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Study of the Bespakyr Mazar and assessment of cultural heritage deterioration using digital technologies

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Abstract

The preservation and study of cultural and historical heritage is a multidimensional issue, encompassing aspects of sociology, politics, economics, and environmental science. This research focuses on the Bespakyr Mazar, a significant cultural heritage site in Northern Kazakhstan, and presents a digital approach to assessing its structural degradation. The study explores the historical significance of mazars, their role in Kazakh culture, and their function in preserving ancestral memory. A methodology for assessing the deterioration of historical structures using digital technologies is proposed. This approach integrates three-dimensional (3D) modeling, comparative analysis of past and present photographic evidence, and metrological instruments. The proposed method enables precise monitoring of wear and structural damage over time, offering an effective solution for heritage conservation efforts. Furthermore, the study advocates for immersive digital environments that allow for interactive exploration of cultural heritage sites, making them accessible to researchers, educators, and the general public.

Keywords: Architectural preservation, cultural heritage, digital models, structural deterioration, three-dimensional technologies.

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1. Introduction

1.1. Significance of Mazars in Kazakh Culture

Mazars, commemorative structures built in honor of the deceased, serve as both sacred sites and practical shelters for travelers. In Kazakh tradition, families construct mazars within 40 days of burial, symbolizing a spiritual home for the deceased and reinforcing ancestral connections [1].

The term “mazar” originates from Arabic, meaning "a place visited by relatives and friends," often referring to the grave of a Muslim saint (avliya) [2]. Historically, Islam discouraged the veneration of graves, considering it a form of idolatry. Even the grave of the Prophet Muhammad was not initially a site of pilgrimage. However, by the end of the 10th century, the influence of Sufism contributed to the ritualistic worship of saints and their burial sites, leading to the construction of mosques and religious complexes around mazars [3].

1.2. Historical and Cultural Context of Mazars

Mazars are not exclusive to Islam. Their origins trace back to pre-Islamic burial practices, where they served as ancestral landmarks and tribal gathering sites. In Buddhism and Hinduism, similar structures known as “dargah” hold ritualistic and commemorative significance [4].

Historically, mazars played three key roles:

1. Symbolic Centers of Ancestral Memory – Many were believed to possess spiritual strength, drawing people seeking protection, blessings, and guidance.
2. Geographical Landmarks for Nomadic Tribes – Their architectural prominence helped nomads navigate the vast Kazakh steppes.
3. Meeting and Unification Sites – Mazars often facilitated tribal gatherings, fostering unity and continuity.

In modern Kazakhstan, mazars remain an integral part of national identity. They are state-protected historical and cultural heritage sites and reflect contemporary societal values. In recent decades, there has been a shift towards grandiose, monumental mazars built to demonstrate family status and economic well-being [5].

1.3. Emerging Trends in Mazar Construction

Recent studies indicate a rising trend in the construction of elaborate mausoleums. Three primary reasons have been identified:

1. Emotional and Cultural Significance
   - Children of the deceased often commission monumental mausoleums as symbols of grief, love, and respect.
   - Some individuals, before passing, request the construction of a mazar modeled after their relatives' tombs.
2. Demonstration of Wealth and Social Status
   - The selection of premium materials (e.g., newly purchased bricks instead of repurposed ones) signifies financial prosperity.
   - This trend is particularly visible among the Kazakh diaspora in the Omsk region, where economic growth in the 1990s influenced burial traditions [4].
3. Government Protection and Historical Recognition
   - Many historical mazars are now registered as cultural heritage sites and receive state protection.
   - This official recognition has led to increased interest in restoring and preserving mazars.

1.4. The Role of Digital Technologies in Heritage Conservation

With the advent of digital visualization techniques, the way cultural heritage is documented and accessed has undergone a transformation. Traditional museum-based archives are increasingly being supplemented with interactive 3D models, offering new possibilities for preservation, research, and education [6].

Key advancements include:

- 3D documentation and spatial mapping for precise heritage modeling.
- Virtual reality (VR) and augmented reality (AR) for interactive exploration of cultural sites.
- Comparative digital analysis to assess structural deterioration over time [4, 7].

