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URBAN LANDSCAPE AND DIGITAL PRESERVATION OF HERITAGE SITES: A CASE STUDY OF THE ANCIENT CITY OF SHANDAN IN GANSU, CHINA

Purpose *of the study is to explore the application of digital technology in the preservation and restoration of ancient urban landscapes and heritage sites, with a specific focus on the Ancient City of Shandan in Gansu, China.*

Methodology. *A review of relevant literature on digital preservation, the historical context of the ancient city of Shandan and the implementation of digital technologies such as 3D scanning, modelling and virtual reality. The methodology covers the detailed process of scanning and modelling key sites within Shandan, as well as assessing the outcomes of these digital preservation efforts through public VR experiences and educational applications.*

Results. *The historical significance of the ancient city of Shandan and its strategic importance along the ancient Silk Road is highlighted. The use of digital technology has enabled the accurate preservation and reconstruction of key architectural elements and the cityscape. High-resolution aerial photography and photogrammetry were used to create detailed 3D models of the site, facilitating virtual tours, educational programs, and potential digital restoration of damaged structures. Pilot public VR experiences demonstrated the effectiveness of these models in enhancing public understanding and appreciation of Shandan's cultural heritage.*

Scientific novelty *lies in bringing the innovative application of digital technology to the conservation and restoration of the ancient city of Shandan. High-resolution data acquisition methods such as drone aerial photography and laser scanning were combined with advanced 3D modelling techniques to generate accurate and detailed digital images of the site. A comprehensive digital conservation approach is provided by accurately capturing the historical and architectural features of the ancient city of Shandan, including texture mapping to restore original materials and colours.*

Practical significance *of this study lies in its demonstration of how digital technologies, such as 3D scanning, modeling, and virtual reality, can be effectively used to preserve and restore ancient urban landscapes. It provides a model for protecting cultural heritage and offers innovative methods to enhance public education and engagement with historical sites.*

Keywords: *digital preservation, environmental design, urban landscape, cultural heritage, 3D modeling, virtual reality, Chinese architecture.*

Introduction. The Ancient City of Shandan, a crucial post along the ancient Silk Road, is located in the strategic Gansu Corridor in Shandan County, Gansu Province, China. This millennia-old city holds a significant geographical position, controlling the vital passage between Gansu and other regions and acting as a critical juncture from the Central Plains to the Western Regions. The city has a rich human civilization and deep cultural heritage, including government offices, military camps, residential houses, and shops, marking its notable political, military, and cultural status in history. The Shandan Pass, found within Shandan County, Gansu Province, is an important strategic point on the Silk Road. Known for its impregnable location, the pass has been a military stronghold since the Han Dynasty and was further fortified during the Ming and Qing Dynasties with garrison camps and defenses. The historical and cultural significance of Shandan Pass, along with its associated ancient city, beacon towers, wells, and other relics, represents the extensive historical defensive system of the region. Shandan Ancient City is a popular destination

for tourists exploring the Silk Road due to its historical Han and Ming Great Wall sections, often referred to as China's "open-air Great Wall museum", attracting visitors with its unique historical value and artistic charm.

Degradation / Damage of the Site Constructed in the second year of the Wanli era of the Ming Dynasty (1574 AD), Shandan Ancient City covers an area of 190,000 square meters. Its walls, constructed from rammed earth with an outer layer of bricks and a stone foundation, represent a composite structure of bricks, stones, and timber. The city's robust gate towers, reinforced with iron filling in the brickwork, were once considered impregnable, earning the moniker "Iron City". Facilities within the city, including ancient government offices, temples, shops, and barracks, have been eroded by the elements over centuries and no longer exist.

