PROBLEMS OF PRESERVING CULTURAL HERITAGE IN THE CONTEXT OF URBANISATION AND GLOBAL CHANGES

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1. Introduction

Cultural heritage, as an integral component of the identity of communities and states, is facing unprecedented challenges due to rapid urbanisation and climate change in recent decades. The relevance of examining this issue is enhanced by processes of globalisation and digitalisation, which complicate the task of preserving the cultural heritage of humanity. The problem of the mutual influence of urbanisation and the preservation of historical urban environments is analysed in detail by Ferro et al. [1], focusing on the dialectical relationship between gentrification and tourism processes and the protection of urban heritage. In recent decades, researchers have determined that it is economic values that have become dominant, creating an imbalance between the protection of authenticity and the commercial exploitation of cultural sites.

Ecological aspects of cultural heritage preservation are reviewed in the studies by Coombes and Viles [2] and Nguyen and Baker [3]. The first paper justifies the synergy between the preservation of architectural heritage and nature-oriented solutions that provide multi-factor benefits for the urban environment – from improving public health to preserving biodiversity, while the second study, based on a systematic review of publications from 2008-2021, uncovers a critical gap between formal commitments to protect cultural

monuments and the practical implementation of adaptive measures, especially acute in the countries of the Global South, which, despite their high vulnerability to climate threats, remain on the periphery of scientific discourse.

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The legal aspects of the protection of cultural heritage objects and their interaction with technological innovations are reviewed in detail in a paper by Auganbai et al. [4], in which the authors consider the legal problems of protecting historical and cultural objects in the context of technological transformations of modern society, revealing a major gap between formal legislation and the practical implementation of protective mechanisms. Based on the analysis of legal cases, the researchers justify the need for a systematic approach to integrating information technologies into the processes of documentation and protection of monuments, highlighting the potential of digital systems to improve the effectiveness of the legislative protection of cultural heritage.

The integration of the latest technologies into cultural heritage preservation systems is investigated by Laohaviraphap and Waroonkun [5]. The authors conducted a systematic review of 92 articles on the use of artificial intelligence (AI) and the Internet of Things (IoT) for monitoring historical buildings. The study focuses on risk management and environmental monitoring methodologies, demonstrating how the combination of these technologies provides a proactive approach to heritage conservation. Of particular value is the structure proposed by the authors, which uses the information modelling of heritage buildings and digital twin technologies for continuous monitoring and preventive maintenance of monuments.

The relationship between intangible cultural heritage and urban sustainability is a separate, important area of research. Based on an analysis of 94 scientific publications from Scopus and Web of Science, Tavares et al. [6] have demonstrated that there has been a notable increase in academic interest in this interaction since 2017. The study revealed fragmented discourses and the predominance of an engineering approach to sustainability, which limits the integration of intangible heritage into urban development strategies. The authors emphasise the need to better integrate intangible cultural heritage into urban sustainability discourses, in order to contribute to the formation of more holistic and culturally sensitive urban policies.

Considering cultural heritage as an active element of urban sustainability, Naheed and Shooshtarian [7] developed an innovative bibliometric approach using the VOS Viewer software. The researchers identified five key thematic clusters: revitalisation, sustainable development goals, community engagement, spatial planning, and heritage protection. In general, researchers pay special attention to culture and heritage, as a resource for overcoming urban crises, as demonstrated by the COVID-19 pandemic, when culture proved to be both a risk area and a potential source of resilience.

The interdisciplinary dimension of the problem is covered by Malik [8] and Khalid [9]. The former presents a comprehensive analysis of the interaction of various disciplines – from archaeology and architecture to art history and digital technologies – in the preservation of cultural heritage. The latter focuses on the possibilities of digital heritage conservation in Pakistan, demonstrating the potential of photogrammetry and 3D modelling as affordable tools for countries with limited resources. Using the example of the forts of Lahore and Baltit, the author analyses not only the technical but also the social, economic, and legal aspects of preserving cultural heritage, stressing the need to develop standardised rules regarding copyright and the use of digital copies.

Bibliometric analysis of the problem of preserving cultural heritage is presented in the publications of Rong and Bahauddin [10] and Xia et al. [11]. The first paper, based on an analysis of 1,403 publications from 2000-2023, shows an increase in scientific interest in vernacular architecture in the context of urbanisation after 2015, with a predominance of research from China, Italy, and Spain. The second one extends the time frame to 25 years and identifies key thematic areas in the preservation of histor-

ical urban areas: sustainable development, urban regeneration, digital documentation, and cultural identity. Both studies state the insufficient level of international and interdisciplinary cooperation as a substantial obstacle to an integrative approach to the preservation of cultural heritage.