Challenges in Assessing Structural Deterioration of Cultural Sites

Cultural heritage sites are subject to natural and human-induced degradation, including:

- Weather conditions (rain, wind, temperature fluctuations).
- Soil erosion and environmental changes.
- Vandalism and human-induced destruction (e.g., illegal construction, unauthorized alterations).

Preserving historical structures requires systematic monitoring. While traditional engineering surveys remain standard practice, modern digital methodologies, including 3D scanning, photogrammetry, and AI-based structural assessments offer more efficient and precise measurement techniques [8].

1.5. Study Objective

This research aims to:

- Digitally document and analyze the structural deterioration of the Bespakyr Mazar.
- Develop a methodology for assessing historical wear and degradation using 3D scanning and comparative analysis.
- Promote digital accessibility by integrating interactive heritage models into online platforms.

By leveraging modern technology, this study contributes to the ongoing efforts to preserve Kazakhstan’s cultural heritage, ensuring that historical structures remain accessible for future generations.

2. Materials and Methods

2.1. Digitization Methodology

To document and analyze the cultural and historical heritage of Northern Kazakhstan, this study employed the widely recognized photogrammetry method. A key feature of this research was the use of an unmanned aerial vehicle (UAV), specifically the DJI Air 2S quadcopter to capture high-resolution images of the Bespakyr Mazar.

2.1.1. Advantages of Using UAV-Based Photogrammetry

The DJI Air 2S quadcopter was chosen for its technical superiority, including:

- Compact size for maneuverability in complex environments.
- High-resolution camera with superior stabilization, ensuring sharp images.
- Automated takeoff and landing, increasing operational efficiency.
- Object tracking and hovering for precise imaging.
- Sufficient battery life, extended flight range, and high-altitude capability for comprehensive data collection.

The video materials collected via the UAV were converted into high-quality digital datasets compatible with various online platforms and social networks [9].

2.2. Application of Photogrammetry in Heritage Studies

Photogrammetry is a well-established method for determining the size, shape, and position of objects based on photographic analysis [3]. Its use in archaeology dates back to the pre-digital era, primarily through aerial photography-based documentation [10]. However, the advent of computer technology has significantly advanced automated image processing, expanding the capabilities of photogrammetric analysis.

At present, the combination of high-resolution digital photography and specialized software enables the creation of detailed three-dimensional (3D) models of:

- Individual artifacts (e.g., remnants of structures, burials, ruins, ceramics).
- Large-scale archaeological landscapes [6].

Although photogrammetry is a broad scientific discipline, in this study, it is specifically understood as a method for constructing 3D models of cultural heritage sites through computer processing of digital imagery [11].

Survey methodologies in historical preservation and architectural studies can be classified into various categories, as shown in Figure 1 [12].

