Frontiers in Economics and Management Volume 6 Issue 9, 2025
ISSN: 2692-7608 DOI: 10.6981/FEM.202509_6(9).0016

Digital Research on the Art of Xuan Paper Making from the Perspective of the Metaverse

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Abstract

As a pivotal carrier of China's intangible cultural heritage, the art of Xuan paper making faces dual challenges of inheritance and innovation in the digital era. This study explores the potential of metaverse technology in facilitating the digital transformation and immersive experience of Xuan paper craftsmanship. Through a questionnaire survey, it analyzes users' cognition, demands, and expectations regarding metaverse-enabled Xuan paper experiences, and systematically discusses technical empowerment, practical dilemmas, and innovative pathways. The findings reveal strong user expectations for the metaverse to enhance experience authenticity and cultural communication efficiency through immersive scenarios, digital twin-driven global dissemination, and a virtual-real symbiotic economic ecosystem. However, three key challenges are identified: technical adaptability, cultural authenticity preservation, and financial constraints. Correspondingly, innovative strategies such as hierarchical experience design, community-driven cultural ecosystems, and standardized technology integration are proposed. The conclusion indicates that metaverse technology can break the temporal and spatial limitations of traditional inheritance through multi-dimensional empowerment, constructing a "virtual-real symbiotic" system for cultural protection and innovation, thereby providing sustainable solutions for the dynamic inheritance of intangible cultural heritage. This research offers theoretical and practical insights for the digital transformation of traditional crafts, supporting the global dissemination and value reconstruction of Chinese culture in the digital age.

Keywords

Xuan Paper Making Technique; Metaverse; Digitization; Immersive Experience; Dynamic Inheritance.

1. Introduction

Xuan paper, renowned for its uniform ink absorption, exceptional toughness, and long-term preservation, is hailed as "Paper of Millennium Longevity" and stands as an outstanding representative of traditional Chinese culture. As a project in the first batch of the National List of Intangible Cultural Heritage Representative Projects, the Xuan paper making technique was inscribed on the UNESCO Representative List of the Intangible Cultural Heritage of Humanity in 2009. It serves as an indispensable carrier of traditional Chinese calligraphy and painting art, embodying millennia of historical memory and cultural inheritance [1]. With the rapid development of the times and the rapid advancement of science and technology, the inheritance and protection of traditional craftsmanship face unprecedented challenges [2]. In the fast-paced, digital modern society, how to inject new vitality into this ancient technique and attract

ISSN: 2692-7608 DOI: 10.6981/FEM.202509_6(9).0016

more attention and participation has become an urgent issue to be addressed. In recent years, the rise of metaverse technology has provided new opportunities and platforms for the inheritance and innovation of traditional culture [3]. As a brand-new world where virtuality and reality are deeply integrated, the metaverse has opened up an unprecedentedly broad prospect for the inheritance and promotion of the Xuan paper making technique.

Through metaverse technology, immersive digital spaces can be constructed. Jiang Xinyi et al. used virtual reality, augmented reality, and 3D animation technologies to digitally display Cao Cao's cultural heritage, providing a new perspective for the protection and dissemination of cultural heritage [4]. Digital technologies can not only be used for the protection of intangible cultural heritage but also play an important role in its exhibition and promotion. By combining field theory with intangible cultural heritage-themed exhibition design, Liu Xinyue provided new methodological support for the exhibition design of the Xuan paper making technique [5]. Based on the "Technology-Organization-Environment" framework, Liu Qian analyzed how metaverse technology promotes the transformation of cultural tourism ecosystems, thereby influencing the digital exhibition and promotion of intangible cultural heritage such as the Xuan paper making technique [6]. In the inheritance of intangible cultural heritage, exploring effective digital inheritance models is crucial. Taking the Xuan paper making technique as an example, Tang Duoxian discussed the possibility of transforming from individual inheritors to collective inheritors, providing a new perspective for the inheritance of intangible cultural heritage [7]. Existing studies have shown that the application of digital technologies can effectively improve the efficiency of preservation, dissemination, and utilization of intangible cultural heritage. Especially driven by metaverse technology, it provides new possibilities for the digital transformation of traditional techniques. Future research can further explore the specific application paths of metaverse technology in the protection and inheritance of intangible cultural heritage, such as restoring and reproducing the entire process of the Xuan paper making technique through virtual reality, augmented reality, and other technical means, and how to use blockchain technology to ensure copyright protection and data security of digital content. In addition, research can be conducted on how to combine traditional paper-making techniques with modern design concepts to create new cultural products and services, so as to promote the innovative development and realization of economic value of intangible cultural heritage.