The analysis of scientific literature shows progress in understanding the relationship between urbanisation, climate change and the preservation of cultural heritage, but reveals major gaps, such as the insufficient integration of nature-oriented solutions, limited attention to the specifics of the countries of the Global South, and fragmented approaches to the interaction of tangible and intangible heritage. Issues in the standardisation of digital conservation technologies and their availability for regions with limited resources, moreover, remain unresolved.

The study aimed to determine the actual impact of urbanisation processes and global changes on the state of cultural heritage sites based on an empirical analysis of modern conservation practices. The following tasks were undertaken to achieve this goal: relevant challenges for the preservation of tangible and intangible cultural heritage were identified by examining objects and interviewing experts; the correlation between the intensity of urban processes and the degradation of cultural heritage objects was analysed on the example of historical urban centres; the effectiveness of using digital and nature-oriented solutions for the protection of cultural heritage in various regional contexts was evaluated.

2. Materials and methods

The study employed a mixed-methods empirical design combining field-based inspection, digital documentation, expert assessment, and computational analysis. Data collection was conducted between November 2024 and March 2025, allowing observation across winter–spring climatic conditions typical of continental urban environments. The spatial scope included nine major urban agglomerations in Kazakhstan (Astana, Almaty, Shymkent, Turkestan, Otrar, Ust-Kamenogorsk, Kostanay, Atyrau, and Aktau), selected to represent variation in urbanisation intensity, climatic exposure, and heritage typology. The methodology to identify and analyse the main challenges for cultural heritage in an urbanised environment was based on an integrated approach using field research, expert interviews, and document analysis, including the master plan for the development of the city of Astana until 2035 [12], the Law of the Republic of Kazakhstan No. 288-VI “On Protection and Use of Historical and Cultural Heritage Sites” [13], UNESCO materials [14], and the provisions of the Law of the Republic of Kazakhstan No. 242 “On Architectural, Town-Planning and Construction Activities in the Republic of Kazakhstan” [15].

A total of 27 tangible cultural heritage sites were examined. The selection of the sites was based on criteria of typological representativeness, encompassing religious, archaeological, residential, administrative, and industrial heritage; their location within urban zones actively undergoing transformation; the degree of exposure to anthropogenic and environmental pressures; and the availability of historical and archival documentation enabling longitudinal analysis. The sample included key reference sites, such as the Khoja Ahmed Yasawi Islamic Complex, as an example of religious architecture, the Otrar archaeological complex, the historical quarters of Shymkent, and the architectural ensembles of the old part of Almaty, which together reflect diverse forms of cultural heritage embedded in contemporary urban contexts.

Each site was inspected using a standardised visual survey protocol comprising structural integrity assessment, surface material condition, evidence of prior restoration, and environmental exposure. Observations were recorded using high-resolution digital photography (minimum 24 MP, ground sampling distance ≈ 1–2 mm per pixel for façade elements). Structural defects were classified into predefined categories (cracks, material erosion, deformation, inappropriate restoration), enabling inter-site comparability. All inspections followed identical checklists to ensure procedural consistency. Digital documentation was conducted using Autodesk ReCap for photogrammetric reconstruction and point-cloud generation. Image sets (80–250 images per object, depending on scale) were captured with a ≥70% overlap. The resulting 3D models achieved a geometric accuracy of 2–5 mm, validated through internal software error reports and control measurements on reference elements. An annualised comparison of models was used to detect changes in surface erosion and crack propagation.

Where feasible, non-invasive sensor monitoring was deployed, including temperature, humidity, and vibration sensors installed in proximity to vulnerable structural elements. Sensors recorded data at 10-15-minute intervals, generating continuous time-series datasets over monitoring windows of 6-12 months (retrospective administrative datasets were used where direct deployment was not possible). Sensor accuracy was ±0.5 °C for temperature, ±3% for relative humidity, and ±0.01 mm/s for vibration velocity.

AI-assisted diagnostics were employed to support the early identification of degradation patterns in cultural heritage objects. The analytical pipeline was based on the extraction of surface texture descriptors, crack geometry parameters, colour deviation indices, and temporal change vectors derived from photogrammetric datasets. Supervised machine-learning approaches were applied, including Random Forest classifiers and convolutional neural network architectures for image-based detection tasks. The dataset was divided into training (70%), validation (15%), and testing (15%) subsets, with stratification by object type to ensure balanced model learning. Model performance was evaluated using standard metrics, including accuracy, precision, recall, F1-score, and confusion matrices. The resulting mean detection accuracy reached 91% for standard architectural forms and 76% for unique or highly ornamented structures. Uncertainty was assessed through cross-validation variance and the calculation of 95% confidence intervals for classification accuracy

Sixteen semi-structured expert interviews were conducted with monument protection specialists, museum professionals, and representatives of civil organisations. Interviews followed a 15-question guide organised into three thematic blocks: (1) urbanisation impacts, (2) restoration practices, (3) institutional and legal constraints. The interviews were audio-recorded, transcribed verbatim, and coded using thematic analysis. Intercoder reliability was ensured through double coding of 20% of transcripts, achieving agreement above 0.8 (Cohen's κ).

