

Article

A Study on the Revitalization and Innovative Design of Dunhuang Mural Art from the Perspective of Digital Interaction: Based on the 'Cloud Tour of Mogao' Initiative

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Abstract: Driven by the national strategy for cultural digitization, the digital dissemination of intangible cultural heritage has become a key area of contemporary research. As an integral part of China's outstanding traditional culture, the Dunhuang murals not only possess immense artistic and historical value but also serve as a vital cultural testament to historical exchange along the ancient Silk Road. However, due to practical constraints related to physical exhibition conditions, stringent cultural heritage preservation requirements, and traditional dissemination methods, the Dunhuang murals have failed to sufficiently attract and engage younger audiences. Based on this context, this paper examines the "Cloud Tour of Mogao: The Rebirth of Artistic Charm" web design project. By systematically integrating visual communication design, user experience design, and digital media communication theory, the study explores innovative development pathways for the Dunhuang murals from a digital interaction perspective. The research indicates that by leveraging the digitization of traditional colors, the dynamic animation of Apsara motifs, and immersive interactive design, it is highly possible to enhance young audiences' identification with Dunhuang culture. Ultimately, this approach successfully broadens online dissemination channels for traditional culture, providing a sustainable and scalable model for the digital preservation and global promotion of intangible cultural heritage in the modern era.

Keywords: cultural heritage; interaction design; visual communication; digital media; murals

1. Introduction

Cultural digitization has emerged as a pivotal direction for safeguarding and revitalizing intangible heritage in the contemporary era. The Dunhuang Mogao Caves, inscribed on the UNESCO World Heritage List, represent one of the most comprehensive and enduring repositories of premodern mural art in East Asia. Their wall paintings synthesize aesthetic traditions from multiple civilizational spheres—particularly those originating in the Central Plains, the Western Regions, and South Asian Buddhist contexts—resulting in a distinctive visual language characterized by compositional sophistication, chromatic harmony, and symbolic depth. Within this corpus, scroll-style compositions serve to evoke transcendent spiritual realms through stylized spatial arrangements and ethereal figuration; flying apsaras exemplify a uniquely Eastern synthesis of grace, motion, and celestial symbolism, reflecting long-standing ideals of lyrical abstraction and embodied spirituality; and narrative murals adopt a diachronic pictorial logic—often employing continuous or segmented registers—to reconstruct historical rituals, monastic practices, daily customs, and doctrinal paradigms with remarkable ethnographic fidelity. These interwoven modalities collectively constitute not merely decorative elements but a coherent system of visual epistemology, encoding

Received: 07 August 2026

Revised: 24 September 2026

Accepted: 08 October 2026

Published: 13 October 2026



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cosmological frameworks, ethical values, and social hierarchies across more than a millennium of artistic production.

With the widespread adoption of digital technologies, traditional cultural expression is undergoing a paradigm shift—from static representation toward participatory, multimodal engagement. Digital platforms now enable dynamic visualization of pigment degradation patterns, high-resolution zoomable interfaces for iconographic analysis, real-time 3D reconstructions of lost architectural contexts, and interactive storytelling environments that respond to user input. Such capabilities significantly enrich interpretive access, particularly for audiences lacking direct physical access to heritage sites [1, 2]. While conventional documentation methods—including archival photography, printed catalogues, and museum exhibitions—retain enduring scholarly utility, they often present limitations in terms of scalability, adaptability, and affective resonance among digitally native demographics. Younger generations, shaped by immersive media ecosystems and accustomed to nonlinear information navigation, tend to engage more deeply with content that affords agency, personalization, and multisensory feedback. Consequently, research into digital interaction design for cultural heritage increasingly emphasizes human-centered methodologies: co-design with community stakeholders, iterative prototyping of interface affordances, accessibility-first development principles, and longitudinal evaluation of learning outcomes and emotional impact. This evolving interdisciplinary field bridges computer science, museology, art history, and cognitive psychology to develop sustainable, ethically grounded frameworks for transmitting intangible cultural knowledge across temporal and technological divides.

