

Digital Humanities Empowering the Opening of Public Educational Resources: Lessons and Insights from the Digital Dunhuang Project

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Abstract. As an emerging interdisciplinary field, Digital Humanities provides innovative pathways for the digital preservation of cultural heritage and public educational services through the deep integration of cutting-edge digital technologies and open resource strategies. Taking the nationally significant cultural initiative "Digital Dunhuang" as a case study, this paper systematically examines the pivotal role of Digital Humanities in high-precision digital acquisition, intelligent information processing, and the establishment of multi-level collaborative mechanisms. This study examines how these methodologies have promoted the worldwide dissemination, pedagogical implementation, and long-term use of Dunhuang's artistic assets. Our research demonstrates that the "Digital Dunhuang" initiative not only employs theoretical models like open education, public goods, and situated learning to shift cultural heritage from static conservation to dynamic revitalization, but also greatly improves dissemination effectiveness and educational impact by building a comprehensive digital resource platform and interdisciplinary collaborative networks. This successful practice offers replicable and scalable systemic solutions and implementation paradigms for digitally preserving cultural heritage and developing public educational resources nationally and globally.

Keywords: Digital Humanities, Public Education, Digital Dunhuang, Empowerment Effects, Empowerment Mechanisms

1. Introduction

Digital humanities constitute an interdisciplinary field employing computational and data science methodologies to study traditional humanities disciplines such as literature, history, and art. The advent of digital humanities has increasingly focused interdisciplinary attention on the digital preservation of cultural heritage and the provision of open access to public educational resources. Existing research predominantly concentrates on technological applications, yet lacks in-depth exploration of systematic empowerment mechanisms. Taking the "Digital Dunhuang" project as a case study, this paper employs case analysis grounded in open education, public goods, and situated learning theories. It investigates digital humanities' operational mechanisms and implementation

pathways within cultural heritage digitisation and educational resource sharing, aiming to provide theoretical references and methodological insights for related practices.

2. Overview and core content of the "Digital Dunhuang" project

The Dunhuang Caves represent a resplendent artistic treasure of ancient Chinese civilisation. With 735 extant caves, 45,000 square metres of murals, over 3,000 coloured sculptures, and over 60,000 documents unearthed from the Library Cave, they are the pinnacle of Chinese Buddhist art from the 4th to 14th centuries. However, due to natural erosion and human damage, the Dunhuang Caves face irreversible deterioration and ageing crises, with approximately 20% of the murals exhibiting varying degrees of deterioration. The Dunhuang Research Academy began exploring digital preservation pathways in the 1980s to address these challenges. It systematically advanced the "Digital Dunhuang" project from the 1990s onwards, currently a flagship Chinese digital humanities initiative.

The project digitally preserves Dunhuang's cultural heritage using VR, AR, and interactive reality, overcoming spatiotemporal limitations for public access and research. High-precision scanning, 3D laser reconstruction, and remote sensing are employed to achieve millimeter-level accuracy in digitizing the Mogao Caves and their contents. This initiative has systematically archived numerous caves, creating an extensive digital repository that combines cultural preservation, education, and tourism [1]. Since its launch in 2016, the repository has provided global users with extensive high-definition imagery and panoramic navigation content. The core objective of the Digital Dunhuang project is to achieve the permanent preservation and sustainable utilisation of Dunhuang's cultural and artistic heritage, while leveraging internet platforms to advance global academic research and cultural sharing [2].

