Research on Interactive Digital Narrative of Virtual Museum Mini-Programs: A Case Study of the 'Cloud Tour Dunhuang' Post-Print

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Abstract

【Objective】 Virtual museums based on mini-program design are gradually becoming important platforms for the display and dissemination of cultural heritage in the contemporary era. This study takes the "Cloud Tour Dunhuang" mini-program as its research object to explore the application of interactive digital narrative in virtual museums, and analyze how it constructs interactive narrative forms through multimedia technology, thereby promoting the digital preservation and inheritance of cultural heritage.

【Methods】 Employing methods such as literature research and case analysis, this paper analyzes the application of interactive digital narrative in the "Cloud Tour Dunhuang" mini-program from the perspectives of application status, design performance, and fundamental characteristics.

【Results】 Through innovative interactive digital narrative designs in game-based experiences and audio-visual imagery, virtual museum mini-programs construct interactive narratives and user participation that permeate both within and beyond the text, creating immersive experiences across three dimensions: spatial, temporal, and emotional, and facilitating the circulation of narrative content and cultural experiences across diverse media and platforms.

【Conclusion】 Moving forward, the interactive digital narrative of virtual museum mini-programs must endeavor to expand the scope of narrative subjects, optimize interactive technologies, and strengthen the spiritual expression of narrative content.

Full Text

Preamble

Exploring Interactive Digital Narrative in Virtual Museum Mini-Programs: A Case Study of the "Cloud Tour Dunhuang" Mini-Program

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Abstract

[**Objective**] Virtual museums based on mini-program design have gradually become important platforms for the display and dissemination of cultural heritage. This paper examines the "Cloud Tour Dunhuang" mini-program as a research subject to explore the application of interactive digital narrative in virtual museums, analyzing how it constructs interactive narrative forms through multimedia technology to advance the digital preservation and transmission of cultural heritage. [**Method**] Using literature review and case analysis methods, this study analyzes the application of interactive digital narrative in the "Cloud Tour Dunhuang" mini-program from perspectives including current application status, design performance, and fundamental characteristics. [**Results**] Virtual museum mini-programs construct interactive narratives and user participation that permeate both within and beyond the text through innovative interactive digital narrative designs in gaming experiences and audio-visual media, creating immersive experiences across three dimensions—spatial, temporal, and emotional—and facilitating the circulation of story content and cultural experiences across diverse media and platforms. [**Conclusion**] Moving forward, interactive digital narrative in virtual museum mini-programs should focus on expanding the scope of narrative subjects, optimizing interactive technologies, and strengthening the spiritual expression of narrative content.

Keywords: Interactive Digital Narrative; Cultural Heritage Preservation; Virtual Museum Mini-Program; Digital Narrative

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Chinese cultural heritage carries a profound historical and cultural legacy. President Xi Jinping has emphasized the need to systematically organize traditional cultural resources, bringing to life artifacts hidden in palaces, heritage displayed across the land, and texts written in ancient books [1]. The 2023 *Overall Layout Plan for Digital China Construction* issued by the CPC Central Committee and the State Council explicitly calls for the creation of comprehensive digital cultural display platforms. Virtual museums reconstruct historical artifacts through digital means, breaking spatiotemporal constraints to enable broader and more convenient dissemination [2]. Particularly in the mobile internet era,

mini-program-based virtual museums have emerged as an innovative approach to exhibition and communication. Mini-programs not only offer convenient access but also integrate multimedia, virtual reality (VR), augmented reality (AR), and other technologies to provide rich interactive experiences and immersive cultural education.

As audience needs evolve, museum exhibition models have shifted from object-centered to human-centered approaches, replacing traditional pathways with thematic routes for information and meaning construction [3]. In virtual museums, interactive digital narrative allows audiences to actively engage with exhibits, explore history, and even reconstruct historical scenes in virtual spaces. This narrative mode features strong interactivity and responsiveness, demonstrating the appeal of nonlinear narrative through immersive experiences, and holds significant importance for cultural heritage preservation and research.

1. Interactive Digital Narrative Theory and Its Application in Virtual Museum Construction

The rise and development of interactive digital narrative theory involves the intersection of computer science, literary theory, communication studies, and ludology. Research in this field can be traced back to 2008, when the establishment of the International Society for Interactive Narrative (ISIN) marked the standardization and institutionalization of the discipline, driving deeper theoretical development. As technology advances, the practical scope of interactive digital narrative has gradually expanded from interactive texts, films, and games to applications in cultural heritage preservation and higher education.

