Research on Paper Cuttings Digital Cultural and Creative Product Development and Experience Innovation Based on 3D Reconstruction

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ABSTRACT As one of the first batch of national intangible cultural heritage and human intangible cultural heritage masterpieces in China, Paper Cuttings takes two-dimensional plane as the core form of existence and faces practical difficulties such as fault of skill inheritance, homogenization of cultural and creative products, lack of experience interaction, and single dimension of cultural communication in the digital wave. The 3D reconstruction technology provides cross dimensional technical support for the digital transformation of Paper Cuttings art, cultural and creative product development and experience mode innovation by virtue of high-precision data collection, three-dimensional model construction, dynamic rendering and cross platform adaptation capabilities.

INDEX TERMS 3d reconstruction,paper-cutting art,digital cultural products,immersive interaction,cultural heritage digitization

I. INTRODUCTION

A. RESEARCH BACKGROUND AND SIGNIFICANCE

PAPER Cuttings art is the "living carrier" of Chinese folk culture, and it has four core cultural characteristics: folk custom, symbolic, regional and inheritance[1-3].

Folk custom: Paper Cuttings is rooted in folk festivals, weddings and funerals, sacrificial rites, daily life and other scenes, and is an important part of folk activities. Spring Festival window decorations, wedding celebration flowers, birthday flower cutting, and sacrificial flower offerings carry folk functions such as exorcism and blessing, good luck and prosperity, reproductive worship, and ancestor worship, and are deeply bound to people's lives[4].

Symbolism: Paper Cuttings takes "auspicious implication" as the core, and transforms flowers, birds, fish and insects, auspicious animals, auspicious birds, human allusions, and geometric patterns into cultural symbols by means of "homophonic, symbolic, and understanding". A complete symbolic system is formed, such as "Bat Fortune", "Deer - Fortune", "Magpie - Happiness", "Peony - Fortune", "Fish in the Year of Lotus - Abundant Years"[5].

Regionalism: Influenced by regional culture, living environment, and aesthetic habits, different regional schools with distinct styles are formed. Northern Paper Cuttings (Ansai, Shanxi, Paper Cuttings) is bold and unconstrained, simple in shape and thick in lines; Southern Paper Cuttings (Yangzhou, Jiangsu, Foshan, Guangdong) is exquisite and beautiful, with complex composition and exquisite knife technique; Ethnic Paper Cuttings (Miao, Manchu) combines national totem and belief with unique style[6].

Inheritance: Paper Cuttings is mainly inherited through "oral transmission, mentoring and family continuity". Its skills include cutting, carving, tearing, burning, dyeing and other techniques. Its core is "intaglio" (lines are broken, block surface is reserved), "embossed" (lines are connected, lines are reserved), and "yin and yang mixed". Through thousands of years of inheritance, a stable technical system has been formed[7].

B. PROCESS CHARACTERISTICS

The core characteristics of Paper Cuttings technology are "plane hollowing, manual creation, simple materials and flexible lines", which determines the technical difficulties of digital collection and 3D reconstruction[8].

Plane hollowing out: Paper Cuttings is a two-dimensional plane art, and its core aesthetic sense originates from "hollowing out and transparent". The lines are uneven in thickness and different in hollowing out shapes. Complex works include multi-layer nesting and fine patterns (the minimum line width is only 0.2mm), and 3D modeling is prone to surface breaking, leakage, and structural distortion[9].

Handmade uniqueness: Pure handmade creation results in each piece having uniqueness, with subtle differ ences in knife marks depth, line curvature, wrinkle shape, and edge

burrs, forming a "handmade texture beauty". Digitization requires precise capture of microscopic details[10].

Material particularity: traditional Paper Cuttings is made of rice paper, red paper, raw edge paper, silk and silk, which is light and thin, easy to be damaged, strong in light transmittance, and fine in texture. It is easy to deform under the influence of light source and pressure when scanning, and requires non-contact high-precision collection.

Structural simplicity: Paper Cuttings composition is based on the principle of "symmetry, balance and conciseness". Its shape is exaggerated and deformed. It pays attention to "spirit rather than shape". Three dimensional reconstruction needs to retain artistic exaggeration to avoid cultural distortion caused by over realism[11].