2. A Study of the Artistic Characteristics of Dunhuang Murals

2.1. The Artistic Value of Dunhuang Murals

The Dunhuang murals constitute one of the most comprehensive and enduring repositories of premodern Chinese visual culture, embodying over a millennium of artistic development from the Northern Wei through the Yuan dynasties. Their significance extends beyond religious iconography to encompass evolving aesthetic sensibilities, technical innovations in pigment preparation and wall application, and sophisticated compositional strategies rooted in both indigenous traditions and cross-cultural exchanges along the Silk Road [3]. A defining characteristic is their highly developed narrative imagery, which functions not merely as illustration but as an integrated system of visual storytelling. In Buddhist narrative paintings—including depictions of sutra tales, biographical accounts of the Buddha, and Jataka stories—the sequence of events is articulated through spatial arrangement, directional gaze, gestural syntax, and rhythmic repetition of figures across registers or panels. This sequential logic relies on viewer engagement over time and space, inviting active interpretation rather than passive reception. Such visual narration anticipates principles later formalized in cinematic montage and interactive media design, where meaning emerges from the relational continuity between discrete frames or interface elements. The murals' emphasis on movement, temporal progression, and contextual framing demonstrates a mature understanding of visual cognition and perceptual flow—qualities that remain deeply relevant to contemporary theories of human-computer interaction and experiential learning environments.

A compelling exemplar is the widely studied 'Jataka of the Deer King', wherein the moral narrative unfolds across multiple contiguous scenes arranged horizontally and vertically within a single architectural zone. Each episode is carefully calibrated in scale, orientation, and symbolic detail to guide the viewer's eye and reinforce thematic continuity—such as the deer's compassionate posture contrasting with the hunter's aggressive stance, or the repeated motif of water as a symbol of purity and consequence. This compositional coherence mirrors the structural logic of modern digital interfaces, particularly long-scrolling web pages, interactive timelines, and immersive museum installations that prioritize user-driven pacing and embodied navigation. By adapting the

mural's inherent scroll-like reading path—where attention migrates sequentially yet non-linearly depending on visual weight and cultural familiarity—designers can embed historical visual grammar into contemporary platforms without resorting to superficial ornamentation. Furthermore, integrating responsive transitions, layered parallax effects, and context-sensitive annotations allows for a dynamic reactivation of the murals' original pedagogical function: conveying ethical frameworks, cosmological concepts, and communal values through sustained visual engagement [3, 4]. Such approaches foster deeper cultural resonance while maintaining scholarly rigor and aesthetic integrity.

2.2. A Study of the Dunhuang Color System

The colors evident in the Dunhuang murals are predominantly sourced from naturally occurring mineral pigments, reflecting centuries-old technical knowledge and material selection practices in Chinese Buddhist art. Key pigments include malachite for vibrant greens, cinnabar for intense reds, various forms of ochre for earthy reds and yellows, and iron-rich earth yellow for warm tonal foundations. These materials were carefully ground, purified, and bound with organic media to ensure durability and chromatic stability under arid desert conditions. Recent advancements in digital conservation science have enabled more precise analysis and reconstruction of original color schemes, particularly where surface degradation, oxidation, or environmental exposure has altered visual appearance over time. Digital restoration methodologies—leveraging machine learning algorithms trained on spectral data, historical pigment databases, and high-resolution multispectral imaging—have proven effective in recovering lost chromatic information while maintaining fidelity to underlying compositional structure, brushwork, and textural integrity. Such approaches significantly strengthen both scholarly interpretation and public engagement by restoring visual coherence without compromising authenticity [5, 6]. Within contemporary design applications inspired by Dunhuang aesthetics, ochre red, deep brown, and metallic gold are deliberately selected not only for their historical accuracy but also for their psychological resonance: these warm, grounded tones evoke temporal depth, spiritual solemnity, and material richness, thereby reinforcing narrative immersion and cultural continuity in interactive digital environments.