This study aims to deeply explore the digital transformation and in-depth experience of the Xuan paper making technique from the perspective of the metaverse. Through questionnaire survey method, it attempts to understand users' expectations, needs, challenges, and opportunities regarding the experience of the Xuan paper making technique in the metaverse, and put forward targeted improvement suggestions, in order to provide new ideas and methods for the inheritance and innovation of the Xuan paper making technique.

2. Methodology

The questionnaire designed in this study mainly includes sections such as demographic characteristics, cognition of metaverse and Xuan paper making technique, expectations for digital experience of Xuan paper making technique, needs for interactivity and immersion, in-depth exploration of content and functions, social and community interaction, educational and training functions, and future outlook and prospects. The main question type is multiple-choice questions, while the future outlook and prospects section uses open-ended questions. The questionnaire was generated using Wenjuanxing (an online survey platform) and distributed through channels such as QQ Space and WeChat Moments. It was released on December 31, 2024, and the survey concluded on February 2, 2025, with a total of 325 questionnaires collected, including 322 valid responses.

ISSN: 2692-7608 DOI: 10.6981/FEM.202509_6(9).0016

Table 1. Demographic Characteristics of the Sample

Characteristic	Category	Number	Pct. (%)	Characteristic	Category	Number	Pct. (%)
Gender	Male	169	52.48	Education	High school or below	163	50.62
	Female	153	47.52		Bachelor's degree	106	32.92
Age	≤18 years	16	4.97		Master's degree or above	41	12.73
	18–25 years	74	22.98		Other	12	3.73
	26–30 years	75	23.29	Occupation	Student	38	11.80
	31–40 years	65	20.19		Educator	59	18.32
	41–50 years	31	9.63		Artist/Designer	56	17.39
	51–60 years	42	13.04		IT Professional	52	16.15
	>60 years	19	5.90		Cultural Worker	52	16.15
					Other	65	20.19

As shown in Table 1, the sample consisted of 52.48% males and 47.52% females. In terms of age, the three largest groups were 18-25 years old, 26-30 years old, and 31-40 years old, each accounting for over 20% of the sample. Respondents under 18 years old accounted for 4.97%, and those over 60 years old accounted for 5.9%. Regarding educational background, half of the sample (163 respondents) had an education level of high school or below, 32.92% held a bachelor's degree, and 12.73% had a master's degree or above. In terms of occupation, educators accounted for 18.32%, artists/designers for 17.39%, technology/IT professionals and cultural workers each for 16.15%, and students accounted for a smaller proportion at 11.8%. Overall, the sample characteristics were consistent with those of the target audience.

3. Questionnaire Survey Results

3.1. User Cognition and Expectations

The survey found that very few respondents (approximately 4.97%) were completely unfamiliar with the Xuan paper making technique. Most respondents had some basic knowledge, having heard of Xuan paper or even used Xuan paper products. This foundational awareness provides an audience base for the dissemination and promotion of Xuan paper making technique in the metaverse. However, only 39.75% of respondents demonstrated a full understanding of its profound cultural heritage and unique craftsmanship, indicating significant room for metaverse technology to deepen public engagement. Through virtual experiences and interactive teaching, users can gain deeper insights into Xuan paper's historical culture and production processes.

The metaverse, as a novel concept, has already been experienced by 80% of respondents through virtual reality (VR), augmented reality (AR) games, or virtual social platforms. These users expressed strong interest in metaverse-based experiences of Xuan paper making technique. 90% of respondents expected to visit virtual Xuan paper factories to explore the integration of traditional and modern technologies.Over 80% hoped to collect and trade virtual Xuan paper artworks.55.9% desired to simulate the entire Xuan paper production process—from raw material collection to finished product—with hands-on experience of each step.Over 30% anticipated collaborative creation with virtual artists and learning specific skills such as pulp mixing and paper fishing.

3.2. Interactivity and Immersion

Respondents widely agreed that realistic tool/material simulation and detailed environmental sound effects are critical for enhancing experience quality. They expected to use virtual tools like paper fishing screens and drying racks, accompanied by ambient sounds (e.g., water flow, pulp stirring), to engage with every detail of Xuan paper making.

