Digital Reconstruction of Architectural Heritage through Virtual Reality: The Samarkand Aksaray Monument Case Study

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Abstract: The use of digital technologies for the digitisation and virtual reconstruction of architectural heritage has gained global relevance. This paper presents the initial stage of a scientific and practical study aimed at digitally reconstructing the 15th century Aksaray Palace in Samarkand, Uzbekistan, and creating a virtual tour using virtual reality (VR) tools. The research analyses the preliminary results obtained in the field of cultural heritage. Taking a multidisciplinary approach, the project uses 3D scanning and VR technologies to propose innovative and sustainable methods of preserving architectural heritage by digitising the monument and developing a reconstruction concept. The project's primary objective is to disseminate knowledge about the palace to a wider audience, integrating interdisciplinary perspectives from architecture, art, information technology, history and archaeology. The project was implemented in several stages. First, laser scanning was conducted to collect measurements, which were then processed to create a 3D model and virtual representation of Aksaray, reflecting its current state as well as the original decorative features of its interior. Based on historical, archival, and geometric analyses of ornaments, decorations, colours, and compositions, a step-by-step reconstruction model was prepared simultaneously.

1 INTRODUCTION

Virtual Reality (VR) technology first emerged in the 1950s, with its initial experimental applications gradually evolving into what is now known as “Immersive Virtual Reality” (IVR) [1]. Since then, IVR technology has advanced significantly, becoming a highly relevant field for contemporary society. In its early stages, VR technology was confined largely to military and scientific research activities. But over time, new uses for VR have appeared. For example, it is now used in education and training [4], as well as to make cultural heritage more popular [5].

VR is an interactive, evolving technology that provides a fully immersive experience by representing digitally created environments or objects in real time within Reality [6]. Today, VR technologies have become more sophisticated and compact, enabling effective implementation in tourism and at cultural heritage sites via smart devices. Technologies that integrate digital content into real environments are considered a vital part of Industry 4.0. Globally, research is increasingly focusing on preserving architectural monuments, ensuring their sustainability and promoting their efficient use [9]. Additionally, practical measures are being taken in urban planning, architecture and construction to address urgent challenges, improve education and research, promote innovative construction development and ensure the intentional preservation and utilization of architectural heritage [10].

In this regard, protecting medieval architectural monuments, enhancing their effective use and improving accessibility are critical tasks of our time [11]. This study focuses on the 15th century Aksaray Palace in Central Asia, which is an essential part of Uzbekistan's National Heritage and an integral component of the world's shared cultural heritage [12]. This research is dedicated to reconstructing the decorative elements of the Aksaray's interior. According to historical sources, the interior of the Aksaray was adorned with gilded kundal patterns blending shades of turquoise, violet, blue and pistachio in the 15th century, creating a unique brilliance [13]. Niches, muqarnas, shelves and their intricate ornamental decorations were designed in harmony with each architectural element.

Today, much of this decorative heritage, including patterns, colors, and interior ornamentation, has been lost [14]. Therefore, preserving and reconstructing such monuments remains an urgent and significant task in the 21st century [15]. Advanced documentation and reconstruction methods such as 3D laser scanning, digital modelling and VR technologies play a vital role in cultural heritage research. These methods help to prevent restoration errors, accelerate reconstruction processes, and make it possible to create immersive simulations that accurately reflect the material and spatial environment of the monument. Such simulations allow users to virtually explore and experience the architectural atmosphere of the past [16].

This study aims to investigate the possibilities of preserving, studying scientifically, and showcasing architectural heritage by digitally documenting the Aksaray complex, developing a scientifically grounded reconstruction model, and presenting it in a VR environment. By combining historical analysis with advanced visualization technologies, the project will establish a methodological framework for preserving and experimentally interpreting Central Asian architectural heritage [17].