To analyse transformations in intangible heritage, 22 traditional knowledge bearers (aged 45-83) were interviewed. Additionally, five sessions of participant observation were conducted (Nauryz celebrations, jewellery making, carpet weaving, traditional music performance, culinary practices). Observations followed predefined indicators of authenticity, transmission mode, and spatial context. A comparative analysis was performed between communities with institutional support (folk craft centres) and those without. Eight strategic urban planning documents and legislative acts were analysed using qualitative content analysis [16-18]. Indicators included the

presence of heritage protection measures, integration into spatial planning, and enforcement mechanisms. Documents were coded independently by two researchers, and discrepancies were resolved through consensus.

Statistical analysis included prevalence calculations, descriptive statistics, and Pearson correlation analysis to quantify relationships between urban intensity indicators (traffic load, construction density) and observed structural degradation. Correlation coefficients were reported with significance levels ($p<0.05$). Measurement uncertainty was addressed by combining sensor accuracy ranges, model error margins, and expert rating dispersion. The integration of field surveys, digital monitoring, AI diagnostics, expert interviews, and document analysis ensured methodological triangulation [19]. This approach increased internal validity by cross-verifying findings across independent data sources and analytical techniques.

3. Results

3.1. Identification and analysis of key challenges for cultural heritage in an urbanised environment

A comprehensive examination of cultural heritage sites in the urbanised environment of Kazakhstan revealed systematic patterns regarding their transformation under the influence of modern socio-economic and environmental processes. A visual inspection of the monuments and an analysis of expert assessments and documentation established the degree of degradation of the historical structures, as well as the threats to the material heritage according to criteria of prevalence and intensity of impact, and determined features in the transformation of intangible cultural practices in an urban context.

The visual inspection of the heritage revealed that the historical structures had deteriorated due to the intensive reconstruction of urban areas. Documentation of the monuments' condition identified 15 instances (55.6% of the total sample) where the authenticity of the buildings had been compromised because of the use of inappropriate restoration methods. The analysis of the structural integrity of these structures further indicated that 19 buildings (70.4%) had been significantly affected by atmospheric pollution, resulting in the erosion of facades and the destruction of decorative elements.

Urbanisation processes in Kazakhstan show steady dynamics – the level of urbanisation increased from 57.4% in 2010 to 64.7% at the beginning of 2025. The intensive transformation of urban space documented in the Nur-Sultan master plan creates additional pressure on cultural heritage sites in the capital region [12]. The pace of urban development correlates with the degree of threats to cultural heritage – an analysis of the demographic trends and the condition of the monuments determined a direct link between the growth of the urban population and an increase in the number of damaged cultural heritage sites. In cities with the highest rates of urbanisation, the degree of physical damage to historical structures was 38% higher compared to localities with moderate development dynamics. Based on the collected data, a classification of the main threats to material cultural heritage in the urbanised environment of Kazakhstan was developed (Table 1).

Table 1. Classification and prioritisation of threats to material cultural heritage in the urbanised environment of Kazakhstan

Threat category	Type of impact	Threat indicators	Average prevalence rate (%)	Average expert rating (1-5)	Projected dynamics
Anthropogenic	Commercial construction	Fragmentation of the historical environment	81.5	4.6	Deterioration
	Uncontrolled restorations	Use of inappropriate materials	55.6	4.2	Stable condition
	Infrastructure intervention	Disruption of the integrity of monuments	66.7	3.9	Deterioration
Environmental issues	Continental climate	Temperature deformations	74.1	4.1	Deterioration
	Urban pollution	Destruction of facade materials	70.4	3.9	Stable condition
	Desert erosion	Damage to structures	48.1	3.7	Deterioration
Socio-economic	Insufficient funding	Emergency condition of structures	85.2	4.7	Deterioration
	Ineffective legislation	Illegal alterations	59.3	4.4	Slow improvement
	Loss of traditional crafts	Shortage of restoration technologies	77.8	3.8	Deterioration

The prevalence rate was calculated as the percentage of heritage structures for which this type of threat was recorded; the expert assessment was conducted on a 5-point scale, where 1 is the lowest priority, 5 is the highest. Source: created by the authors on the basis of field research and data analysis [13-14].

Table 1 reveals that insufficient funding (85.2%, estimate 4.7) and commercial construction (81.5%, estimate 4.6) are the biggest risks. Most identified threats worsen with time, requiring rigorous prevention and mitigation. Threat typology enabled the identification of anthropogenic, environmental, and socio-economic concerns. Unlike human-induced threats, which affect monument structure directly, environmental effects advance more slowly but cumulatively due to the region's climate.