ISSN: 2692-7608 DOI: 10.6981/FEM.202509_6(9).0016

Seventy percent of respondents desired unrestricted exploration of virtual spaces, including not only core production areas but also hidden craftsmanship secrets or artists' studios. This free exploration mechanism satisfies curiosity, fosters discovery, and enhances interactive engagement. Dynamic weather systems-such as the impact of sunny or rainy conditions on production-were highlighted as immersion boosters, with 49.07% of users hoping to experience how weather affects processes like pulp drying (e.g., slower drying in rain, faster drying in sunshine).

Additionally, 35.4% of respondents emphasized the importance of real-time feedback systems, such as instant evaluations of paper fishing techniques with improvement suggestions, to enhance learning efficiency and user experience.

3.3. Content and Function Preferences

Over 90% of respondents selected physical Xuan paper ordering/customization services linked to the metaverse, hoping to directly purchase physical Xuan paper based on virtual designs-reflecting demand for virtual-physical integration.

68.94% wanted live streams or replays of virtual artists' creative processes to learn techniques and creativity, highlighting interest in professional skill acquisition.

40% expected diverse Xuan paper types (e.g., raw Xuan, processed Xuan, gold-flecked Xuan) and production methods (handmade vs. machine-made) to meet personalized exploration needs.A minority (27.33%) desired custom pattern/texture design tools to create unique artworks, catering to personalized aesthetic preferences.

3.4. Social and Community Interaction

Respondents expressed strong demand for interaction with fellow enthusiasts and artists:90% wished to join or create Xuan paper making communities to share experiences, exchange insights, and build cultural identity.40% sought workshops or courses for skill development, emphasizing professional guidance needs.31.68% anticipated exhibitions to showcase works and learn from peers, while 47.52% supported artwork trading/exchange to promote cultural circulation and creative motivation. These social activities were recognized as key to enhancing user experience and cultural inheritance.

3.5. Educational and Training Functions

Eighty percent of respondents viewed the metaverse as an effective educational tool, supporting:Virtual internships: Simulating full production processes (e.g., raw material preparation, finished product manufacturing) to reduce material costs and risks, allowing repeated practice in a stress-free environment.Online courses: Covering basic theories, historical context, craftsmanship, and material selection, delivered via videos, audio, and graphic materials to accommodate diverse learning styles. Respondents emphasized the need for systematic, regularly updated curricula enabling self-paced, anytime learning.

4. Discussion and Analysis

4.1. Multi-Dimensional Empowerment Mechanism of Metaverse Technology for Xuan Paper Making Technique

4.1.1. Immersive Scenario Construction and Cultural Authenticity Restoration

Leveraging VR and AR technologies, the metaverse can highly replicate various scenes of Xuan paper making, such as the traditional processes of "steeping, boiling, paper fishing, and drying" in ancient workshops. User surveys indicate that over 80% of respondents hope to experience realistic operations of tools like paper fishing screens and drying racks, along with ambient sounds such as water flow and pulp stirring. This requires technical integration of physical

ISSN: 2692-7608 DOI: 10.6981/FEM.202509_6(9).0016

engines and dynamic rendering to approximate real-world tactile sensations. The introduction of dynamic weather systems-such as rainy days slowing pulp drying-further enhances scene realism, satisfying users' expectations for cultural authenticity while enabling "living inheritance". Immersive scenarios effectively convey cultural connotations [4], and the virtualization of Xuan paper technique may serve as a breakthrough for traditional craftsmanship inheritance.

4.1.2. Digital Twin-Driven Global Dissemination of Cultural Heritage

Through digital twin technology, Xuan paper production processes can be precisely replicated in virtual spaces, breaking geographical barriers. For instance, virtual workshops in the metaverse can allow global users to participate in paper fishing and drying, while blockchain technology generates unique digital certificates for each virtual artwork to ensure copyright ownership. Intangible cultural heritage exhibitions need to transcend physical boundaries [5], and the metaverse's global nature provides technical support for this.

4.1.3. Virtual-Real Symbiotic Economic Ecosystem and User Co-Creation Mechanisms

The metaverse not only provides virtual experience scenarios for Xuan paper technique but also spawns new economic models. Surveys show 90% of respondents wish to convert virtual Xuan paper designs into physical products, while nearly 70% expect to learn artists' techniques via live streams. This demand drives the formation of a closed-loop economic chain: "user creation-platform connection-physical production". Additionally, the rise of community co-creation models (e.g., virtual gallery transactions, collaborative creation) shifts Xuan paper technique inheritance from traditional "master-apprentice inheritance" to "collective co-creation" [7], enhancing cultural identity and injecting vitality into industrialization.

