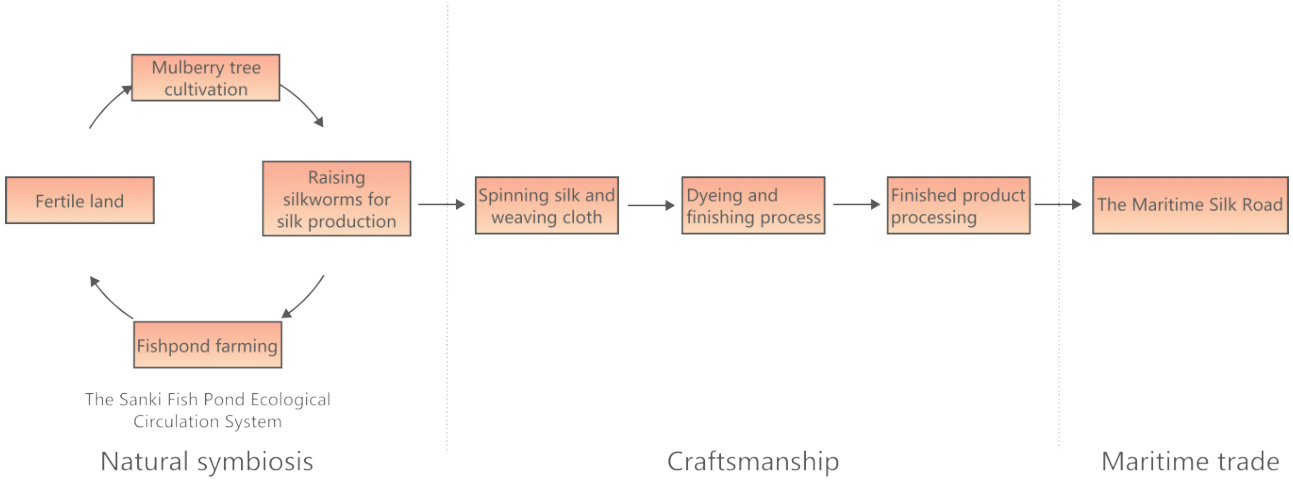


Figure 8 | "Natural Symbiosis - Artisanal Craftsmanship - Transoceanic Trade" narrative axis

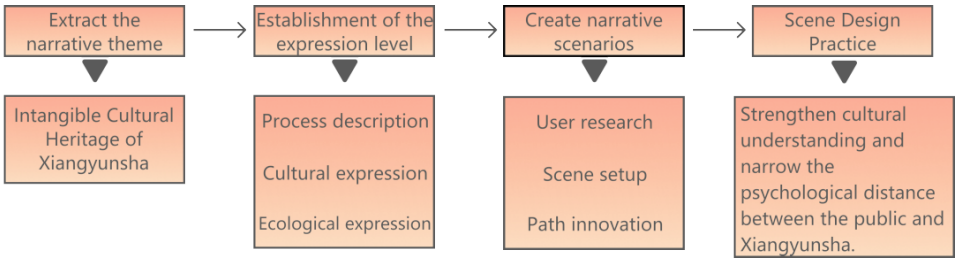


Figure 9 | Digital design process diagram of Xiangyunsha intangible cultural heritage

VR Presentation and Interactive Experience Design of Xiangyunsha Dyeing and Finishing Techniques

This research employs AIGC for the image translation of narrative axes, and through the sequential and scene-based expression of images, establishes a four-level digital display design process for Xiangyunsha dyeing and finishing techniques: the refinement of narrative themes, the establishment of expression levels, the creation of narrative scenes, and the specific practice of scene design (Figure 9). This aims to achieve an immersive, structured, and multimodal digital communication effect, enhancing users' perception and understanding of the intrinsic semantics of intangible cultural heritage, and promoting the transformation of immersive narrative experiences from viewing to understanding, and from formal reproduction to cultural transmission.