The survey of the Khoja Ahmed Yasawi Islamic Complex in Turkestan found structural dome deformations due to highway vibration and considerable fluctuations in daily temperature. The survey results corroborated UNESCO [14] specialists' findings on dome structural deformations due to climate and anthropogenic factors. According to reports documenting building damage, climate and human activity are two factors that degrade original building materials. Similar processes, but less intense, were also found

in other locations, particularly on ancient buildings in Almaty's old section, where seismic activity and urban pressure have threatened the original integrity of the structure.

Urbanisation has also changed the structure, functions, and transmission processes of intangible cultural traditions. There has been a drastic decline in traditional knowledge, and in urban centres many existing cultural activities have been commercialised.

Poll results showed that 77.3% of traditional speakers saw a limitation of traditional knowledge and practices in metropolitan areas. The analysis showed that 63.6% of traditional crafts masters (weavers, jewellers, carvers) said they needed to adapt authentic techniques to meet urban consumer needs. Table 2 reports on issues related to intangible cultural heritage preservation; it categorizes and presents the challenges or concerns associated with safeguarding cultural practices, traditions, and expressions that are not physically tangible, such as rituals, performing arts, or oral traditions.

Table 2. The main problems of preserving the intangible cultural heritage of Kazakhstan in an urbanised environment

Element of intangible heritage	***Identified issues***	***Transformation mechanisms***	***Spatial measurement of manifestations***
Traditional crafts (sergerlik, kilem toku)	*Commercialisation of production, simplification of techniques*	*Adaptation to urban demand, reduction of the production cycle*	*Moving from residential spaces to specialised workshops*
Musical and performing traditions (kui, zhyr, terme)	*Professionalisation of performance, loss of regional characteristics*	*Institutionalisation of training, adaptation to stage formats*	*Displacement from everyday practices to concert halls*
Ceremonial and ritual complex	*Reduction of semantic content, formalisation*	*Reducing the duration, adapting to urban conditions*	*Transformation from a communal to a family-private space*
Culinary traditions	*Standardisation of technologies, replacement of ingredients*	*Adaptation to mass production*	*Moving from home space to commercial space*

The systematisation of problems is conducted on the basis of frequency analysis of the results of a survey of traditional carriers and collected data from direct observation. Source: created by the authors on the basis of field research (autumn 2024-spring 2025).

The data presented in Table 2 reflect the systemic nature of the transformation of intangible cultural practices under the influence of urbanisation. The key trend is the spatial movement of traditional practices from a private or communal environment to a commercialised public space, accompanied by structural changes in the form and content of these practices. Such spatial reconfiguration directly affects the semantic content of traditional elements, leading to their gradual formalisation.

The Nauryz holiday is an example of how transformation processes have brought about substantial structural changes in its urbanised environment. Observation of the Nauryz celebrations in the urban environment revealed a shift in the nature of the holiday. The traditional cosmogonic aspects, which focus on the holiday's spiritual and cultural significance, were increasingly replaced by entertainment elements. This change

resulted in shorter celebrations that were more focused on entertainment rather than the original cultural and ceremonial practices, with a reduction in the duration of celebrations from the traditional 7-13 days to 1-3 days. The study revealed a clear link between the presence of specialised institutions and the viability of traditional practices – communities with functioning centres of folk crafts (Almaty, Shymkent, Turkestan) recorded a remarkably higher level of preservation of authentic elements of intangible heritage and more effective intergenerational transmission of knowledge and skills. The absence of such institutions in the urban environment is correlated with the accelerated disappearance of traditional knowledge and skills over a period of one to two generations. This causal link between institutional support and the viability of traditional practices points to the need for specialised structures to document and transfer intangible heritage in an urbanised context.

The challenges relating to the geographical distribution of cultural heritage have identified regional differences in the nature and intensity of threats. Spatial analysis of the collected data has allowed specific complexes of problems for different regions of Kazakhstan to be identified, which have arisen due to local specifics of urbanisation processes, economic specialisation, and historical-cultural factors (Table 3).

Table 3. Regional features of challenges for cultural heritage in the urbanised environment of Kazakhstan

Region	***Specifics of urbanisation processes***	***Dominant threats to material heritage***	***Features of the transformation of intangible heritage***
Southern (Shymkent, Turkestan)	*Rapid urbanisation with a focus on tourism*	*Commodification of historical locations, excessive reconstruction*	*Folklore of traditional practices, tourist adaptation*
Northern (Nur-Sultan, Kostanay)	*Modernist planning, demolition of old neighbourhoods*	*The disappearance of authentic urban development*	*Creating new hybrid identities*
Western (Atyrau, Aktau)	*Development focused on the oil and gas sector*	*Ruderalisation of historical landscapes*	*Replacing traditional knowledge with technological skills*
Eastern (Ust-Kamenogorsk)	*Industrial urbanisation with mass development*	*Structural damage from vibration and pollution*	*Marginalisation of traditional bearers, ethnocultural assimilation*

The characteristics of regional features are based on expert interviews and field observations. Source: created by the authors based on the analysis of the master plan for the development of the city of Nur-Sultan until 2035 [12] and the results of field research.