2 DIGITIZATION OF CULTURAL HERITAGE

Over the past few decades, the processes of documenting and virtually reconstructing architectural heritage in the digital sphere have advanced rapidly [18]-[21]. Numerous scientific studies and practical projects have demonstrated the significant advantages of using VR technologies to preserve, interpret and disseminate cultural monuments to the public [18]-[20]. Experimental initiatives in this field have contributed to the development of innovative ICT-based solutions, encompassing a broad spectrum of tools - from mixed reality (MR) applications to fully immersive VR experiences [21].

Several international projects have developed precise methodologies for laser scanning and photogrammetric surveying of monuments, as well as for generating highly accurate 3D models based on the acquired data [15], [22]. These approaches have been successfully used to document archaeological sites, historical monuments, museum artefacts and large-scale urban ensembles, to assess their technical condition, and to support virtual reconstruction and public dissemination. At the same time, several conceptual studies on digital heritage emphasize the need to link such technologies with sustainable development objectives and long-term preservation strategies [8], [9], [18].

In this broader context, the Samarkand Aksaray monument is a distinctive and relevant case study for investigating how 3D documentation and VR technologies can be used for the partially preserved architectural heritage of the period of the Timurids - both as a tool for scholarly research and as a medium for restoration, interpretation and public communication.

2.1 Case Study: The 15th Century Samarkand Aksaray Monument

This section presents the case study of the Samarkand Aksaray monument and outlines its historical development, architectural significance, and state of preservation. The case study provides the scientific basis for the digital reconstruction process described in the subsequent sections. To ensure a more consistent structure, the historical background - previously embedded within the case study - is now reorganized and summarized in Section 2.2.

Two prominent monuments bearing the name Aksaray (“White Palace”) are known from the Timurid architectural tradition: the monumental Aksaray in Shahrisabz and the smaller, more refined structure in Samarkand. The latter, located southeast of the Gur-i Amir complex (Fig. 1), preserves only its lower crypt and portions of its decorative program; yet despite its ruinous state, it remains a key example of late Timurid architectural innovation.

Figure 1: Map of Aksaray and its physical location in Samarkand.

Scholarly opinions diverge regarding the building’s original function. While tradition identifies it as a mausoleum associated with the Timurid dynasty, several researchers argue that the structure initially served as a garden pavilion (kushk) within Muhammad Sultan's chaharbagh, and that an iwan added in 1464 marked its transformation into a mausoleum. Across these interpretations, scholars broadly agree that the Samarkand Aksaray dates to the second half of the 15th century (the period of Abu Sa'id and Sultan Ahmad) [25].

Architecturally, the monument is remarkable for its spacious cruciform hall, soaring arches, and transitional systems employing brick, squinches, and muqarnas. The interior originally reached 20-25 meters in height with a span exceeding 30 meters, demonstrating both engineering mastery and cosmological symbolism. The ornamental program - comprising majolica, carved brick, ganch reliefs, and exceptionally delicate painted panels - evokes themes of sacred authority, cosmic harmony, and dynastic legitimacy.

The underground crypt, consisting of a central vestibule and a series of inclined burial chambers, represents the best-preserved portion of the structure today. Figures 2-7 reference archival drawings and photographs from the mid-20th century; due to the age and inherent quality limitations of these historical materials, some appear in lower resolution.

Figure 2: View of Aksaray [42].

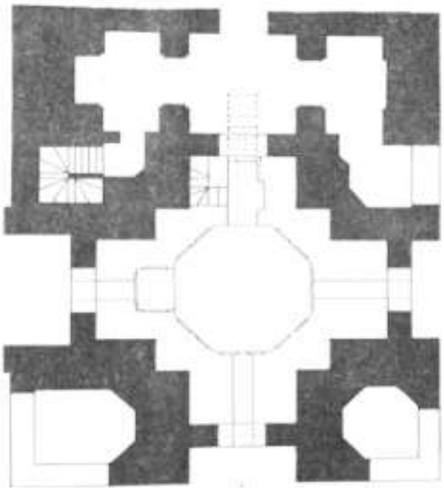

Figure 3: Plan showing the location of the crypt [42].