The digital display focuses on the "image narrative characteristics of Xiangyunsha dyeing and finishing techniques", emphasizing the integration of educational and aesthetic values in value dissemination, and clarifying the dual goals of reaching the general public and cultural inheritance. Immersive scene construction is carried out from three dimensions: ecology, craftsmanship, and culture. The ecological narrative space image of the mulberry pond and fish pond conveys the ecological awareness of the harmony between Xiangyunsha and nature; the visualization of the dyeing and finishing process images realizes the complete reproduction of the craftsmanship; and the exploration of the maritime silk trade scene reveals the systematic relationship between the evolution of the craftsmanship and cultural flow. Based on AI image generation and virtual reality (VR) technology, a digital display system is designed and constructed, integrating the visual language style transfer of the Lingnan School of Painting, dynamic interpretation of the craftsmanship process, immersive exhibition environment, and interactive interface design. Further, through user experience and usage requirements, the usability of this design is verified to achieve an emotional connection between the public and intangible cultural heritage. This display design path that integrates the value of intangible cultural heritage with digital technology forms a dyeing and finishing techniques display process from value exploration to interactive experience through image narration, which can enhance the public's overall cognition and perceptual participation in Xiangyunsha intangible cultural heritage.

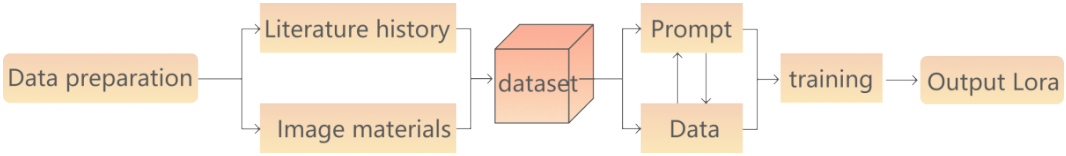


Figure 10 | Flowchart of LoRa model training

AIGC process visualization image generation

The narrative space, content, and context of the Xiangyunsha dyeing and finishing technique are presented through AIGC-generated images, forming an emotional connection between the viewer and the intangible cultural heritage content through visual information such as composition, color, rhythm, and symbols[11]. Through multi-level narrative perspectives, it guides the viewer's involvement and presents the information hierarchy and logic of the technique's value in the changes of narrative rhythm. It carries deep cultural semantics through space, manufacturing, and trade activities, forming a visually recognizable memory.

The design systematically collects and organizes the narrative space forms of the mulberry pond fishpond, the patterns and process images of Xiangyunsha, covering pattern data from historical documents, museum collection images, and local workshop records. By deconstructing the semantics of these visual materials, it identifies the process features and cultural symbols contained within: for example, the interaction between fabric and land and water flow in the sun-drying process reflects the symbiotic relationship between Xiangyunsha dyeing and finishing technique and the natural ecosystem; the deep black luster formed by repeatedly applying the tuberous morning glory liquid in the "blackening" process has strong oriental aesthetic connotations and ritualistic characteristics. This process builds a semantic coordinate system for the Xiangyunsha process images, providing a semantic annotation basis for AIGC stylized image generation. By sorting out the intuitiveness (concrete form of visual reproduction), symbolism (image translation of cultural traditions), and simultaneity (parallel arrangement of process images from different historical stages) of the images, it achieves an effective transition from image understanding to content generation, ensuring the accuracy and continuity of cultural semantics in the generated images during style transfer and image narration.