1.1 Interactive Digital Narrative Theory

With ongoing digitalization, narratology has increasingly integrated with various media forms, permeating digital media domains such as film, hypertext, and games [4]. In the postclassical narratology stage, research focus has shifted from text-centered analysis to broader historical and cultural contextual analysis [5]. Leveraging the powerful interactivity provided by computer technology, humans have achieved closer connections with technology, objects, and surrounding environments through interactive interfaces. This connection not only strengthens interactivity but also highlights human agency, thereby advancing the development of interactive digital narrative and opening new pathways for narratological research and application. Scholars such as Hartmut Koenitz, in *Interactive Digital Narrative: History, Theory and Practice*, divide its development into three trajectories: text-based interactive digital narrative, including interactive fiction and hypertext fiction; interactive films and series integrating audio-visual technology; and experimental forms characterized by complex narrative design, including video games and VR-based games [6]. *Avatars of Story* also explores the relationships between narrative and media, and narrative and interactivity, analyzing emerging narrative forms from interactive fiction to AI-supported in-

teractive drama, and comparing the film *The Truman Show* with the reality show *Survivor* to demonstrate how stories as meaning forms transform across old and new media [7].

Traditional narrative modes center on the narrator, emphasizing top-down linear structures, whereas digital technology has gradually replaced plot-centered logic with "interactivity" and "immersion" as key narrative elements. Narratees participate indirectly or actively in story creation through virtual means. Marie-Laure Ryan identifies the core of interactive digital narrative as interactivity, utilizing compelling story elements—such as adventure games or interactive narratives—in programmed and participatory environments to stimulate participants' agency, making narratives more open and flexible [8]. From the audience experience perspective, immersion constitutes the core characteristic of interactive digital narrative. Christian Roth and Hartmut Koenitz evaluate user experience across twelve dimensions including usability and credibility [9]. Ryan categorizes "immersive" narrative experiences into narrative immersion and ludic immersion, with narrative immersion encompassing spatial, temporal, and emotional dimensions [10].

In summary, interactive digital narrative refers to the construction of interactive and participatory narrative experiences through digital technology and multimedia means. Its core characteristics can be summarized as interactivity, immersion, and cross-media nature. Interactivity encompasses various interaction modes both within and beyond the text, granting audiences greater participation and control. Immersion draws audiences into a simulated virtual world through multi-dimensional experiences (emotional, spatial, temporal, etc.), enhancing story engagement and 代入感. The cross-media characteristic manifests not only in diverse narrative techniques but also in profoundly reshaping relationships among content, audience, and technology, breaking boundaries of traditional narrative forms. Interactive digital narrative represents not merely formal innovation but also reflects the deep integration of technology, art, and culture, demonstrating new dimensions of storytelling in the digital age.

1.2 Current Application of Interactive Digital Narrative Theory in Virtual Museum Construction

Current applications of interactive digital narrative theory in virtual museum construction primarily manifest as the integration of "digital interactive technology" with museums, providing participants with high-engagement, cost-effective interactive experiences. "Digital interactive technology" design can be categorized into two types: digital/virtual image interaction and intelligent perception interaction.

The core objective of digital and virtual image interaction technology is to provide more realistic and stunning visual effects. This can be achieved through VR, AR, and 3D modeling technologies. For example, the "Renaissance from the Ashes—Immersive AR Exhibition of Notre-Dame de Paris" at the National

Museum of China uses AR and 3D technology to allow users to "walk into" Notre-Dame and experience its history and culture. The "Panoramic Palace Museum" on the Palace Museum' s official website employs VR panoramic technology to provide an immersive visual feast. The digital exhibition hall of the Shaanxi History Museum features VR exhibitions on different themes such as "Treasures of the Tang Dynasty" and "Collection of Tang Dynasty Murals." These technologies not only enhance the visual depth of exhibits but also enable audiences to interact immersively with them in virtual environments.

Intelligent perception interaction technology includes voice interaction, haptic interaction, and motion sensing, incorporating audiences' physiological, physical, and psychological factors into design considerations to realize exhibit-audience interaction. For instance, the Shanghai Museum' s WeChat mini-program features voice guide functionality—audiences simply speak the exhibit name or number to receive detailed audio commentary. The Hong Kong Museum of History uses haptic interactive devices to display traditional handicrafts, allowing audiences to touch screens to examine Cantonese embroidery details and watch animated demonstrations of stitching techniques, enhancing intuitive cognition and experience. At the American Museum of Natural History, audiences interact with virtual dinosaur environments through body movements—jumping may trigger a pterosaur flying overhead.