C. REALISTIC PAIN POINTS OF PAPER CUTTINGS DIGITAL TRANSFORMATION

Pain points of protection and inheritance

Physical preservation dilemma: paper Paper Cuttings is prone to damp, mildew, moth eaten, fading, and damage. Traditional collections (mounting, refrigeration) have high costs and limited effects. A large number of old Paper Cuttings of the Qing Dynasty and the Republic of China are on the verge of destruction, and the risk of permanent loss of technical details is high[12].

Skill inheritance gap: The aging of inheritors is severe, and young people are unwilling to learn due to "long cycles, low returns, and low recognition". Traditional "oral transmission" cannot permanently preserve the details of skills (knife angle, strength, speed), increasing the risk of skill loss[13].

Shallow level of digital archiving: Existing digitization mostly focuses on two-dimensional images and video shooting, unable to record three-dimensional textures, hollow layers, and translucent textures. The integrity and fidelity of digital archives are insufficient, making it difficult to support in-depth research and innovative development.

Pain points of cultural and creative products

Single form solidification: The product is limited to two-dimensional planes, and the categories are concentrated in stickers, hanging paintings, ornaments, and clothing printing, lacking three-dimensional forms, interactive functions, and innovative carriers, resulting in serious homogenization[14].

Low added value: Handmade production has low efficiency, high costs, mismatched product prices and values, weak market competitiveness, and difficulty in forming brand effects and economies of scale.

Insufficient technological integration: The combination of cultural and creative industries with digital technology is shallow, with only simple addition of electronic components or AR animations, without deep innovation based on 3D models, and the value of technology serving culture is not reflected[15].

D. APPLICABILITY AND APPLICATION VALUE OF 3D RECONSTRUCTION TECHNOLOGY

3D reconstruction technology has all-round adaptability and core application value for the pain points of Paper Cuttings digital transformation, as shown in Table 1 below:

TABLE 1. Key Technical Indicators of 3D Reconstruction for Paper-Cutting Art

Indicator Item	Specification Requirement	Testing Result
3D scanning accuracy	0.005–0.01 mm	0.008 mm
Point cloud density	$\geq$ 1.2 million points per model	1.86 million points
Number of model faces	300,000–800,000 (lightweight mode)	450,000 faces
Texture resolution	4K–8K	8K
Interactive frame rate	$\geq$ 60 fps	62 fps
Model loading time (mobile)	$\leq$ 1.2 s	0.9 s
Hollow structure integrity	$\geq$ 99%	99.4%

To sum up, 3D reconstruction technology is the core technical support for solving the pain points of Paper Cuttings digital transformation, realizing cultural protection, product innovation, experience upgrading and industrial development, and has irreplaceable application value.

II. CONSTRUCTION OF 3D RECONSTRUCTION TECHNOLOGY SYSTEM BASED ON PAPER CUTTINGS CHARACTERISTICS

A. PAPER CUTTINGS FULL ELEMENT 3D DIGITAL ACQUISITION SCHEME

In view of the characteristics of Paper Cuttings, such as "thin and fragile, exquisite hollowed out, manual texture, and cultural diversity", a non-contact acquisition scheme of all elements in a trinity of "material layer, technical layer, and cultural layer" is designed to ensure data integrity, high precision, and cultural authenticity[16].

1) Collection equipment and parameter configuration

The combination equipment of "industrial structured light scanner+3D laser scanner+4K ultra-high definition microscope system+motion capture system" is used to adapt to different types of Paper Cuttings works (singlelayer/multilayer, small/large, traditional/modern).

Structured light scanner: precision 0.005mm. While the paper medium is subject to environmental warping, this sub-millimeter precision—maintained within the strictly controlled constant temperature and humidity platform—is essential for capturing the microscopic "handmade texture," such as the depth of knife marks and edge burrs, which are critical for high-fidelity texture mapping and preventing light-leakage in the model's hollow structures.

Three dimensional laser scanner: precision 0.01mm, scanning range 1000mm $\times$ 800mm, suitable for large, rugged, single-layer Paper Cuttings, and fast acquisition of overall shape[17].

4K Ultra HD Microscopic System: With 12 million pixels and a magnification of 50-200 times, it captures microscopic textures such as paper texture, edge burrs, and color gradients.

Motion capture system: 16-lens infrared capture with an accuracy of 0.1mm. Rather than serving the static 3D model directly, this system records the dynamic "technique layer" (knife trajectory, angle, and speed) to provide a behavioral data foundation for the virtual teaching aids and immersive theater components, enabling a complete digital reconstruction of both the artifact and the intangible skill.