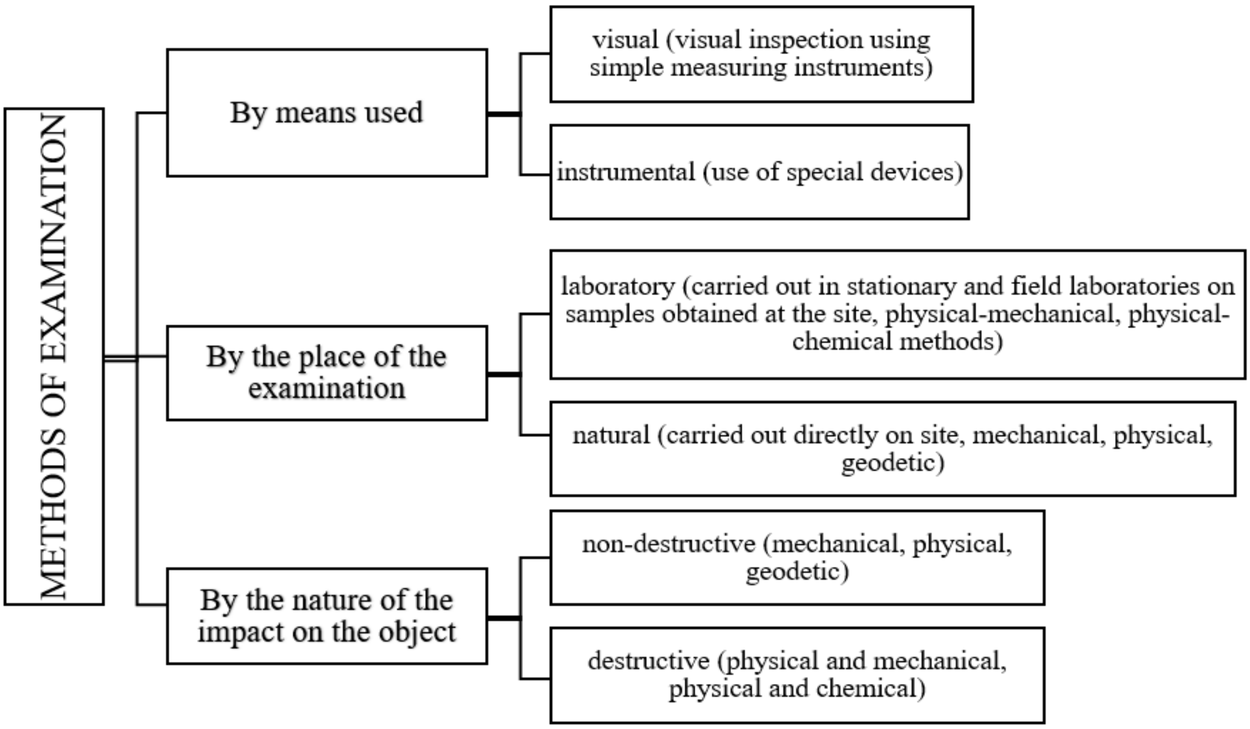

Figure 1.
Classification of Methods for Surveying Buildings and Structures.

2.3. Survey Methods for Structural Analysis

2.3.1. Visual Inspection Method

A visual engineering and technical survey was conducted as an initial assessment of the Bespakyr Mazar. This basic and widely used approach in cultural heritage conservation involves:

- General condition assessment based on direct visual observations.
- Identification of structural defects through qualitative analysis.
- Classification of heritage sites based on predefined criteria (e.g., "well-preserved" vs. "requires restoration").

Manual tools such as rulers and height gauges were used to measure structural deviations, while basic acoustic techniques (e.g., tapping) helped detect internal cracks, voids, or foreign inclusions [13].

Visual inspections typically include:

- Photographic documentation of structural damage.
- Control measurements of deteriorated sections.
- Damage classification and defect mapping in diagrammatic representations.

2.3.2. Instrumental Survey Method

For precise data acquisition, an instrumental engineering survey was conducted to evaluate the structural integrity of the mazar. This method is particularly useful when:

- Comprehensive restoration decisions need to be made.
- More accurate measurements of wear and tear are required.
- Geodetic, mechanical, and material assessments are necessary.

Key Instrumental Survey Techniques:

1. Geodetic Methods – Identify structural deformations using:

- Levels.
- Theodolites.
- Measuring tapes.

2. Mechanical Methods – Assess material strength and durability using:

- Local Destruction Tests – Measures fracture resistance.
- Plastic Deformation Tests – Identify permanent material distortions.
- Elastic Rebound Tests – Evaluates structural flexibility.
- Impact Impulse Tests – Determines shock resistance [9].

2.4. Analysis of Structural Wear and Deterioration

2.4.1. Factors Contributing to Structural Degradation

Numerous studies highlight the primary causes of deterioration in historical monuments:

- Environmental stressors (e.g., temperature fluctuations, humidity, precipitation).
- Foundation instability and soil erosion.
- Human-induced damage (e.g., vandalism, unauthorized modifications).
- Material degradation due to natural aging processes [8].

In cultural heritage conservation, the term “wear” refers to the progressive loss of structural integrity, often measured in percentage-based deterioration assessments.

2.4.2. Quantifying Structural Wear in Cultural Heritage Sites

Wear analysis in cultural heritage studies typically involves engineering and technical evaluations to assess both physical and functional deterioration.

Definition of Physical Wear:

The degree of wear is calculated by comparing the estimated cost of future repair work with the total replacement cost of the historical site.

