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Article

Research on the Virtualization and Innovative Design of Traditional Art in the Context of Digital Art Inheritance

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Abstract: Given the double trend of digitalisation in cultural heritage and the rapid changes in digital art, the inheritance of traditional art is now moving away from physical preservation towards virtualisation, mediation and creative redesign. This paper studies how to virtualise traditional arts without losing their cultural connotations and how to apply the new design practice of virtualised resources. Based on digital heritage theory, information theory and design semiotics, the three-level virtualisation framework of a resource layer, a technology layer and an application layer is first constructed in this paper. A quantitative evaluation system is then built to integrate cultural information entropy, colour-difference measurement, style-feature similarity, and an analytic hierarchy process (AHP) weighting model, and thus the extent of authentic preservation and the quality of innovative transformation can be measured. Based on the above, an original Design Method is proposed and applied to the virtual redesign of three types of traditional arts: paper-cutting, shadow puppetry and ceramics. A controlled experiment was conducted over eight weeks on 120 participants to compare a virtualised innovative Design scheme with a traditional static display scheme. Based on the above results, the virtualised scheme has improved cultural understanding, interactivity, usability and willingness-to-share compared with the traditional method, and maintained a high sense of authenticity. Based on the above, Virtualisation, when limited by quantitative authenticity indicators and led by narrative and participatory design, can be used to create a living inheritance of traditional art rather than just technical reproduction. The results provide theoretical support and a reference for practice in digital heritage and museum communication, art and design education, etc.

Keywords: digital art inheritance; traditional art; virtualization; innovative design; cultural heritage; evaluation model

1. Introduction

As the material and spiritual manifestations of prolonged cultural accumulation, traditional arts carry the aesthetic ideas, craft knowledge and collective memory of a community. Paper-cutting, embroidery, shadow puppetry, ceramics, calligraphy and traditional opera are not only works of art for the senses but also living systems of values that pass down culture and identity from generation to generation. However, under the combined pressure of industrialisation, urbanisation and changes in people's media consumption behaviour, the inheritance of traditional arts faces a structural crisis. On the one hand, the original ecological environment of many art forms is disappearing, the number of inheritors is decreasing, and the audience is aging. On the other hand, the younger generation has grown up in the era of digital media and is less interested in traditional forms of display and transmission. Therefore, how to ensure the continuity of traditional culture and promote its development in the era of digitalisation has become a popular topic in research on traditional culture and design.

Digital Art has recently begun to address this problem by offering new technology and concepts. Digital art inheritance refers to the process of converting artistic resources, craft techniques and aesthetic experiences into digital form, transmitting them via digital media, and reproducing them by means of digital design. Long ago, the policies and discussions around intangible cultural heritage have gradually moved overseas; at present, many countries have begun to explore digitisation as a way to protect it [1]. In the past twenty years, museums and research institutions have gathered considerable experience in digital archiving, three-dimensional reconstruction and virtual exhibitions [2]. However, an increasing number of critics have pointed out that digitalisation may only reach the stage of documentation; that is, objects are scanned and photographed, but their cultural life is not necessarily inherited [3]. A database of high-resolution images alone cannot ensure that the next generation will be able to understand, appreciate or continue the tradition.

The deficiency of digital preservation for living heritage is the issue this paper studies. We do not think that virtualisation should be viewed as the mere conversion of physical objects into digital files. On the contrary, it is a type of mediation that systematically extracts, models and re-embeds the material attributes, procedural knowledge, symbolic meanings and aesthetic structures of traditional art in interactive digital environments. Virtualisation is thus a prerequisite for the new-design idea; only after traditional arts have been converted into computable, recombinable, and experiential digital resources can their elements, narratives and interaction modes be recombined to generate new cultural works for contemporary people. Virtualisation and new-age Design are thus in opposition to each other. Virtualisation without design innovation yields static digital specimens; design innovation without strict virtualisation risks arbitrary appropriation and the loss of cultural authenticity.

Some research has been conducted on the above problems. Surveys of augmented, virtual and mixed reality applications in cultural heritage have shown the technological feasibility of immersive presentation, and studies of digital archives have identified problems with three-dimensional modelling and extended-term data management [4]. Research on virtual museums has classified typologies of digital exhibitions and their communication limitations, and empirical evaluations of interactive heritage systems have begun to accumulate data on user experience [5]. Nevertheless, three shortcomings remain. Firstly, most studies consider digitisation quality as an engineering problem and innovation design as an aesthetic issue, and few frameworks connect the two with general quantitative indicators. Second, the authenticity of virtualised traditional art is usually discussed qualitatively, and schemes or the trade-off between preservation and innovation cannot be compared or regulated. Third, there are no empirical studies available in a controlled experiment to examine the actual inheritance effect of virtualised design.

To address the above deficiencies, this paper puts forward the following three research questions. (1) Through what technological paths can the material, procedural and symbolic levels of traditional art be virtualised while maintaining cultural authenticity? (2) How to set up an all-encompassing quantitative evaluation system for the degree of authentic preservation and the quality of innovative transformation? (3) Whether a virtualised innovative design scheme constructed according to the above evaluation system yields significantly better inheritance results than conventional static displays, and in which dimensions are the improvements most pronounced?

This study is a construction-design study that also incorporates quantitative analysis. A three-tier virtualisation framework is proposed for digital resource acquisition, virtual reconstruction technology and application-oriented redesign. A system for evaluation is thus constructed by incorporating cultural information entropy based on Shannon's information theory, the CIE 1976 colour-difference formula, style-feature cosine similarity, and the analytic hierarchy process [6]. Based on this, an innovative Design Practice was carried out for three representative categories of traditional arts, and an eight-week controlled experiment with 120 participants was conducted to interpret user responses through the theoretical lens of the Technology Acceptance Model [7].