4.2. Practical Dilemmas: Triple Constraints of Technology, Culture, and Market

4.2.1. The Tension between Technical Adaptability and User Experience

The application of metaverse technology in digitizing Xuan paper making technique faces conflicts between technical adaptability and user experience. Despite users' expectations for highly realistic operational experiences via virtual tools and dynamic weather systems, existing technologies struggle to fully replicate the tactile feedback and physical properties of traditional craftsmanship. For example, inadequate precision of physical engines in simulating pulp flow may lead to discrepancies between virtual and real operational feel; limited dynamic rendering capabilities for complex environments (e.g., multi-light drying scenes) may reduce immersion. Furthermore, developing real-time feedback systems requires high computational power, increasing technical costs. While technology must dynamically adapt to user needs, technical fragmentation-such as poor VR device compatibility and inconsistent blockchain standards-causes experience fragmentation, necessitating cross-disciplinary technical integration.

4.2.2. Balancing Cultural Authenticity and Digital Expression

In digitization, simplifying cultural symbols may lead to the loss of craftsmanship essence. For instance, over-simplifying virtual tool operations could weaken the complexity of ancient techniques and the spirit of craftsmanship. Xuan paper technique is deeply intertwined with natural environments and regional customs [8], and metaverse abstraction may sever this cultural ecology. Meanwhile, users' demand for diverse craftsmanship requires platforms to balance standardized processes with personalized expression to avoid cultural fragmentation.

4.2.3. Addressing Financial Pressure and Market Competition

Metaverse projects incur high development costs, requiring sustained investment in dynamic scene construction and blockchain-based copyright protection. Small and medium-sized cultural institutions, constrained by funding, rely heavily on government subsidies or corporate partnerships. Intensified competition among similar ICH digitization projects exacerbates

ISSN: 2692-7608 DOI: 10.6981/FEM.202509_6(9).0016

market pressure, forcing platforms to balance differentiation and sustainable operation to meet user demands for content depth and functional innovation.

4.3. Innovative Pathways: Demand-Oriented Collaborative Development Strategies

Based on user needs and practical dilemmas, this study proposes a collaborative development strategy centered on "hierarchical design-community co-construction-technical integration" to promote sustainable inheritance and innovation of Xuan paper making technique in the metaverse.

4.3.1. Hierarchical Experience Design Framework: Stepped Empowerment from Entry to Professional

To address user diversity (e.g., casual enthusiasts, artists, ICH researchers), a differentiated experience hierarchy is proposed:

Entry Level (Popularization): Focus on low-threshold interaction with "one-click" virtual tours. Users gain quick insights into Xuan paper's history and basic craftsmanship through voice narration and animated modules. For example, drawing on digital exhibition technologies proposed by Liu et al. [9], the four key processes ("steeping-boiling-fishing-drying") are decomposed into modular animations for flexible viewing.

Intermediate Level (Skill Enhancement): Offer high-freedom simulation functions (e.g., pulp ratio experiments, paper fishing force control) integrated with AI real-time error correction. Users receive instant instructional videos and personalized learning reports upon operation errors, making this level suitable for vocational training in educational institutions.

Professional Level (Industry-Academia-Research Integration): Introduce "virtual internship certification". Upon completing intermediate tasks, users earn digital certificates and are recommended for physical workshop internships. Platforms can collaborate with enterprises to develop "user co-created products" (e.g., producing gold-flecked Xuan paper designs from virtual platforms), forming a "design-production-sales" closed loop.

4.3.2. Community-Driven Cultural Ecosystem Construction: Sustainable Cycles from Interaction to Co-Creation

To meet high social and co-creation demands, an integrated "creation-dissemination-transaction" cultural ecosystem is proposed:

Creation Communities: Host regular "ICH inheritor residency programs", where Xuan paper artisans conduct live teaching via avatars, enabling real-time Q&A and interactive creation. "Craftsmanship challenges" with physical Xuan paper prizes for community-voted winners will stimulate participation.