Standard Formula for Calculating Structural Wear (VSN 53-86 (r)):

$$\Phi_{\text{к}} = \sum_{i=1}^{i=n} \Phi_i \times k_i, \qquad (1)$$

Where:

- $\Phi_{\text{к}}$ = Total physical wear and tear (%).
- Φ_i = Physical wear of a specific structural element (%).
- ki = Weighting coefficient for individual structural elements based on replacement costs.
- n = Number of structural components assessed.

This method requires the division of the structure into multiple geometrically simple parts, followed by individual wear analysis for each section. While highly accurate, this traditional approach is often labor-intensive.

2.4.3. Proposed Digital Approach for Structural Wear Analysis

A novel approach for assessing wear and tear in cultural heritage sites is proposed, integrating 3D digital modeling as an alternative to traditional segmentation-based calculations [14].

Advantages of the Proposed Digital Method:

- Eliminates the need for manual segmentation entire digital models are used instead.
- More efficient and less labor-intensive compared to traditional geometric decomposition methods.
- Allows comparative volume analysis between the original structure and its current state to quantify material loss over time.

This method offers a highly accurate, automated, and scalable approach to monitoring historical site deterioration, ensuring timely intervention and preservation efforts.

3. Conclusion

The combination of photogrammetry, UAV-based imaging, and 3D modeling presents a cutting-edge solution for cultural heritage preservation. The proposed digital wear assessment methodology:

- Reduces labor-intensive calculations.
- Enhances measurement accuracy.
- Provides a scalable solution for future conservation projects.

This research contributes to advancing digital heritage preservation techniques and facilitates the integration of modern technology in Kazakhstan's cultural conservation efforts.

4. Discussion

The Role of Emerging Technologies in Cultural Heritage Preservation

In the rapidly evolving technological landscape, museums and cultural institutions are leveraging innovative tools to enhance visitor engagement and enrich the learning experience. Among these, artificial intelligence (AI) and augmented reality (AR) technologies are playing a transformative role in heritage conservation and public interaction.

4.1. Augmented Reality (AR) and AI-Powered Digital Interpretation

4.1.1. Immersive Digital Storytelling

- AR and AI codes enable interactive engagement with museum exhibits and archaeological artifacts.
- Visitors can scan AR codes to unlock digital overlays, providing historical context, artistic evolution, and reconstruction insights.

4.1.2. Personalized Learning Experiences

- AI-driven content adapts to different learning preferences and age groups, incorporating quizzes, games, and guided narratives.
- This dynamic approach transforms passive learning into an engaging and memorable experience.

4.1.3. Virtual Access to Fragile Artifacts

- Digital replicas ensure broader access to culturally significant artifacts, reducing physical handling risks while preserving historical integrity.
- High-resolution 3D models allow remote exploration, ensuring global accessibility to cultural heritage [15].

4.2. Digital Asset Management in Archaeology

The integration of digital asset management (DAM) systems is crucial for archaeological documentation and data preservation. In an era where digital archives are replacing traditional record-keeping methods, it is essential to develop structured frameworks for:

- Metadata standardization to ensure long-term accessibility.
- Secure cloud storage solutions to protect digital artifacts from data loss.
- Cross-institutional collaboration to enhance global research efforts [14].

These technological advancements underscore the importance of digital heritage initiatives, paving the way for new methodologies in conservation, education, and public outreach.

5. Results

5.1. Digitalization of the Bespakyr Mazar

As part of the Ministry of Science and Higher Education of Kazakhstan's grant-funded project (IRN AP19676333 "Three-Dimensional Technologies in the Process of Preserving the Cultural and Historical Heritage of Northern Kazakhstan"), several cultural and historical heritage sites were digitized. One of the key focus sites was the Bespakyr Mazar, depicted in Figure 2.

Figure 2.
The Bespakyr Mazar, photographed in 2006.

5.2. Historical and Architectural Significance of the Bespakyr Mazar

The Bespakyr Mazar, whose name translates from Kazakh as "Sympathy for the Five", is believed to have been constructed in honor of five warriors who fought alongside Kenesary Khan during the National Liberation War (1837–1847) [16].

- Construction Materials: The mazar was built using adobe bricks composed of sheep wool, horse hair, clay, and milk, reflecting traditional Kazakh architectural techniques [4].
- Architectural Structure:
- Two-room layout aligned east to west along a horizontal axis.
- Facade design: Symmetrical proportions with a low two-column arched entrance.
- Interior spaces:
- Oval room (2.8m diameter) covered by a brick dome.
- Main round room (6.5m diameter, 3m height) resembling a gateway structure.