Image generation is based on LoRA model training. The selection of LoRA fine-tuning was based on the characteristics of Xiangyunsha intangible cultural heritage image generation. Compared with full-model training methods, LoRA requires fewer training resources and can achieve efficient model adaptation with a relatively small number of domain-specific samples. This advantage is particularly suitable for intangible cultural heritage scenarios, where specialized image datasets are limited but the preservation of cultural and visual characteristics is essential. Therefore, LoRA was adopted to improve training efficiency while maintaining the semantic consistency and visual representation of Xiangyunsha cultural elements. In the data preparation stage, historical images related to Xiangyunsha, traditional process photos, and typical works of the Lingnan School of Painting are systematically organized and collected to ensure that the materials have high resolution, accurate cultural annotations, and consistent style. The collected visual resources mainly include Xiangyunsha dyeing and finishing process images, traditional craftsmanship records, cultural pattern references, and ecological environment images related to the mulberry-dyke-fishpond system. These materials are integrated from historical documents, museum collection images, and local workshop records, forming a multi-source visual dataset that supports LoRA model fine-tuning and the learning of Xiangyunsha-related cultural semantics. Based on the characteristics of intangible cultural heritage image generation, the dataset focuses on preserving the process characteristics, cultural symbols, and visual styles of Xiangyunsha, providing a reliable visual foundation for subsequent semantic annotation and model training. (**Figure 10**) In the data set construction and label setting stage, the original images are classified and structured into multi-dimensional structured data sets, and specific semantic labels (such as "silkworm", "spraying the tuberous morning glory water", "dyeing", "traditional process scene", etc.) are set to provide clear semantic guidance for model learning. The semantic labeling strategy is established based on the key process characteristics, environmental contexts, and visual features of Xiangyunsha intangible cultural heritage. The labels are divided into three categories: process-related semantic labels, environmental context semantic labels, and cultural visual semantic labels. Process-related semantic labels describe specific dyeing and finishing procedures, such as dyeing, spraying the tuberous morning glory water, and sun-drying process, enabling the model to learn the characteristics of traditional craftsmanship. Environmental context semantic labels represent the ecological environment and spatial contexts associated with Xiangyunsha production, such as the mulberry-dyke-fishpond system and traditional workshop scenes. Cultural visual semantic labels focus on the artistic characteristics and symbolic elements of Xiangyunsha, including traditional patterns, natural dyeing colors, and Lingnan artistic styles. Through this hierarchical semantic annotation strategy, the relationship between visual features and cultural meanings is strengthened, helping maintain semantic coherence and cultural consistency in generated images. On this basis, prompt data for training is gener-