Virtual Cultural Databases: Build open repositories for user artworks, annotated with craftsmanship and inspiration sources to form searchable "Xuan paper technique digital archives". Regional cultural symbols-such as sandalwood forests and mountain springs in Jingxian County workshops-are reconstructed in virtual communities to enhance cultural identity.

Virtual-Real Trading Markets: Establish blockchain-based copyright protection, generating unique digital certificates (NFTs) for virtual works to facilitate trading or redemption for physical Xuan paper. A revenue-sharing model distributes transaction profits among creators, ICH workshops, and platforms, forming a sustainable benefit distribution chain.

4.3.3. Technical Integration and Standardization: From Fragmentation to Collaborative Infrastructure

To resolve technical fragmentation and lack of industry standards, cross-disciplinary integration and standardization are critical:

ISSN: 2692-7608 DOI: 10.6981/FEM.202509_6(9).0016

Technical Integration Paths:① AI+Physics Engine Optimization: Use machine learning algorithms to reduce computational costs for dynamic weather systems, ensuring smooth operation on low-end devices.② Blockchain+Digital Twin: Record full-process data (e.g., raw material sources, process parameters) on blockchain, enabling users to trace the "cultural gene" of virtual works and enhance trust.③ Open Cross-Platform Interfaces: Provide standardized APIs to support third-party developers in adding custom functions, enriching platform ecosystems.

Industry Standard Development:① Process Modeling Norms: Collaborate with industry associations to establish unified standards (e.g., motion capture precision for paper fishing, pulp ratio ranges) to ensure cultural authenticity.② Data Security and Ethics Guidelines: Clarify user privacy protection rules to mitigate risks of technical abuse.

In light of Shen Xianchen et al.'s view that "the metaverse drives new productive forces" [10], governments should establish special funds to support small and medium-sized ICH institutions in technical R&D and use tax incentives to encourage enterprises to invest in standardization.

5. Conclusion

Based on questionnaire surveys and analysis, this study systematically demonstrates the enabling effects and implementation pathways of metaverse technology in the digital transformation of Xuan paper making technique. The research shows that the metaverse provides multi-dimensional solutions for the living inheritance and innovative transformation of traditional crafts through immersive scene reconstruction, digital twin mapping, and virtual-real interactive economic ecosystems. Specifically, the high-precision replication of ancient papermaking processes by virtual reality technology effectively meets the dual demands of audiences for cultural authenticity and operational immersion, while blockchain-empowered digital certificate systems and virtual-real integrated customization services promote the global dissemination and industrial extension of the technique. Furthermore, the in-depth integration of community co-creation mechanisms and educational functions has transformed Xuan paper technique from closed "master-apprentice inheritance" to open "collective participation", significantly enhancing cultural identity and dissemination efficiency.

However, practical constraints such as technical adaptability bottlenecks, risks of cultural symbol deconstruction, and imbalances in funding supply pose challenges to the sustainability of metaverse empowerment. In response, this study proposes a collaborative development framework centered on "hierarchical experience design-community-based ecological construction-standardized technology integration": First, achieve precise matching of user needs through stepwise experience levels; second, build an integrated "creation-dissemination-transaction" cultural ecosystem relying on virtual communities to strengthen participants' value co-creation capabilities; third, promote cross-disciplinary technology integration and industry standard development to address the problem of technical fragmentation. This framework not only provides guidance for the living protection of Xuan paper making technique but also constructs a reference model for the digital transformation of similar intangible cultural heritage.

Future research needs to further explore the in-depth integration mechanisms between metaverse technology and traditional crafts, such as optimizing haptic feedback algorithms to enhance the operational realism of virtual tools, or integrating regional cultural symbols to strengthen cultural identity in virtual scenes. Meanwhile, it is suggested to build a government-led special support system to promote the transformation of intangible cultural heritage digitization from experimental projects to large-scale application through fiscal and tax incentives and technical standard formulation. Only by achieving synergistic resonance among

ISSN: 2692-7608 DOI: 10.6981/FEM.202509_6(9).0016

technological innovation, cultural preservation, and market mechanisms can we perpetuate the cultural gene of Xuan paper's "millennium-old ink charm" in the process of digital civilization.

Acknowledgments

This work was supported in part by a grant from Anhui Provincial Social Science Innovation and Development Research Project: Research on the Path of Activating Inheritance of Xuan Paper Making Techniques from the Perspective of Metaverse (Project No.: 2023CX087).

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