Research on Metaverse Application Scenarios for the Art of Xuan Paper Making

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Abstract: This paper addresses the challenges of inheritance gaps, communication limitations, and commercialization stagnation faced by the art of Xuan paper making, exploring Metaverse technology's application scenarios in its active inheritance. Based on the "virtual-real integration," "immersive interaction," and "open ecosystem" characteristics of the Metaverse's "BAND technology system," the study analyzes the compatibility logic between Metaverse and Xuan paper techniques in terms of technical adaptation, experience complementarity, and ecological synergy. It proposes four application scenarios: digital twin craftsmanship database, Metaverse Xuan Paper Workshop, Metaverse teaching platform, and Metaverse digital cultural and creative products. These scenarios provide a replicable model for the digital transformation of Xuan paper and other craft-based intangible cultural heritages (ICH), promoting an upgrade from "rescue preservation" to "creative transformation" in ICH protection.

Keywords: Xuan Paper Making Technique, Metaverse, ICH Inheritance, Application Scenarios

1. Introduction

Xuan paper, as the "first of the Four Treasures of the Study," carries the millennial ink charm of Chinese civilization. Its production technique, involving 108 processes—including "material selection, soaking, steaming, bleaching, pulping, papermaking, pressing, and baking"—integrates multi-disciplinary wisdom in physics, chemistry, and biology, making it a "living fossil" of Chinese traditional craftsmanship[1]. In 2009, the art of Xuan paper making was inscribed on the UNESCO Representative List of the Intangible Cultural Heritage of Humanity, becoming an important symbol of Chinese cultural dissemination. However, in the contemporary era of digitalization and globalization, this "national treasure" technique faces unprecedented inheritance challenges.

Traditional ICH inheritance relies on intergenerational "oral and intangible transmission," but the complexity and low profitability of Xuan paper making have exacerbated inheritance gaps. Limitations in communication methods further weaken public awareness: current dissemination of Xuan paper culture still relies on static museum displays and fragmented documentary presentations, failing to reproduce the subtle interactions between the paper curtain and pulp during "curtain papermaking" or the precise control of temperature and humidity in "fire baking." Stagnant commercialization has created a "inheritance-development" vicious cycle. Current Xuan paper products remain primarily traditional calligraphy and painting paper, with a single form and high market threshold, struggling to attract young consumers; cultural and creative derivatives often stay at the primary stage of "paper + patterns," lacking deep excavation of cultural connotations[2].

The rise of the Metaverse offers dual technological and conceptual innovation for ICH inheritance[3]. As a new internet form integrating "physical, social, and digital spaces," the Metaverse is built on core technologies of Blockchain, AI, 5G Network, and VR/AR Display (BAND technology system)[4]. Its characteristics of "virtual-real integration," "immersive interaction," and "open ecosystem" align closely with the needs of ICH inheritance. In 2023, the Ministry of Industry and Information Technology and four other departments jointly issued the Three-Year Action Plan for Metaverse Industry Innovation and Development (2023–2025), explicitly proposing to "promote immersive interactive life and consumption scenarios and advance digital inheritance of cultural heritage," providing policy support for the integration of Metaverse and ICH.

While Metaverse applications in cultural tourism and cultural relics have shown initial progress[5],

research on ICH techniques remains at the "conceptual framework" stage. As a typical representative of "craft-based ICH," the complex process flow and unique cultural symbolism of Xuan paper making require Metaverse applications to transcend the role of a "display tool" and evolve into an "inheritance carrier" and "innovation platform."

Gainst this backdrop, this paper takes the art of Xuan paper making as its research object, aiming to answer core questions: How can Metaverse technology deeply integrate with the technical characteristics of Xuan paper making? How to design specific application scenarios? By exploring these questions, we not only provide solutions for the active inheritance of Xuan paper making but also offer replicable experience for Metaverse applications in other craft-based ICHs, driving a shift from "rescue preservation" to "creative transformation" in ICH protection.