1.3 Unique Advantages of Virtual Museum Mini-Programs in Interactive Digital Narrative Application

With the proliferation of mobile internet and smartphones, virtual museum mini-programs have emerged as novel digital platforms. Leveraging their lightweight, convenient, and social attributes, they are becoming new carriers for virtual museums. Mini-program platforms can not only inherit existing interactive design technologies from virtual museums but also demonstrate unique advantages in application innovation when combined with interactive digital narrative.

1.3.1 Balancing Convenient Access and Personalized Experience A distinctive feature of mini-programs is "instant use" —users need not undergo cumbersome download and installation processes, accessing content simply by scanning QR codes or searching. This convenience significantly lowers usage barriers, aligning with modern society' s demand for immediate information access in fast-paced lifestyles. According to the Technology Acceptance Model (TAM), individual technology acceptance is primarily influenced by "perceived ease of use" and "perceived usefulness." In the virtual museum mini-program context, this convenient access characteristic satisfies contemporary society's urgent need for rapid, convenient information acquisition, thereby reducing perceived costs during use and enhancing initial acceptance willingness. While meeting convenient access needs, virtual museum mini-programs can develop personalized modes based on user autonomy. The mini-program homepage features multiple cultural theme sections, allowing users to click into specific sections according

to their interests. The mini-program then provides deeper, more diverse interactive activities based on selected sections, enabling users to conduct in-depth cultural experiences and interactive learning within their areas of interest. This enhances user engagement and satisfaction while strengthening usage stickiness.

1.3.2 Lightweight Design and Efficient Integration of Multi-Media Forms Compared to traditional virtual museum websites, mini-programs typically feature more streamlined and lightweight interaction design. Interface design pursues simplicity and fluidity to accommodate mobile operation convenience. This simplified design enables audiences to quickly locate exhibits of interest and directly participate in interactions without being distracted by cumbersome content or complex interfaces. Interactive digital narrative typically involves the integration of multiple media forms (text, images, video, audio, etc.) to construct a complete story context. As a lightweight platform, mini-programs demonstrate exceptional flexibility in integrating these cross-media elements, providing users with rich multimedia interactive experiences. For example, users can browse high-definition exhibit images while accessing multi-dimensional information through short videos and voice commentary. The mini-program' s streamlined architecture enables rapid content loading and interface display, reducing cumbersome page switching and complex loading processes common in traditional virtual museum websites, ensuring fluidity and immediacy in interactive narrative. This efficient performance allows mini-programs to maintain content richness while delivering smooth user experiences when implementing interactive digital narrative.

1.3.3 Social Sharing Functions Expanding Narrative Extensibility Traditional digital museums often focus on professional curation with information transmission as the primary mode. Mini-programs, relying on social platforms like WeChat and Douyin, provide more multi-dimensional and extensible experiences for interactive digital narrative. After visiting virtual museums, users can share their photographed virtual exhibits or visit reflections through mini-programs, participating in online discussions and challenge activities based on exhibit themes. Through social networks' information diffusion effects, this triggers online discussions around exhibit themes, creating widespread interactive effects. During sharing and participation, users continuously deepen their cognition and understanding of exhibits, integrating their emotions, reflections, and cultural insights, thereby transforming exhibits from isolated cultural symbols into carriers of user emotion and digital interaction. This strengthened emotional connection further drives users to actively integrate into the interactive digital narrative system, becoming indispensable organic components of the narrative chain. User-generated content (UGC) —whether discussion viewpoints, creative stories, or challenge results—forms dynamic, continuously evolving narrative branches within social platforms' communication networks, greatly enriching the relatively fixed narrative content of virtual museums and enhancing narrative diversity and extensibility.

2. Design Performance of Interactive Digital Narrative Thinking in the "Cloud Tour Dunhuang" Virtual Museum Mini-Program

President Xi Jinping has emphasized: "Protecting the Mogao Caves well and inheriting Dunhuang culture well is a responsibility the Chinese nation should bear for the progress of world civilization." In this context, the Dunhuang Research Institute, together with People' s Daily New Media and Tencent, launched the "Cloud Tour Dunhuang" mini-program—the first integrated mini-program for exploring, touring, and protecting Dunhuang cave art. Its digital construction employs extensive multimedia technology, integrating diverse forms of expression including text, images, and sound while incorporating human interactive behavior to create a multi-dimensional, participatory cultural narrative space. As of October 2024, the "Cloud Tour Dunhuang" WeChat mini-program has attracted over 200 million online interactions, becoming an important digital platform for promoting Dunhuang culture and advancing cultural heritage preservation. Its interactive digital narrative thinking manifests in two specific design types.