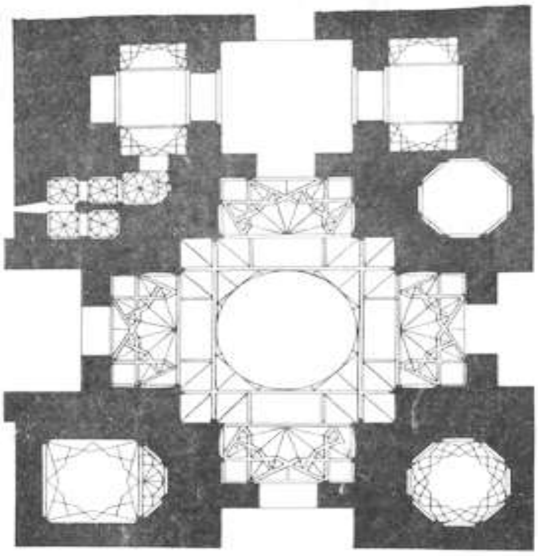

Figure 4: Plan showing the projected roofing system [42].

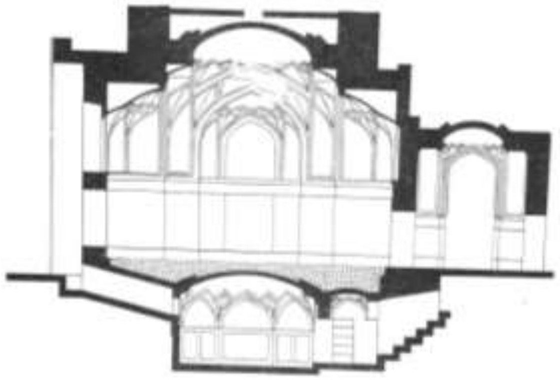

Figure 5: Section view of Aksaray [42].

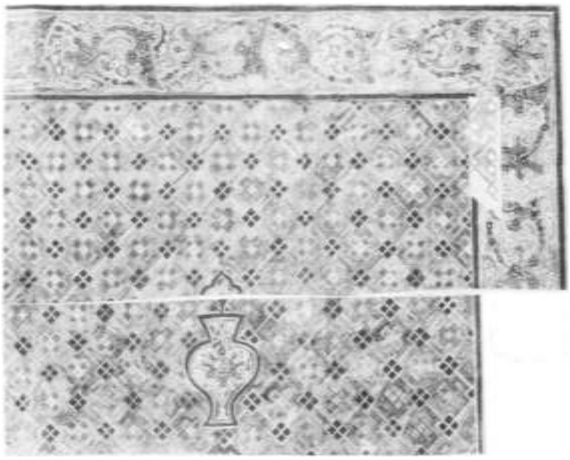

Figure 6: Panel reconstruction by I. K. Mrochkovskii [42].

Figure 7: Aksaray panel remainder.

2.2. Historical Background and Research Legacy

Interest in the Aksaray began in the late 19th century with travelers' accounts, though systematic documentation only emerged in the early 20th century. Between 1924 and 1930, M. E. Masson conducted important archaeological excavations that clarified burial practices associated with the Timurid dynasty [25], [38]. A. A. Semyonov contributed epigraphic documentation, advancing philological analyses of Timurid monuments [39].

In 1936, B. N. Zasypkin carried out additional excavations and restorations, contributing to the scientific preservation of the site [40]. The most comprehensive mid-century research was conducted by G. A. Pugachenkova, whose architectural-archaeological synthesis established a methodological basis for the study of Central Asian architecture [19], [26]. Her analyses of the Aksaray's structural system, decorative program, and architectural planning remain foundational.

Thus, by the mid-20th century, a systematic scientific framework for studying the monument had emerged - yet many historical questions remain unresolved, particularly due to the absence of written sources and the extensive losses suffered by the building.

2.3 Data Collection and Processing

In 2024, laser scanning and research activities were conducted at the Aksaray monument, involving professors, lecturers and master's students from Turin Polytechnic University in Tashkent, as well as the Tashkent University of Architecture and Civil Engineering. The aim of this research was to further scientific inquiry in the fields of architecture, digital documentation and conservation, and to develop an accurate 3D measurement model of the monument (see Fig. 8).