Analysis of previous studies. Potential of Digital Technology in Preservation Presently, research in China encompasses various aspects focusing on the protection, inheritance, and utilization of cultural heritage. Government and cultural institutions are refining policies on intangible heritage conservation, and scholars are conducting in-depth studies on historical evolution, classification, current state of inheritance, and protective measures [4; 5]. The initiatives of non-governmental organizations and community residents towards self-protection and heritage promotion are gaining attention, with the application of digital technology becoming increasingly widespread in this domain [7]. In the current research environment, there are vibrant examples: for instance, governmental and cultural institutions across the country are employing photogrammetry to digitally preserve significant cultural sites [17]. In Shandan Ancient City, high-resolution aerial photographs taken by drones are being used to model and preserve the site's original appearance. This technology not only helps in preserving history but also provides interactive virtual experiences that bring people closer to ancient culture. Another example is the dissemination of digital preservation achievements. Banpo Village has digitally preserved traditional buildings using photogrammetric technology and shared these virtual models with visitors, allowing them to experience historical changes through virtual reality and promoting village tourism [16]. However, under the theme of "Digital Preservation of Shandan Ancient City Site", previous research in China requires more in-depth exploration. Focusing on digital preservation, how to better apply digital technology to heritage sites and resolve potential practical application issues are challenges to be addressed. Additionally, effective dissemination and sharing of digital preservation outcomes and balancing the essence of intangible cultural heritage during the digital preservation process are pressing matters [8; 9]. Therefore, research on "Digital Preservation of Shandan Ancient City Site" will concentrate on innovative technological applications, practical problem-solving, and cultural value inheritance, aiming to provide a more comprehensive theoretical and practical operation guide for the digital preservation of the Shandan Ancient City site [11].

Significant advancements have been made internationally in the digital preservation of ancient city sites. Agencies and universities worldwide have initiated research projects in this field [18; 20]. For instance, the U.S. National Park Service employs high-precision photogrammetry to digitally model ancient sites within national parks for long-term conservation and public education [21]. French National Institute for Preventive Archaeological Research focuses on digital preservation of ancient sites through laser scanning and photogrammetry, creating high-accuracy digital models for the protection and study of historical value. The Italian Cultural Heritage Preservation Agency utilizes a combination of technologies, including laser scanning, photogrammetry, and virtual reality to digitally reconstruct ancient sites,

safeguarding cultural heritage and promoting tourism [6]. Korean Cultural Heritage Research Institute refines digital reconstruction of ancient sites using photo modeling and explores VR applications for immersive cultural experiences. Japan's Center for Cultural Heritage Digitization is dedicated to developing high-accuracy digitization techniques for the preservation and research of ancient sites, using digital models to reconstruct ancient architecture for insights into historical buildingtechniques. These case studies focus on utilizing technologies such as laser scanning and photogrammetry for high-precision 3D modeling, restoration, and preservation of ancient city sites, applying digital outcomes to cultural heritage and tourism experiences [1; 22].

Domestically, although some progress has been made in related research, there are still various deficiencies overall. For instance, existing studies are scattered, lacking systematic and in-depth discussion; the practical application of digital technology and problem-solving needs strengthening; and further exploration is required in preserving cultural connotations and disseminating results [15]. Therefore, taking the ancient city of Shandan as a case, a systematic study of its digital preservation technology routes, practical applications, and cultural value inheritance could effectively fill domestic research gaps.

Objectives. This paper explores the application and impact of digital technology in preserving and restoring the Ancient City of Shandan in Gansu, China. It aims to assess the historical significance and current state of Shandan, investigate the use of 3D scanning, modeling, and virtual reality in capturing and preserving heritage details, and develop a digital preservation strategy for key sites. The study documents methodologies including data collection, modeling, and virtual reconstruction, and evaluates the effectiveness of interactive 3D models and virtual tours in enhancing public understanding and appreciation of Shandan's heritage. Through in-depth theoretical and practical exploration, this study is expected to provide more comprehensive and innovative theoretical guidance and technological routes for the digital preservation of the ancient city of Shandan and other domestic sites.

Research results. The research will concentrate on applying photogrammetry to the preservation of the Shandan Ancient City site in Gansu (Fig. 1). This involves studying how to capture accurate site data with high-resolution photographs and transforming it into digital models [15]. The advantages of this technology in cultural heritage conservation need to be highlighted, such as reducing physical site disturbance and preserving the true historical appearance. Incorporating the digital reconstruction results with virtual reality technology to create enriched cultural heritage experiences will be explored. This includes applying digital models for virtual exhibitions, virtual tours, and other experiences, allowing for an immersive understanding of the site's history and culture (Fig. 2).