2.1 Game-Based Interactive Narrative Design

The core characteristic of games lies in players driving story development through choices, actions, and decisions, making each player' s story experience unique and profound. The game design in the Digital Dunhuang mini-program can be divided into two categories: immersive deep-interaction games based on nonlinear narrative, and lightweight interactive games aimed at enhancing user experience and personalized participation.

The "Digital Sutra Cave" represents the deep-interaction game based on nonlinear narrative. Combining high-definition scanning technology and game engine physical rendering, it successfully recreates the Sutra Cave and its artifacts 1:1 in the game world. Players assume different roles, traveling to historical periods such as the late Tang and Northern Song dynasties to personally experience the cave' s development. Through free exploration, game interaction, complex narrative, and cross-temporal immersion design, players gain deep understanding of Dunhuang culture and history, stimulating interest in the Mogao Caves.

In contrast, lightweight interactive games primarily enhance user engagement and personalized participation through simple, interesting interaction forms. These games typically involve no complex plots but enable easy participation and unique experiences through simple operations and choices. For example, in the "Cloud Tour Dunhuang Animated Drama" section, users can freely select Dunhuang animated dramas and dub mural stories. "Dunhuang Seasonal Solar Terms" allows users to select their birth date to generate corresponding Dunhuang seasonal backgrounds and images, helping users understand related traditional festivals, customs, and Dunhuang art. "Lighting Up the Mogao Caves" utilizes digital and blockchain technology to allow users to online recreate the millennium-old tradition of lighting lamps at the Mogao Caves, experiencing

the history and inheritance of Dunhuang culture.

2.2 Audio-Visual Image-Based Interactive Narrative Design

Interactive narrative design using images as carriers typically combines visual imagery, sound, and animation as narrative media, creating entirely new narrative experiences through audio-visual integration, free choice, and emotional interaction. In mini-program usage, users can personally select narrative images, time-spaces, and segments.

The "Seeking the Realm of Dunhuang" section employs 360-degree panoramic technology and other technological capabilities to achieve 1:1 high-precision three-dimensional restoration of Cave 285, providing an immersive virtual visiting experience. In the online version, users can freely explore the cave, browse mural stories, and understand the cave' s cultural connotations. After entering "Seeking the Realm of Dunhuang," users first watch a short video introducing Cave 285's background, then interactively click "light the lamp"to enter the cave for virtual visitation. The entire experience centers on the theme of "goodness," divided into four chapters: Believing in Goodness, Encouraging Goodness, Aspiring to Goodness, and Symphony of Civilizations. Each chapter drives users to deeply understand stories behind Dunhuang murals through different interactive designs. For instance, in Chapter 2 "Encouraging Goodness," users "click on immortal grass to scatter good-will medicine" to learn the story of *The Five Hundred Bandits Becoming Buddhas*. Chapter 4 "Symphony of Civilizations" allows users to click on different religious deity patterns in murals to light up musical scores and play ethnic instruments like pipa, suona, and drums, conveying the cultural connotations of Cave 285 and the significance of multicultural fusion through multi-sensory audio-visual experiences of different religious, ethnic, and regional artistic styles. After completing chapters, users can independently click on mural details for visitation. After lighting up 10 mural details, users can also share their interactions.

3. Basic Characteristics of Interactive Digital Narrative in the "Cloud Tour Dunhuang"Virtual Museum Mini-Program

As a representative of digital platform construction, virtual museum mini-programs represent the latest stage of interactive digital narrative theory in practice. They not only inherit traditional museum display functions but also, through digital means, make interactions between exhibits and audiences more multi-dimensional and expressive. The following analysis of the Cloud Tour Dunhuang mini-program' s functions is based on three core characteristics of interactive digital narrative theory: interactivity, immersion, and cross-media nature.

3.1 Interactivity: Constructing Interactive Narrative and User Participation Permeating Within and Beyond the Text

In digital museum interactive narrative, enhancing interactive participation with users is the ultimate goal throughout the entire digital museum's interactive narrative process. Users actively integrate into and experience the virtual museum' s narrative progression through partial or complete participation. The Cloud Tour Dunhuang mini-program attracts user participation through multi-level interactive design within and beyond the text.

3.1.1 Intra-Text Interactivity: Deepening Content Immersion Text design in interactive digital narrative-based virtual museums aims to construct "cohesive narratives" that ensure narrative complexity and realism while helping users deeply understand narrative event content and significance. Narrative games represent the latest application stage of interactive digital narrative development. Interactive narrative methods in game design mainly include three types: embedded narrative, emergent narrative, and node-based narrative [11]. Embedded narrative integrates story backgrounds into user interaction for discovery without user intervention. Emergent narrative emphasizes dynamic changes, adjusting story direction in real-time based on user behavior. Node-based narrative, positioned between the two, refers to story development pushed forward through multiple nodes, with users driving stories in different directions through different nodes.