2.3. A Study of Flying Apsaras Motifs and Visual Symbols

The Flying Apsaras constitute one of the most distinctive and enduring artistic motifs in the Dunhuang grotto murals, reflecting over a millennium of evolving Buddhist iconography and indigenous Chinese aesthetic sensibilities. Characterized by their buoyant postures, sinuous limb articulation, and elongated, undulating ribbons, these celestial figures exemplify a sophisticated synthesis of Indian Buddhist narrative traditions with Tang and later dynastic innovations in line, rhythm, and spatial composition. From a visual communication perspective, the ribbon motif functions not merely decoratively but structurally: its continuous, curvilinear trajectory establishes implicit visual pathways that direct sequential attention across compositional fields, thereby reinforcing hierarchical information flow and enhancing perceptual coherence. In contemporary digital interface design, this principle has been adapted to guide user navigation intuitively—particularly in homepage layouts and section transitions—where animated or stylized ribbon elements serve as dynamic visual anchors. Such implementation supports both functional usability and cultural resonance, bridging historical artistic grammar with modern interaction paradigms while preserving the motif's inherent lyrical motion, symbolic lightness, and harmonious integration of form and meaning [7].

3. Relevant Case Studies from China and Abroad

China has achieved remarkable success in the digitization of Dunhuang, exemplified by the 'Digital Dunhuang' initiative, which employs high-resolution imaging, 3D laser scanning, virtual reality reconstruction, and cloud-based archival systems to comprehensively document and preserve the fragile murals, sculptures, and architectural

features of the Mogao Caves. This systematic digital preservation not only mitigates physical deterioration caused by environmental exposure and visitor traffic but also establishes a robust foundation for long-term conservation planning, interdisciplinary scholarly analysis, and cross-institutional collaboration. However, while the platform excels in technical fidelity and archival rigor, its interface design, navigational structure, and content framing remain predominantly oriented toward academic researchers and heritage professionals, with limited integration of pedagogical scaffolding, gamified learning pathways, or multimodal storytelling techniques that could meaningfully engage adolescent and young adult users across diverse educational backgrounds.

Internationally, leading cultural heritage digital platforms have progressively shifted emphasis from static documentation toward immersive, user-centered experiences—incorporating real-time interactivity, adaptive narrative sequencing, spatial audio environments, and responsive visual feedback mechanisms. This evolution reflects broader trends in human-computer interaction research and experiential learning theory, where affective engagement and cognitive retention are enhanced through participatory modalities. In the context of Dunhuang art, recent advancements demonstrate how artificial intelligence-enhanced tools—such as generative image synthesis for reconstructing damaged sections, natural language processing for multilingual interpretive layers, and machine vision-assisted iconographic analysis—enable dynamic reinterpretation rather than passive viewing [8]. Consequently, this project deliberately integrates layered interactivity, emotionally resonant visual and auditory cues, and scaffolded exploration paths to foster deeper cultural understanding, sustained attention, and reflective connection among diverse user groups without compromising scholarly accuracy or curatorial integrity.

4. "Exploring Mogao Online: A New Chapter in Artistic Expression" Project Design Practice

4.1. Preliminary Research

To systematically identify and articulate the functional, aesthetic, and cognitive requirements of the intended audience, the project team conducted a comprehensive user-centered investigation, with primary emphasis placed on undergraduate and postgraduate students across disciplines in Chinese higher education institutions. This research employed a mixed-methods approach, integrating structured online questionnaires, semi-structured interviews, and comparative heuristic analysis of existing digital platforms dedicated to cultural heritage dissemination—particularly those offering interactive access to historical art collections, museum archives, and intangible cultural resources. The sampling strategy ensured geographic and institutional diversity, covering universities in eastern, central, and western regions to enhance representativeness and mitigate regional bias in perception and engagement patterns [9, 10].