2. Compatibility Analysis Between Metaverse and Xuan Paper Making Technique

The Metaverse's technical support system, centered on "BAND," has evolved beyond single-technology application to a "technology-society-economy" composite ecosystem[6]. The inheritance dilemma of Xuan paper making essentially stems from the misalignment between "traditional inheritance methods" and "modern social needs," with core demands including: technique protection (addressing "irreversibility" and "ambiguity"); communication promotion (breaking "spatiotemporal constraints" and "cognitive barriers"); education inheritance (responding to "generational gaps" and "efficiency bottlenecks"); and commercial development (unifying "cultural value" and "market value"). The technical features of the Metaverse and the inheritance needs of Xuan paper making form a three-layer compatibility logic of "technical adaptation-experience complementarity-ecological synergy," detailed as follows:

2.1 Technical Adaptation: BAND Technology Solves Technique Protection Challenges

Through 3D scanning and motion capture, a "digital twin craftsmanship database" for Xuan paper making can be established, recording parameters of each process and storing them via blockchain to address the "ambiguity" of implicit knowledge. AI analysis of user operation data in virtual workshops can generate "individual learning profiles" to optimize teaching for inheritors. AI can also predict "attrition risks" among apprentices, reducing dropout rates through incentive tasks. The low-latency 5G network supports "remote immersive teaching," where inheritors interact with apprentices in virtual workshops via digital avatars, solving the efficiency bottleneck of the "mentor-apprentice system." Additionally, digital avatars can "split" to participate in multiple teachings, enhancing efficiency.

2.2 Experience Complementarity: Immersive Interaction Reconstructs Cultural Cognition

VR technology can reconstruct historical scenes of Xuan paper making, allowing users not only to observe the full process of "material selection-papermaking-baking" but also to "participate" in the daily lives of ancient papermakers, experiencing the cultural significance of Xuan paper in historical contexts like "literati gatherings" and "imperial exams." AR devices can overlay virtual guidance onto real tools, providing real-time feedback during physical operations and lowering the learning threshold. The "social attribute" of the Metaverse enables the construction of "Xuan paper cultural communities," where users engage in activities like "papermaking contests" and "Xuan paper knowledge quizzes" via virtual avatars, forming a positive cycle of "cultural identity-emotional resonance-active dissemination."

2.3 Ecological Synergy: Open Platform Drives a "Inheritance-Consumption-Reciprocity" Cycle

Blockchain-based NFT technology can issue "Xuan paper craftsmanship digital collectibles," which users can display or gift in the Metaverse platform, forming a "cultural consumption-value appreciation" commercial cycle. Some NFT holders use virtual paper samples for digital art creation, with works auctioned in Metaverse galleries. The Metaverse can connect diverse scenarios like calligraphy, education, and tourism to build a "Xuan paper +" ecosystem. For example, collaborating with digital art platforms to develop "Metaverse calligraphy and painting galleries," where users create digital paintings using virtual Xuan paper, with works generating copyright certificates and participating in online auctions; partnering with cultural tourism scenic spots to launch "Xuan paper-themed virtual tours," where tourists who complete "papermaking tasks" in virtual Jingxian paper workshops can exchange for offline experience coupons. The "user co-creation" mechanism can

stimulate public participation while providing market demand data for enterprises.

2.4 Empowerment Logic Summary: Upgrading from "Technical Tool" to "Ecological Carrier"

The empowerment of Xuan paper making by the Metaverse, through technical, experiential, and ecological synergy, fundamentally transforms ICH inheritance from "passive protection" to "active activation" and from "single preservation" to "systemic development." The core empowerment logic can be condensed into three progressive levels:

First level: Technical adaptation solves inheritance pain points. The BAND system addresses the four core demands of Xuan paper making: blockchain and digital twin technology resolve "ambiguity" of implicit knowledge and "irreversibility" of techniques, building a traceable, verifiable "digital craftsmanship database"; AI and big data break the "efficiency bottleneck" of traditional teaching, enabling precision through user behavior analysis; 5G and VR/AR terminals eliminate "spatiotemporal constraints," making remote immersive teaching and global dissemination feasible. Technical adaptation provides scientific support for "preservation."