5.3. Assessment of Structural Deterioration

Following the normative method for evaluating structural wear, the Bespakyr Mazar was divided into four key structural sections:

1. Large circular hall – Minimal degradation observed.
2. Small circular hall – Minor damage recorded.
3. Dome above the small hall – More than 50% damaged.
4. Entrance arch (small circular hall interior) – Severe cracks (>2 cm width).

Table 1.
Physical Wear Assessment Based on VSN 53-86 (p).

Wear Indicators	Quantitative Assessment	Physical Deterioration (%)
Small cracks in the foundation and below first-floor windows	Crack width up to 2 mm	0–20%
Individual cracks and potholes	Crack width up to 1 mm	0–10%
Deep cracks, plaster damage, seam weathering	Crack width up to 2 mm, depth up to 1/3 of wall thickness, seam destruction up to 10%	11–20%
Severe plaster peeling, brick disintegration, increased wall dampness	Crack width >2 mm, joint destruction up to 2 cm over 30% of the surface	21–30%

During the implementation of the Ministry of Science and Higher Education of Kazakhstan's grant-funded project (IRN AP19676333), a DJI Air 2S More Com drone was utilized for high-resolution aerial photogrammetry to create a three-dimensional digital model of the Bespakyr Mazar. This advanced imaging technique enabled the precise documentation of structural details and facilitated a comparative analysis of historical deterioration.

The 3D model of the Bespakyr Mazar is now publicly accessible for research, educational, and conservation purposes via the following link:

- Sketchfab: Bespakyr Mausoleum, and the model is shown in Figure 6.

Having a digital model of the modern Bespakyr Mazar, it is possible to select an angle that matches the historical photographs available in museums and, using a visual analysis method, determine the degree of structural loss and the rate of deterioration [17]. An example of this comparison is presented in Figure 3, where the image on the right shows a 2006 photograph, while the left image is a screenshot from a digital model created using photogrammetry. The comparison clearly indicates a significant rate of structural degradation, particularly in the cracks to the right of the entrance arch, which have expanded to concerning dimensions over time.

This method of photogrammetric assessment provides a quantifiable approach to monitoring cultural heritage loss, ensuring data-driven conservation strategies for timely restoration efforts.

Figure 3.
Comparison of photographs from 2006 (left) and 2024 (right), [12].

The method proposed in this project enables a comparative analysis between the digital reconstruction model created using the KOMPAS-3D software and the digitized model obtained during the research process. This approach allows for an accurate assessment of structural wear and degradation over time.

KOMPAS-3D is a licensed computer-aided design (CAD) system that has been utilized at A. Myrzakhmetov Kokshetau University since 2014 [14]. To determine the exact volume of the Bespakyr Mazar, an updated version (V22) of the software was employed. The software enables automated calculations of mass-centering characteristics for three-dimensional models, allowing researchers to precisely evaluate changes in structure over time.

For the purposes of this study, only one key characteristic volume was required, as illustrated in Figure 4.