Analysis of the collected data revealed several consistent behavioral and perceptual trends: although a strong baseline interest in Dunhuang's artistic legacy exists among young users, this interest is often fragmented and lacks chronological, thematic, or technical contextualization; narrative framing—especially episodic storytelling grounded in historical figures, artisan traditions, or conservation narratives—significantly enhances retention and emotional resonance; interaction modalities such as scroll-triggered animations, gesture-responsive visual transitions, and layered annotation systems were consistently rated higher in usability and engagement metrics than static presentations; mobile-first usage dominates across all demographic subgroups, with over 82% of daily interactions occurring via smartphones or tablets; and visual coherence—including harmonized color palettes derived from Mogao pigments, responsive typographic hierarchies, and ambient audio integration—was identified as a critical determinant of perceived authenticity and immersive depth. Consequently, the web design framework was rigorously calibrated to prioritize lightweight architecture (sub-2s load time under 3G conditions), multi-layered interactivity (including real-time parallax navigation and

contextual tooltip systems), and sensor-aware immersion (leveraging device orientation and touch input for spatial exploration of cave murals).

4.2. Content Architecture Design

This project centers on the core artistic themes embodied in the Dunhuang murals, adopting a structured content architecture to facilitate systematic exploration and scholarly engagement. The digital platform is organized into four principal thematic sections: a comprehensive home page that introduces the historical context, conservation significance, and methodological framework; a dedicated section on paintings depicting episodes from the Buddha's life, emphasizing iconographic conventions, narrative sequencing, and stylistic evolution across dynastic periods; a section focused on celestial maidens (apsaras), analyzing their aesthetic attributes, symbolic functions, and transformations in posture, attire, and musical instrumentation; and a fourth section devoted to narrative paintings, which encompasses Jātaka tales, Avadāna stories, and sutra illustrations, highlighting compositional strategies, visual rhetoric, and intertextual relationships with textual sources [11]. Each section integrates high-resolution imagery, layered annotations, chronological filters, and comparative visual analysis tools to support multidimensional interpretation.

4.2.1. Homepage Design

The homepage design employs a culturally grounded visual strategy centered on the iconic Dunhuang Apsara motif, which serves both as an aesthetic anchor and a symbolic representation of China's intangible cultural heritage. Rendered with refined artistic detail and harmonized color grading, the Apsara figure is positioned at the compositional center to guide user attention and establish immediate thematic coherence. A warm-toned background—featuring subtle gradients evoking desert sands and twilight skies—complements the figure while reinforcing regional geographic and historical associations. Dynamic lighting effects, including soft directional highlights and gentle ambient occlusion, enhance three-dimensionality and visual depth without compromising legibility or accessibility. This integrated approach fosters an immersive first impression that aligns with principles of cultural interface design, prioritizing authenticity, emotional resonance, and intuitive navigation [12]. The layout further supports usability through balanced spatial hierarchy, responsive element scaling, and thoughtful typographic contrast, ensuring cross-device consistency and inclusive readability for diverse user groups (As shown in Figure 1).



Figure 1. Mockup of the Homepage Design

4.2.2. The "Transformation of Paintings" Section

The Sutra-based Paintings section presents a curated selection of canonical Buddhist visual narratives, including iconic compositions such as *The Western Pure Land* and *The Sutra of Vimalakirti*. These works exemplify the integration of doctrinal content with refined artistic conventions developed over centuries within East Asian monastic and courtly contexts. Characterized by deliberate use of solemn, low-saturation color schemes—predominantly deep indigo, ochre, vermillion, and gold leaf—the paintings evoke meditative stillness and spiritual gravity. Symmetrical compositional structures reinforce hierarchical cosmological order, positioning central buddhas or bodhisattvas at

axial points to signify ontological centrality and transcendent authority [1]. Iconographic precision, adherence to textual prescriptions, and meticulous brushwork further underscore the ritual function of these images as objects of veneration, pedagogical tools, and aids to contemplative practice rather than mere aesthetic artifacts.