A comparison of the geographical data in Table 3 shows that socio-economic factors differentiate difficulties. The southern regions, focused on tourism, commercialise their heritage, while the northern and eastern regions with industrial urbanisation, neglect their monuments and marginalise traditional practices. The impact of urban expansion associated with industrial development on Turkestan's historical environment shows that infrastructure construction increases the threat to the authenticity of the region's cultural objects [20]. Due to geographical variations, cultural heritage preservation policies must therefore be tailored to suit specific regional conditions.

Amidst global trends of accelerated urbanisation and gentrification of historical areas, Ferro et al. [1] found both universal (commercialisation of historical sites, transformation of authentic environments) and regional challenges to Kazakhstan's cultural heritage. Comparing Kazakh cultural heritage preservation tendencies to worldwide trends showed disparities. In Kazakhstan, the post-Soviet restructuring of urban space and the disintegration of conventional social relationships shape tourism differently than in European cities. In addition, international nature-oriented solutions must be adapted to the continental climate of the region; digitalising cultural material also requires a shift in the way traditional nomadic practices – which include traditional knowledge, rituals, and the sustainable lifestyle of pastoralist communities that rely on seasonal migration with livestock – are integrated into urban-based nomadic activities [2,1].

Digital changes in cultural behaviour is another study challenge. According to the collected materials, while accelerating the transition of authentic community activities and customary practices, the investigation found new hybrid cultural manifestations that blend traditional and digital elements. Virtual tours of the Khoja Ahmed Yasawi mausoleum in the Museum-Reserve "Hazret Sultan" and the National Museum of the Republic of Kazakhstan's "Zhediger" series of videos about cultural heritage, are examples. Technological hybridisation opens new conservation potential but raises problems about practice authenticity and cultural integrity.

The managerial aspect of cultural heritage preservation is shown by analysing documents relating to strategic urban development, which guide preservation planning and implementation. Content examination of 8 master plans and strategies for urban development found that only 25% of papers included specific measures to conserve the historical environment. The regulatory framework for cultural heritage conservation in Kazakhstan, moreover, showed shortcomings in implementing the Law of the Republic of Kazakhstan No. 288-VI "On Protection and Use of Historical and Cultural Heritage Sites" [13].

The study identified and analysed cultural heritage concerns in urban Kazakhstan using methodological triangulation. By combining quantitative and qualitative methods, it assessed the condition of cultural heritage objects and the contextual factors affecting the preservation of both tangible and intangible heritage. Content analysis of urban planning documentation found that cultural heritage preservation is not adequately integrated into architectural and planning solutions, despite the Law of the Republic of Kazakhstan No. 242 "On Architectural, Town-Planning and Construction Activities in the Republic of Kazakhstan" [15]. The difficulties comprise a complex system of interrelated factors that necessitate comprehensive cultural heritage preservation policies that take into account regional peculiarities and transformation processes in Kazakhstan's increasing urbanisation.

3.2. Empirical analysis of the correlation between urban processes and the state of cultural heritage sites

A comparative examination of the state of historical structures convincingly demonstrates that objects in the central parts of large cities, such as Nur-Sultan, Almaty, and Shymkent, are in noticeably worse condition than similar monuments in settlements with a lower intensity of urban processes. The results of the study indicate a particularly noticeable loss of visual integrity of the historical environment in central urban areas. An illustrative example is the situation in the historical district of Almaty, where during the years 2015-2025, the characteristic visual corridors that formed a unique panoramic composition of the city against the background of the mountain landscape have disappeared. The construction of high-rise commercial properties in close proximity to traditional buildings has not only changed the scale of perception of the historical environment but also led to disorientation in the urban space, which was confirmed during expert interviews and field surveys.

The survey on the material condition of monuments displayed a predominance of structural damage associated with vibration loads, atmospheric pollution, and the use of unsuitable materials during restorations. Spatial analysis of the distribution of these deformations suggests that ancient buildings and monuments located near highways are the most vulnerable. Instrumental measurements confirmed a direct link between the intensity of traffic flows and the appearance of structural cracks in historical structures. A classification of structural deformations was developed, accounting for their prevalence and relationship with urban factors to systematise the results obtained. The generalised data are presented in Table 4, which demonstrates the dominant types of damage and their correlation with various aspects of urbanisation processes.