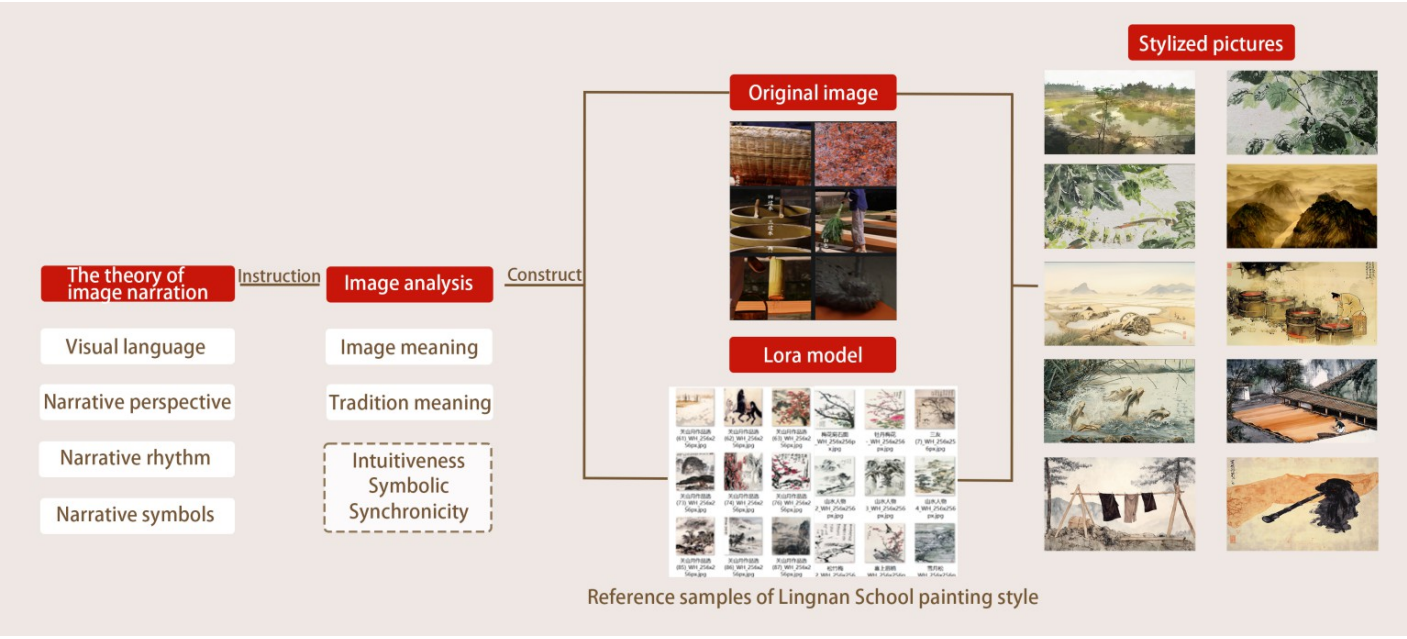


Figure 11 | Flowchart of AIGC process visualization image generation

ated, such as "traditional dyeing and finishing scene in the style of the Lingnan School of Painting", "the scene of a craftsman sun-drying", etc., to enhance the model's understanding of the target image's semantics and style. Then, in the model training stage, based on the Stable Diffusion model, the LoRA (Low-Rank Adaptation) fine-tuning method is adopted. By injecting low-rank matrices into the key layers of the model, efficient parameter updates and enhanced style transfer capabilities are achieved. During the training process, reasonable hyperparameters (such as a learning rate of 1e-4, batch size of 2, and training rounds of 10-15) are set, and a combined text-image training strategy is used to improve the semantic and style consistency of image generation. Finally, in the model export and application deployment stage, the trained LoRA weight files are exported and integrated into the basic model system, supporting stylized image generation based on prompt control. (Figure 11) This process generates images with distinct characteristics of the Lingnan School of Painting, highly restoring the ecological basis and aesthetic features of the Xiangyunsha dyeing and finishing technique, and coordinating the integration of the Xiangyunsha process imagery, cultural expressiveness, and artistic appeal, forming a clear semantic and unified style visual narrative of intangible cultural heritage.

Interactive experience design for Xiangyunsha production

In the digital presentation of Xiangyunsha dyeing and finishing techniques, interactive experience design effectively enhances users' sense of immersion and can improve the understanding and dissemination efficiency of intangible cultural heritage knowledge. To build an immersive experience with cultural depth and technical compatibility, the design explores from four dimensions: game mechanics, interaction logic design, natural interaction methods, and visual presentation, to construct an interaction system that aligns with the Xiangyunsha dyeing and finishing technique and user psychological models (Figure 12).