Auxiliary equipment: Constant temperature and humidity acquisition platform (temperature 22 $\pm$ 1 °C, humidity 50 $\pm$ 5%), a high-precision vacuum suction stage combined with electrostatic flattening technology to eliminate microvibrations and paper fluttering, a non-contact fixed bracket, and a multispectral light source to ensure the 0.008mm precision is physically achievable without material deformation[18].

2) Three layer collection content and process

Physical layer collection (core): collect full details of Paper Cuttings physical form. Process: Work cleaning $\rightarrow$ Non contact fixation $\rightarrow$ Multi angle scanning (0 °, 45 °, 90 °, 135 °, 180 °) $\rightarrow$ Microscopic texture shooting $\rightarrow$ Color calibration (standard color card) $\rightarrow$ Preliminary data verification. Key points to capture: contour shape, hollow structure, line thickness, depth of knife marks, wrinkle form, paper texture, transparency, color information.

Skill level collection: collect the whole process of Paper Cuttings creation skills. Process: Inheritor Creation Recording $\rightarrow$ Motion Capture (Hand and Tool Trajectory) $\rightarrow$ Knife Movement Parameter Collection (Angle, Force, Speed) $\rightarrow$ Technique Explanation Recording $\rightarrow$ Step Disassembly Record. Coverage: cutting/carving/ tearing/dyeing techniques, intaglio/intaglio techniques, composition process, key points of detail process ing[19].

Cultural layer collection: Collecting cultural connotations and background information of works. Process: Interview with inheritors $\rightarrow$ Record of folk symbolism $\rightarrow$ Annotate regional style $\rightarrow$ Organize historical background $\rightarrow$ Collect usage scenarios. Content: Work name, meaning explanation, folk function, regional genre, creative background, related legends, cultural value[20].

B. POINT CLOUD DATA PROCESSING AND 3D MODEL RECONSTRUCTION

1) Point Cloud Data Preprocessing

The collected raw point cloud data contains noise, redundancy, and misalignment, and requires preprocessing to ensure modeling quality:

Denoising processing: A combination of statistical filtering and radius filtering algorithm is used to remove scanning noise, clutter, and redundant points, while retaining effective data. The denoising rate is controlled within 15% to avoid loss of details.

Point cloud registration: The ICP (Iterative Closest Point) algorithm is used to complete multi view point cloud stitching, with a registration error of $\leq$ 0.005mm, ensuring the overall integrity of the model.

Simplification and optimization: For high-density point clouds (single model 5-10 million points), curvature simplification algorithm is adopted to retain key feature points (lines, hollows, textures), reducing the number of points by 40% -60% after simplification, ensuring subsequent modeling efficiency.

Coordinate normalization: unify the model coordinate system, set the center point and datum plane, and facilitate subsequent model editing and cross platform adaptation.

2) Core Reconstruction Algorithm for 3D Models

Aiming at the difficulties of Paper Cuttings "complicated hollow structure, multi-layer nesting, and fine lines", we developed an adaptive reconstruction algorithm for hollow structure. The core process is as follows:

Contour extraction: based on the edge detection algorithm, accurately extract the inner and outer contours of Paper Cuttings, hollow edges, and distinguish between lines and block surface structures.

Surface reconstruction: Adopting an improved Poisson surface reconstruction algorithm, optimizing the topology generation logic for hollow areas to avoid surface breakage and leakage; The multi-layer Paper Cuttings adopts the layered reconstruction+splicing technology to restore the nested structure.

Thickness generation: according to the Paper Cuttings material (rice paper 0.05 – 0.1mm, silk 0.03 – 0.08mm), give the model a uniform ultra-thin thickness (0.05 – 0.1mm), restore the sense of lightness.

Topology optimization: Optimize the topology structure of the model mesh, reduce the number of triangular faces (control complex models within 1-3 million faces), improve rendering fluency, and ensure structural integrity.

3) Texture Mapping and Manual Texture Restoration

High definition texture mapping: Accurately map 4K microscopic texture images to 3D models, using UV unfolding optimization algorithm to avoid texture stretching, distortion, and misalignment, with a texture fit of $\geq$ 98%.

Handmade texture dynamic mapping technology: For handmade details such as knife marks, wrinkles, and burrs, a combination of normal mapping, bump mapping, and roughness mapping technology is used to restore the three-dimensional texture and translucent texture; Simulate subtle differences in manual creation to avoid model "mechanization and homogenization".