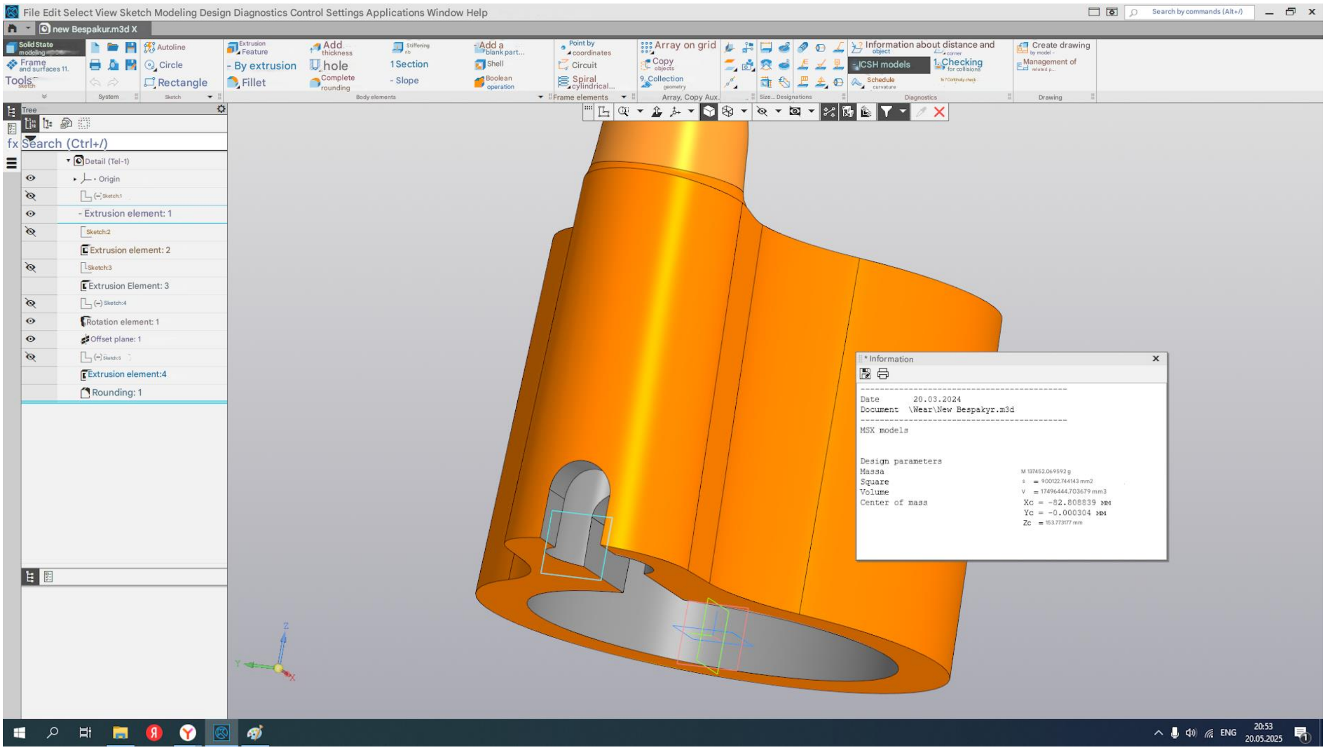

Figure 4.
Model of reconstruction of the Bespakir mazar with definition of the model volume , [12].

The model of the reconstructed Bespakyr Mazar is conditional, as it does not incorporate the detailed texture of the brickwork. Instead, it provides a simplified geometric representation of the structure, which allows for a more straightforward volumetric comparison.

To accurately calculate the degree of wear, a correction factor of 0.01 is applied to account for the brickwork texture, ensuring that minor surface irregularities do not significantly distort the overall volume estimation. By incorporating this correction factor, a simplified digital model with smooth walls is created for comparative analysis.

The creation process of this conditional model is illustrated in Figure 5.