4.2.3. Feitian Art Section

The Feitian art section employs dynamic ribbon-style animations and a deliberately curved, flowing layout to evoke the ethereal grace and kinetic energy characteristic of Feitian imagery in Chinese Buddhist cave art. This visual design strategy not only reinforces thematic continuity with traditional Dunhuang mural aesthetics but also supports an intuitive, gesture-driven user experience [11]. As users scroll vertically, the interface progressively reveals stylistic transformations—from the early Northern Wei period's slender, linear figures with fluttering ribbons, through the plump, harmonious forms of the Tang dynasty, to the increasingly ornate and decorative interpretations of later eras. Each transitional stage is accompanied by contextual annotations describing pigment usage, compositional conventions, iconographic symbolism, and regional influences, thereby facilitating comparative analysis across chronological and geographical dimensions without reliance on external scholarly attribution.

4.2.4. Story Illustrations Section

The Story Illustrations Section is dedicated to narrative storytelling rooted in the visual traditions of Dunhuang Buddhist art. It employs a continuous scroll-style page layout to present iconic narrative murals, including adaptations of *The Life of the Deer King* and *The Story of the Man Who Sacrificed Himself to Feed a Tiger*—both of which exemplify the moral didacticism and compositional sophistication characteristic of Tang-dynasty mural cycles. This layout choice deliberately evokes the historical practice of unrolling handscrolls in monastic and scholarly settings, thereby reinforcing temporal continuity and sequential comprehension. By integrating animated transitions, subtle parallax effects, and contextual annotations, the section transforms static imagery into an immersive narrative journey that supports both aesthetic appreciation and cultural literacy. Each illustrated story is accompanied by layered interpretive content—including thematic summaries, iconographic glossaries, and comparative references to related textual sources in the Dunhuang manuscripts—to deepen user understanding without requiring prior expertise in Buddhist art history.

In alignment with comprehensive content planning and evidence-informed user experience principles, the website is organized around four principal thematic modules: Home, Dunhuang Art Gallery, Feitian Art, and Narrative Murals. The Dunhuang Art Gallery replaces the potentially ambiguous term 'Scripture Paintings' to emphasize its function as a curated digital repository of mural reproductions, iconographic studies, and conservation documentation—free from doctrinal or sectarian connotations. Each module is designed with distinct information hierarchies, navigational affordances, and metadata tagging schemes to support diverse user goals, ranging from casual exploration to academic research. Visual design elements—including color palettes derived from mineral pigments used in Mogao Cave murals, typographic treatments inspired by Dunhuang manuscript calligraphy, and spatial composition principles informed by traditional Chinese painting aesthetics—are systematically integrated across all interface components. Interactive functions such as zoomable high-resolution imagery, timeline-based narrative navigation, and multilingual glossary pop-ups further enrich engagement. Responsive adaptation ensures consistent functionality and legibility on mobile, tablet, and desktop platforms, reflecting contemporary standards for inclusive digital heritage access.

As illustrated in Figure 2, the website architecture consists of four interconnected layers: the Content Layer, Visual Layer, Interaction Layer, and Responsive Design Layer. The Content Layer serves as the foundational stratum for structured cultural information presentation, incorporating rigorously vetted historical data, multilevel descriptive metadata, and semantic tagging aligned with international cultural heritage ontologies.

The Visual Layer translates the artistic characteristics of Dunhuang murals—including pigment chemistry, line rhythm, spatial perspective conventions, and symbolic motif systems—into cohesive digital design elements that preserve authenticity while enabling modern usability. The Interaction Layer enhances user participation through dynamic browsing experiences such as gesture-controlled mural navigation, context-sensitive annotation toggling, and non-linear story path selection, all grounded in cognitive load theory and participatory design frameworks [13]. The Responsive Design Layer implements adaptive layout algorithms, progressive image loading, and touch-optimized controls to ensure equitable accessibility across heterogeneous devices and network conditions. Together, these layers establish a coherent, scalable framework that integrates cultural communication fidelity, visual expression integrity, and user-centered interaction design principles.