Material and Light Shadow Adjustment: Set the material parameters of Xuan paper/red paper/silk (transparency 0.3-0.5, roughness 0.2-0.4, high light intensity 0.1-0.2) to simulate natural light transmission and reflection effects, enhancing realism.

C. MODEL OPTIMIZATION AND CROSS PLATFORM ADAPTATION TECHNOLOGY

1) Multi dimensional optimization of 3D models

Precision optimization: For complex hollow areas, local refinement processing is carried out to repair broken surfaces, gaps, and distortion problems. The geometric error of the model is $\leq$ 0.008mm, and the cultural restoration degree is $\geq$ 96.7%.

Lightweight optimization: Using model reduction and LOD (Level of Detail) technology, high, medium, and low precision versions are generated: high precision (1-3 million faces, used for archiving and 3D printing), medium precision (300000-800000 faces, used for PC display), and low precision (50000-200000 faces, used for mobile and VR/AR real-time interaction), ensuring smooth operation of different devices (frame rate $\geq$ 60fps).

Dynamic optimization: add physical engine simulation to achieve the effect of slight swing, bending, light and shadow changes of the Paper Cuttings model, restore the soft texture of the paper, and improve the dynamic realism.

2) Cross platform format output and adaptation

Build a "one source, multi terminal" output system to meet the needs of different scenarios:

Digital archive:. obj/. fbx/. stl (high-precision, uncompressed);

3D printing:. stl/. 3mf (closed model, wall thickness adapted printing process);

VR/AR interaction:. glb/. gltf (lightweight, PBR material, compatible with Unity/Unreal engine);

Mobile/web:. usdz/. glb (compressed format, loading speed $\leq$ 2s);

Digital collectibles:. fbx+blockchain authentication information (unique identifier, copyright traceability). This comprehensive optimization framework ensures that the digital assets are not only high-fidelity replicas but also flexible enough for industrial application. Building upon these technical achievements, the following section outlines the strategic shift from digital preservation to creative product development.

III. DEVELOPMENT OF PAPER CUTTINGS DIGITAL CULTURAL AND CREATIVE PRODUCTS BASED ON 3D RECONSTRUCTION

A. DEVELOPMENT PRINCIPLES OF DIGITAL CULTURAL AND CREATIVE PRODUCTS

1) Principle of Cultural Authenticity

Adhere to the core of this traditional craft, retaining key patterns and regional styles. Invite master practitioners and regional experts to deeply participate in the development, ensuring accurate and authentic cultural expression without excessive commercialization; Invite inheritors of intangible cultural heritage to deeply participate in the development, ensuring accurate and authentic cultural expression.

2) Principle of Technical Adaptability

Taking "technology service culture and experience priority" as the core, not blindly pursuing technological complexity; Choose mature, stable, low-cost, and easily accessible technologies to adapt to different scenarios and user groups, and enhance product practicality and implementation.

3) Principle of Experience Innovation

Breaking through the limitations of traditional "viewing" and building a full process experience of "viewing learning creation customization collection sharing", integrating multi sensory interaction, personalized customization, and social sharing to meet the diverse needs of young users.

4) Market Adaptability Principle

Focus on the four core users of Generation Z, cultural and tourism consumers, cultural and creative enthusiasts, and educational groups, and develop young, China-Chic, practical, cost-effective products; Balancing collection value, practical value, and social value, enhancing market competitiveness and economic benefits.

5) Principles of Sustainable Development

Adopting the model of "digital model reuse+flexible production+industry chain integration" to reduce development costs and improve efficiency; Pay attention to copyright protection (blockchain certification) and build a sustainable ecosystem of "development operation iteration profit".

B. CLASSIFICATION SYSTEM AND FORM DESIGN OF DIGITAL CULTURAL AND CREATIVE PRODUCTS

Based on the characteristics of 3D models and market demand, a Paper Cuttings digital cultural and creative product matrix with four categories and more than 20 forms was constructed, covering the whole field of digital virtualization, immersive experience, physical hardware, and personalized customization.

1) Digital Collection Products (Virtual Assets)

Using 3D models as the core, create high fidelity, collectible, and traceable digital assets to meet the needs of collection, viewing, and dissemination.

High precision 3D digital collectibles: based on blockchain technology for ownership confirmation (unique identification, copyright traceability), limited edition release for each item; Support 360 ° rotation viewing, microscopic detail zooming, dynamic light and shadow display, and folk commentary; Compatible with mobile phones, computers, and VR devices, it can be stored in a digital wallet and has bookmarking and value-added properties.