The accuracy of data collection and processing is a cornerstone in the digital preservation of ancient city sites, ensuring that digital replicas accurately reflect the original structures and artifacts. This is achieved through the use of high-resolution imaging and precision instruments like laser scanners that can capture details to millimeter accuracy (Fig. 3).

To validate this data, control points with known positions are established, and reference data from previous surveys is employed for cross-verification (Fig. 4).

In the context of complex archaeological site environments, the focus is on how to capture photographic data from various angles and conduct pre-processing to eliminate variations in lighting, shadows, and distortions, thereby providing accurate data for subsequent modeling (Fig. 7 is an illustration of photo acquisition points).

Fig. 1. Satellite map of the area sourced from Google Maps

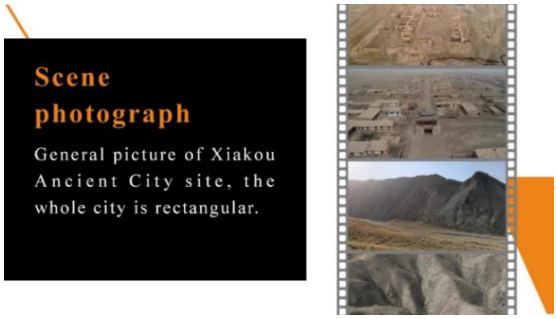

Fig. 2. Site photos

Fig. 3. Data acquisition tool – drone

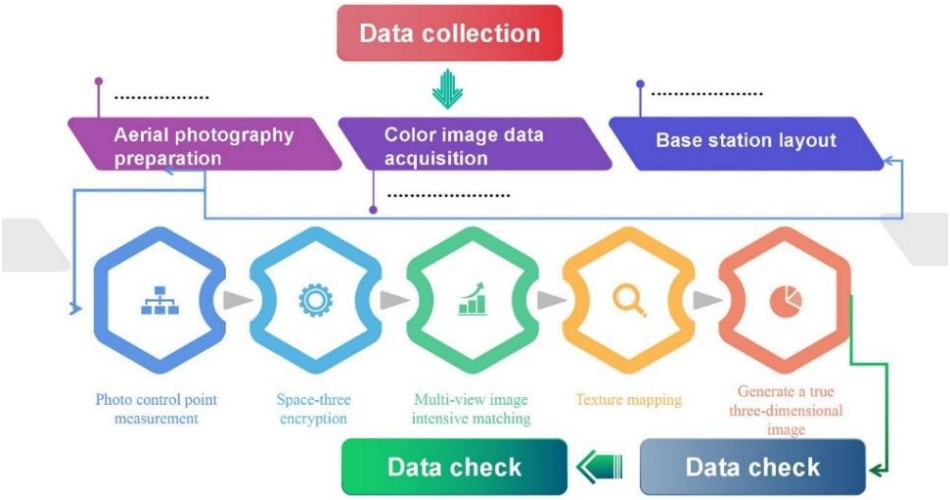

Fig. 4. Overall workflow diagram

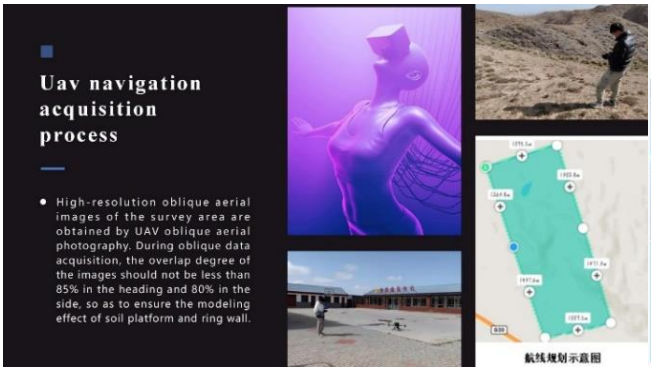

Fig. 5. Arrangement and selection of collection points

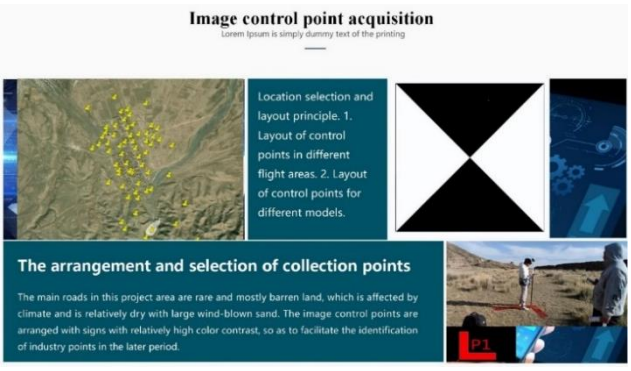

Fig. 6. Drone navigation acquisition process

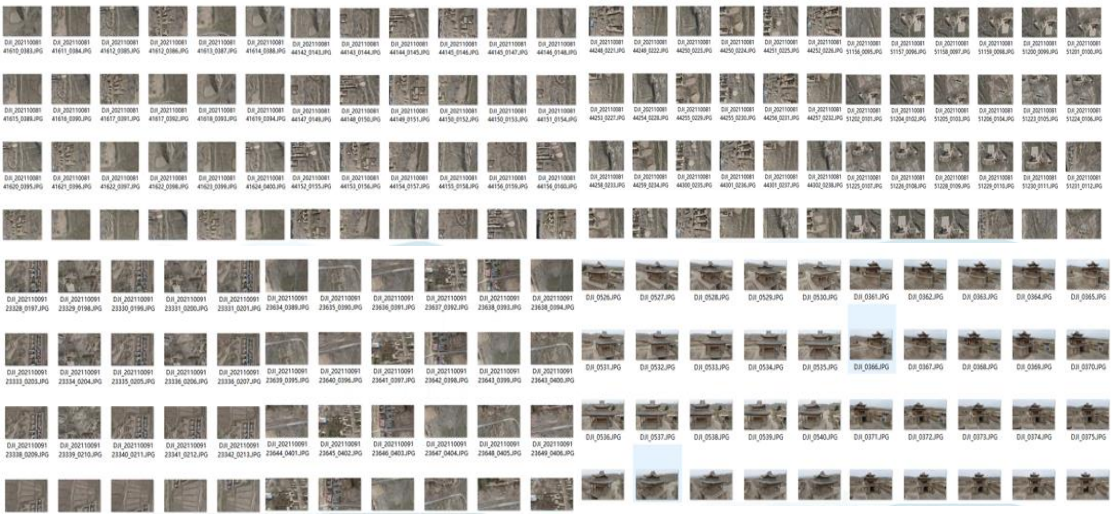

Fig. 7. Image result sampling

a b

Fig. 8. Small-angle circular shooting
a – and dual-layer multi-point shooting; b – captured by the author in Shandan, Gansu