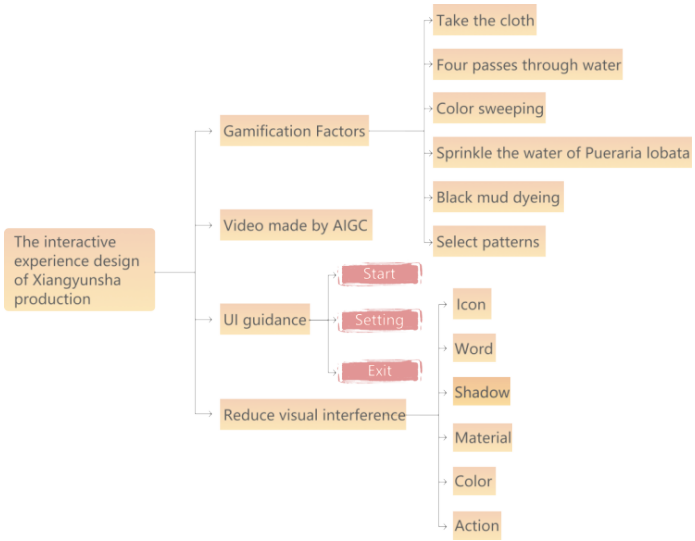


Figure 12 | Flowchart of AIGC process visualization image generation

To break through the limitations of static browsing in traditional intangible cultural heritage (ICH) exhibitions, the system introduces a gamification mechanism. Through role-playing, task-driven and instant feedback methods, it enhances users' immersion and cultural participation[12]. Users will enter the virtual Xiangyunsha dyeing and finishing workshop as "apprentices" and complete the production

Figure 13 | Video clip of the "four water washes" process

Figure 14 | Video clip of the “sweeping color” process

Figure 15 | Video clip of the "sprinkling the latex water" process figure

Figure 16 | Video clip of the "blackening" process

processes of "taking the fabric - four water washes (Figure 13) - sweeping color (Figure 14) - sprinkling the latex water (Figure 15) - blackening (Figure 16) - selecting patterns" in sequence in the digital environment according to the real process. Each process is equipped with operation guidance and task challenge mechanisms, and users will receive dynamic scores and instant feedback based on the accuracy and completion of their operations, which encourages them to keep trying and learning. After completing all the process tasks, the system will unlock the virtual "Xiangyunsha Exhibition Hall" space, prompting users to view the virtual Xiangyunsha samples they "made by hand" and other historical patterns, process evolution, and cultural imagery displayed together, forming a complete experience chain from "hands-on practice" to "value perception". This interaction mechanism not only enhances users' active participation but also helps to deeply disseminate the knowledge of Xiangyunsha ICH and reconstruct cultural emotional connections.

The system is equipped with AIGC process videos to achieve an immersive experience of dynamic guidance and instant feedback. Before users carry out operations such as sweeping color, sprinkling latex, and drying, video clips will be automatically played in combination with the current interaction tasks and scene nodes, presenting the standard operation process and key process actions in real time, establishing a "see - learn - do" learning path, significantly enhancing the intuitiveness and cultural immersion of the interaction. The AIGC videos' strong semantic adaptation ability and flexible invocation mechanism will intelligently adjust the playback content based on the user's task progress, pause duration, or incorrect operation behavior[13]. At the same time, users can query process details, control playback progress, or repeat key steps through voice interaction commands, experiencing the content delivery of image narratives through both visual and auditory levels, enhancing the convenience and depth of personalized interaction.

To reduce the operational difficulty for users, the interaction process is modularized, breaking down complex process steps into clear operation nodes. This is complemented by visual illustrations, voice guidance, and animated demonstrations to form a multi-dimensional guidance system. The UI design adopts a minimalist style, creating a clearly partitioned interface layout and dynamic interaction prompts to ensure the immediacy and smoothness of information acquisition, avoiding excessive cognitive load and transforming the intangible cultural heritage process into an understandable and operable digital experience[14]. To enhance the user's immersion and cultural perception in the virtual environment, the system adheres to the "information minimization" principle in interface design, retaining only key prompts and necessary operation instructions, and mini-

Figure 17 | Restoration of the morphology of the Wok-ear house residential building

Figure 18 | Construction of the environment scene of the Xiangyunsha workshop

mizing interface distractions by reducing non-essential elements such as icons and text to prevent visual attention dispersion. During the interaction experience, users will be placed in the ecological space of Lingnan's mulberry pond fish ponds, always immersed in the first-person perspective of a craftsman, simulating their body movements and operation rhythms, and enhancing the "presence" and "participation" in the Xiangyunsha dyeing and finishing process. Through meticulous control of light, materials, and colors in the virtual space, the aesthetic tone of traditional Chinese craftsmanship is maintained, and the narrative coherence and visual concentration of the images are maximized, thereby more deeply conveying the cultural connotations and aesthetic features of the Xiangyunsha dyeing and finishing techniques[15].