3. A multidimensional perspective on digital humanities empowering the Dunhuang project: theoretical framework, efficacy generation, and mechanism of action research

3.1. Examination within the theoretical framework: the multi-dimensional empowerment mechanism of the Digital Dunhuang project

Dahlman posits that open education theory's core lies in dismantling knowledge acquisition barriers [3]. The "Digital Dunhuang" project exemplifies this principle in the digital age, perfectly embodying both his advocacy for "removing all obstacles" and Wedemeyer's concept of "independent learning" [4]. By establishing an online repository, "Digital Dunhuang" transforms the cave-hidden mural treasures into digital resources accessible anytime, anywhere, and on demand by global users, completely dismantling the dual barriers of time, space, and identity in traditional cultural heritage education. More significantly, it rigorously adheres to the "5R" principles of UNESCO's Paris Declaration [5]: users may retain and reuse high-definition images and revise them into teaching materials, remix them into new creations, and redistribute derivative works. This elevates "Digital Dunhuang" beyond a mere digital archive, transforming it into an open platform that sparks global educational innovation and knowledge reproduction, propelling the Socratic spirit of shared inquiry to unprecedented breadth and depth.

Public goods theory explains Digital Dunhuang's sustainability. Its digital resources are largely non-rivalrous and non-excludable, resembling pure public goods and thus prone to "market failure." [6]. However, the project does not rely solely on sustained government funding. Instead, it innovatively employs Buchanan's concept of "club goods," devising a sophisticated tiered licensing

mechanism: medium-resolution resources are fully open under the CC0 licence, fulfilling its public mission. At the same time, ultra-high-definition data operates under an application-based usage system, introducing measured "exclusivity" [7]. As inspired by Coase, this institutional design significantly reduces management transaction costs by clearly defining the "property rights" and usage rules for different tiers of resources. It simultaneously safeguards inclusive educational equity while preserving the value of core digital assets and the project's potential for sustainable development [8], offering a hybrid governance solution rooted in Chinese wisdom to address the dual challenges of "financing incentives" and "usage exclusivity" in cultural heritage digital public goods.

Situated learning theory explains how Digital Dunhuang fosters immersive learning beyond traditional methods. Lave & Wenger noted effective learning via "legitimate peripheral participation" in "communities of practice." [9]. This project successfully reconstructs an online "Dunhuang Art Community of Practice" through VR, panoramic imaging, and related technologies. Learners are no longer passive observers viewing isolated images. Instead, they virtually traverse and "enter" the caves, exploring and investigating with a "legitimate" identity within near-authentic historical, religious, and artistic contexts. This contextualised cognition activates knowledge that often becomes "inert" when encountered behind traditional museum glass cases [10]. Learners construct profound understandings of Dunhuang's artistic styles, historical evolution, and cultural significance through autonomous path selection, detail magnification, and cross-cave comparisons. This process facilitates an identity shift from cultural periphery to core engagement, achieving deep integration of knowledge, emotion, and cultural identity.

3.2. Demonstrating the impact of digital humanities in the Dunhuang project

3.2.1. Significant advancements in digital heritage preservation

By August 2025, the "Digital Dunhuang" project had achieved substantial progress in the digital preservation of cultural heritage. Systematic digital documentation had been completed for 320 caves across the Dunhuang Mogao Caves, Xianqifodong Caves, and Yulin Caves. Building upon this foundation, the Dunhuang Digital Cultural Heritage Repository has added 2,000 high-definition digital artefacts. These encompass murals, coloured sculptures, and documentary relics from the sites above, spanning a temporal range from the Northern Dynasties to the Yuan Dynasty. The project achieved non-contact high-resolution acquisition by employing cutting-edge techniques, including multi-image 3D reconstruction, laser scanning, and 8K macro scanning. Individual mural data files exceed 10GB, enabling millimetre-level detail representation. Concurrently, through multispectral imaging and AI algorithms, the project has accomplished virtual reconstruction and dynamic restoration of partially damaged murals [11, 12].