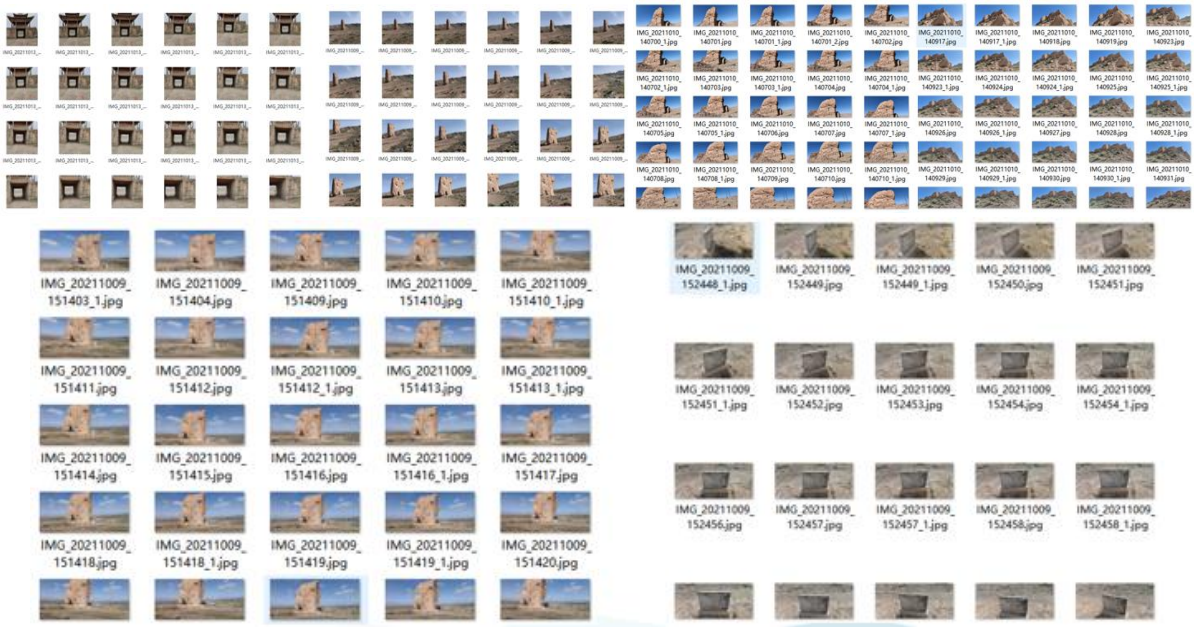

Fig. 9. Camera fill-in photo results

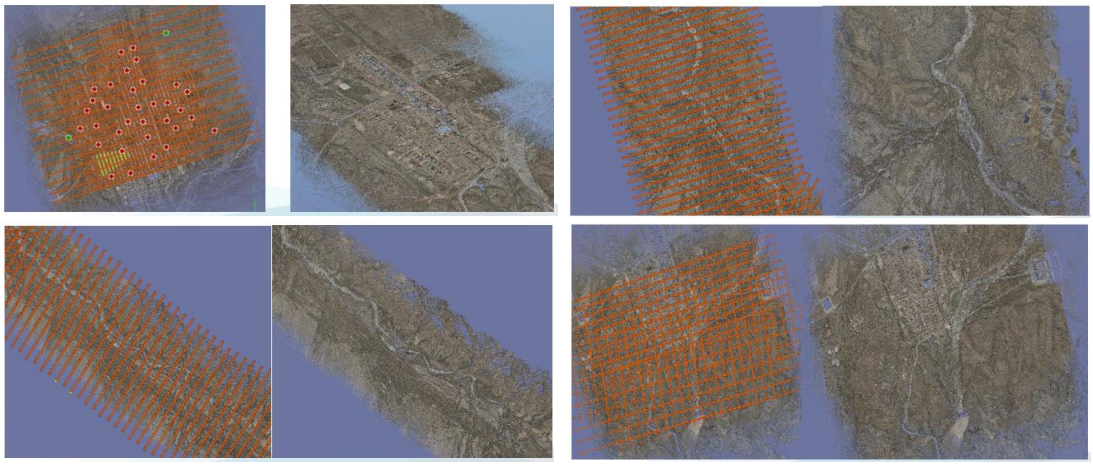

Fig. 10. Air 3 encryption results

Fig. 11. True model reduction captured by the author in Shandan, Gansu, using a drone and processed with Photoshop

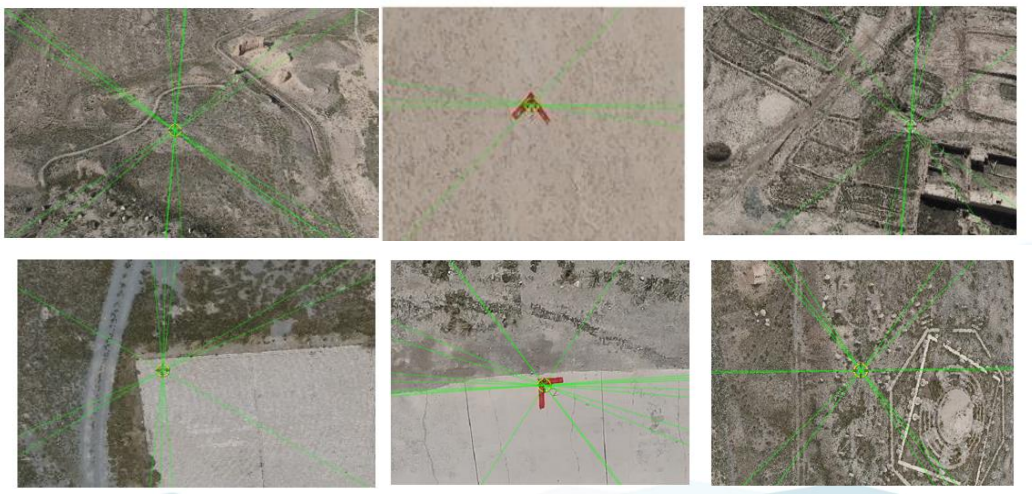

Fig. 12. Image control points measured in Shandan, Gansu, by the author using a drone

a b

Fig. 13. Overall 3D model rendering results
a – Textured rendering front view; b – Textured rendering side view