In the first stage, a topographic polygonal network (geodetic network) was established to cover the main components of the monument and its surroundings. This network served as the reference coordinate system for orienting and georeferencing the point cloud (Fig. 9). The laser scanning focused primarily on documenting the interior decorations of Aksaray and the accessible sections of its exterior.

On-site surveying was carried out using a FARO Focus M70 terrestrial laser scanner. This device has a measurement range of up to 70 meters and ensures millimeter-level accuracy under standard conditions. Given the relatively compact dimensions of the interior of the Aksaray, this configuration was sufficient to achieve complete coverage of both structural elements and ornamental details.

Figure 8: Laser scanning and research activities, 2024.

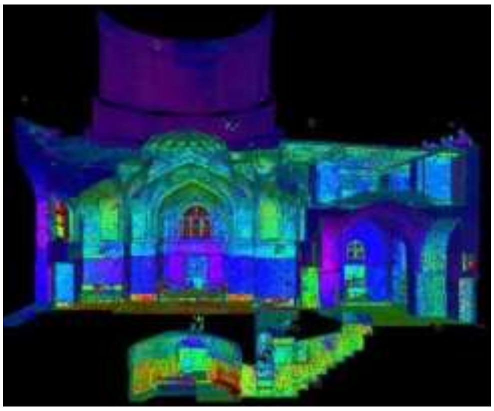

Figure 9: Cloud of point from laser scanning survey.

A total of 48 laser-scanning stations were deployed throughout the site to ensure comprehensive spatial data acquisition. Of these, only six stations were dedicated to documenting the primary interior space, namely the central hall. The station placement strategy was defined as follows: one scanner was positioned beneath each arch, a decision that enabled complete coverage of the upper structural zones and facilitated precise point-cloud registration during subsequent processing.

In addition to these, a supplementary station was installed at the geometric center of the interior, functioning as a principal reference node that ensured the coherent integration of all individual scans. Moreover, an additional station was placed at the entrance to secure continuous geometric linkage with the subterranean spaces of the monument.

The placement of the stations was guided by the following key criteria:

- Maximizing coverage of complex domes, squinches, and muqarnas.
- Minimizing ‘blind zones’ hidden behind columns or deep recesses.
- Ensuring adequate overlap between adjacent scans (typically 35-40%).
- Maintaining visibility of at least three reference targets from each station to guarantee stable registration.

The real conditions of the site presented several challenges. Narrow and elongated staircases required careful adjustment of tripod height and scanner positioning. Limited natural lighting inside the monument, especially in deep recesses and shadowed areas, required the calibration of lighting and reflectivity settings to ensure sufficient signal quality. Additionally, the dense urban fabric and the close proximity of residential buildings restricted the placement of exterior scanning points, resulting in fewer outdoor stations.

Despite these constraints, the surveying process successfully produced a high-density point cloud covering the interior and accessible exterior areas. The raw data were processed in FARO Scene and Autodesk ReCap Pro, where the individual scans were aligned within a unified coordinate system. The resulting point cloud had an average point spacing of a few millimeters on the primary architectural surfaces and comprised several hundred million points in total. The registration error remained sufficiently low, at a few millimeters, which fully corresponds to advanced international practices for cultural heritage documentation [15], [22].

The unified point cloud was then exported from ReCap Pro into other software environments. Based on these data, precise plans of the roof, floor and substructure, as well as several sectional drawings, were produced in AutoCAD (see Fig. 13a-13b). These drawings form the geometric basis for the reconstruction of the architectural configuration of Aksaray.

3 MODELING

3.1 Modeling of Interior of Aksaray

In the studies conducted on the interior of the Aksaray, 3D laser scanning was the main method employed. This process consisted of the following stages:

The Aksaray complex was analyzed on site and the entire monument was scanned using a FARO Focus M70 laser scanner (Fig. 10).

Figure10: The FARO focus M70 laser scanner.

