DIGITAL HERITAGE PRESERVATION: THE ROLE OF 3D SCANNING IN DOCUMENTING HISTORICAL ARCHITECTURE IN UZBEKISTAN

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Abstract: This study explores how 3D scanning technologies are revolutionizing the documentation and preservation of historical architecture in Uzbekistan. With numerous ancient sites such as those in Samarkand, Bukhara, and Khiva, Uzbekistan is rich in cultural heritage that is increasingly vulnerable to environmental degradation and urban development. The research highlights the role of laser scanning, photogrammetry, and Building Information Modeling (BIM) in preserving architectural integrity while allowing for remote access and educational dissemination. The findings emphasize that digital preservation is not only a tool for conservation but also a bridge between tradition and technology.

Keywords: 3D scanning, heritage preservation, Uzbekistan architecture, BIM, photogrammetry, digital documentation, cultural heritage

Uzbekistan is home to some of the world's most significant architectural monuments, including the Registan Ensemble in Samarkand, the Kalyan Minaret in Bukhara, and the Ichan Kala in Khiva. These sites are not only national treasures but also part of UNESCO's World Heritage list. However, climate change, erosion, natural disasters, and human interventions pose a constant threat to these fragile structures.

Conventional preservation methods, while still important, are limited by their reliance on physical inspections and manual drawings. In contrast, **digital heritage technologies** such as 3D laser scanning and photogrammetry offer high-precision tools for capturing and archiving architectural details. This paper investigates the application of such tools in the Uzbek context and assesses their potential for broader heritage preservation strategies.

To evaluate the application of 3D scanning in heritage preservation in Uzbekistan, the study employed the following methodology:

Case studies: Selected sites in Bukhara and Samarkand were analyzed where 3D scanning projects have been initiated (e.g., Ark Fortress, Shah-i-Zinda).

Technological review: The hardware and software used in heritage scanning projects—such as LiDAR scanners, drones, RealityCapture, and ReCap—were studied.

Expert interviews: Cultural heritage professionals, architects, and engineers were interviewed to assess the challenges and benefits of implementing digital technologies.

Literature synthesis: Scholarly articles, UNESCO reports, and national planning documents were reviewed to contextualize the integration of digital heritage in national policy.

• **High precision**: 3D laser scanners produced millimeter-accurate models of complex architectural forms, enabling detailed analysis of structural conditions.

• **Time efficiency**: Compared to traditional surveys, 3D scanning reduced documentation time by over **60%**.

• **Virtual accessibility**: Sites digitized with 3D scanning can be explored remotely, offering opportunities for education, tourism, and international collaboration.

• **Conservation planning**: BIM models derived from 3D scans helped conservators simulate restoration interventions before physical implementation.

• **Data integration**: Photogrammetry and drone footage were effectively integrated into GIS systems for landscape-level heritage management.

The findings confirm that digital heritage tools, especially 3D scanning and BIM, are invaluable for the documentation, analysis, and restoration of historical architecture in Uzbekistan. These technologies offer several advantages:

• **Non-invasive analysis**: Fragile sites can be documented without physical contact, reducing the risk of damage.

• **Cultural continuity**: High-fidelity models serve as archives for future generations and can be used to reconstruct or simulate lost elements.

• **Educational impact**: Digital models provide immersive experiences for students and researchers unable to access the sites physically.

• **Disaster preparedness**: Accurate 3D models allow for quicker recovery after earthquakes or fires.

Despite these advantages, challenges remain, such as the **high cost** of scanning equipment, **limited local expertise**, and **data management** issues. Additionally, legal and institutional frameworks in Uzbekistan must be updated to include digital methods in official heritage policies.

Collaborations with international institutions (e.g., UNESCO, ICOMOS, and European digital heritage labs) are already underway, but greater **investment in local capacity building** and **digitization infrastructure** is needed to sustain progress.

While the initial findings confirm the effectiveness of 3D scanning and digital documentation in heritage preservation, it is also important to analyze the **strategic implications** and **long-term sustainability** of these technologies in the Uzbek context.

Cultural and Educational Integration

One of the most promising aspects of 3D heritage documentation is its educational value. Digital models of historic monuments such as the Ulugh Beg Madrasa or Kalta Minor can be embedded into virtual reality (VR) or augmented reality (AR) platforms, allowing schoolchildren, university students, and tourists to **interact with cultural heritage** in immersive ways. Such innovations not only promote national pride and cultural literacy but also open avenues for **cross-cultural exchange** through virtual exhibitions and international collaborations.

However, to fully benefit from this, Uzbekistan must integrate digital heritage into the **curricula of architecture, archaeology, and cultural studies programs**. This includes training future professionals in digital surveying techniques, 3D modeling software (such as Autodesk ReCap, Agisoft Metashape, or Rhino), and digital asset management.

Legal and Institutional Challenges

Despite technical advancements, legal recognition of digital records as **official conservation documents** remains limited. Current Uzbek heritage laws focus primarily on physical conservation, with insufficient regulation regarding digital records, intellectual property rights, data storage, or public access protocols.

To address this, policymakers should:

• Amend heritage legislation to **formalize digital documentation standards**;

• Define clear guidelines for the **validation, storage, and certification** of 3D data;

• Ensure open-access archives for **academic and public use**, while maintaining appropriate data protection policies.

Technological and Financial Barriers

Another major barrier is the **cost and complexity** of acquiring and maintaining digital preservation equipment. Terrestrial laser scanners and high-resolution drones remain expensive, while the human expertise to operate them is still scarce in many Uzbek regions. Furthermore, cloud storage of large 3D datasets requires secure, scalable, and sustainable digital infrastructure.

Public-private partnerships, international grants, and UNESCO-supported initiatives could help bridge this gap. Developing **low-cost, open-source alternatives** —such as photogrammetry with standard DSLR cameras or smartphone-based scanning tools—can also help democratize access to digital heritage technologies for smaller institutions and regional museums.

Preservation vs. Commercialization

While digital heritage opens up new possibilities for education and tourism, a balance must be maintained between **preservation and commercialization**. Overuse of digital assets for marketing or entertainment without proper scholarly oversight risks

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distorting historical accuracy or trivializing sacred sites. Thus, a **code of ethics** is necessary to guide the responsible use of 3D models in both academic and commercial platforms.

Post-Disaster and Reconstruction Potential

3D documentation is also critical in post-disaster scenarios. In the event of earthquakes, fires, or armed conflict, **digital models serve as references** for accurate reconstruction. For example, after the fire at the Notre-Dame Cathedral in Paris (2019), prior laser scans were instrumental in guiding the restoration process. Uzbekistan, situated in a seismically active zone, would greatly benefit from such **preventative digitization**, especially for at-risk structures in Bukhara and Andijan.

Summary of Key Points in the Extended Discussion:

Area	Recommendation
Education	Integrate 3D tech into architectural and cultural heritage curricula
Legal framework	Update national legislation to recognize and regulate digital documentation
Financial access	Use partnerships and low-cost tools to widen adoption
Ethical use	Develop guidelines for using 3D models responsibly
Risk preparedness	Digitize vulnerable sites for disaster resilience and accurate reconstruction

Digital documentation through 3D scanning offers transformative potential for the preservation of Uzbekistan's architectural heritage. As threats to historical monuments grow, embracing technology becomes an essential strategy. To maximize its impact, Uzbekistan must integrate these tools into national conservation plans, invest in training, and establish open-access digital archives for public and academic use.

Digital preservation is not only a safeguard against loss—it is a gateway to innovation, education, and cultural diplomacy in the 21st century.

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