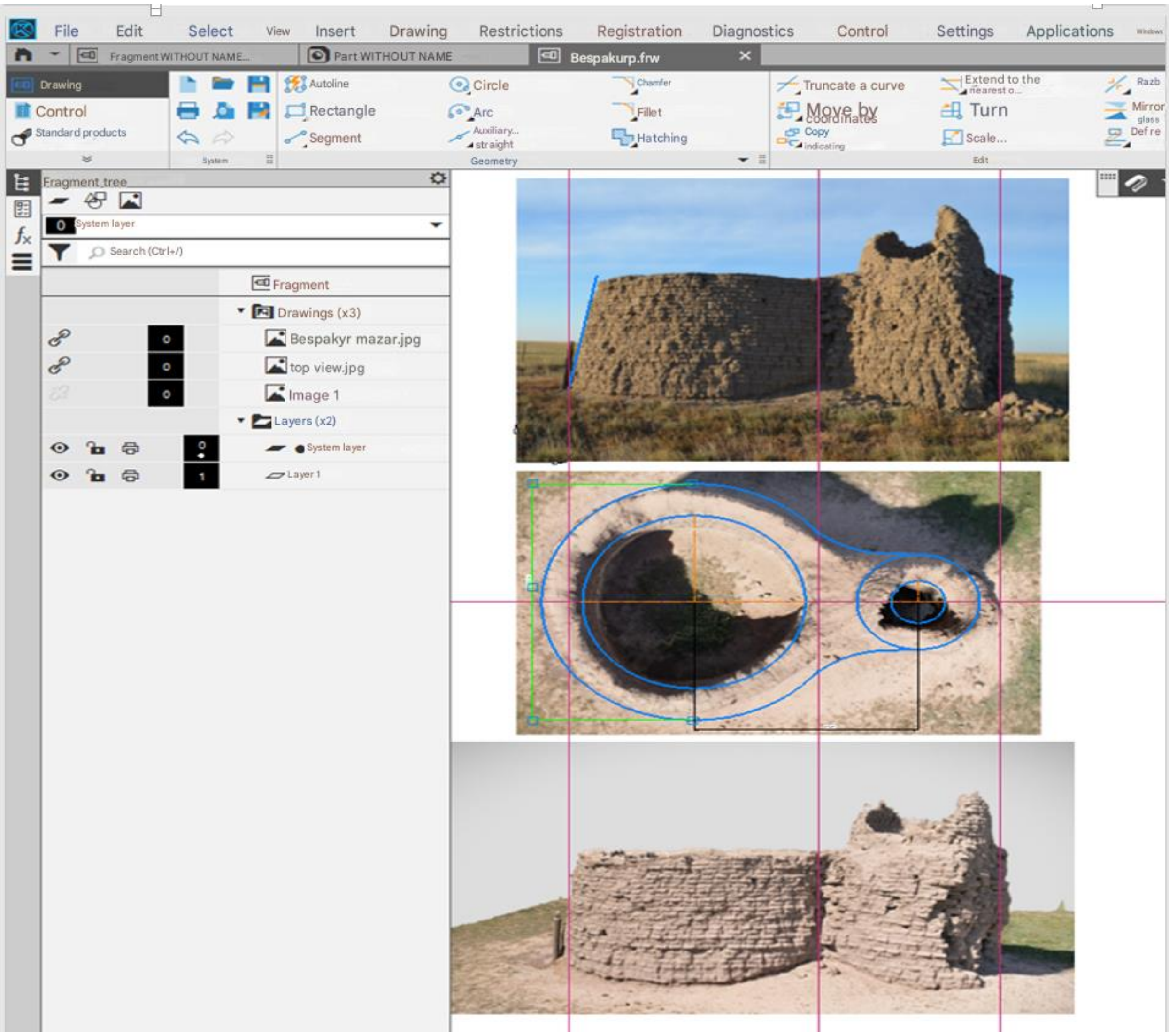

Figure 5.
Working in the KOMPAS-3D program to create a reconstructed model of the Bespakyr mazar [12].

Figure 6.
Digital model of the Bespakyr mazar obtained by photogrammetry on the website https://sketchfab.com.

The volume of the three-dimensional model created based on the assumed original dimensions of the Bespakyr Mazar was Vp = 17,496,444.65 mm³. After processing the digitized model, the KOMPAS-3D software determined its current volume as Vc = 11,022,760.35 mm³ [12].

To calculate the percentage of structural wear, the difference between the reconstructed volume and the current digitized volume is divided by the reconstructed volume. This provides a quantifiable metric of material loss, allowing for precise deterioration assessments. The formula used for this calculation is:

$$И = \frac{V_p - V_c}{V_p} \times 100\%$$

Where:

- И = percentage of wear and tear of the structure.
- Vp = volume of the reconstructed model (mm^3).
- Vc = volume of the modern model at present (mm^3).

For the Bespakyr Mazar, the wear and tear percentage is calculated as follows:

$$И = \frac{17496444{,}65 \quad - 11022760{,}35}{17496444{,}65} \times 100\% = 36{,}9\%$$

Thus, taking into account the correction factor, the total structural wear for the current state of the Bespakyr Mazar is approximately 36%. This value closely aligns with traditional engineering survey methods based on building codes, demonstrating the accuracy and efficiency of digital modeling techniques in cultural heritage assessments [12].

During the project, a total of eight mazars were examined using the same methodology. Among them, two distinct groups were identified:

- Mazars most susceptible to wear, requiring immediate restoration.
- Restored mazars, which demonstrated minimal signs of deterioration.