Prototype development of the Xiangyunsha experience exhibition hall system

The design selects value elements such as architecture, rivers, and mulberry pond fish ponds from the ecological foundation of Xiangyunsha, and uses Maya for 3D modeling. It focuses on restoring the traditional residential form of the "Wok-ear House" (**Figure 17**) in Lingnan, as well as environmental elements in the Xiangyunsha workshop such as the drying ground, water tanks, and traditional drying racks, to construct a virtual display scene and create a narrative space atmosphere with regional characteristics (**Figure 18**).

Digital resources such as architectural models, natural scenes, production tools, terrain materials, typical patterns, and interactive operation interfaces are uniformly organized and imported into the Unity engine environment to achieve resource integration and system prototype development, providing a stable guarantee for subsequent interaction design and system deployment. The interaction system construction comprehensively uses the SteamVR Plugin and Playmaker plugin combination to develop virtual reality interaction logic. Among them, the SteamVR Plugin provides basic head-mounted display tracking and controller interaction support, ensuring that the system can be fully integrated with VR hardware devices; while Playmaker simplifies the non-programming development process through the visual state machine (FSM) mechanism, making the construction of interaction logic more intuitive and efficient, suitable for multi-person collaboration and rapid iteration. The final system supports users to experience the dyeing and finishing process of Xiangyunsha in an immersive way, interactively select pattern samples, and view the status and evolution of Xiangyunsha in the maritime silk trade along the narrative axis of "natural symbiosis - craftsmanship - maritime silk trade", forming multiple interaction experiences from learning to exhibition(**Figure 19**-**Figure 22**).

Experiment

The digital display design of the Xiangyunsha dyeing and finishing techniques, which was established by the research through the combination of "image narrative + AIGC generation + VR immersion", needs to be evaluated for usability through user experience to verify the public's experience and feelings[16], so as to promote the improvement and optimization of the design. The usability experiment recruited 43 participants, covering different age groups from 18 to 65 years old, among which 40% were college students, 30% were enthusiasts of intangible cultural heritage, 20% were ordinary people, and 10% were inheritors of Xiangyunsha. This ensured the diversity and representativeness of the sample. All participants experienced the virtual reality scene constructed in this study through VR devices, which included three modules: "Sangji Fishpond Ecological Space", "Dyeing and Finishing Process Dynamic Interaction", and "Maritime Silk Road Trade Scenario Display". The experience duration was controlled within 30 minutes, and participants filled out the system usability scale after the experience.

The research designed the SUS scale with 10 standard questions, evaluating the user experience from dimensions such as "system ease of use", "learning curve", and "operation smoothness". For reverse-scored questions like "I found this system too complicated" and "I need technical support to operate this system", the original scores needed to be converted to positive scores. The total score after conversion

Figure 19 | Demonstration of the VR interaction system for Xiangyunsha

Figure 20 | Learning the making of Xiangyunsha

Figure 21 | "Guo Wu" interaction session

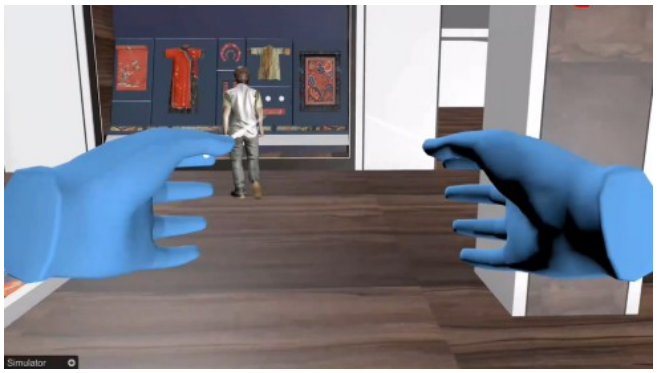


Figure 22 | Visiting the Xiangyunsha Virtual Exhibition Hall

for all questions was 35.08 points, and after multiplying by 2.5, the total SUS score of the system was 87.7 points. The specific questionnaire questions and score results are shown in Figure 23. To further verify whether the system usability reached the industry benchmark level, this study used a one-sample T-test to compare the actual score with the theoretical benchmark value.