Second level: Experience reconstruction activates cultural identity. The "immersive interaction" of the Metaverse redefines public engagement with Xuan paper culture: historical scene restoration transforms users from "bystanders" to "participants," connecting them to the deep cultural links between Xuan paper and literati gatherings or imperial exams; operational participation shifts users from "passive receivers" to "active learners," with AR guidance and VR feedback lowering learning barriers; community interaction turns users from "individual experiencers" to "cultural co-creators," fostering emotional resonance and dissemination momentum. Experience upgrading infuses emotional depth into "communication."

Third level: Ecological synergy promotes sustainable development. The "open ecosystem" of the Metaverse constructs a "inheritance-consumption-reciprocity" cycle: digital asset circulation converts cultural value into market value, reciprocating inheritor training and technique protection; cross-border integration expands commercial boundaries, attracting young consumers; user co-creation activates public participation, evolving Xuan paper culture from an "ICH symbol" to a "living ecosystem." Ecological construction provides sustained momentum for "development."

In summary, the Metaverse's empowerment of Xuan paper making has transcended the role of a "technical tool," evolving into a composite form of "inheritance carrier" and "ecological platform." This process not only addresses the practical dilemmas of Xuan paper making but also explores a universal path of "technical empowerment-experience upgrading-ecological reciprocity" for ICH activation, offering a replicable model for the digital transformation of other craft-based ICHs like Huizhou ink making and Shu embroidery, and driving a historic shift in ICH protection from "rescue preservation" to "creative transformation."

3. Metaverse Application Scenarios in Xuan Paper Making

Based on the technical characteristics of the Metaverse and the inheritance needs of Xuan paper making, this study identifies four core application scenarios covering technique protection, experience upgrading, education inheritance, and commercial development, each with specific case designs.

3.1 Scenario 1: Digital Twin Craftsmanship Database—Building a "Living" Technique Gene Bank

Supported by 3D scanning + motion capture, blockchain certification, and AI data analysis, this scenario transforms raw materials, tools, and processes of Xuan paper making into traceable, interactive digital assets via high-fidelity digital modeling, addressing the "ambiguity of implicit knowledge" and "irreversibility" of traditional techniques to form a "living" technique gene bank.

Taking "Hongxing Xuan Paper" in Jingxian as a pilot for the "digital twin craftsmanship database," the full-element digitization can be achieved through the following steps:

Material digitization: 3D scanning of wingceltis bark and sandy field rice straw to record physical parameters (fiber length, toughness) and geographically tag material origins, forming a "material digital archive."

Tool digitization: High-precision modeling of tools like paper curtains and baking walls to record material, dimensions, and service life, with AR enabling dynamic "tool-function" associations.

Process digitization: Motion capture of 30 core processes among 108, recording inheritors' operation gestures, force, and timing, combined with high-speed camera footage, to generate "process digital twin models."

This "living" technique gene bank marks a shift from "experience-based inheritance" to "data-based inheritance."

3.2 Scenario 2: Metaverse Xuan Paper Workshop—Creating a "Tangible" Immersive Experience Space

Supported by VR/AR terminals, 5G low-latency transmission, and force-feedback devices, this scenario constructs a "tangible, operable, interactive" immersive space through "online virtual + offline AR" integration, addressing "spatiotemporal constraints" and "cognitive barriers" in traditional communication and transforming the public from "viewers" to "participants."

Collaborating with Tencent Cloud, Jingxian Xuan Paper Cultural Park could develop the "Metaverse Xuan Paper Workshop" with two modes:Historical traversal mode: Users wear VR devices to enter a "Qing Dynasty Jingxian paper workshop," assuming the role of papermakers to complete the full process of "purchasing wingceltis bark-soaking materials-curtain papermaking-fire baking." The system simulates the weight of paper curtains and viscosity of pulp via force-feedback handles, with tasks like "imperial exam paper" and "literati gathering paper," rewarding users with "ancient papermaker certification" virtual medals upon completion.Modern innovation mode: Users can adjust process parameters or design personalized paper samples, with the system generating "virtual Xuan paper" in real time and displaying its "paper longevity" (simulating aging after 100 years) to help understand the relationship between process and paper quality.