Following this expansion, the platform's total collection has surpassed 12,000 items, with cumulative visits reaching 210 million, further cementing its position as the world's largest database of Dunhuang culture. This initiative establishes a permanent, high-fidelity digital archive for the Dunhuang caves and actively responds to national policies advocating enhanced protection and utilisation of cave temples. The 2020 State Council General Office document Guiding Opinions on Strengthening the Protection and Utilisation of Cave Temples explicitly calls for "accelerating the formulation of relevant standards and specifications, and advancing the digitisation of cave temples" [13]. Against this backdrop, the technological framework and operational protocols developed by the Digital Dunhuang project provided crucial practical foundations for formulating local technical documents such as the "Procedures for Three-dimensional Laser Scanning and Digital Acquisition

of Cave Temple Cultural Relics" [14]. This has been a model for advancing standardisation in the digital preservation of cave temples nationwide.

3.2.2. Digital Dunhuang: resource sharing and research-education innovation

As the world's largest shared platform for Dunhuang art resources, the Digital Dunhuang repository [15] provides multidimensional support for academic research and educational practice through its systematic digital development and open-access mechanisms.

Digital Dunhuang's high-precision digitization of numerous caves has created a comprehensive database with multispectral imagery, 3D models, and HD video, enabling advanced research. AI-driven image stitching, fragment reconstruction, and knowledge graph generation boost research efficiency. Scholars use these resources for non-invasive analyses of murals, artistic styles, and historical changes, expanding research into digital humanities, computer vision, and materials science.

The project has formed multi-level partnerships with academic institutions, using AR/VR and AI-assisted simulations to enhance interactive teaching. Gamified mini-programs like "Digital Patron" and "Cloud Tour of Dunhuang" have engaged hundreds of thousands of youths, raising awareness of Dunhuang culture. The Dunhuang Colour Library provides over 2,000 mineral pigment charts for art education, serving as a key reference. Select vector data interfaces support advanced research and creative work. The "Digital Dunhuang" and "Dunhuang Research Academy" websites integrate digital resources and literature databases, offering public online access and courses, thus establishing a hybrid educational system that balances outreach and professional training.

In June 2025, the "Digital Cave of the Buddhist Scriptures" database was launched, cataloging 74,651 cultural relics, including 9,900+ scrolls and 60,700+ images, and identifying 8.4M characters. Utilizing Tencent's Hunyuan Large Model, the platform provides multilingual translation, intelligent summarization, and full-text search. Its RAG-based retrieval system achieves sub-second document location with 95% accuracy. The analysis module supports character-column-text parsing, cross-version comparisons, and knowledge graph construction. Collaborating with international institutions, it advances digital restoration, enabling global sharing and digital reconstruction of Dunhuang manuscripts [16].

3.2.3. Continued expansion of social dissemination and cultural influence

The Digital Dunhuang project has significantly expanded Dunhuang culture's social influence and public engagement through innovative dissemination mechanisms. In terms of global outreach, the "Digital Dunhuang Global Touring Exhibition" has been successfully held in numerous countries worldwide, including the United States, France, and the United Kingdom, attracting substantial international audiences and garnering widespread global attention and positive acclaim. In 2024, the Digital Dunhuang repository surpassed 23 million visits across 78 countries worldwide, with UNESCO commending it as "a model for safeguarding humanity's shared heritage." The rise of digital technology has forged new pathways for Dunhuang culture to transcend temporal and spatial barriers, establishing it as a vital vehicle for cultural soft power in the contemporary era [17].

Concurrently, the second phase of the Mogao Grottoes Digital Exhibition Centre introduced advanced 8K ultra-high-definition display and immersive theatre technologies. Creating a multi-sensory environment significantly extended visitors' average dwell time, greatly enhancing the depth and impact of cultural dissemination [12]. The digital platform, developed with tech companies, saw high user engagement. Short videos significantly impacted global social media, attracting young,

international audiences to Dunhuang culture. The project supports cultural public welfare by providing digital resources for aesthetic education in schools in central and western China, promoting educational equity and rural development through digital heritage.

3.3. Exploring the mechanisms of digital humanities: empowering the Dunhuang project

The success of the "Digital Dunhuang" project stems from a systematic, multi-tiered digital humanities empowerment mechanism. This framework deeply integrates four dimensions—technology, resources, collaboration, and education—to establish a sustainable model for the digital preservation and open utilisation of cultural heritage.