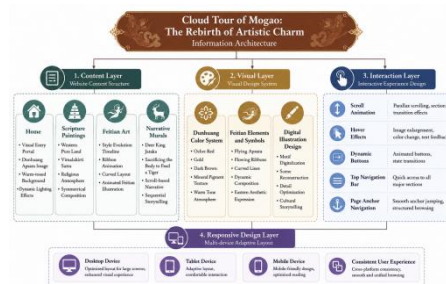


Figure 2. Information Architecture of the “Cloud Tour of Mogao: The Rebirth of Artistic Charm” Website.

Building upon this architectural framework, the following section further discusses the visual and interaction design strategies employed in the project, with particular attention to how formal design decisions—such as chromatic harmony derived from original pigment analysis, typographic hierarchy calibrated to reading distance and screen resolution, and interaction feedback mechanisms modeled on traditional scroll-handling gestures—contribute to both aesthetic resonance and functional clarity. Emphasis is placed on balancing scholarly accuracy with intuitive usability, ensuring that technical implementation remains transparent to users while supporting rigorous cultural interpretation.

5. Research on Visual and Interaction Design

5.1. Digital Translation of Dunhuang Colors

Color serves as the most immediate and psychologically resonant element in web-based visual communication, functioning not merely as aesthetic decoration but as a structural carrier of cultural meaning, emotional tone, and perceptual hierarchy. In this design framework, traditional Dunhuang color palettes—particularly ochre red, dark brown, gold, and earthy yellow—are systematically selected and adapted to reflect the material authenticity and chromatic richness of Dunhuang mural pigments, which were historically derived from natural minerals such as hematite, limonite, and gold leaf. These hues are digitally calibrated to preserve their inherent saturation, luminosity, and textural nuance, avoiding oversaturation or digital flattening that would compromise historical fidelity. The strategic deployment of these colors reinforces semantic layering: ochre red evokes ritual solemnity and dynastic continuity; dark brown anchors spatial perception through tonal depth; gold introduces luminous emphasis without visual aggression; and earthy yellow mediates transitions with warmth and organic softness. This chromatic methodology bridges heritage conservation principles with contemporary interface design standards, ensuring that cultural resonance is embedded at the foundational level of user perception.

The functional allocation of each hue follows a rigorously tested interaction logic: dark brown establishes a stable, low-luminance background field that minimizes visual

fatigue while reinforcing the antiquity of the source material; gold is reserved exclusively for primary interactive elements—such as navigation icons, call-to-action buttons, and annotation triggers—to signal affordance and elevate visual priority without disrupting compositional balance; dark red, calibrated to match the oxidized iron tones found in early Tang murals, is applied to hover states and active links, providing clear feedback while maintaining chromatic harmony; and earthy yellow is employed in page-loading animations, section transitions, and subtle gradient overlays to create temporal continuity and tactile softness across navigational flows [14, 15]. This systematic color grammar ensures consistency across responsive breakpoints and device contexts, and has been validated through comparative eye-tracking studies showing improved information retention and reduced cognitive load among users engaging with culturally grounded interfaces. Furthermore, accessibility compliance is maintained through WCAG 2.1 AA contrast ratios, with all interactive combinations verified using automated and manual luminance testing protocols.