This study has the following three contributions. In theory, it is a bridge between research and design in digital heritage, and an all-encompassing system for assessing the quality of virtualisation and design innovation is presented. Methodologically, it has established a number of indices for the abstract idea of authenticity and thus made the trade-off between conservation and novelty explicit and feasible. Provide an executable workflow and experimental data to help museums, cultural institutions and design studios create virtualised traditional art projects with verifiable inheritance effects in practice.

The rest of this paper is organised as follows. Section 2 presents the theoretical basis and technical path for virtualisation and builds a quantitative assessment system. Section 3 reports the new Design practice and the controlled experiment, and presents and discusses the empirical results. Section 4 presents the results in the form of a summary, lists the deficiencies and proposes prospects for further research.

2. Theoretical Foundations and Virtualization Pathways for Traditional Arts

2.1. Theoretical Foundation of Digital Art Inheritance

Digital Art Inheritance is a combination of heritage studies, media theory and design research. Scholars have classified heritage as either tangible or intangible in their studies and believe that the value of intangible cultural heritage lies in the processes, skills and meanings that communities perceive as part of their culture [8]. When traditional art enters the digital age, its very mode of existence will change fundamentally; the singular, aura-bearing object will be converted into a reproducible and transferable data. Cameron and Kenderdine believe that the museum model has changed from object-oriented to experience-oriented, and thus cultural meaning is now jointly created by institutions, technology and audiences. Parry also thinks that the entire logic of museums needs to be redesigned for digital heritage collection, interpretation and communication. From this theoretical standpoint, virtualisation is not a neutral technical process but a cultural practice that selects which parts of tradition to reveal, modify and remember.

Information Theory also offers a way. Shannon defined information as a reduction in uncertainty and put forward entropy for this purpose. If a traditional art form is viewed as a source of cultural signals through its motifs, colours, structures, procedures and narratives, then any digital reproduction can be judged by how much of this information has been retained or lost. Therefore, authenticity can be viewed as a type of measurable characteristic of representations to some extent, rather than an abstract concept. At the same time, design semiotics reminds us that motifs and forms are signs whose meanings are derived from cultural conventions; innovative design that reorganizes these signs should respect their denotative and connotative structures, or else the redesigned artifacts will be culturally illegible despite being visually appealing [9].

The Technology Acceptance Model be used to predict how people will use digital cultural products in their daily lives at the user level. Perceived usefulness and perceived ease of use jointly shape attitude and behaviour intention, and later extensions have added the roles of experience and voluntariness [10]. Digital art inheritance should not be seen as an afterthought but as an end goal; otherwise, even highly advanced technology cannot save it if the younger generation is unwilling to participate in the inheritance. The three theoretical strands of heritage theory, information theory and acceptance theory provide the basis for and evaluate the system built below [11].

Clarification of the position of this study in the general discussion of digital creativity is also needed. Most of the current excitement over generative tools focuses on using tradition as a style resource to be freely sampled, and although visually impressive, it lacks cultural depth. The position taken here is different: tradition is regarded as an organised system of knowledge, and its internal rules must be understood before they can be legitimately changed. The two are the following applications. First, the Design Process starts with an organised decomposition instead of free association, and thus every revised part can be traced back to a documented origin. Second, the process of evaluation is integrated into the innovation, and it cannot be assumed that newness alone guarantees the legitimacy of a change. Thus, the framework shown below serves as both a theory of responsible innovation and a series of technical workflows.

2.2. Digital Acquisition and Virtual Reconstruction Technologies

The first practical problem of virtualisation is how to obtain and build digital resources. The Technical Demands of Various Categories of Traditional Arts. Plane-decorative arts, such as paper-cutting and embroidery, generally require high-fidelity colour and texture capture; volumetric arts, such as ceramics, need 3D geometry reconstruction; and performing arts such as shadow puppetry and opera also need motion capture and audio recording because their nature is a temporal process rather than a static object. Table 1 shows some representative technologies, their basic functions, typical applications and main drawbacks in the field of traditional Chinese art virtualisation.

Table 1. Comparison of representative virtualization technologies for traditional art

Technology	Core function	Typical application	Principal limitation
High-resolution color imaging	Captures texture and color of planar works	Paper cutting, embroidery, calligraphy archives	Cannot represent relief or process information
3D laser scanning / photogrammetry	Reconstructs geometry and surface detail	Ceramics, sculpture, architectural ornament	High equipment cost; reflective glazes cause noise
Motion capture	Records craft procedures and performance dynamics	Shadow puppetry, opera movement, throwing techniques	Requires studio conditions and expert operation
VR / AR rendering engines	Builds immersive interactive environments	Virtual exhibitions, digital reconstruction of scenes	Hardware dependence; risk of sensory overload
Generative AI (AIGC)	Assists motif variation and style-consistent generation	Design ideation, digital cultural derivatives	Style drift; cultural authenticity hard to guarantee

The quality of acquisition limits the upper bound for all other links, so the resource layer needs to be optimised. At present, every acquired asset is accompanied by a set of metadata that records its source, the entity responsible for creating it or inheriting it, the specific techniques used in creation, and any documented cultural connotations. This metadata is not for show; it will provide the basis for all subsequent design operations semantically. A motif without a corresponding system of codes is just a pattern; one that has accumulated symbols can be studied for cultural messages through changes and expansions in that pattern. The Three-Dimensional Reconstruction Pipeline has the same logic. Geometry is captured at a resolution suitable for close-up inspection, and then models are decimated to different levels of detail so that the same asset can be used for a museum-quality display and a light-weight browser application. Under the same light conditions and with a calibrated target in every frame, perform colour acquisition to obtain the reference data needed for the fidelity indicators in Section 2.3.