The project employs multi-tech integration and AI for efficient digital preservation, utilizing 3D scanning, multispectral imaging, and 8K capture for mm-level reconstruction of murals and caves. AI algorithms enable auto-stitching, virtual restoration, and knowledge graph construction, enhancing data processing. Cloud computing supports data storage and access, ensuring a seamless user experience. This framework sets high standards for digital preservation and offers a replicable technical approach.

Digital Dunhuang uses tiered authorization and hybrid governance for resource access, balancing public access with sustainable operation. Low-to-medium resolution images are openly available under CC0, while ultra-high-definition data and raw 3D models require application approval. This balances open sharing with intellectual property protection and revenue generation, modeling public goods supply in digital cultural heritage.

Digital Dunhuang's open, multi-stakeholder collaboration, involving government, academia, business, and international organizations, optimizes resource allocation. Integrating diverse expertise, it advances technology, establishes research platforms, and digitizes cultural heritage, enhancing global impact and public engagement.

In education and dissemination, "Digital Dunhuang" employs contextualised learning design and interactive communication strategies to transform cultural heritage education from passive reception to active engagement. Through gamified applications such as VR/AR, panoramic navigation, and the "Cloud Tour of Dunhuang," it reconstructs historical and artistic contexts, encouraging learners to transition from passive absorption to active exploration. The public can participate in cultural preservation through online lectures and the Digital Patron Programme, strengthening cultural heritage education's social penetration and modern transformation.

3.4. Implications for similar initiatives

The Digital Dunhuang project offers multifaceted insights for comparable international initiatives in cultural heritage digitisation and public education resource accessibility. Firstly, digitisation strategies should prioritise integrating high-precision acquisition with intelligent processing technologies. Non-contact, high-fidelity digitisation methods establish permanent digital archives for artefacts, laying foundations for subsequent research, education, and applications. Secondly, its "tiered access" model can be emulated regarding resource access mechanisms: fully open low-to-medium resolution resources while managing high-precision core data through an application-based usage system, thereby balancing public benefit with project sustainability.

A multi-stakeholder mechanism involving government, industry, academia, research, and application is recommended for collaborative ecosystems. This includes engaging technology firms for technical support, collaborating with universities for joint research and talent development, and expanding international cooperation for resource integration and efficiency. Additionally, VR/AR

and gamified programs should be utilized to enhance educational dissemination and public engagement through immersive, interactive learning. This will encourage users to transition from passive recipients to active explorers, strengthening cultural identity and fostering awareness of social preservation. Overall, the success of "Digital Dunhuang" demonstrates that cultural heritage digitisation projects require systematic coordination across multiple dimensions—technology, institutional frameworks, collaboration, and education—to establish an open, sustainable digital ecosystem. This approach ensures the permanent preservation of cultural resources, facilitates efficient research, and delivers social benefits to all.

4. Conclusion

Taking the "Digital Dunhuang" project as a case study, this paper systematically examines digital humanities' enabling mechanisms and implementation pathways within the context of open public educational resources. The research demonstrates that through high-precision digital acquisition and intelligent processing, a tiered resource access mechanism, multi-stakeholder collaborative models, and contextualised educational dissemination strategies, the project has successfully permanently preserved Dunhuang's cultural heritage, global sharing, and educational innovation. This has fostered a sustainable ecosystem where technology, resources, collaboration, and education are organically interconnected. This study has limitations: its single case study design impacts generalizability, requiring further validation. Reliance on public data limits insights from frontline operations and user feedback. The international comparison lacks depth, failing to thoroughly contrast domestic and international projects.

Future research may explore the following avenues: first, conducting comparative multi-case studies incorporating other domestic and international cultural heritage digitisation projects to distil more universal practical paradigms and second, introducing user research and learning analytics methodologies to evaluate the impact and user experience of open educational resources.

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