The experimental results showed that the system achieved positive performance in terms of usability and user-friendliness. Participants indicated a willingness to use the system frequently (Q1 = 3.21) and considered the system user-friendly (Q3 = 3.41). Furthermore, most participants believed that they could quickly learn and operate the system (Q7 = 3.54), demonstrating that the system achieved relatively good performance in terms of usability and learnability.

However, some limitations were identified in the dimensions of complexity and technical support requirements. The results showed that participants had relatively low perceptions of system complexity (Q2 = 1.07, reverse-scored to 3.93) and technical support requirements (Q4 = 0.95, reverse-scored to 4.05), indicating that further improvements could be made in simplifying the interaction process and reducing the technical threshold.

To further investigate users' acceptance and perception differences across different dimensions, this study classified the ten evaluation items in the questionnaire into three key perception dimensions: usability, complexity, and user-friendliness. The usability dimension includes Q1, Q3, and Q7, focusing on users' overall evaluation of system practicality and ease of learning. The complexity perception dimension consists of Q2, Q4, and Q10, reflecting users' perception of system complexity and the need for technical assistance. The user-friendliness dimension contains Q5, Q6, Q8, and Q9, which evaluates users' perception of functional integration, consistency, and overall confidence and comfort during system operation.

To examine whether statistically significant differences existed among users' evaluations of different dimensions, this study employed Paired-Samples T-Tests (PST). Since the same participants evaluated multiple dimensions of the system, paired comparisons were conducted to analyze differences among usability, learnability, and functional integration. This statistical method is appropriate for the experimental design, as it compares the mean differences between two related conditions within the same group of participants. The test statistic is calculated as follows:

$$t = \frac{\bar{D}}{s_D/\sqrt{n}} \quad (1)$$

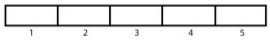
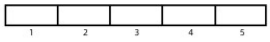
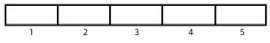
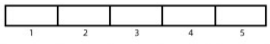
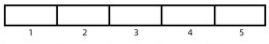
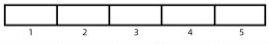
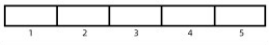
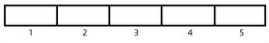
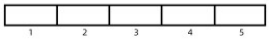
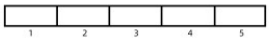
	disagree ⟷ agree	b question	Mean Score	Transformed Score
1. I believe I would be inclined to use this system frequently.		Q1	3.21	3.21
2. I find this system overly complex.		Q2 (Reverse)	1.07	3.93
3. I consider this system remarkably user-friendly.		Q3	3.41	3.41
4. I require technical support to operate this system effectively.		Q4 (Reverse)	0.95	4.05
5. The integration of features within the system is seamless.		Q5	2.73	2.73
6. I perceive substantial inconsistencies among the system's functionalities.		Q6 (Reverse)	1.75	3.25
7. Most individuals can swiftly master the use of this system.		Q7	3.54	3.54
8. Interacting with this system feels excessively cumbersome.		Q8 (Reverse)	1.64	3.36
9. I feel highly confident when utilizing this system.		Q9	3.26	3.26
10. A significant amount of prior learning is necessary to operate this system.		Q10 (Reverse)	0.66	4.34
		SUS Score	55.55	87.7

Figure 23 | SUS survey questionnaire (a) and score results (b)

Table 1 | Average scores on survey questions by dimension

Compairing Dimension	Mean Difference	T-alue	P-value	Significance Judgment
Usability (3.35) vs. Learnability (3.92)	-0.57	-7.01	1.40×10^{-8}	Significant difference
Usability (3.35) vs. Integration (3.30)	0.05	0.55	0.588	No significant difference
Learnability (3.92) vs. Integration (3.30)	0.62	5.13	7.06×10^{-6}	Significant difference

$\bar{D}$ denotes the mean of the paired differences; s_D denotes the standard deviation of the paired differences; n is the sample size (43 in this experiment); the significance level is set at α.