The interactive narrative structure of the "Digital Sutra Cave" project in Cloud Tour Dunhuang primarily employs node-based narrative supplemented by embedded narrative. Upon entering the game, players can choose three main lines for exploration: Line S1 browses artifact exhibitions and collects knowledge points; Line S3 explores cave artifacts and understands culture; Line S2 is the main interactive narrative line, unfolding around the Sutra Cave' s history with Tang, Song, and Qing dynasties as clues, developing four chapters through node-based narrative: The Monk' s Cave, Birth of Wine, Century-Long Sealing, and Tragedy of Artifacts. The game features 15 interaction points and 6 interactive games, with at least 3 interaction points and one interactive game designed at each chapter. These interactive contents are embedded with historical knowledge, forming full interaction between users and narrative texts. For example, at game point TG2, when users carve cave walls, they must operate from top to bottom following realistic carving sequences. This interactive design not only increases fun but also helps players understand the Sutra Cave' s history and culture through practice.

As the game progresses, players gradually connect story blocks to understand the Sutra Cave' s past and present. From a knowledge construction perspective, through repeated interaction with the text, highly participatory experiences can be achieved, strengthening users' accumulation of Sutra Cave knowledge and subtly influencing their cognition [Figure 1: see original paper].

3.1.2 Extra-Text Interactivity: Strengthening User Social Connections Beyond intra-text interactive design, the Cloud Tour Dunhuang mini-program also emphasizes interaction between users and the virtual museum system itself, other users, and the platform. The "Today' s Words" function recommends a Dunhuang mural, related story, and classic aphorism daily, allowing users to interact with others through comments, likes, and shares, continuously updating cultural content while increasing extra-text interaction. Additionally, after completing the full Digital Sutra Cave experience, QR codes are generated for sharing, granting users the title of "Cultural Relic Rescuer" and displaying cumulative user travel years, unlocked scenes, and collected knowledge cards, enhancing users' sense of belonging and encouraging them to share achievements with others. On Weibo, the #CloudTourDunhuang topic has reached 120 million views, with numerous secondary creation videos also appearing on Bilibili. Introducing social elements beyond the narrative text allows users to interact with others and establish emotional connections while participating in narratives. This emotional sharing and dissemination is crucial in cultural entertainment products, deepening users' identification with narrative texts while driving cultural dissemination and strengthening overall cultural resonance through group interactions.

3.2 Immersion: Creating Three-Dimensional Immersive Experiences Across Space, Time, and Emotion

In the development of interactive digital narrative theory, immersion plays a vital role, not only enhancing user engagement and experience quality but also profoundly influencing story dissemination effects and user emotional resonance. Based on Ryan' s classification of immersion types, the following analysis of Cloud Tour Dunhuang examines spatial immersion, temporal immersion, and emotional immersion.

3.2.1 Spatial Immersion: Enhancing Sense of Place Narrative spatial immersion refers to users' identification with the geographical space presented in narrative texts within virtual spaces, achieving a sense of being physically present. Sense of place serves as the emotional bond between users and texts, generating place attachment and spatial immersion through identification with locations. Spatial immersion is primarily achieved through three design aspects. First is realistic spatial simulation: during the collection and restoration phase, the "Digital Sutra Cave" utilizes high-definition digital photogrammetry and 3D modeling to achieve millimeter-level 1:1 high-precision digital twinning of cultural heritage in the virtual world. Additionally, the historical environment and ecological background of the Mogao Caves have been restored. In terms of sound effects, on-site bells, wind sounds, and echoes from the Mogao Caves have been recorded, with ancient Dunhuang melodies as the main theme to recreate authentic ancient Mogao Cave scenes. Second is user dynamic interaction: users can freely walk, explore, and interact in the Digital Sutra Cave, gaining greater spatial control and actively participating in narrative processes by triggering

plots and participating in historical events (such as cave excavation and sutra copying tasks). Third is cultural environment design: a well-constructed virtual space is often combined with cultural contexts, providing richer emotional experiences by embedding specific cultural symbols and narrative clues in the space. For example, the lost *Guiyijun Government Office Wine Expense Register* was divided into three sections, with the middle and end sections scattered in Japan and France. Through the artifact' s tumultuous life journey, users not only understand its historical value but also emotionally resonate with the place, stimulating place attachment and cultural confidence.