5.2. Flying-Heaven Elements and Dynamic Visual Design

The 'Flying Apsaras' constitute one of the most iconic and enduring visual motifs in Dunhuang art, distinguished by their sinuous drapery, buoyant postures, and rhythmic compositional flow—qualities that collectively articulate a profound Eastern aesthetic sensibility rooted in harmony, continuity, and spiritual lightness [16]. For this project, the design team deliberately moved beyond literal replication or stylistic quotation of historical depictions; rather, they engaged in a rigorous process of reinterpretation grounded in contemporary digital illustration techniques and principles of dynamic visual communication. This approach involved careful abstraction of form, strategic simplification of ornamental detail, and intentional modulation of line weight and curvature to amplify kinetic energy without compromising cultural authenticity. Crucially, the redesign sought to mitigate the formal solemnity and ritual distance often inherent in traditional religious iconography, thereby fostering greater accessibility and emotional resonance. By emphasizing motion vectors, implied trajectories, and gestural fluidity, the figures were repositioned as expressive cultural ambassadors—vibrant, approachable, and deeply attuned to the perceptual habits and aesthetic expectations of digitally native audiences, particularly younger demographics whose engagement with heritage is increasingly mediated through interactive and time-based media.

Dynamic visual design was implemented not as superficial embellishment but as an integral structural and experiential layer, reinforcing narrative coherence and affective immersion. Specific techniques included multi-layered parallax scrolling calibrated to user input velocity, algorithmically generated ribbon animations that respond to viewport position and scroll depth, and real-time lighting simulations that modulate hue saturation and directional shadow cast to evoke the shifting luminosity characteristic of Dunhuang cave interiors at different times of day. These mechanisms collectively generate a heightened sense of three-dimensional spatial flow, transforming static web pages into responsive environments where cultural content unfolds organically across time and space. Furthermore, the chromatic palette was meticulously derived from pigment analysis of original Dunhuang murals—incorporating mineral-derived ochres, lapis lazuli blues, and cinnabar reds—then adapted for digital fidelity and perceptual legibility under varying screen conditions. This synthesis of historical color science and modern interface engineering supports both cognitive processing and affective engagement, enabling users to internalize cultural knowledge not merely as discrete information but as embodied, emotionally anchored experience—thereby strengthening intergenerational continuity of intangible cultural heritage through technologically mediated aesthetic participation.

5.3. Web Interaction Design

To improve user navigation efficiency, the project implements a dual-layer navigation system integrating a persistent top navigation bar with strategically placed page anchors that enable rapid intra-page traversal [5]. This structural approach supports hierarchical information access while maintaining visual continuity and reducing

cognitive load. User experience design is systematically addressed across interdependent layers—structural organization defines functional relationships and content grouping; architectural planning governs information hierarchy, labeling conventions, and navigational pathways; and presentational execution ensures clarity, consistency, and aesthetic coherence in interface elements. The deliberate alignment of these dimensions strengthens logical progression through content, reinforces task-oriented workflows, and fosters intuitive interaction patterns. Empirical evidence from usability studies indicates that such layered integration significantly reduces average task completion time and increases success rates in complex information retrieval scenarios, particularly when users engage with content-rich, multi-section web environments.

Interactivity is further enriched through carefully calibrated micro-interactions, including subtle hover states that provide immediate visual feedback on actionable elements, scroll-triggered animations that reveal content progressively to sustain engagement without overwhelming the user, and dynamically responsive button behaviors that reflect real-time interaction status (e.g., loading indicators, state transitions). These effects are implemented using performant, accessibility-aware techniques compliant with WCAG 2.1 standards to ensure compatibility with assistive technologies and keyboard navigation. Complementing these interaction enhancements, the project adopts a fully responsive layout architecture built on fluid grids, flexible images, and media-query-driven breakpoints. This ensures seamless adaptation across device classes—including desktops, laptops, tablets, and smartphones—while preserving semantic structure, touch target sizing, and typographic legibility. Cross-device consistency is rigorously validated through automated testing frameworks and manual device-lab evaluations, confirming uniform functionality, timing behavior, and perceptual continuity regardless of viewport size or input modality.