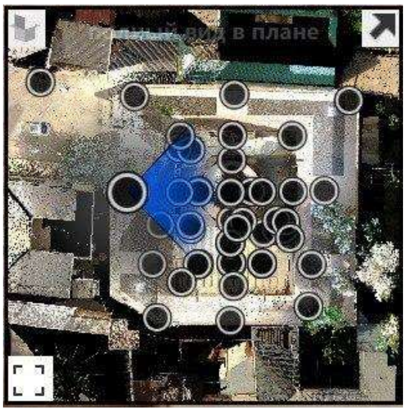

Figure 11: Placement of laser-scanned stations in ReCap software (total: 48)

All data acquired through laser scanning was imported into the Autodesk ReCap Pro platform (see Fig. 11). A three-dimensional (3D) point cloud model of the Aksaray complex was then generated (Fig. 12).

Based on this dataset, accurate plans of the roof, floor and basement, as well as sectional views, were produced using the AutoCAD platform (Figs. 13a–b).

The point cloud was converted into a mesh model in ReCap Pro and subsequently exported to 3ds Max (Fig. 14).

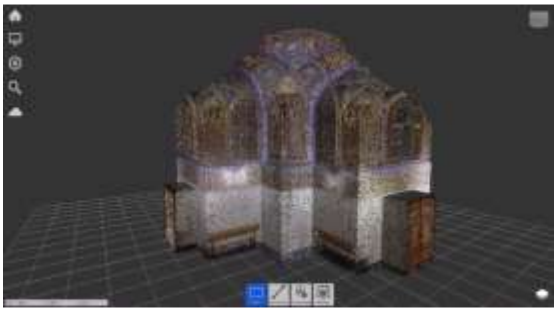

Figure 12: Three-dimensional (3D) point cloud model of the Aksaray.

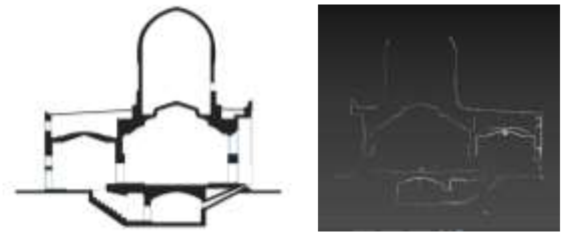

Figure 13: a) Section plan 1 drawn in Auto CAD. b) Section plan1 from ReCap Pro.

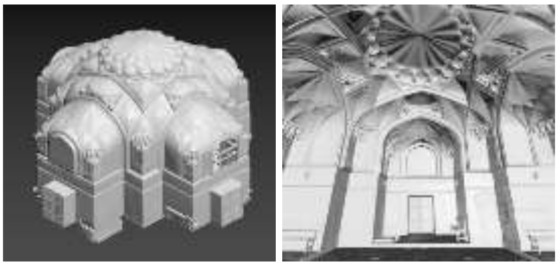

Figure 14: Mesh-converted view of the interior of the Aksaray.

3.2 Reconstruction of the Interior Ornamentation of Aksaray

The texture of the interior panels of Aksaray was reconstructed by combining archival sources, historical photographs and surviving decorative fragments still present on the monument (see Fig. 15).

First, a 3D model reflecting the monument's current state was created. The preserved portions of the polychrome carved panels were then documented using high-resolution photography and compared with the reconstruction drawings prepared by I. K. Mrochekowski and G. A. Pugachenkova [11], [26].

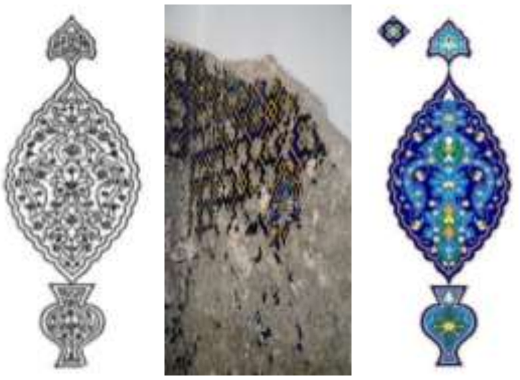

Figure 15: Surviving ornaments on the present panel of the Aksaray interior and the reconstructed.