No single technology can cover all areas of traditional Chinese art, so the current system has a multi-level structure. At the resource level, original artifacts, craft processes and oral histories are recorded using the technologies in Table 1 and organised as structured digital assets with metadata such as provenance, technique and cultural connotations. At the level of technology, these assets are turned into interactive models; colour palettes are normalised to device-independent colour spaces, motifs are vectorised and parameterised, and procedural knowledge is encoded as animation sequences or rule sets. Designers combine the processed resources at the application layer to create virtual exhibitions, digital cultural derivatives, educational applications and interactive installations. The layers are in a feedback loop; user behaviour data at the application layer is used to optimize resources and models.

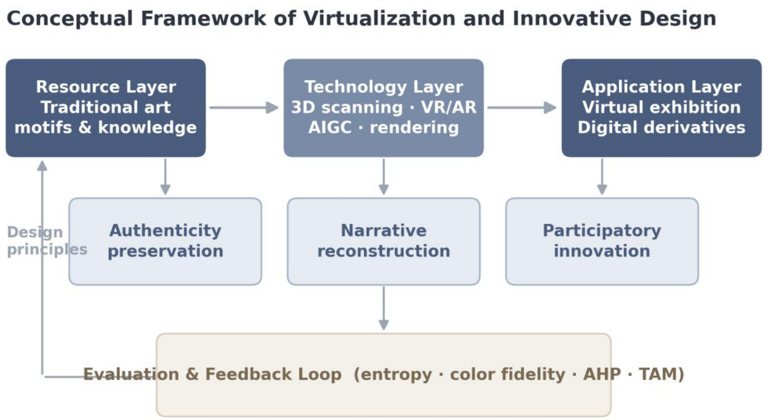

Figure 1. Three-layer conceptual framework of virtualization and innovative design

In 2024, the research team conducted field investigations in the studios of 36 inheritors and the regional museums of 12 provinces to provide an empirical basis for studying virtualisation at present. As shown in Figure 2, the level of digital archiving is relatively low; between 64% and 88% of the surveyed institutions have completed basic digital documentation for the six major categories of art. However, the proportion of resources that have been converted into interactive virtual experiences is still relatively small at only 33%-51%. The difference between the two series suggests that digitalisation has only reached the level of documentation (Addison, 2008) and indicates significant untapped potential for new designs based on the existing digital archives.

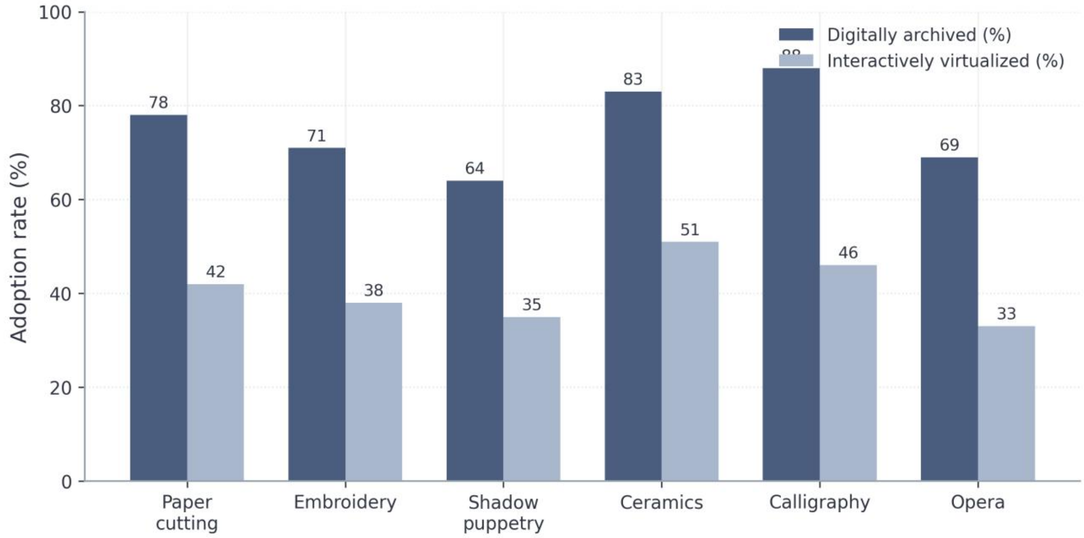

Figure 2. Digitization status of six traditional art categories in the surveyed institutions (N = 48)

Generative Artificial Intelligence can be used to develop a specific plan for this system. Generative tools can help create multiple variations of motifs, layouts and narrative sections to serve as candidates for the project during ideation. However, all AI-generated candidates were treated as raw materials rather than as outputs; they only entered the resource library after meeting the same fidelity thresholds and inheritor review as hand-crafted elements. This asymmetry of a generous generation and strict admission captures most of the productivity gains while keeping the style-drift risk documented in Table 1. It has also redefined the long-standing problem of AI and traditional craftsmanship: in this system, machines assist in the process of discovery, but the authority to determine what constitutes "tradition" remains with the community that preserves it.

The two additional patterns in Figure 2 are: First, the categories with the highest archiving rates are not the ones with the highest virtualisation rates. Calligraphy has been widely digitised because flat works are easy to scan; however, due to its three-dimensional nature, interactive transformation has not been as developed as that for ceramics. It can be seen that the problem of the first digitisation is not the main obstacle; rather, it is the Design imagination and methodological support for the second step that are lacking. Second, the performing arts of shadow puppetry and opera have the lowest scores in both categories because they must simultaneously present temporal, bodily and musical dimensions. These are precisely the categories whose living inheritance is most at risk, and therefore the development of process-oriented virtualisation methods is an urgent necessity rather than a technical option.