3.2.2 Temporal Immersion: Enhancing Engagement The Cloud Tour Dunhuang mini-program achieves temporal immersion effects through dual temporal logic, referring to the time of story unfolding and the time of story reading —that is, achieving both narrative design of story time and extension of user gameplay time [12]. Story time narrative design allows users to perceive temporal flow through historical "time travel." In "Digital Sutra Cave," users can not only read or watch stories but also travel to different historical periods including late Tang, Northern Song, and late Qing dynasties, personally experiencing the creation, sealing, rediscovery, loss, and reunion of Sutra Cave artifacts. During exploration, users continuously "return to the past," experiencing the transformation of Dunhuang cultural heritage to gain more profound historical and temporal flow experiences. On the other hand, extending user experience time further strengthens temporal immersion. The mini-program' s narrative structure primarily combines node-based and linear narrative, ensuring story coherence while stimulating users' exploration desires through hierarchical game design. As each puzzle is solved and task completed—such as collecting pigments in the Sutra Cave or observing picture details for Q&A in "Sound Animated Language" —users not only gradually deepen story plots but also gain deeper understanding of Dunhuang artifacts and historical knowledge. The intertwining of game time and story time allows users to simultaneously experience both historical narratives of cultural heritage and personal immersive experiences, enabling them to experience Dunhuang culture' s inheritance and transformation within temporal flow, thereby achieving richer and more profound temporal immersion.

3.2.3 Emotional Immersion: Strengthening Cultural Identity According to pretend play theory, emotional immersion is divided into self-oriented emotion and other-oriented emotion. In the Digital Sutra Cave story experience, users participate in text narrative as story marginal figures, helping NPC (non-player character) Master Hongbian excavate caves, assisting pavilion monks in copying the Diamond Sutra, helping monks seal the Sutra Cave, and finally witnessing personally preserved artifacts being plundered by multiple countries, only to see the digital presentation of the *Wine Expense Register* today. In terms of self-oriented emotion, users experience emotional changes from curiosity to regret to hopefulness. Users' personal emotional investment enhances their iden-

tification with cultural relic protection and cultural renaissance, deepening their understanding of China' s long history and national identity. Other-oriented emotion mainly includes emotions generated toward NPCs in the "Digital Sutra Cave" story and emotions arising from sharing and communication with others. During exploration, users can feel Master Hongbian and his disciples' dedication to protecting Dunhuang culture, allowing users to invest emotions in NPCs and thereby influencing emotional identification with the overall story. Resonance and reflection after sharing and exchanging "Digital Sutra Cave" gameplay experiences with others can stimulate resonance among audiences and connections with external emotions, generating emotional immersion.

3.3 Cross-Media: Facilitating Circulation of Story Content and Cultural Experiences Across Diverse Media and Platforms

Cross-media narrative emphasizes content expansion and extension across different media, enabling story content to flow and develop across multiple platforms and forms, enriching user participation and experience. This analysis examines two aspects of the "Cloud Tour Dunhuang" mini-program' s cross-media characteristics.

3.3.1 Complementary Media Forms Enriching Content Diversity Complementary and integrated media forms refer to the combined use of different media—such as text, images, audio, video, and virtual reality—to compensate for limitations of single media. The "Cloud Tour Dunhuang" mini-program collects and displays extensive artifact information from the Dunhuang Mogao Caves. Murals and sculptures themselves carry substantial artistic information. To help users more comprehensively understand the history and culture behind murals, the mini-program combines images and text in the "Explore" section, categorized by "art form," "dynasty," and "color," and integrates audio and video through a "video" column showing the development history and international dissemination of the Dunhuang Mogao Caves, providing more intuitive and vivid perspectives. In the "New Cultural Creativity" section, interactive elements are incorporated through columns like "Sound Animated Language" and "Cloud Tour Dunhuang Animated Drama" to increase user participation and mobilize enthusiasm, enhancing users' understanding and memory of content through interactive games rather than superficial knowledge points. In the "New Cultural Creativity" section, columns like "Seeking the Realm of Dunhuang" and "Digital Sutra Cave" integrate more complex VR, AR, 3D modeling, and cloud gaming technologies on the above foundation. Through comprehensive application of sophisticated technologies, digital content is combined with users' real worlds to provide more vivid and participatory cultural experiences.