To evaluate the practical application effect and public experience of the system, the System Usability Scale (SUS) was used to quantitatively assess its usability, learnability, and functional integration.

Through statistical analysis of the questionnaire data from 43 public participants, the results showed that the learnability dimension score was significantly higher than that of usability (mean difference -0.57, t = -7.01, p < 0.001) and functional integration (mean difference 0.62, t = 5.13, p < 0.001), indicating that users generally found the system easy to learn and master. Meanwhile, there was no significant difference between usability and functional integration (mean difference 0.05, t = 0.55, p = 0.588), suggesting that the system performed relatively well in terms of operational convenience and functional coordination.

This evaluation result demonstrates that the narrative axis based on "natural symbiosis - craftsmanship - maritime silk trade" has constructed an immersive virtual reality digital display system integrating AIGC image generation and VR technology, which can effectively reduce the learning cost of intangible cultural heritage (ICH) display, provide potential support for users' cultural understanding and emotional engagement, although further empirical studies are still required to verify its impact on cultural identity formation and emotional responses. The relatively lower score of functional integration indicates that there is still room for improvement in multimodal interaction and content organization. This result may be related to the complexity of integrating multiple functional modules, including AIGC-generated visual content, cultural information presentation, and interactive exploration processes. For users who are unfamiliar with Xiangyunsha culture, the simultaneous presentation of multiple information dimensions may increase cognitive load and affect the perceived coherence of the overall interaction experience. Future optimization can focus on simplifying the interaction hierarchy, improving information organization, and introducing adaptive guidance mechanisms to enhance the coordination between different functional modules. Overall, this system provides a practical and feasible demonstration solution for the digital display design of intangible cultural heritage skills, which is conducive to promoting the modern inheritance and innovative dissemination of traditional culture. Furthermore, the proposed digital display approach provides new possibilities for overcoming geographical limitations and expanding the dissemination pathways of Xiangyunsha weaving techniques through digital platforms.

Conclusion

This research, based on the theory of image narrative and the application of virtual reality technology, has constructed a methodological framework for the digital display of the Xiangyunsha dyeing and finishing techniques. It proposes a threefold narrative axis of "natural symbiosis - craftsmanship - maritime silk trade", systematically presenting the

comprehensive cultural value of Xiangyunsha in terms of ecological foundation, artistic features, and cultural flow. Through AIGC-assisted image generation and the extraction of Lingnan style semantics, combined with immersive space modeling and interaction design in virtual reality, the research has broken through the traditional single model of intangible cultural heritage display that mainly relies on physical exhibitions, and explored an innovative system of intangible cultural heritage digital display design that integrates image narrative, sensory experience, and value perception.

The construction and digital presentation of the image narrative axis, using virtual display scenarios, not only achieve the full-process image restoration and contextualized narration of the Xiangyunsha dyeing and finishing process but also, through feasibility assessment, play a positive role in promoting public emotional participation and cultural understanding. This helps intangible cultural heritage move from "visible" to "understandable", enhancing the visual communication power and public recognition of intangible cultural heritage techniques, and realizing the transformation from "exhibition-based preservation" to "immersive activation".

In conclusion, the digital display design system for Xiangyunsha dyeing and finishing techniques links image narrative with immersive experience systems, providing an innovative model that integrates technological innovation and cultural dissemination for similar intangible cultural heritage projects. It also offers a reference sample with theoretical value and practical significance for the inheritance and transformation of intangible cultural heritage under the background of the Digital China strategy. Future related research can further explore multi-sensory integration paths and AI-driven narrative mechanisms, deepening the communication effectiveness of digital intangible cultural heritage in the construction of cultural identity.

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