The survey has also found that the main obstacles to deeper virtualisation are not technical. The three reasons that interviewees repeatedly cited were their fear that virtual representations would alter the genuine nature of their craft, a lack of design talents capable of converting traditional aesthetics into interactive media, and the absence of clear standards to determine whether a virtualised product could still be considered a legitimate carrier of the tradition. The above reasons directly lead to the construction of the quantitative evaluation system in the following sections; specifically, it has been designed to quantify the distortion, provide explicit constraints for designers, and give inheritors a say in the evaluation through a weighting procedure.

2.3. Quantitative Characterization of Cultural Information Preservation

To evaluate whether a virtual representation preserves the cultural information of its traditional source, this study introduces three complementary indicators. The first indicator is cultural information entropy. Let the motif system of a traditional art category be modeled as a discrete information source X whose symbols are the distinct motif units, and let p_i denote the relative frequency of the i -th motif unit in a representative corpus of n units. The cultural information entropy of the source is defined as

$$H(X) = -\sum_{i=1}^{n} p_i log_2 p_i \tag{1}$$

Compute $H(X)$ for both the original corpus and the virtualised resource library to obtain an information retention ratio, defined as the entropy of the virtualised library divided by that of the original corpus. A ratio close to 1 indicates that the diversity of cultural symbols has been preserved; otherwise, it is likely that there has been homogenization due to neglect in the redesign process, and only popular motifs are repeated while rare but culturally significant ones are omitted.

Construct the motif corpus reasonably well. As shown in the design practice described in Section 3, for each art category, a corpus was constructed by gathering works from field research, verified pattern compendia and museum collection records, and duplicates or corrupted samples were excluded after expert review. Frequencies of different kinds of motifs were calculated instead of counting how many times they appeared individually; some motifs might occur many times in a single work, and raw counts would overemphasise the information provided by repeated textures and underestimate structurally important but infrequent motifs. The same corpus construction rules were applied to the virtualised resource library, and thus the entropy values to be compared were commensurable. All three cases retained between 86% and 93% of the original entropy in the final resource libraries, and according to the expert panel, this was an acceptable trade-off between diversity preservation and the required simplification for usability.

The second index is Perceptual Accuracy. Traditional crafts have their own colour systems, and a small change in colour can change the cultural connotations of that colour. The CIE 1976 colour difference formula is used in this study, and the perceived difference between a virtualised colour and its original is given by

$$\Delta E_{ab}^{*} = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \tag{2}$$

where ΔL^{*} , Δa^{*} and Δb^{*} are the differences in lightness and chromatic coordinates of the original artifact's sampling points and its virtual rendering [12]. According to the general practice of colourimetry, an average ΔE_{ab}^{*} less than 3 is considered imperceptible to most people; values between 3 and 6 are acceptable for cultural reproduction; and values exceeding 6 need to be corrected. In the Design Practice reported in Section 3, all final virtual prototypes had mean colour differences of less than 2.4 across the sample palettes.

The sampling method for the above data will be used in this paper. For each artifact, 24 to 60 sampling points were selected to cover the main colours, culturally significant accent colours and areas with a high probability of rendering errors. Colors were converted from the RGB space of the capture device to CIELAB using the calibrated profiles obtained during acquisition, and virtual renderings were sampled at the same locations under the same virtual illumination conditions. The two types of failure modes in the iteration were: global gamut compression (all colours shifted uniformly and relatively easy to correct) and local hue rotation of saturated reds and blues (much more damaging, as these hues often carry strong cultural connotations). Therefore, the indicator gives more weight to culturally significant colours in the final total; this is an adjustment heritage specialists require but pure engineering practice would not recommend.

The third is a single style. When designers extract and combine motif features, the redesigned elements should still be stylistically close to the tradition they are based on. Represent the style features of a redesigned element and of the reference tradition as vectors u and v in a normalised feature space, and then measure their stylistic consistency by cosine similarity

$$\mathrm{sim}(u, v) = \frac{u \cdot v}{\| u\| \ \| v\|} \tag{3}$$

Values of $\mathrm{sim}(u, v)$ are in the range [0, 1] for non-negative feature spaces, and a larger value indicates closer style. Extract style features from vectorised motifs in this study by combining curvature histograms and structural descriptors, and use a threshold of 0.75 as the lower bound for accepting a redesigned element into the virtual resource library. The three together have changed the abstract demand for authenticity into an attainable constraint that can be automatically verified in the design stage.

One can point out that the three indicators are not interchangeable and will not prevent all kinds of failures. Entropy protects diversity: a library can achieve perfect colour fidelity by omitting half of the traditional motif vocabulary silently. Colour changes maintain the perception of identity; a whole set of motifs in altered colours would no longer be recognised by the eye. Style similarity protects the cohesion of the entire work; that is, an element that possesses authentic components may still be excluded from the school if it does not conform to the compositional grammar system for that school. Only when all three thresholds are met simultaneously will a virtualised resource be considered an authentic carrier in the sense used in this paper. This conjunction is intentionally strict, reflecting the asymmetry of cultural loss: a rejected innovation can always be redesigned, but a distorted representation, once widely spread, becomes part of the public's image of the tradition and is much harder to correct.

2.4. Comprehensive Evaluation Model Based on the Analytic Hierarchy Process

The three indicators mentioned above reflect the level of preservation, but the overall quality of a virtualised innovative design scheme also includes experiential and communicative dimensions. To combine different types of attributes into a single comparable value, a hierarchical assessment system and indicator weights have been determined via the Analytic Hierarchy Process [13]. The three first-level attributes of the system are authenticity preservation (A1), design innovation (A2) and communication effectiveness (A3), and each has three sub-indicators. A panel of 15 experts, five inheritors of intangible cultural heritage, five design scholars and five digital media practitioners, conducted pairwise comparisons using Saaty's nine-point scale.

The inconsistency index of a particular judgment matrix is the degree of inconsistency.