3.3.2 Extended Media Narrative Enabling Multi-Dimensional Cultural Experiences The continuation and expansion of narrative texts across different media and platforms can effectively enrich narrative content, enhance

user participation, and thereby achieve more multi-dimensional cultural experiences. The "Cloud Tour Dunhuang" mini-program provides immersive cultural experiences on mobile devices and extends them to PC and other platforms. Through social sharing functions, users can disseminate content of interest to broader social networks, promoting cultural content dissemination and interaction. Additionally, the mini-program enables online-offline cross-media interaction. In the "Explore" section, users can mark murals, sculptures, and other content they are interested in with "want to go," which guides them to focus on relevant works during physical visits, enhancing visit specificity and depth. During offline visits, users can also use the "flip card" function in the mini-program to quickly obtain background knowledge of high-frequency stories or allusions, filling gaps in immediate information common in traditional visit experiences. This online-offline interactive participation allows narrative content to transcend single-platform limitations, enabling users to deepen their understanding of Dunhuang culture from different angles and levels, experiencing and cognizing multi-dimensionally across multiple platforms and media.

4. Construction Effectiveness and Improvement Strategies for Virtual Museum Mini-Programs Under Interactive Digital Narrative

Supported by interactive digital narrative theory, virtual museum mini-programs are revolutionizing cultural heritage display and dissemination methods, providing users with highly personalized and immersive cultural experiences. However, their integration remains in the initial stage, with many dimensions worthy of further deepening and exploration.

4.1 Construction Effectiveness of Virtual Museum Mini-Programs Under Interactive Digital Narrative

As an efficient and convenient digital display tool, interactive digital narrative-based virtual museum mini-programs provide audiences with more personalized and immersive cultural experiences, stimulating audience interest and exploration desire for cultural heritage. Through this innovative interaction model, virtual museum mini-programs not only promote active knowledge acquisition but also deepen audience understanding and perception of cultural connotations, driving broader cultural dissemination.

4.1.1 Enhanced Interactive Experience and Increased User Engagement A core objective of virtual museums is to enhance museum attractiveness through interactive experiences, thereby promoting user participation and visits. Traditional museums often adopt one-way information transmission models, introducing artifacts and history to on-site visitors through exhibition boards and audio guides. Virtual museums, by employing virtual interactive technologies, allow users to actively participate during exhibitions,

selecting topics or exhibits of interest for in-depth understanding. For example, the Cloud Tour Dunhuang main interface is divided into functions like "Explore," "Tour," "Protect," and "New Cultural Creativity." This highly free exploration approach greatly enhances user interest and engagement, transforming them from passive "information receivers" to "active participants." This interactive experience extends beyond simple exhibit browsing to multi-level interaction between users and museum content through various interactive means (virtual tours, information clicking, situational experiences, etc.), establishing deeper emotional connections. Additionally, through lightweight mini-programs, round-the-clock uninterrupted service can be provided, making this high accessibility more suitable for contemporary fast-paced lifestyles and attracting more digital-native younger generations.

4.1.2 Enriched Museum Content and Sustainable Development Through digital and virtual technologies, virtual museum mini-programs can break through traditional museum limitations on space and physical exhibits, transforming large quantities of precious historical and cultural resources into online accessible content. Beyond displaying physical museum collections, they can present artifacts and sites that cannot be exhibited due to preservation or space constraints, expanding museum exhibition boundaries. Simultaneously, virtual museums can create more imaginative and creative display forms, such as overlaying AR technology to recreate historical scenes on mobile phones, like the dynamic display of Dunhuang murals in Cloud Tour Dunhuang, or incorporating interactive stories for role-playing or virtual scene reconstruction, enhancing interactivity between audiences and exhibits. To ensure sustainable development, virtual museums rely not only on rich collection resources but also regularly launch virtual exhibitions and activities timed with festivals and anniversaries, enriching museum content while effectively attracting and maintaining users and enhancing virtual museum activity and appeal, such as the "Dunhuang Seasonal Solar Terms" and "Lighting Up the Mogao Caves" functions launched by the Dunhuang Mogao Caves.

4.1.3 Deepened Social Education and Promoted Cultural Dissemination The emergence of virtual museum mini-programs provides more convenient learning pathways for students in remote areas. Traditional cultural heritage education often relies on offline teaching, limited by geographical location, facilities, and resource allocation, making it difficult for remote area students to access cultural heritage resources. Virtual museums, through digital means, break spatial constraints, enabling remote area students to access, explore, and learn cultural heritage anytime and anywhere via the internet. Students can participate in learning through interactive participation and immersive experiences rather than being limited to traditional "seeing" and "listening," thereby increasing learning engagement and enthusiasm. This virtual learning platform not only provides them with knowledge acquisition opportunities but also opens a richer and more diverse learning environment, helping stimulate their inter-

est in history and culture and strengthening cultural identity and confidence. Furthermore, virtual museum mini-programs break geographical and temporal constraints, forming a digital interconnection system based on shared services and external dissemination, enabling global audiences to access and deeply understand the charm of Chinese culture and art across geographical boundaries, thereby effectively enhancing the international influence and global dissemination strength of Chinese culture.