Dynamic digital Paper Cuttings series: combine the static 3D model with the animation engine to develop the dynamic series of "24 solar terms", "zodiac" and "auspicious meanings"; Simulate Paper Cuttings swing, light and shadow changes, scene interpretation (such as magpies climbing

branches, flowers blooming rich), and adapt to mobile wallpaper, screensaver, social platform avatar, and digital greeting cards.

Paper Cuttings digital art prints: 3D model rendering high-definition digital prints, supporting export of different sizes and styles (realistic/China-Chic/simple); Users can download and print, mount and decorate, or use it for display on digital social platforms.

Intangible cultural heritage digital archives: integrate Paper Cuttings 3D models, technical videos, cultural explanations, and regional data to create an online digital museum; Open to the public, researchers, and students, supporting retrieval, browsing, learning, and research to achieve cultural resource sharing.

2) Immersive experiential products

Integrating VR/AR/digital twin technology to build immersive, interactive, and scenario based experiential products, covering cultural tourism, education, exhibition, and entertainment scenes.

VR virtual Paper Cuttings experience hall: build 1:1 virtual Paper Cuttings workshops, folk scenes and intangible cultural heritage exhibition halls; Users can view classic works 360 °, watch inheritors' virtual skill demonstration, learn Paper Cuttings techniques, participate in virtual creation (drawing contours → automatically generating 3D Paper Cuttings → dynamic display), and save and share works through VR equipment.

AR interactive Paper Cuttings series: develop AR applet/APP, users scan entity Paper Cuttings, printed matter, cultural and creative products, trigger 3D model dynamic presentation, folk story animation, skill explanation, scene interaction (such as scanning "fish for years", 3D fish swimming, water rippling, auspicious voice expla nation appear on the screen).

Digital twin Paper-Cutting display system: This system creates a real-time synchronized bridge between the physical exhibit and the virtual model. By utilizing environmental sensors, the digital twin reflects the exact lighting and airflow conditions of the offline hall onto the 3D model, allowing the virtual artifact to simulate physical properties like translucent light-transmission and structural swaying in response to the real-world environment; Support touch rotation, magnification, disassembly, motion control dynamic effects, and multi screen linkage display; Combining digital twin technology and synchronizing online cloud exhibition halls to achieve an integrated display of "offline+online".

Immersive Paper Cuttings theater: integrate 3D models, holographic projection, dynamic light and shadow, surround sound effects to create an immersive narrative space; The folk tales and historical legends behind Paper Cuttings are interpreted (such as "Cowherd and Weaver Girl" and "Mouse Marry Woman"), and users can experience three-dimensional, dynamic and immersive cultural experience in the light and shadow.

Paper Cuttings interactive educational aids: develop three-dimensional interactive teaching aids for primary and secondary schools and training institutions; Support 3D disassembly of Paper Cuttings patterns, skill step demonstration, virtual exercise, knowledge questions and answers, and work scoring; Integrating gamification mechanisms to enhance learning interest and efficiency.

3) Intelligent cultural and creative hardware products

Using 3D printing and intelligent hardware as carriers, we integrate 3D models with digital interaction to create innovative hardware that combines physical form and digital experience.

3D printing three-dimensional Paper Cuttings series: using high-translucency photosensitive resin and customized PLA composites doped with plant fibers, 3D printing high-precision decorations. The 3D models are pre-processed with parametric algorithms to replicate "edge burrs" and "paper fiber textures" on the printed surface, ensuring the finished product maintains the characteristic translucency and handmade aesthetic of traditional paper while providing modern durability.

Interactive Paper Cuttings intelligent light box: built-in 3D printing Paper Cuttings model, LED light shadow system, sensor, Bluetooth module; Support gesture control (switching light and shadow, adjusting brightness), voice control, and mobile app linkage; It dynamically presents the light and shadow changes of Paper Cuttings, and has the functions of decoration, lighting and interaction.

Paper Cuttings intelligent photo frame: equipped with HD display, built-in 3D digital Paper Cuttings library; Support automatic rotation, manual switching, dynamic display, and folk commentary; Can connect to WiFi to update content, suitable for home, office, cultural and tourism decoration.

AR Paper Cuttings gift box set: including physical Paper Cuttings, 3D printing accessories, AR interactive cards; The user scans the items inside the gift box, triggering an AR 3D interactive experience; Combining collection, viewing, interaction, and gift attributes, it has become a popular cultural and tourism product.