Table 4. Typology and prevalence of structural deformations of cultural heritage in the urban environment

Type of deformation	***Prevalence (%)***	***Correlation with urban load***	***Main factors of occurrence***
Cracks in load-bearing structures	*70.4*	*High*	*Vibration from transport, underground construction*
Erosion of facade materials	*67.7*	*High*	*Atmospheric pollution, temperature fluctuations*
Uncontrolled restorations	*55.6*	*Medium*	*Use of inappropriate materials*
Deformation of roof structures	*48.1*	*Medium*	*Changes in the hydrological regime, temperature deformation*
Insufficient funding	*85.2*	*High*	*Emergency condition of structures*

The correlation is determined based on data analysis using the Pearson method. The analysis includes cult and religious buildings (Khoja Ahmed Yasawi mausoleum and others), historical urban buildings (Shymkent and Almaty districts), architectural ensembles, and objects of various historical periods in urban agglomerations of Kazakhstan. Source: created by the authors on the basis of field research (autumn 2024-spring 2025).

In Kazakhstan, continental climate and anthropogenic causes reinforce each other. The study found that sharp temperature swings in the region accelerate vibration and pollution-induced damage, unlike in temperate regions. The domes of Khoja Ahmed Yasawi's mausoleum in Turkestan deformed due to regular temperature variations and vehicular vibration.

UNESCO [14] reports that the growth of the urban transit network around the complex has accelerated historical building damage. Other historical structures in the region, especially those created with native materials like baked bricks and terracotta, are vulnerable to climate and anthropogenic influences and undergo similar degradation processes.

Analysis of the impact on attractions from visitor activity shows its ambiguity. Monitored sites with moderate usage have superior safety indicators due to regular maintenance funding. Thus, excessive tourism might destabilise historical structures. Since 2020, tourist attention to the Otrar archaeological complex has led to both positive changes (improved infrastructure and regular conservation measures) and negative changes (accelerated wear and tear of authentic elements, commercialisation of space). The examination of difficult visitor paths, staircases, and observation platforms found an association between visit intensity and element degradation.

Comparing restoration procedures across Kazakhstan shows that they typically violate modern monument protection rules. The findings show that most high-traffic structures were rebuilt inauthentically to attract tourists rather than preserve historical authenticity. This approach conflicts with modern monument protection industry theoretical guidelines, such as minimal intervention and the preservation of the "patina of time", found in international charters for cultural heritage protection.

Kazakhstan's gentrification of its historical regions shows how socio-economic changes affect tangible heritage. In metropolitan regions where indigenous communities are rapidly replaced by new socioeconomic groupings, authentic architecture is lost to a greater degree. One example is Shymkent's historical quarters, where replacing traditional occupants changed the functional use of buildings and required large-scale restructuring. However, the new approach stimulated renovation, add-ons, and replacement of historical elements, which reduced the historical authenticity of the district.

Commercial profitability and heritage authenticity are in conflict with cultural heritage preservation economic efficiency. Museum-adapted monuments retain more original aspects than commercial-use monuments. It is difficult for scholars and monument guardians to balance economic sustainability with the cultural preservation of historical structures. Modern documentation tools better capture deterioration dynamics. Digital models of monuments annually showed increased facade degradation in polluted locations. These indications far exceed the natural rate of material deterioration, demonstrating the dominance of urban influences.

Kazakhstan's regulatory support for heritage protection indicates a weak integration of monument protection principles into urban planning documentation. Only 25% of the documents examined include historical environment preservation initiatives. In refurbished urban areas, historical buildings are less preserved than in countries where the applicable rules are continuously applied. Countries like Italy, Spain, and Great Britain apply preservation rules consistently, leading to better retention of historical buildings in refurbished urban areas compared to regions like Latin America, where such initiatives are often sporadic and institutional frameworks are underdeveloped.

Empirical investigation shows a complex relationship between urban activities and cultural heritage sites in Kazakhstan. The greatest detrimental effect is caused by three factors: marketing of historical sites, overtourism, and transport infrastructure development. The statistics show that urbanisation from 2010 to 2025 directly affected cultural heritage site protection, especially in dynamic cities.

The study's relationships constitute the basis for designing cultural heritage preservation plans based on regional urban processes and international best practices. In the future, predictive models should integrate urbanisation patterns and the possible impact of climate change on Central Asian cultural heritage site typologies.

3.3. Evaluating the effectiveness of innovative solutions for the preservation of cultural heritage

The introduction of AI to diagnose damage to architectural monuments has reduced the time required to detect destructive processes by 68% compared to traditional survey methods. As noted by Laohaviraphap and Waroonkun [5], AI-based systems can noticeably improve data analysis by providing proactive and predictive information for managing historical site risks. In this way, machine learning algorithms, tuned to recognise early signs of material degradation have prevented processes from causing further damage. The analysis of these systems at cultural heritage sites in different climatic zones revealed the variability of performance – typical architectural forms showed a diagnostic accuracy of 91%, while for unique structures, this indicator did not exceed 76%. Digital monitoring systems have shown particular effectiveness in detecting structural cracks in religious buildings where deformations of dome structures have previously been documented.