The color palette was established based on on-site observations and published descriptions of gilded kundal painting techniques, which emphasize the harmonious combination of turquoise, violet, blue and pistachio tones [13], [34]. Sample colors extracted from the surviving paint layers were measured and adapted digitally. In areas where the original decoration had completely disappeared, a hypothetical reconstruction was carried out by comparing it with analogous ornamental programs in contemporary Timurid monuments [11], [13], [31].

The ornamental motifs were reprocessed as vector drawings and converted into repeating texture maps. Particular attention was paid to preserving the proportional relationships and geometric construction rules that are characteristic of Islamic geometric ornamentation [10], [33]. These textures were then applied to the relevant architectural surfaces in the 3ds Max environment, such as the vaults, muqarnas elements and wall panels. This ensured accurate alignment with their slopes and complex geometries.

3.3 Data fusion methodology

The reconstruction process required the integration of multi-source data obtained from various references, including precise geometric data derived from 3D laser scanning, historical architectural drawings, archival photographs and textual descriptions. A data fusion methodology was therefore applied to align these sources and clearly distinguish between measured geometry, interpretation-based forms and conditionally reconstructed elements.

During the reconstruction of the Aksaray interior panels, both historical materials and laser-scanning data were used in a complementary manner. Although much of the original wall decoration has not survived, several preserved fragments allowed the identification of the color palette and ornamental patterns. Based on these fragments, the colors were selected, and the composition was reinterpreted using historical panel drawings and archival sketches. The 2D panel representation was created in AutoCAD, where precise proportions and overall geometry were defined. Subsequently, colors derived from authentic historical sources were applied to the panel, ensuring stylistic consistency with the monument’s original aesthetic.

The point cloud containing accurate measurements of the monument's current state was adopted as the primary geometric reference. The plans, sections and elevations that had been prepared by Pugachenkova and other scholars [11], [26], [37], [40] were then digitized and aligned to the same coordinate system. The analysis and documentation of geometric inconsistencies resulting from structural damage, later construction interventions, or stylistic differences in graphic representation was conducted separately.

Ornamental reconstruction drawings and early photographs published in the mid-twentieth century were used to restore decorative zones that are now preserved only in fragmentary form. In such cases, geometric construction methods described in studies of Islamic ornamentation were employed to ensure that the missing segments were modelled without violating proportional coherence or the overall compositional order.

In the subsequent stage, the consolidated point cloud was exported in .e57 format for 3D model generation, resulting in a total file size of 7.51 GB. For point-cloud processing, model refinement, and visual reconstruction, Agisoft Metashape was selected as the primary software. Using Metashape, a complete 3D mesh model was generated from the point cloud, and a high-resolution texture was produced to enhance the visual and geometric accuracy of the model.

In the modelling environment, separate layers and material identifiers were assigned to differentiate between elements with varying degrees of certainty: Specifically, these were categorized as follows:

- Existing fabric: components directly recorded through laser scanning.
- Analytically restored elements: deformed or damaged fragments that were ‘corrected’ based on architectural reasoning.
- Proposed reconstruction elements: modelled components derived from historical analogies and scholarly interpretation.

4 VISUALISATION IN VIRTUAL REALITY

The Aksaray monument's virtual reality environment was developed using the Unreal Engine game engine. The 3D model, created in 3ds Max, was exported in the standard OBJ and FBX formats, and then imported into Unreal Engine to enable real-time visualization and interactive navigation.

4.1 VR Environment Configuration

Within Unreal Engine, the architectural model was divided into modular components and placed in a dedicated in-engine scene (level) representing the interior of Aksaray. The lighting system combines baked global illumination and localized light sources to simulate the interaction between portico lighting and interior illumination while ensuring stable performance during real-time rendering.

A collision model was created to prevent users from ‘passing through’ walls, floors or structural elements while navigating (Fig. 16). This collision layer defines navigation paths and the boundaries of the virtual tour, ensuring stable physical interaction with the environment.

Figure 16: Collision model of the Aksaray interior.