4) Personalized Customization Products (C2M Customization)

Based on a 3D model library and AI algorithms, achieve personalized customization for users to meet their specific needs.

Portrait Paper Cuttings 3D customization: users upload photos, and the AI algorithm extracts contours while automatically mapping them to traditional Paper-Cutting linguistic elements (such as zigzag and crescent patterns). This ensures that personalized derivatives remain stylistically consistent with heritage "authenticity" rather than contributing to modern homogenization; Support digital downloads, 3D printing of physical objects, creation of digital collectibles, and AR interactive cards.

Customized Festival Theme Package: Provides a modular 3D pattern library for zodiac signs, weddings, birthdays, housewarming, festivals, and more; Users can freely combine and add text (names and greetings) to quickly generate exclusive Paper Cuttings cultural and creative (digital+entity).

Cross border co branding customization: cooperate with brands, scenic spots and enterprises to develop co branded cultural and creative works based on 3D models (such as brand logo Paper Cuttings, scenic spot landmark Paper Cuttings, corporate mascot Paper Cuttings); Covering digital collectibles, 3D printing products, AR interactive products, expanding application scenarios.

C. FULL PROCESS OF PRODUCT DEVELOPMENT

1) Preliminary Preparation Stage

Cultural research and screening: research regional Paper Cuttings schools, classic patterns, folk customs, and screen works with high cultural value, strong artistry, and market adaptability (such as zodiac, auspicious patterns, and regional characteristics).

User needs analysis: Conduct research on the needs, preferences, and consumption habits of target users (young people, cultural and tourism consumers, education users), clarify product functions, forms, and price positioning.

Resource database construction: complete the 3D reconstruction of selected works, and establish a high-precision, editable and reusable Paper Cuttings 3D model resource database (including model, texture, animation, and cultural information).

2) Product Design Phase

Product positioning and form design: Determine product category, function, form, interaction logic, and appearance style; Draw design drafts, create renderings, and build product prototypes.

Technical solution design: Clarify technology selection (VR/AR engine, 3D printing process, blockchain platform, hardware module); Design technical architecture, interaction processes, and data formats.

Cultural review: Invite inheritors of intangible cultural heritage and cultural experts to review product designs, ensuring cultural authenticity, accuracy of symbolism, and consistency in artistic style.

IV. INNOVATIVE DESIGN AND EVALUATION OF PAPER CUTTINGS DIGITAL CULTURAL AND CREATIVE EXPERIENCE

A. CORE DIMENSIONS OF EXPERIENCE INNOVATION

1) Sensory Experience Innovation (Multi sensory Collaboration)

Breaking through a single visual system, achieving the integration of multiple senses including sight, hearing, touch, and even smell:

Vision: 3D model 360 ° three-dimensional display, dynamic light and shadow, color gradient, holographic effect, restore the transparent beauty of Paper Cuttings.

Auditory: Combined with traditional Chinese music, folk commentary, and dynamic sound effects (flowers blooming, birds chirping, flowing water), create an immersive atmosphere.

Touch: VR controller force feedback, 3D printed physical touch, touch interaction, enhance realism and participation.

Smell (scenarization): Combining cultural and tourism experience scenes with traditional aromatherapy (sandalwood, mugwort) to enhance the resonance of folk atmosphere.

2) Interactive Experience Innovation (Full Process Participation)

From "passive viewing" to "active participation, deep interaction, and free creation":

Basic interaction: 360 ° rotation, zoom in, zoom out, disassembly, perspective switching, and independent exploration of details.

Operation interaction: gesture control, voice control, touch control, tactile interaction, reducing the threshold for use.

Creation interaction: virtual Paper Cuttings creation (contour drawing → automatic generation of 3D models → dynamic adjustment → saving and sharing), personalized customization, pattern combination.

Social interaction: sharing works, online exhibitions, friend interaction, community communication, strength ening social attributes.

3) Emotional Experience Innovation (Cultural Resonance)

Inspire users' cultural identity, emotional resonance, sense of achievement, and sense of belonging:

Cultural resonance: Deeply presenting folk symbolism, historical stories, and regional culture, triggering emotional connections.

Sense of achievement: virtual creation, completion of works, customization of exclusive products, obtaining a sense of achievement and satisfaction.

Sense of belonging: Participate in the inheritance of intangible cultural heritage and cultural dissemination, enhance cultural confidence and national sense of belonging.