Image acquisition (camera fill-in) When performing camera fill-in (Fig. 8), use a DSLR camera or mobile phone to shoot photos at a fixed distance around the object, ensuring a minimum of 60% overlap and a maximum angle difference of 15 between consecutive photos. The results are shown in (Fig. 9).

The main focus is on how to construct detailed and accurate digital models using high-resolution photographic data (Fig. 10). This includes extracting 3D point cloud and texture information from the photos, as well as generating high-quality digital models using corresponding algorithms (Fig. 11).

In addition to the geometry of the site, there is also a need to focus on how to map the texture of the captured photographs onto the digital model in order to restore the materials, colors and other features of the site (Fig. 12).

Explore how to achieve a multi-scale display of the digital model, from the whole to the details, allowing users to roam the site freely. Considering the complexity of the site, how to optimize the roaming experience is also one of the focuses of the research (Fig. 13).

This entails the study of methods for the sustainable preservation of digital models, including how to periodically update the models to accommodate changes in the site and advancements in technology. It emphasizes the technical challenges faced in current research, such as data processing and model optimization, while also looking forward to future research directions involving more advanced digitization technologies and more detailed cultural preservation measures.

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Application and Public VR Pilot Study – Educational Use of 3D Models. The detailed 3D models of Shandan ancient city's landscape, architecture, and artifacts offer captivating educational experiences unattainable through 2D imagery or physical site visits. Interactive 3D environments facilitate public understanding and appreciation of Shandan's history and culture.

In the project, a Shandan 3D virtual tour was developed for display in schools and museums [19]. Users can navigate through the ancient city streets, enter temples, and residential buildings, and interact with icons to view reconstructed artifacts and other multimedia content. Information panels provide background on daily life and the site's significance. The design of the experience considered accessibility, it works on desktop and mobile devices and offers options in both Chinese and English languages [13].

To test its educational potential [3], the tour was presented to a middle school class studying ancient Chinese history. Students were able to immerse themselves in Shandan in a way not possible through textbooks. In a survey conducted after the virtual tour, 89% of students reported a better understanding of Shandan's layout and architecture, and 91% expressed increased interest in the history of Gansu province. Additionally, printable 3D models were produced for a museum exhibition on the history of the Silk Road. Visitors could handle precise miniature models of Shandan's gates, watchtowers, beacon towers, the Great Wall, rammed earth walls, and infrastructure. This tangible learning experience attracted a large number of visitors, especially children.

The visually appealing and interactive 3D models proved to be an excellent educational medium. They enabled students and the public to gain a deeper insight into cultural sites like Shandan. The digital preservation process offered a novel platform for exploration and

learning, advancing public education objectives.

Virtual Restoration and Reconstruction. Beyond educational applications, the 3D models of Shandan open new possibilities for the digital restoration and reconstruction of damaged or lost structures. Many relics, walls, and buildings of Shandan city are in ruins. Some significant sites, like the inner city gatehouse, have completely collapsed. Virtual reconstructions can be conducted on these features to understand their original design.

For the inner city gatehouse, the remaining foundations and layout are combined with historical documentation and depictions from artists to create an accurate 3D replica. This digital restoration visually presents the gatehouse's entire five-tiered timber and rammed earth structure, offering insights into its purpose as a checkpoint for managing access to the inner city. Animations can depict the gatehouse's historical timeline from its Ming dynasty construction to its eventual ruin.

Similarly, the damaged sections of the outer city's rammed earth walls and watchtowers are digitally reconstructed based on their current state. Virtual repairs allow for a better understanding of the grand scale and strategic role these fortifications played during 600-900 BCE. Other virtually restored assets include the wooden beam frameworks of temples, whose upper structures have vanished over time.