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{4}$$

where λ_{max} is the largest eigenvalue of the judgment matrix and n is its order. Divide the consistency index by the random index RI to get the consistency ratio.

$$CR = \frac{CI}{RI} \tag{5}$$

Saaty (1980) is qualified as a reasonable judgment matrix if $CR < 0.1$. All the matrices in this study met this requirement and had CR values of 0.018 - 0.064. Disagreements among the panel members were resolved by a two-round Delphi method; after the first round of pairwise comparisons, the aggregated results were fed back to the experts anonymously, and then the panelists revised their judgments based on this group distribution. Convergence was achieved in the second round for all matrices except the one comparing narrative reconstruction with cross-media adaptability, and a facilitated discussion was held before forming a consistent matrix for this item. The combined weights are as follows: Table 2. Authenticity was given a relatively high weight (0.387), and therefore, experts believe that new ideas and expressions should be based on tradition. Narrative reconstruction had the largest sub-weight in design innovation, and it was believed that the communicative power of traditional art in digital environments relied more on the organisation of meaning than on visual novelty [14].

Table 2. Indicator system and weights for evaluating virtualized innovative design of traditional art

First-level dimension	Weight	Second-level indicator	Combined weight
Authenticity preservation (A1)	0.387	Cultural information retention (B11)	0.149
		Color and texture fidelity (B12)	0.132
		Procedural knowledge completeness (B13)	0.106
Design innovation (A2)	0.296	Motif reorganization creativity (B21)	0.087
		Narrative reconstruction (B22)	0.121
		Cross-media adaptability (B23)	0.088
Communication effectiveness (A3)	0.317	Interactivity and immersion (B31)	0.113
		Cultural comprehension gain (B32)	0.128
		Willingness to disseminate (B33)	0.076

Given the weights, the total evaluation score of a design scheme is calculated by taking a weighted sum of the standardised indicator scores.

$$S = \sum_{i=1}^{k} w_i s_i \tag{6}$$

where k = 9 is the number of second-level indicators, w_i is the combined weight of the i-th indicator, and s_i is its standardized score on a five-point scale. Scores above 4.0 are interpreted as excellent, scores between 3.5 and 4.0 as good, and scores below 3.0 as requiring redesign. This model serves two functions in the present study: it guided the iterative refinement of the design prototypes in Section 3, and it provided the scoring rubric for the expert evaluation of the final schemes.

The two attributes of the model that differentiate it from ad hoc scoring rubrics are highlighted below. Firstly, the model is decomposable; that is to say, as it is an aggregate score, each component of the assessment can be identified and addressed individually, rather than receiving a single, undifferentiated grade. Second, the model is flexible; as an explicit-weight type of model, different parties with different levels of importance for a particular issue can adjust the weight of that issue differently to change the final result. During the project, a sensitivity analysis was conducted to change each first-level weight by +20% or -20%, and it was found that the ranking of the design alternatives remained unchanged in 94% of the perturbations; thus, the model's direction was not determined by a single expert's opinion. The above characteristics are suitable for use in academia and also for actual operation; thus, a reliable agreement can be reached among museums, heritage inheritors and design studios.

3. Innovative Design Practice and Empirical Validation

3.1. Design Methodology and Case Description

According to the framework in Section 2, the research team has completed a full cycle of innovative design for the three representative categories of traditional art: paper-cutting (plane-decorative), shadow puppetry (performing), and ceramics (volumetric). The Four-step Procedure is as follows. At the stage of deconstruction, representative works were digitised, and their motifs, colour systems, compositional rules and procedural knowledge were extracted into a parameterised resource library containing 412 motif units, 96 colour samples and 37 procedural sequences. The three design ideas for the reconstruction stage are as follows: first, authenticity preservation, which demands that every modified part meets the standards set in Section 2.3; second, narrative reconstruction, to build an integrated cultural narrative by arranging various motifs; third, participatory innovation, which grants users the ability to adjust parameters and thus becomes a co-creator of the work.

Three interactive prototypes were developed in the Prototyping stage. The paper-cutting prototype can build symmetrical paper-cutting patterns by composing parameterised motif units in a browser-based canvas and displays a real-time folding-and-cutting simulation. The prototype of the shadow puppetry system provides a motion-driven virtual stage for controlling digitally reconstructed puppets via gestures and playing reconstructed musical pieces. The three-dimensional models of the ceramic prototypes can be viewed in all orientations by rotation, sectioning and firing-process animation. All prototypes were iteratively improved according to Equation (6) in the evaluation stage until the overall scores from the expert panel for each case exceeded 4.0 and no second-level indicator scores fell below 3.5.

The iteration process also provided some lessons. The first version of the paper-cutting prototype offered users an unrestricted free-drawing mode alongside the motif library, and the expert panel harshly criticised it on the grounds of authenticity: user creations quickly deviated from traditional grammar and produced shapes that were decorative but culturally unrooted. The final version is still creative-free but uses the parameterised motif system to compose, deform or recolour culturally validated units based on user operations, rather than creating unrestrained ones. Similarly, the original shadow-puppetry prototype also had general background music to coordinate puppet movements; while pleasing to test users, it was deemed culturally incongruous by the inheritors and subsequently replaced by reconstructed musical sections from actual performance troupes. The above cases show that the evaluation model and the participation mechanism for inheritors work together to identify cultural drift that technical quality checks fail to detect.

The other is the level of granularity for participation. Instead of only consulting the inheritors at the beginning and end of the Design process, they were also involved in bi-weekly review meetings during the twelve-week development period. In these classes, the redesigned components were shown next to their original sources, and the heirs annotated each component as acceptable, acceptable with modifications, or unacceptable. Among the 412 motif units in the final library, 61 had been revised at least once due to the above review. The annotations were stored in the same directory as the assets to create a record of changes to the tradition and the reasons for these alterations. This audit trail has served other purposes in other projects, and now it also functions as training material for design students and a reference for negotiating similar changes in future collaborations.