Pre-generated textures corresponding to the reconstructed ornaments and architectural surfaces were imported into the Material Editor, where normal and roughness maps were added. This enhanced the realism of the surfaces by simulating their light response properties and tactile qualities. At the same time, the number of materials and textures was optimized to reduce draw calls and the overall graphical computation load, thereby improving system performance.

4.2 User interaction and navigation

To enable free movement within the VR environment, a first-person character controller was implemented in Unreal Engine 5 platform (Fig. 17) and tested using the Oculus Meta Quest 3 headset (512 GB), connected to the computer via a TP-Link Archer C6 wireless router. The virtual ‘capsule’ representing the user's body is sized according to average human height and shoulder width to ensure realistic collisions with walls, door frames and other architectural elements. Users can navigate the environment either via desktop controls (keyboard and mouse) or through a VR headset with motion controllers.

Figure 17: A capsule-shaped character with an attached camera.

In both cases, the interactive design aims to provide an intuitive and comfortable navigation experience. Movement speed is deliberately limited to reduce the risk of motion sickness and encourage careful exploration of the space with attention to architectural details. The camera position has been adjusted to approximate natural human eye height, maintaining a field of view consistent with human visual perception.

Future versions may incorporate optional enhancements such as teleportation between predefined points or interactive panels providing additional information about specific architectural elements.

4.3 Performance and optimization considerations

Applications and environments related to cultural heritage often operate across devices with varying technical capabilities. For this reason, performance optimization was one of the key components of this study. In the Aksaray environment, the polygon count was reduced through mesh simplification and the use of multiple levels of detail (LOD) for distant geometry. The lighting system used static lighting and precomputed illumination with Lightmass to avoid the substantial computational cost of fully dynamic lighting.

Texture resolutions were selected to balance the readability of ornamental detail with memory constraints. Where possible, several smaller textures were combined into a single texture atlas to reduce the number of materials switching operations. Internal testing demonstrated that the environment achieves stable frame rates (FPS) that are considered suitable for VR on modern mid-range hardware platforms.

Although a comprehensive user experience (UX) evaluation has not yet been conducted, initial usability tests involving project participants and a group of students indicated that the VR model effectively conveys the monument's spatial organization and decorative richness. Furthermore, navigation within the environment was perceived as intuitive after a brief adaptation period.

Within the VR section, user interaction was intentionally designed to remain simple and minimalistic. Once the user launches the VR tour via computer, the experience continues through the Oculus MetaQuest 3 headset.

During the creation of the VR environment, the Oculus MetaQuest 3 headset (512 GB memory) was employed, along with a computer equipped with an Intel Core i7-10700K processor and 32 GB of RAM. An 8 GB GPU was used for rendering and graphical processing.

4.4 Quantitative Parameters

The scene obtained from the scanning campaign was exported in *.e57 format. The total size of the exported file was 7.15 GB, comprising both point-cloud data and the accompanying 360° photographs.

Point density varied depending on the placement of the scanning stations. Stations positioned beneath the arches were located relatively close to the walls (at distances of less than 2 m), resulting in very high point density in these areas. By contrast, the central station placed beneath the dome was located at a distance exceeding 8 m, where the average point density was approximately 2 mm.

The FARO Focus M70 Laser Scanner was used for data acquisition. According to its technical specifications, the device's measurement error does not exceed 3 mm.

In this study, the measurement error remained within this specified tolerance range. During the registration of multiple point clouds, the overall alignment error ranged between 2–3 mm. These results indicate that the scanning process was conducted with high accuracy and that the reconstructed geometry corresponds closely to the physical characteristics of the real monument.

5 IMPLICATIONS

5.1 Comparison with international virtual heritage practice

Against the backdrop of international virtual heritage initiatives, the Aksaray project shares several common objectives while simultaneously addressing region-specific needs. For instance, the documentation efforts of the CyArk initiative at sites such as Angkor Wat and Bamiyan, as well as the digital programs developed by Google Arts & Culture and various European virtual heritage networks, have demonstrated the potential of 3D documentation and VR technologies to increase access to UNESCO World Heritage Sites and support conservation planning.