4.2 Improvement Strategies for Virtual Museum Mini-Programs Under Interactive Digital Narrative

The current combination of virtual museums and interactive digital narrative has initially matured, demonstrating enormous potential in cultural heritage curation and dissemination. With technological advancement and changing user needs, this combination can be further improved and deepened, opening broader spaces for digital cultural innovation and development.

4.2.1 Diversified Expansion of Narrative Subject Scope As one of the main subjects of interactive digital narrative, audiences can influence and shape narrative content. Program design can introduce different cultural backgrounds and professional identities, encouraging audiences to interpret exhibits or themes from their own perspectives and providing richer information experiences. Beyond in-program interactive experiences, embodied experiences should be expanded, motivating users to participate in creative activities such as cultural relic story writing and character design through social media and creation platforms, leveraging user-generated content (UGC) secondary creation capabilities to drive cultural re-creation. Additionally, cross-disciplinary cooperation can provide more accurate and rich cultural interpretations for exhibition content, making virtual museum displays not only academic but also forming multi-interactive cultural experiences at artistic and creative levels. Digital narrative training workshops and cultural heritage creativity workshops, such as those organized by UNESCO, can help cultural heritage protectors, museum practitioners, artists, and educators worldwide master digital narrative technologies. However, when expanding narrative subject boundaries, attention must be paid to content integration and accuracy to avoid information fragmentation affecting audiences' overall understanding of museum culture.

4.2.2 Optimizing the Depth of Interactive Technology Application Technology is an important driving force for the continuous development of interactive digital theory, determining the depth and breadth of its narrative structure, forms, interaction modes, and user experiences. Current technology trends continuously evolve toward humanization, intelligence, and immersion, allowing audiences in virtual environments to interact with exhibits in natural and simple ways, forming a ubiquitous interaction model that is "intangible yet omnipresent, tangible yet naturally harmonious" [14]. However, in the actual gameplay experience of Digital Sutra Cave, there remains room for optimization,

such as insufficient free interactive exploration in some scenes, task systems still leaning toward single linearity, and underdeveloped personalized interactive experiences. By introducing AIGC technology, higher levels of personalization and diversity can be achieved in automated narrative text generation, helping users conduct more autonomous exploration and interaction in virtual worlds and injecting more intelligent elements into virtual museum mini-program interactive experiences. For example, using text-to-video large models to automatically generate historical scenes related to exhibits helps users better understand historical content, improving experience quality while reducing costs and increasing efficiency.

4.2.3 Strengthening Cultural Spirit Expression in Narrative Content
The design concept of interactive digital narrative is not limited to entertainment and user attraction but, more importantly, strengthens cultural identity by creating deep emotional resonance. Currently, many virtual museum mini-program designs tend to overemphasize visual presentation of exhibits, using technologies like high-definition images and virtual tours to provide immersive exhibition experiences. However, their story plot design and interactive gameplay often remain at the surface level of "material display," lacking profound interpretation of the cultural spirit behind exhibits. Cultural spirit is the "soul" of cultural heritage and the core of interactive digital narrative design in virtual museum mini-programs. The combination of interactive digital narrative and cultural artifacts should not be viewed merely as an exhibit display task but as a process of transmitting traditional Chinese cultural spirit, thoughts, and values. Therefore, when designing interactive digital narrative works, cultural backgrounds must be thoroughly excavated before narrative text creation, with careful consideration given to elements such as cultural symbols, language design, narrative structure, and cultural thinking. This allows users to subtly receive and understand the cultural spirit and values embedded within during interaction with narrative texts, achieving more profound and lasting cultural transmission effects that help them realize cultural identity and value reflection through interaction.

Interactive digital narrative, as a new method in the digital era, integrates advantages from multiple disciplines. When applied to virtual museum mini-program design, it can not only achieve digital immortality of cultural heritage but also extract and reconstruct the core spirit and cultural connotations of artifacts, endowing them with new forms of expression and vitality. Furthermore, through multi-dimensional interactive design, it achieves deep links between users and cultural heritage, driving secondary creation and dissemination of cultural heritage. However, in practical application, attention must be paid to cultural spirit expression in narrative content, breaking away from traditional narrative thinking, expanding narrative subjects, and simultaneously using AI to optimize interactive design to provide more personalized experiences for users. In the future, as technology continues to develop, interactive digital narrative will unleash greater potential in virtual museums, contributing to the dissemination

of Chinese culture and promoting global cultural exchange and integration.

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Note: Figure translations are in progress. See original paper for figures.