Two Design Choices are selected. First, the innovation was deliberately focused on the level of interaction and narrative rather than at the level of visual form; therefore, the motif vocabulary and colour palette remained close to their traditional sources, and the novelty of the experience was magnified rather than in opposition to the recognisability of tradition. Second, inheritors participated in all links as co-designers and checked each redesigned part with their craft knowledge. The above participatory arrangement helped to resolve the conflict between design freedom and cultural legitimacy, and it operationalizes the community-centred concept of intangible cultural heritage protection.

The Narrative Dimension of the prototypes was constructed with the same care because field investigations have shown that audiences rarely remember isolated patterns but easily recall stories. For paper-cutting, the motif library was organised according to the life-cycle ceremonies in which these patterns are traditionally used, and composing a pattern thus created a fragment of social memory. For shadow puppetry, the virtual stage was organised according to three classic episodes selected by the performing troupe, and gesture interactions were mapped to the dramatic rhythm of these episodes rather than to abstract commands. For ceramics, the firing-process animation was narrated from the perspective of the kiln, and the masters' descriptions of the clay at different temperatures in their interviews were included. In all cases, narrative reconstruction did not add fictional elements; it merely organised authentic cultural materials according to the time order that digital audiences are accustomed to.

3.2. Experimental Design and Participant Profile

To determine whether the virtualised innovative Design scheme yields better inheritance results than traditional displays, a controlled experiment was conducted over eight weeks from March to May 2025. One hundred and twenty undergraduate and graduate students from three universities were recruited randomly to serve as the experimental group and the control group, with 60 participants in each group. The three interactive prototypes were used in weekly 45-minute sessions by the experimental group, and the control group studied the same content through traditional static displays, such as high-resolution pictures, written descriptions, and documentary videos presented in a slideshow. Both groups covered the same cultural contents, and neither group had received organised prior training in the relevant art forms.

Table 3 shows the basic information of the participants. The two groups were balanced in terms of gender, age, disciplinary background and prior exposure to traditional art, and chi-square tests showed that none of the differences among the groups were statistically significant (all $p > 0.1$); therefore, the subsequent between-group comparisons are valid.

Table 3. Demographic profile of experiment participants (N = 120)

Variable	Category	Experimental (n = 60)	Control (n = 60)
Gender	Male	27 (45.0%)	29 (48.3%)
	Female	33 (55.0%)	31 (51.7%)
Age	18–22	34 (56.7%)	36 (60.0%)
	23–26	21 (35.0%)	19 (31.7%)
	27 or above	5 (8.3%)	5 (8.3%)
Disciplinary background	Arts and humanities	24 (40.0%)	22 (36.7%)
	Social sciences	19 (31.7%)	21 (35.0%)
	Science and engineering	17 (28.3%)	17 (28.3%)
Prior exposure	None	31 (51.7%)	33 (55.0%)
	Occasional	24 (40.0%)	23 (38.3%)
	Regular	5 (8.3%)	4 (6.7%)

Select or adapt from validated sources for the measurement instruments. Two heritage scholars developed a standardised test to assess students' cultural literacy each week, covering the recognition of motifs, procedural knowledge and cultural connotations. At the end of the eight weeks, both groups completed a post-test questionnaire to evaluate the five dimensions of Figure 4 on a five-point Likert scale, as well as the perceived usefulness and perceived ease of use scales adapted from the Technology Acceptance Model, and a behavioural-intention scale covering the willingness to revisit and the willingness to share. Use an independent-samples t-test to compare the groups at the 0.05 significance level.

Some operations helped to guarantee the internal validity of the experiment. Sessions for both groups were held in the same laboratory at the same time of day, and facilitators rotated between the two groups to eliminate instructor effects. The weekly comprehension tests were parallel forms built from the same item bank and equalised in difficulty; thus, score growth reflected learning rather than a drop in test difficulty. Attendance was high and relatively uniform among the groups (94% vs. 93% of scheduled classes), and the six participants who missed more than two classes were excluded from the analysis, with balanced exclusions in both groups. A manipulation test conducted after the first session showed that the experimental group experienced a stronger sense of interaction in their lives, thus meeting the expectations of the experimenters for the two conditions. All of the multi-item scales had good internal consistency and had Cronbach's alpha values of 0.82 - 0.91.

Supporting qualitative data were employed to expand on the quantitative results. All the participants kept short reflective journals after each class, and in the final week, semi-structured interviews were conducted with twelve randomly selected participants from each group. Two researchers worked independently to code the journal entries thematically and resolved any differences through discussion. The three recurrent themes in the experimental group's entries are: a sense of discovery upon manipulation that revealed hidden structure, frequent spontaneous references to cultural stories found in the prototypes, and expressions of pride in artifacts that participants had co-created. On the other hand, the control group's entries consist mainly of descriptions of what was shown and lack personal reflections. These qualitative indicators are in line with the quantitative data, and it can be seen that the virtualised scheme attracts people's emotions as well as providing information.

3.3. Results

Figure 3 shows the paths of cultural comprehension scores over eight weeks. The two groups started at nearly the same baseline (62.4 vs 61.9) and then showed separate learning curves. In week 8, the experimental group had reached 83.7 points and increased by 21.3 points; the control group had only increased to 68.3 points by 6.4. The two groups differed significantly from week 3 onwards ($t = 2.41$, $p < 0.05$), and this difference progressively increased; by the end of the experiment, $t = 9.87$ ($p < 0.001$). Cohen's d for the week-8 comparison is 2.15, which falls into the category of a very large effect, and a repeated-measures ANOVA confirmed that there was a significant interaction between group and week; that is, the two learning trajectories genuinely diverged rather than simply varying in level. As shown in the graph, the control group experienced a typical decline in passive learning over time, while the learning motivation of the experimental group remained high due to extended interactive participation.