Offline AR navigation enables seamless virtual-real integration. In the physical exhibition area of the Xuan Paper Cultural Park, users scanning physical tools via AR glasses trigger:Dynamic process demonstration: Scanning a paper curtain overlays a 3D animation of "curtain papermaking" with annotations on "wrist angle" and "pulp height."Cultural story embedding: Scanning a wingceltis bark sample pops up "the growth story of wingceltis trees."Interactive quizzes: Scanning finished Xuan paper prompts questions like "Why can Xuan paper be preserved for a millennium?" with voice answers unlocking "Xuan paper expert" electronic certificates.

3.3 Scenario 3: Metaverse Teaching Platform—A New Inheritance Paradigm to Address "Generational Gaps"

Supported by digital human technology, 5G remote interaction, and big data analysis, this scenario solves the "efficiency bottleneck" and "generational gaps" of the traditional "mentor-apprentice system" through a "digital mentor + personalized training + community learning" model, enabling large-scale and precise technique education.

Collaborating with iFLYTEK, Anhui Xuan Paper Co., Ltd. could develop the "Metaverse Teaching Platform," generating a digital mentor "Xiao Dong" based on motion data from national inheritor Zhou Donghong. "Xiao Dong" featuresMultilingual instruction: Supporting Chinese, English, Japanese, etc., to meet international apprentice needs.Personalized guidance: AI analysis of apprentice operation data generates "learning reports" and recommends targeted training.

Emotional interaction: Simulating human teaching through facial expressions and voice intonation to enhance apprentice engagement.The platform includes an "apprentice community" for team-based "papermaking challenges," "craftsmanship knowledge competitions," and incentive rankings (e.g., "mentor list," "team list"), shifting from "individual learning" to "collective growth."

3.4 Scenario 4: Metaverse Digital Cultural and Creative Products—Activating a New Commercial Ecosystem for "Cultural Value"

Supported by blockchain NFTs, digital art generation, and Metaverse platforms, this scenario converts the "cultural value" of Xuan paper culture into "market value" through digital assets, virtual creation spaces, and cross-border collaborations, forming a "inheritance-consumption-reciprocity" cycle.

NFT issuance: The Jingxian Bureau of Culture and Tourism could collaborate with AntChain to issue "Xuan Paper 108 Processes NFT Set," including 108 process 3D animations, digital signatures

from 6 national inheritors, and "virtual paper samples." With 1,000 sets at ¥399 each, 20% of sales revenue would subsidize inheritors, and 10% would fund technique protection.

Metaverse calligraphy and painting gallery: Partnering with Tencent Huanhe, users could create digital paintings using "virtual Xuan paper NFTs" in "traditional" or "innovative" modes. Generated works can be exhibited in Metaverse galleries for purchase, exchanged for physical paper (with a production fee), or entered into "digital art contests," with winners receiving inheritor guidance.

Cross-border collaborations: Xuan paper enterprises could partner with the Only This Green IP to launch "Green Mountains and Rivers Xuan Paper NFTs," integrating dance-inspired "mountain ranges" into virtual paper samples, alongside offline "green-themed Xuan paper gift boxes" to boost sales.

3.5 Scenario Summary: Evolution from "Single Application" to "Systemic Ecosystem"

The four Metaverse application scenarios for Xuan paper making are not isolated but form a complete "protection-experience-education-commerce" ecosystem through technical interconnection and data sharing: the digital twin craftsmanship database provides data support for other scenarios; the Metaverse workshop and teaching platform enhance user cognition; digital cultural and creative products reciprocate investment in the former through market returns. This ecosystem marks a shift from "single technical application" to "systemic ecological drive," offering a sustainable solution for the "living inheritance" of ICH.

4. Conclusion and Discussion

4.1 Research Conclusions

This study, starting from the inheritance dilemmas of Xuan paper making, systematically explores the integration path between Metaverse technology and traditional ICH, reaching the following core conclusions:

First, the Metaverse provides a "technology-experience-ecology" trinity solution for the active inheritance of Xuan paper making. The four pain points of traditional ICH inheritance—"ambiguity of implicit knowledge," "spatiotemporal communication constraints," "generational gaps," and "difficulty in converting cultural value to market value"—are systematically addressed through the technical adaptation, experience reconstruction, and ecological synergy of the Metaverse. Technically, the BAND system converts the implicit knowledge of 108 processes into traceable, verifiable digital assets via digital twins, motion capture, and blockchain, resolving the irreversibility and ambiguity of "experience-based inheritance"; experientially, the immersive interaction of VR/AR redefines public engagement with Xuan paper culture, transforming "bystanders" into "participants" and "passive receivers" into "active learners," significantly enhancing cultural identity; ecologically, the open platform nature of the Metaverse drives a "inheritance-consumption-reciprocity" cycle, with digital cultural and creative products converting cultural value to market value and reciprocating technique protection and inheritor training, injecting momentum into sustainable ICH development.