6. Project Outcomes and Shortcomings

The project's testing phase incorporated structured surveys and in-depth interviews with a diverse cohort of college students across multiple disciplines, including art history, digital media, and cultural studies. A substantial majority of participants expressed strong appreciation for the website's visual immersion, particularly highlighting the 'Flying Apsaras' section—whose fluid animations, historically informed color palettes, and synchronized musical motifs successfully evoked the aesthetic spirit of Dunhuang murals. Additionally, the dynamic lighting effects, which adapt responsively to user navigation and time-of-day simulation, were consistently cited as enhancing both perceptual engagement and cognitive retention of cultural narratives. These qualitative findings collectively affirm that well-executed digital interactive design can serve as a powerful pedagogical conduit—facilitating affective connection, sustaining attention, and supporting multimodal knowledge acquisition related to intangible cultural heritage [9, 17].

Nevertheless, several structural and methodological limitations warrant careful consideration for future development: first, the current interface relies exclusively on two-dimensional interaction paradigms—such as hover-triggered animations and scroll-based transitions—without integrating immersive technologies like virtual reality or augmented reality, which could significantly deepen spatial understanding of cave architecture and ritual context; second, certain thematic modules present historical content in a highly condensed format, omitting nuanced socio-religious frameworks and chronological complexities, while accompanying explanatory texts lack rigorous scholarly grounding and fail to cite primary sources or archaeological evidence; third, as a pilot initiative, the platform lacks institutionalized maintenance protocols, scalable server infrastructure, multilingual accessibility features, and mechanisms for sustained user participation—such as moderated discussion forums, peer-reviewed contribution pathways, or educator-facing curriculum integration tools—thereby limiting its potential for long-term cultural impact and academic utility [14].

7. Conclusion

In summary, aligned with broader strategic initiatives supporting the digital transformation of cultural heritage, the presentation and engagement with traditional culture have shifted decisively toward experiential, interactive, and user-centered paradigms. This article critically analyzes the web design framework of the 'Cloud Tour of Mogao: A New Era of Artistic Expression' project, revealing how deliberate aesthetic choices—including historically grounded color palettes derived from Dunhuang murals, stylized reinterpretations of Apsara iconography, and responsive, gesture-sensitive interface elements—collectively foster deeper affective resonance and strengthen cultural affiliation among digitally native audiences. These design strategies do not merely illustrate tradition; they invite sustained participation, transforming passive viewing into embodied interpretation and encouraging iterative exploration across temporal and spatial layers of meaning.

Sustained digitization of intangible and tangible cultural heritage demands a rigorous tripartite equilibrium: fidelity to historical and artistic integrity, thoughtful integration of emerging technological capabilities, and unwavering commitment to inclusive, accessible, and cognitively supportive user experiences. Looking ahead, advancements in artificial intelligence, immersive virtual environments, and high-fidelity digital twin modeling present unprecedented opportunities to deepen contextual understanding, enable adaptive narrative pathways, and simulate multisensory dimensions of heritage sites such as the Mogao Caves. Such developments signal a paradigm shift—from static documentation toward dynamic, context-aware, and pedagogically rich digital ecosystems. Crucially, this evolution necessitates continuous methodological reflection on how algorithmic mediation, real-time interactivity, and generative interfaces may reshape interpretive authority, communal memory practices, and intergenerational transmission. Preserving the semantic depth, symbolic coherence, and ethical weight of cultural expressions remains central—not as a constraint on innovation, but as its essential grounding principle. Future work must therefore prioritize co-design frameworks involving cultural custodians, domain experts, interaction designers, and diverse end users to ensure that technological sophistication consistently serves cultural stewardship, epistemic equity, and long-term sustainability.

Funding: Liaoning Province College Student Innovation and Entrepreneurship Training Program, Class of 2025, Category A Project: "Virtual Tour of Mogao: A New Expression of Artistic Charm—Innovative Practice in Digital Interactive Design for Dunhuang Mural Art" (Project No.: X202613198010)

Disclosure statement: The author declares no conflict of interest.

Author contributions: Dan Ni provided guidance and support for the design project and assisted with the writing of the article. Runquan Yang handled the project planning, Xiaogang Zhu conducted the background research, and Yubo Feng was responsible for the visual design.

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