The Aksaray case study uniquely contributes to this global landscape by focusing attention on a lesser-known, yet architecturally and historically significant, Timurid monument in Central Asia. It shows how international virtual heritage practice standards, such as millimeter-level 3D documentation, transparent reconstruction methodologies, and immersive visualization, can be adapted to local institutional capacities and site-specific conditions.

The model's clear differentiation between measured, analytically interpreted, and proposed reconstructed elements, together with its emphasis on documenting the logic of ornamental reconstruction, strengthens the methodological sustainability of digital heritage projects in the region.

5.2 Results

The research conducted yielded several scientific and practical achievements based on the virtual model of Aksaray.

Firstly, the developed digital environment enabled real-time navigation through the interior of the monument and its domed chambers (Fig. 18). This provided researchers and users with a visual impression and a deeper understanding of the site's spatial, volumetric and structural characteristics.

Secondly, several previously proposed scholarly hypotheses were tested through the 3D model during the digital reconstruction of the architectural elements (Fig. 19). In particular, the functional and aesthetic application of certain structural solutions, as well as issues of compositional harmony within the architectural design, were re-evaluated using modern technological tools.

From educational and scholarly presentation perspectives, historians, architects and local specialists recognized the project as an effective and innovative instrument. The virtual model demonstrated its ability to communicate the historical and artistic value of the monument to students and the general public in a simplified yet spatially accurate and interactive way. This further highlights the importance of digital technologies in integrating cultural heritage into contemporary educational practices.

At the same time, however, several challenges were identified during the research process. The first relates to the limited availability of sufficient historical and archaeological data. The second relates to the complexity of accurately reconstructing textures and decorative elements, which often required analogy-based interpretation and partial modelling. The third challenge involves the practical difficulties of developing and continuously maintaining such projects, particularly VR environments, within educational and research institutions that often have restricted budgets and technical resources.

Nevertheless, this case study shows that careful planning of laser scanning, data integration and VR visualization can substantially improve the documentation, interpretation and communication of endangered architectural heritage.

Figure 18: The finalized interior of the Aksaray in Unreal Engine.

Figure 19: Aksaray 3D animation and sound.

6 CONCLUSIONS

The research conducted has expanded the possibilities for studying and presenting the Aksaray architectural monument in a digital environment. The virtual model enabled real-time navigation of the interior and domed chambers of the monument, giving researchers a deeper understanding of its spatial and structural features. At the same time, several scientific hypotheses concerning the reconstruction of architectural elements were re-examined and their functional and aesthetic aspects reassessed using modern technological tools.

From an educational and scholarly perspective, the virtual model has proven to be an effective tool for integrating cultural heritage objects into the learning process. This approach has shown that the historical and artistic value of the monument can be communicated to students and the general public in an interactive and accessible way.

However, the study also encountered several challenges, including:

- The lack of sufficient historical data, which meant that certain interpretations were necessarily hypothetical.
- The complexity of accurately reconstructing textures and decorative elements meant that analogies had to be used during the modelling process.
- The challenges associated with implementing and adapting such projects in institutions with limited budgets.

In education, virtual models should be widely introduced into the teaching of architectural history and conservation. They should serve as a key tool for developing students' spatial thinking and for organizing effective, interactive learning processes.

In scientific research, the use of digital environments is recommended for testing hypotheses, examining structural solutions and re-evaluating contested issues in architectural history.

In cultural tourism, virtual models can be used to create interactive tours and ‘digital tourism’ programs for visitors, conveying the artistic and historical value of the Aksaray to a global audience.

In restoration practice, digital modelling should be used as an effective technology for fully documenting architectural elements, hypothetically reconstructing lost parts and assessing their state of preservation.

In popularizing cultural heritage, virtual platforms can be used to promote historical architectural heritage among local communities and young people, thereby strengthening their sense of respect and responsibility towards national heritage.

Thus, this study has not only expanded the possibilities for exploring the Aksaray of Samarkand in a digital environment, but has also established a methodological foundation for future research. Virtual models have proven their great potential as an innovative tool for education, science, tourism and conservation.

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