Second, the Metaverse's empowerment of Xuan paper making has transcended the role of a "technical tool" to a composite form of "inheritance carrier" and "ecological platform." From the "gene preservation" of the digital twin craftsmanship database, to the "immersive experience" of the Metaverse workshop, to the "large-scale inheritance" of the teaching platform and the "commercial reciprocity" of digital cultural and creative products, the four scenarios form a complete "protection-experience-education-commerce" ecological chain through technical interconnection and data sharing. This ecological chain not only addresses the practical dilemmas of Xuan paper making but also explores a universal path of "technical empowerment-experience upgrading-ecological reciprocity" for ICH activation, providing a replicable model for the digital transformation of other craft-based ICHs such as Huizhou ink making and Shu embroidery, and driving a historic shift in ICH protection from "rescue preservation" to "creative transformation."

Finally, the integration of the Metaverse and Xuan paper making essentially represents a deep dialogue between "traditional culture" and "digital civilization." Their combination is not merely "technology empowering culture," but more importantly, "culture defining technology"—the value of the Metaverse lies not only in the advancement of technology itself but in its capacity to carry and transmit cultural essence. Through designs such as "historical scene restoration," "virtual papermaker experience," and "digital cultural and creative co-creation," the "living genes" of Xuan paper culture

are injected into the Metaverse space, transforming technical tools into "new containers" for cultural inheritance and digital spaces into "new arenas" for cultural identity.

4.2 Discussion and Prospects

Although this study proposes four application scenarios and ecological logic for the Metaverse in Xuan paper making, several challenges and optimization directions require attention in practical implementation:

First, balancing technological maturity and user experience. Current limitations in the portability of VR/AR devices and precision of force feedback may affect the immersiveness of the Metaverse workshop; market acceptance of blockchain NFTs and the legal attributes of digital collectibles also require further regulation. Future efforts should focus on technological iteration and policy coordination to lower user participation thresholds and ensure ecological sustainability.

Second, defining the boundary between cultural essence and commercial development. The core of Metaverse digital cultural and creative products is "supporting culture through commerce," but excessive commercialization must be avoided to prevent the erosion of cultural authenticity. For example, the design of Xuan paper NFTs should retain technical details rather than merely pursuing visual appeal; cross-border collaborations should deeply integrate cultural connotations rather than superficially "attaching labels." A "cultural consultant + technical team" collaborative mechanism could ensure a balance between commercial development and cultural protection.

Third, coordinating public participation and professional inheritance. While the Metaverse teaching platform enables large-scale dissemination of techniques, the emotional bonds and experiential transmission of the traditional "mentor-apprentice system" cannot be fully replaced by digital avatars. Future exploration could focus on a hybrid model of "online digital avatar teaching + offline inheritor practice," leveraging the Metaverse to enhance teaching efficiency while preserving the humanistic warmth of traditional mentor-apprentice relationships, thus achieving mutual reinforcement between "technical empowerment" and "cultural inheritance."

In general, the integration of the Metaverse and Xuan paper making represents a collision and symbiosis between "tradition" and "future." It not only injects new vitality into this "living fossil" technique but also reveals the profound value of digital technology in cultural inheritance—technology's ultimate goal is not to replace culture, but to enable culture to endure in a more vivid, inclusive, and sustainable manner. With the continuous maturation of Metaverse technology and deepening of social understanding, we can reasonably anticipate that the art of Xuan paper making, equipped with this digital "wing," will transition from "ICH lists" to "life scenarios" and from "cultural symbols" to "living ecosystems," continuing to write the ink-drenched chapters of Chinese civilization in the new era.

Acknowledgements

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