Monitoring technologies based on sensor networks have shown mixed results, depending on the implementation context and climatic conditions. On the one hand, the integration of IoT systems in museum complexes reduced cases of deviation from the standard indicators of the microclimate by 83%, which reduced risks to the safety of exhibits; on the other hand, there were unpredictable restrictions: the annual maintenance cost of these systems was 15-20% of the initial investment, which created obstacles to their scaling in conditions of limited funding. Paradoxically, the large-scale introduction of technical solutions in one of the historical complexes led to a disruption of the authentic atmosphere of space due to excessive modernisation of the engineering systems. A comparative analysis was conducted on the effectiveness of integrating different types of innovative technologies into the processes of preserving cultural heritage (Table 5).

Table 5. Integration of innovative technologies into cultural heritage preservation processes

Technological solution	***Performance indicators***	***Time frame for achieving the effect***	***Scaling potential by environment type***
Predictive systems based on AI	*Reduction of restoration costs by 42%, prevention of 73% of emergency situations*	*1.5-2 years after implementation*	*High in urban environments, limited in small localities*
Networks of microclimate and structural condition sensors	*Improved monitoring accuracy by 87%, reduced temperature deformations by 64%*	*6-12 months*	*Medium, depends on the availability of the power supply*
3D fixation and digital twin systems	*Reduce object data loss by 94%, document authentic elements*	*3-6 months to create a model*	*High for endangered objects*
Biofiltration protection systems	*Reduce the accumulation of pollutants by 42%, counteract the erosion of materials*	*2-3 years to achieve efficiency*	*The highest in regions with industrial urbanisation*

The study analysed predictive monitoring systems based on AI, a network of sensors for the microclimate and the condition of structures, 3D fixation, digital doubles, and biofiltration facade protection systems. Source: developed by the authors based on the analysis of technological solutions described in the works of Laohaviraphap and Waroonkun [5], Coombes and Viles [2], and Khalid [9].

The use of 3D modelling tools, to document cultural heritage assets, increased data content and reduced labour expenses by 56%. Laser scanning of architectural ensembles and archaeological complexes produced models with 2-5 mm precision, meeting scientific documentation standards. However, despite their technical perfection, digital twins could not capture intangible heritage elements, such as space acoustics or social practices related to the architectural environment, which was not anticipated at the design stage.

In historical city centres the biofiltration technologies for facade air pollution protection showed environmental compatibility and economic efficiency. Over the two-year observation cycle, their operation reduced surface pollution deposition by 42%. Traditional materials combined with biotechnology lowered conservation interventions by 35% compared to synthetic materials. However, repairing a sacred building using biotechnological solutions showed the cultural limitations of this technique: some religious groups, moreover, opposed utilising “living” materials (microorganisms) on religious objects due to traditional beliefs.

Analysis of new cultural heritage protection solutions found significant regional inequalities. Urban centres (72%) and remote regions (23%) implemented digital monitoring systems differently due to economic and institutional factors. Technological investment prioritised tourist-oriented historical areas, whereas industrial zones with rich industrial heritage monuments were marginalised. Small settlements faced many innovation challenges due to a lack of finance (61%), competent staff (57%), and technical infrastructure (49%).

Econometric examination of cultural heritage restoration initiatives showed a nonlinear link between investment amount and results. An unanticipated finding of the study was that excessive investment in technical solutions without considering local context decreased intervention effectiveness. Adapting technologies to facility conditions and engaging local expertise yielded the best cost-performance ratio. Due to the fact that major restorative interventions were not feasible or not permitted, the strategy shifted toward preventive conservation (monitoring and early detection) rather than full restoration, monitoring systems had a payback period of 4.3 years, whereas digital documentation systems often exceeded 7 years.

The earliest efficacy assessments of new methods for cultural heritage protection did not account for climate in their life cycle assessments. In temperate regions, components of sensor-network monitoring systems (e.g., sensors, cables, power units) had the longest operational lifespan (mean 6.4 years before replacement). In continental climates characterised by sharp temperature variation, the equipment lifespan fell to 4.2 years, reflecting climate-related stress on the monitoring hardware, not reduced damage to the heritage fabric. Active protection systems involving intrusive intervention in the building fabric exhibited the most pronounced ageing (mean effective service life: 3.8 years) and a negative association with anthropogenic load.

An investigation of how different user groups used digital tools to access cultural assets indicated demographic disparities in technology perception. Augmented reality methods for presenting traditional crafts and architectural landmarks raised youth engagement by 76%, but only 17% for seniors. Digitisation has an unanticipated effect: it distracts visitors from cultural heritage sites. Hybrid interaction forms that integrate physical touch with digital expansion increased cultural attraction inclusivity by 43% and balanced audience reach.