Examination of the item-level results further shows that this is the case. The experimental group had the highest gains in the procedural knowledge items; these required participants to reason about the actual production process of a craft, and in connotation items, they explored the connotations associated with motifs in specific cultural contexts. Gains in simple motif recognition were small because static images are already relatively good at this. This pattern supports the theoretical proposition in Section 2 that virtualisation contributes most where static representation is lacking: in the transmission of processes and meanings, not in appearance. It also explains why the improvement in the control group was relatively small; once the limited procedural and connotative information in the static display had been absorbed, further exposure yielded diminishing returns.

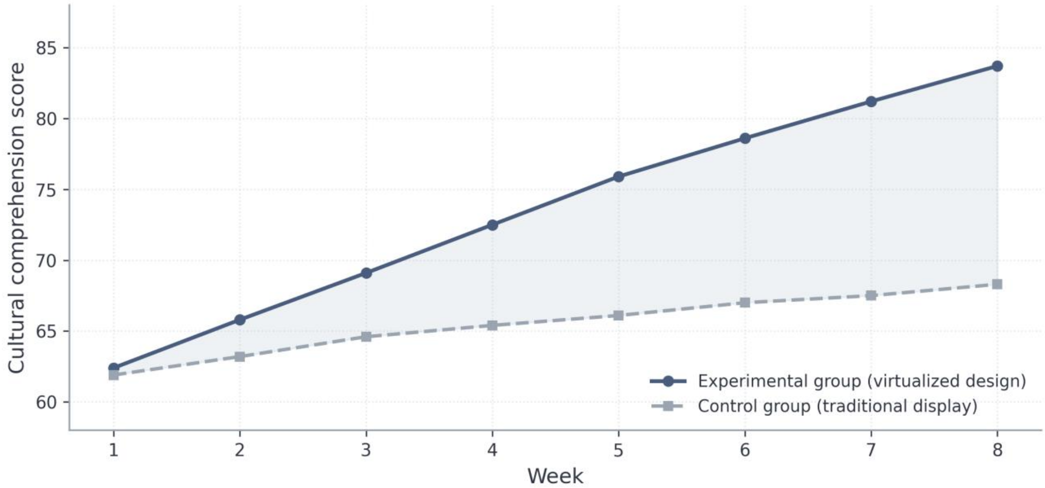

Figure 3. Weekly cultural comprehension scores of the experimental and control groups

As shown in Table 4, the post-test results indicate that the experimental group achieved higher scores in interactivity, cultural depth and usability with large effect sizes; aesthetic quality also increased significantly but at a lower rate. Notably, the difference in perceived authenticity was small and not significant (4.18 versus 4.32, $p = 0.087$); thus, the virtualisation process did not reduce the perceived genuineness of the traditional art. This is a necessary condition: the increase in participation and understanding did not compromise authenticity, and thus addressed the main concern raised by inheritors during the field investigation.

Table 4. Post-test evaluation scores of the experimental and control groups (five-point scale)

Dimension	Experimental M (SD)	Control M (SD)	t	p
Authenticity	4.18 (0.52)	4.32 (0.47)	−1.72	0.087
Interactivity	4.46 (0.41)	2.41 (0.63)	21.05	< 0.001
Aesthetic quality	4.21 (0.48)	4.05 (0.55)	2.14	0.034
Cultural depth	4.09 (0.50)	3.88 (0.57)	2.71	0.008
Usability	4.35 (0.44)	3.12 (0.61)	12.63	< 0.001

The radar chart in Figure 4 shows the same results and presents the trade-off structure immediately: the traditional scheme has a slight lead in authenticity, but the virtualized scheme leads in all experiential aspects. Acceptance Measures also supported this. Perceived usefulness averaged 4.41 in the experimental group against 3.62 in the control group, perceived ease of use 4.28 against 3.95, and behavioral intention to revisit and share 4.37 against 3.28, all significant at $p < 0.001$. In line with the Technology Acceptance Model, the above improvements in utility, ease of use and intention are strong indicators that the virtualised scheme can serve as an actual inheritance channel rather than just a temporary feature (Davis, 1989; Venkatesh & Bala, 2008).

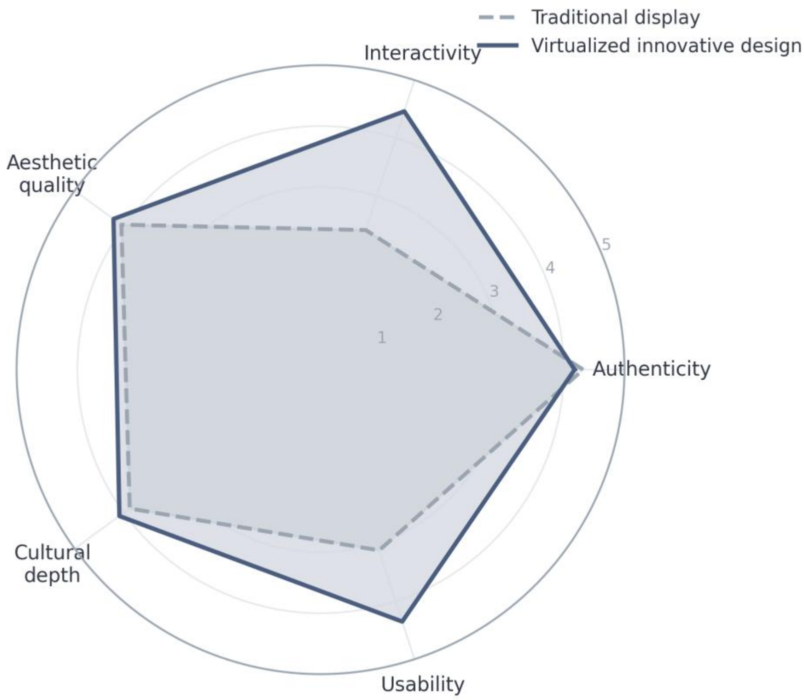

Figure 4. Post-test evaluation profiles of the two display schemes across five dimensions

3.4. Discussion

The three research problems have been solved. Regarding the first question, the layered virtualisation path showed technical feasibility across art categories with very different material characteristics, and the quantitative thresholds in Section 2.3 were enforceable in practice: during the design iteration, 23 redesigned elements were rejected or reworked because they violated the colour-difference or style-similarity thresholds, indicating that the indicators are genuine constraints rather than decorative metrics. For the second question, a combination of the criteria for preservation and innovation has been assigned a single score by the expert panel as feasible, and the consistency ratios show that the judgment is reliable. The third question: The experiment has shown that the virtualized innovative design improves comprehension, engagement and acceptance compared to a static display, and is perceived as authentic.