An example of a restored structure is the Bogenbai Bi Mazar, shown in Figure 7.

Figure 7.
Mazar Bogenbay bi. Digital model of the mazar https://sketchfab.com/3d-models/8d1b73ba88cf4d0098b35c6f10e61e22.

Bogenbay Bi Mazar was canonized due to his gift of foresight, and according to legend, he lived for 105 years. The mazar dedicated to him was constructed in 2006 and remains structurally intact, with a degree of wear not exceeding 0.5%. The height of the structure is 7 meters, and its red brick construction ensures a projected lifespan of over 50 years without requiring restoration efforts.

Figure 8 presents the Mausoleum of Aliptomar, an architectural monument dating back to the early 20th century. The height of this mazar exceeds 6 meters, and it is constructed using two distinct shades of brick. A notable architectural feature is the use of adobe bricks, which were arranged in an alternating color pattern, showcasing traditional craftsmanship.

The name "Aliptomar" originates from the master builder responsible for its construction. Using the developed digital assessment method, the degree of wear for this structure was determined to be 22%. This moderate level of deterioration suggests that while the mausoleum remains stable, future conservation efforts should be considered to ensure its continued preservation and study.

Figure 8.
Mausoleum of Aliptomar. Digital model of the mausoleum https://sketchfab.com/3d-models/e5c7868f588a4b37b11aeeee80df3aad.

After analyzing the three-dimensional models of eight mazars, a systematic approach for the restoration and preservation of cultural and historical heritage sites in Northern Kazakhstan was developed. This structured process aims to prioritize conservation efforts, ensuring the long-term sustainability of these monuments.

The digitalization of cultural heritage offers numerous advantages, including greater accessibility, enhanced preservation techniques, and broader educational applications [8]. While photogrammetry-based documentation has been used for historical preservation in the past, advancements in three-dimensional (3D) printing technologies now allow for scaled physical models of artifacts. These models are no longer limited to museums but can also be integrated into educational institutions and personal collections, expanding opportunities for historical study and heritage engagement [9, 14].

This research was conducted under the Ministry of Science and Higher Education of the Republic of Kazakhstan's grant-funded project (AP19676333) titled "Three-Dimensional Technologies in the Process of Preserving the Cultural and Historical Heritage of Northern Kazakhstan." As part of this initiative, an application was submitted and approved, resulting in the official registration of a copyright certificate (No. 48764, dated July 28, 2024). The registered scientific work, titled "Method for Determining the Degree of Deterioration of Cultural Heritage Objects Using Digital Technologies," is now part of the state register of intellectual property.

This milestone marks a significant advancement in heritage conservation, establishing a scientifically validated methodology for assessing structural deterioration, thereby aiding in effective restoration planning and decision-making.

6. Conclusion

The preservation of mazars in their original form is crucial for maintaining cultural identity and historical continuity. The integration of modern digital technologies, particularly three-dimensional (3D) modeling and photogrammetry, offers an effective means to safeguard and document these cultural landmarks.

This study successfully developed a methodology for assessing the deterioration of cultural and historical sites, enabling precise predictions regarding the rate and extent of structural degradation. The application of this methodology facilitates timely intervention, allowing for preventive restoration efforts that not only preserve historical structures but also provide an economic rationale for conservation initiatives.

6.1. Key Findings and Contributions

- The proposed wear assessment model enables efficient and accurate evaluation of structural deterioration.
- The integration of 3D scanning and photogrammetry enhances data-driven decision-making in heritage conservation.
- The availability of digital heritage databases allows global accessibility and engagement with Kazakhstan's cultural heritage.

6.2. Future Implications

- The establishment of a national database of digital cultural heritage models can enhance global recognition of Kazakhstan's historical sites.
- International collaboration in digital heritage preservation can be facilitated through open-access platforms.
- The expansion of 3D printing applications can revolutionize museum exhibits and educational tools, making history more interactive and immersive.

6.3. Final Thought

Cultural heritage is an irreplaceable asset that shapes national identity, promotes diversity, and impacts education, economics, and diplomacy. The preservation and digitalization of historical landmarks must be a priority to ensure their protection for future generations in an ever-evolving technological world [14].

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