This digital restoration using 3D models helps reconnect the fragments and lost elements of Shandan's architectural heritage. Visualization of the site's original state provides a more comprehensive understanding of the ancient city's aesthetics, engineering, and functions. Virtual recreations also aid conservation efforts, offering records for potential future physical restorations.

Public VR Experience Results and Feedback. To gauge public interest in the 3D reconstructed model of Shandan, a temporary VR experience zone was set up at the Shandan Museum [10]. Visitors could immerse themselves in the ancient cityscape using VR headsets and hand controllers. The VR experience included a 10-minute virtual tour showcasing key sites such as the inner city gatehouse, temples, residential houses, and market streets.

During the two-week pilot, the VR experience attracted over 300 visitors of varied ages and backgrounds [12]. Feedback on satisfaction, immersion, and knowledge gained was collected through surveys and interviews.

Key findings from the VR pilot study:

82% of users rated the overall experience as "excellent", with a realistic environment that allowed for free exploration.

90% agreed the visual quality was high and the 3D models accurately portrayed Shandan's architecture and layout.

75% felt a strong sense of immersion during the VR tour, especially when navigating streets and entering buildings.

88% learned new information about Shandan from the experience, including a better understanding of its defensive structures and daily life.

Encouraged by the positive VR experience, 62% expressed a desire to visit the actual Shandan site.

During the display in the VR experience area of the Shandan Museum, some visitors showed great interest in the exhibition and provided positive feedback. "The VR tour was amazing! It felt like walking through the ancient city". "The 3D models were incredibly detailed and realistic. I gained a new understanding of Shandan's history". "Exploring the virtual environment showed me a lifelike representation of the site". Meanwhile, some participants offered constructive comments during random interviews: "Initially, it was difficult to master the use of hand controllers". "I wish the VR tour included more historical facts".

Additionally, comments noted that despite some initial operational difficulties,

participants appreciated this novel way of engaging with cultural heritage.

In summary, the public VR demonstration provided an exciting proof-of-concept for digital preservation and educational objectives. The enthusiastic responses from users highlighted the potent role of immersive 3D models for heritage sites like Shandan. The study further demonstrates significant potential for further research and practical application of VR in this field. Beyond the on-site VR experience, the immersive digital experience can be made accessible to a wider public through mobile apps [13], websites, and other channels. For mobile device users, a dedicated Shandan Ancient City AR/VR application can be developed, allowing users to virtually visit the ancient site through their smartphones or tablets. The app can offer free-roaming, scene narration, multimedia interactions, and multi-language support to attract domestic and international tourists.

Another approach is to establish a web-based virtual tourism platform, where users can experience the 3D scene visualization system embedded in the web page without installing dedicated software. The platform can also integrate social networking, guided tours, e-commerce, and other features to provide the public with a richer online experience.

This multi-channel coverage facilitates widespread promotion and utilization of the digitized ancient city site. The public can choose a suitable experience mode according to their conditions, thereby increasing public participation and enhancing the social impact of cultural heritage protection. Through diversified public experience channels, digital technology not only presents the heritage itself but also serves as a powerful educational and communication platform, allowing more people to conveniently understand and personally experience the unique charm of the Shandan Ancient City [21.52].

Digital preservation technology presents numerous advantages and limitations. Firstly, it can create highly accurate digital records, effectively safeguarding sites and artifacts from further damage or loss. Secondly, it facilitates convenient access and understanding of sites beyond physical visits through remote or virtual interactive exploration. Furthermore, it allows virtual restoration using historical data, enabling students and the public to engage with cultural heritage through compelling educational media. It also can model and visualize the complex multi-phased construction history of sites, providing data to support future physical restorations.

However, there are limitations to digital preservation technology. Initial investments in 3D scanning and computing hardware / software can be substantial. Detailed processing and modeling of large sites require significant time and human resources. In virtual restoration, a balance between authenticity and speculative reconstructions must be maintained. Moreover, the application of digital preservation does not replace traditional physical conservation efforts. Public use of virtual reality technology is still constrained by equipment costs and availability. The ongoing evolution of digital technologies and file formats also poses preservation risks. Lastly, further research into pedagogical design principles for educational virtual reality technology is necessary.