Pleasure: Smooth experience, full of fun, visually beautiful, and a relaxed and enjoyable emotional experience.

B. CONSTRUCTION OF EXPERIENCE SCENE SYSTEM

Build four core experience scenarios for different users and scenarios, achieving cross scenario and full coverage experience adaptation.

1) Experience Scenarios in Cultural and Tourism Scenic Spots

Targeting tourists, creating an immersive intangible cultural heritage experience+cultural tourism consumption scene:

Experience content: VR Paper Cuttings experience hall, AR interactive wall, digital twin exhibition, 3D printing self-service machine, on-site customized service.

Scene features: Immersive experience within the scenic area, instant consumption, souvenir purchase, cultural check-in, social sharing; Drive secondary consumption in scenic areas and enhance the added value of cultural tourism.

2) Museum/Cultural Center Experience Scene

Targeting audiences, researchers, and students, creating a scene of "cultural display+popular science education+academic research":

Experience content: digital twin exhibition hall, holographic Paper Cuttings theater, online cloud exhibition hall, digital archives, interactive education teaching aids.

Scene characteristics: systematic cultural display, popular science education, academic research, public wel fare opening; Realize the integration of intangible cultural heritage protection, education, and dissemination.

3) Educational and Teaching Scenarios

Targeting primary and secondary schools, universities, and training institutions, creating a scenario of "intan gible cultural heritage education+technique learning+innovative practice":

Experience content: virtual Paper Cuttings classroom, 3D interactive teaching aids, technique disassembly animation, interactive exercises, creative practice, and works exhibition.

Scene characteristics: knowledge popularization, technique learning, innovative practice, and quality education; Stimulate students' interest and cultivate cultural confidence.

4) Household/Personal Consumption Scenarios

Targeting ordinary consumers and young people, creating a scenario of "daily use+personalized customiza tion+digital collection":

Experience content: Mobile AR interaction, digital collectibles, smart hardware, personalized customization, home decoration, social sharing.

Scene characteristics: anytime, anywhere experience, personalized customization, daily practicality, digital collection, social communication; Integrate into daily life and expand the influence of intangible cultural heritage.

C. CONSTRUCTION OF EXPERIENCE EVALUATION SYSTEM (AHPSICAS MODEL)

1) Construction of Evaluation Model

By integrating the SICAS user behavior model with the Analytic Hierarchy Process (AHP), a "five dimensions, eighteen indicators" evaluation system is constructed to quantitatively evaluate the experience effect, as shown in Table 2.

TABLE 2. Development System of 3D Reconstruction-Based Paper-Cutting Digital Cultural and Creative Products

Product Category	Main Forms	Application Scenarios	Technical Support
Digital Collection	3D digital antiques, dynamic wallpapers	Online platforms, metaverse, NFTs	3D modeling, blockchain
Immersive Experience	VR museums, AR interactive installations	Museums, scenic spots, exhibitions	VR/AR, digital twin
Intelligent Hardware	3D-printed crafts, interactive lamps	Home decoration, cultural gifts	3D printing, sensor control
Customized Services	AI-generated personalized paper-cutting	E-commerce, festivals, weddings	Parametric design, AI generation
Educational Products	Virtual teaching, interactive courseware	Primary & secondary schools, training bases	3D animation, interactive demonstration

2) Evaluation Process

Determination of indicator weights: Invite 15 experts (intangible cultural heritage experts, digital technology experts, user experience experts) and use the AHP method to determine the weights of each dimension and indicator (see Table 2).

Selection of evaluation subjects: Select 120 evaluation users, covering various age groups from 18 to 65 years old (30 people aged 18 to 25, 40 people aged 26 to 35, 30 people aged 36 to 45, and 20 people aged 46 to 65), including users from different professions, educational backgrounds, and regions.

Evaluation implementation: After users experience various products and scenarios, score each indicator on a scale of 1-5 points; Conduct interviews simultaneously and collect qualitative feedback.

Data processing: Quantitative data statistical analysis (mean, standard deviation, satisfaction); Qualitative data encoding and induction, extracting core issues and optimization directions.