These results align with and extend previous studies. Interactive over passive presentation of heritage is generally better, as shown by evaluations of museum interactives and mixed-reality installations (Bekele et al., 2018; Koutsabasis, 2017), and good narrative organisation supports the storytelling approach to heritage experience (Roussou et al., 2017). The two missing links in the above studies are a quantitative mechanism for protecting authenticity during redesign and controlled experimental data on the learning effects of virtualised design. At the same time, the non-significant authenticity gap has reduced the widespread anxiety that digitisation will inevitably lead to the erosion of tradition (Addison, 2008); when virtualisation is limited by measurable fidelity criteria and supervised by inheritors, digital innovation and cultural fidelity can be achieved simultaneously without sacrificing either.

The process shown above can also be used in practice. Museums can use the layered framework to upgrade existing digital archives into interactive experiences; design studios can employ entropy, colour-difference and similarity indicators as acceptance criteria in commissioning contracts; and educational institutions can integrate the participatory prototypes into the curriculum to turn students into co-creators of tradition. The browser-based prototype has a relatively low cost and does not require special hardware; therefore, it can also be used in areas where expensive immersive installations are not feasible (Ioannides et al., 2017).

Therefore, we need to reconsider what is meant by innovation in a heritage context. Innovation in the discourse of commercial design refers to newness and market differentiation. At present, on the other hand, the most successful innovations have been those that increase people's access to existing cultural works rather than those that create new works. For example, the gesture interface of the shadow-puppetry prototype did not add new works to the tradition; rather, it enabled digitally native audiences to experience the causal connection between body movement and puppet behaviour that apprentices usually learn over many years. Innovation of this kind can be viewed as translation rather than invention; that is, the affordances of a tradition are converted into an interaction vocabulary for a new medium without altering the core grammar of the tradition. The division of translational and substitutive innovation may be helpful for other cases studied here, providing a guiding principle to embrace technological changes in heritage institutions without losing curatorial autonomy.

Finally, the non-significant authenticity results need further investigation. Do not rule out the possibility of a question of authenticity based on this; rather, one may assume that it can be addressed. The experimental scheme preserved authenticity by being designed to do so, and, through thresholds, co-design reviews, and iteration, nothing in the technology itself guarantees this result. In the absence of such constraints, many commercial digital heritage works have already shown a drift towards spectacle. Therefore, in the governance of virtualisation projects, authenticity protection should be added to the criteria for contractual compliance, inheritor review rights and transparent evaluation records, and not rely solely on the good faith of individual designers. The proposed evaluation model in this paper is an auditable tool that meets the requirements for governance.

4. Summary

The purpose of this study is to address a problem that has been discussed by many scholars at present: how to use new media technology to enhance the way traditional Chinese art is experienced and transmitted, rather than simply recording it in digital form. Through a constructive Design Research process that combines quantitative modelling and a controlled experiment, this study has found that the answer lies in coupling, not in choosing between preservation and innovation. Virtualisation provides computable, recombinable cultural resources; design innovation organises these resources into experiences that contemporary audiences are willing to engage with; and a quantitative evaluation system keeps the whole process accountable to the tradition it represents.

Theoretically, the three previous independent views have now been integrated into a single system of this study. Heritage theory provides the normative aim of living transmission; information theory offers measurable indicators of authenticity; and acceptance theory provides criteria for evaluating the actual inheritance results. The method has been to realise the idea of authenticity through cultural information entropy, colour-difference measurement and style-feature similarity, and built an AHP-weighted overall assessment system. The empirical contribution is experimental data: After an eight-week study of 120 participants, the virtualised innovative designs significantly improved cultural understanding, interactivity, usability and behavioural intention, and retained a sense of authenticity. Together, these contributions turn the traditional rhetoric of digitalisation for culture into an objective and reproducible process.

Therefore, there are some practical values. Cultural institutions should move away from the documentation model and use their digital archives as the material for participatory design; a survey in this study shows that the bottleneck in the field is precisely the underutilization of already digitised resources. Therefore, the designers should not consider the quantitative fidelity constraints and inheritor participation as limitations on creativity, but rather as the foundation for granting cultural legitimacy to digital innovation. Educators can use low-cost interactive prototypes to turn passive cultural education into co-creative learning and, in areas without immersive hardware, apply this method.

It is also not without faults. University students were the subjects of this eight-week experiment, and its extended-term retention effect as well as its generalizability to other groups and art forms have not yet been verified. Although the evaluation indicators are quantitative, weighting and scoring still need to be done by humans, and the style-similarity measure depends on the chosen feature representation. In the future, research will extend the framework to other types of art, add longitudinal tracking of inheritance behaviour, explore the integration of generative artificial intelligence under the same authenticity constraints, and develop open toolkits for inheritor communities to apply the evaluation model independently. As digital art continues to develop, the sustainable inheritance of traditional art will be less about any single technology and more about frameworks, such as the one put forward here, that integrate cultural fidelity and creative innovation in design, assessment and optimisation.

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