In conclusion, this study suggests that digital preservation technology should serve as a complement, not a replacement, to the conservation of tangible heritage sites and artifacts. Only with the proper application of these emerging technologies can conservation efforts be enhanced while strengthening people's connection to heritage sites.

Conclusions. This paper explores the transformative potential of digital conservation technologies, such as 3D scanning, modeling, and virtual reality, in the preservation and understanding of ancient sites like Shandan. By generating detailed digital records, these technologies protect vulnerable sites and artifacts, while interactive 3D models and

virtual experiences facilitate remote exploration and enrich educational media. Despite the advantages, challenges such as high costs and significant human resource requirements persist, highlighting the necessity of complementing, rather than replacing, traditional physical conservation efforts. Continuous innovation and research are essential in refining educational VR design and ensuring reconstruction authenticity.

The project reveals viable pathways for expanding research and practice in digital preservation. Future priorities include virtual modeling of more of Shandan city, developing educational applications and games, experimenting with AR and multi-user VR, studying the impact of VR on learning, and 3D printing replicas. Additionally, opportunities exist to advance automated computer vision, contribute 3D data to repositories, establish best practices, and engage in international collaboration. Cooperation among heritage institutions, technology experts, and educators will drive future advancements.

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МІСЬКИЙ ЛАНДШАФТ ТА ЦИФРОВЕ ЗБЕРЕЖЕННЯ ПАМ'ЯТОК: НА ПРИКЛАДІ СТАРОДАВНЬОГО МІСТА ШАНЬДАН У ПРОВІНЦІЇ ГАНСУ, КИТАЙ

Мета: *дослідити застосування цифрових технологій у збереженні та реставрації стародавніх міських ландшафтів та пам'яток, з особливим акцентом на стародавнє місто Шаньдан у провінції Ганьсу, Китай.*

Методологія. *Огляд відповідної літератури про цифрове збереження, історичний контекст стародавнього міста Шаньдань та впровадження цифрових технологій, таких як 3D-сканування, моделювання та віртуальна реальність. Методологія охоплює детальний процес сканування та моделювання ключових об'єктів у Шандані, а також оцінку результатів цих зусиль зі збереження цифрової спадщини через публічні VR-дослідження та освітні програми.*

Результати. *Висвітлено історичне значення стародавнього міста Шаньдань та його стратегічне значення вздовж стародавнього Шовкового шляху. Використання цифрових технологій дозволило точно зберегти та реконструювати ключові архітектурні елементи та міський ландшафт. Аерофотозйомка з високою роздільною здатністю і фотограмметрія були використані для створення детальних 3D-моделей об'єкта, що полегшує проведення віртуальних турів, освітніх програм і потенційну цифрову реставрацію пошкоджених споруд. Пілотний досвід публічного використання віртуальної реальності продемонстрував ефективність цих моделей у покращенні розуміння та сприйняття культурної спадщини Шандану громадськістю.*

Наукова новизна *інноваційне застосування цифрових технологій для збереження та реставрації стародавнього міста Шаньдань. Методи збору даних з високою роздільною здатністю, такі як аерофотозйомка з дрону і лазерне сканування, були поєднані з передовими методами 3D-моделювання для створення точних і детальних цифрових зображень об'єкту. Комплексний підхід до цифрової консервації забезпечується шляхом точної фіксації історичних та архітектурних особливостей стародавнього міста Шаньдань, включаючи текстурне мапування для відновлення оригінальних матеріалів і кольорів.*

Практична значущість *цього дослідження полягає в демонстрації того, як цифрові технології, такі як 3D-сканування, моделювання та віртуальна реальність, можуть ефективно використовуватися для збереження та відновлення давніх міських ландшафтів. Дослідження показує модель захисту культурної спадщини та пропонує інноваційні методи для покращення освіти та залучення громадськості до історичних пам'яток.*

Ключові слова: *цифрове збереження, дизайн середовища, міський ландшафт, культурна спадщина, 3D-моделювання, віртуальна реальність, архітектура Китаю.*

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