D. EVALUATION RESULTS AND ANALYSIS

Quantitative evaluation results

The results are shown in Table 3 below:

TABLE 3. User Experience Evaluation Index System

First-level Index	Second-level Index	Weight	Score Range
Cultural Perception	Cultural authenticity, information integrity, symbolic expression	0.263	1–5
Interactive Experience	Operation convenience, response speed, fault tolerance	0.235	1–5
Visual Aesthetics	Model accuracy, color restoration, dynamic effect	0.212	1–5
Emotional Satisfaction	Fun, immersion, willingness to share	0.189	1–5
Practical Value	Utility, cost performance, collection value	0.101	1–5

1) Result Analysis

The comprehensive experience improved significantly: the comprehensive score of digital cultural innovation was 4.53 points, and the satisfaction rate was 91.7%, 45.2% higher than the traditional Paper Cuttings experience (3.12 points), verifying the effectiveness of experience innovation.

The most prominent improvement in interactive experience: the interactive experience score is 4.68 points (the highest), an increase of 65.4%, indicating that "full process participation and deep interaction" accurately solves the pain point of "passive singularity" in traditional experiences.

Satisfaction in all dimensions exceeds 88%: sensory, emotional, cultural, and functional experience satisfaction exceeds 88%, achieving five dimensional collaborative improvement.

Age difference analysis: Young users aged 18-35 scored the highest (4.68 points) and had the strongest willingness to share (4.72 points), indicating that the product accurately meets the needs of young people; Users aged 46-65 have the highest cultural experience score (4.69 points), recognizing the authenticity and inheritance value of culture.

Core optimization direction:

Technical aspects: Mobile loading speed (average 2.3s), compatibility with low configuration devices, and lagging rendering of some complex models;

Experience level: personalized creative freedom, depth of cultural content, and convenience for elderly users to operate;

At the product level, the cost-effectiveness of some physical products, 3D printing details polishing, and intelligent hardware battery life are shown in Table 4.

TABLE 4. Comparative Analysis of Traditional and 3D Reconstruction-Based Paper-Cutting Products

Evaluation Index	Traditional Paper-Cutting Products	3D Reconstruction Digital Products	Improvement Rate
Cultural transmission	Single form, limited scope	Multi-scenario, interactive communication	+67.2%
User experience	Passive viewing	Interactive, immersive, customizable	+42.5%
Added value of products	Low, homogeneous	High, diversified, collectible	+186.3%
Preservation stability	Easy to damage, difficult to store	Permanent digital storage	+92.7%
Production efficiency	Manual, low efficiency	Digital batch production	+1521.4%

2) Qualitative Feedback Summary

Positive feedback from users: "Stereoscopic realism, interesting interaction, rich culture, novel experience, worth sharing"; Negative feedback concentrated: "Some scenes load slowly, the operation is slightly complex, and the content can be more diverse. The overall recognition of the experience innovation brought by 3D reconstruction technology is that"Paper Cuttings can be made alive, fun and valuable".

V. CONCLUSION

Paper Cuttings art is a cultural gene flowing in the daily life of the Chinese nation, carrying the aesthetic pursuit, life ideal and spiritual sustenance of the people for thousands of years. In the era of digitization, intelligence, and networking, traditional folk art is facing both the pressures of declining dissemination, weak inheritance, and shrinking industries, as well as historical opportunities for technological empowerment, experiential innovation, and market expansion.

The three-dimensional reconstruction technology provides an important support for the contemporary transformation of Paper Cuttings art with its ability to restore space, dynamic expression and multi scene adaptation. It is not only a digital archiving tool, but also a cultural translation method, an experiential innovation medium, and an industrial upgrading path. Through three-dimensional reconstruction, Paper Cuttings has changed from fragile flat paper to digital cultural assets that can be permanently preserved, freely displayed, deeply interacted and diversified developed, realizing closed-loop development of "protection inheritance innovation industry".

The Paper Cuttings digital cultural innovation development system and experience innovation model constructed in this study not only enrich the theory of intangible cultural heritage digital protection, but also explore the modern transformation practice of traditional crafts. In the context of the strategy of cultural power and the integrated development of culture and tourism, it is expected that more technical, design and industrial forces will participate in the digital activation of intangible cultural heritage, so that Paper Cuttings, an ancient art, will be reborn in the three-dimensional digital world, and will move towards the future with a more fresh, modern and international attitude, so as to truly realize the long-term goal of "making intangible cultural heritage live in the present, move towards the world, and pass on to future generations".

AUTHOR CONTRIBUTIONS

Bi FengXia designed, collected and analyzed the data, and drafted the manuscript. Bi FengXia conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Bi FengXia participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

FUNDING

This research received no external funding.

ACKNOWLEDGEMENTS

Not applicable.

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