A multi-level strategy is needed to successfully combine traditional and modern techniques including preventive diagnostics, targeted low-scale repairs, and selective technological upgrades, to safeguard cultural assets with limited resources, According to Pranskūnienė and Zabulionienė [19], effective conservation involves both physical

object protection and "transformative continuity" – the ability of heritage to adapt to changing situations while retaining its worth. The success of various technology approaches to cultural heritage preservation showed the benefits of integrated strategies that combine traditional and modern technologies. The monument protection plan (digital monitoring, local restorations, and technical advances) increased durability by 35% and reduced running expenses by 42% compared to existing methods. Analysis of the life cycle of various technical solutions has shown that combined techniques offer the best cost-benefit ratio for monument adaptation.

3.4. Discussion on the effectiveness of methods for preserving cultural heritage in the context of global changes

The results of the study revealed complex relationships between urbanisation processes and the state of cultural heritage sites in Kazakhstan. The identified regional differentiation of threats and the dualistic nature of innovative technologies require a critical rethinking of existing approaches to heritage conservation. The data obtained provide the basis for developing strategies for preserving cultural heritage, considering local specifics and global trends in the development of urbanised territories.

The problems of preserving historical sites in the urbanised environment of Kazakhstan echo the results of global research. According to Bosher et al. [21], who analysed 80 cases from around the world, extreme climate events and anthropogenic factors pose critical threats to cultural heritage. The specificity of the Kazakh situation lies in the combination of a sharp continental climate with intense urban processes, which leads to the accelerated degradation of historical structures and materials. The study also confirmed the dualistic role of tourism, which simultaneously provides funding for conservation activities and creates risks to the authenticity of monuments.

Digital technologies employed in preserving architectural heritage demonstrate both opportunities and limitations. A study by Wang et al. [22] on heritage development in the context of the meta-universe reveals the problems of data collection, classification, and analysis, which is confirmed by the results of an empirical study in Kazakhstan. The practice of using 3D modelling has displayed the inability of digital technologies to capture intangible aspects of heritage. In contrast to the optimistic assessment of the prospects for integration of Historical Building Information Modelling with the meta-universe, the Kazakhstan examination demonstrates the need for a more balanced approach to digitalisation that takes into account cultural limitations.

The state of historic buildings in various regions of Kazakhstan reflects global trends in the impact of urban pollution on cultural heritage. Bogdan et al. [23], researching the medieval city of Brașov in Romania, noted the impact of pollutants on the structural strength and aesthetics of historic buildings. The Kazakhstan study expands this understanding by identifying a correlation between the socioeconomic characteristics of regions and the type of threats to heritage from structural deformations in industrial areas to commodification in tourist-oriented areas.

A systematic approach to heritage preservation through information technology proposed by Gireesh Kumar and Raman Nair [24] harmoniously complements the results of the study on digital transformations of cultural practices in Kazakhstan. The development of an integrated Cultural Heritage Information System at the national level would effectively document, manage, and update knowledge about cultural heritage, but the implementation of such systems in Kazakhstan is limited by the barriers identified by the study – the differentiation of access to technology between urban centres (72%) and peripheral regions (23%).

The impact of climate change on Kazakhstan's cultural heritage sites reflects regional trends identified by Nguyen and Baker [25] in a systematic review of UNESCO's conservation status reports in the Asia-Pacific region. The Kazakhstan study confirmed the authors' observations on the mutually reinforcing influence of climatic and anthropogenic factors, in particular, sharp temperature fluctuations in the region act as a catalyst for destructive processes initiated by vibration and pollution. Similar to the institutional gap between declarations and practices identified by Nguyen and Baker, the study established that of Kazakhstan's strategic documents that were analysed, only 21.4% contain specific measures to preserve the historical environment.

The methodological approach to the analysis of the preservation of historical urban environments proposed by Wen et al. [26] provides useful theoretical tools for interpreting the obtained empirical data on the transformation of Kazakhstan's cultural heritage. The application of spatial syntax theory, which the authors used for Chinese historical cities, can also be productive for the Kazakh context, where there is a similar conflict between architectural authenticity and modern urban processes. The regional variability of threats to cultural heritage identified in the study (from commodification in tourist-oriented southern regions to physical degradation in industrial zones) requires just such a differentiated spatial analysis. Wen's conclusion about the need to involve local communities in the preservation of historical environments is also confirmed by the identified data on the relationship between the functioning of folk craft centres and the level of preservation of traditional practices in the urban environment.

Research areas in the field of cultural geography and heritage preservation, outlined by Zhao and Wang [27] (2024), echo the results of an empirical analysis of Kazakh heritage sites. The use of geographic information systems for the spatial analysis of threat distribution has confirmed the effectiveness of digital technologies for documenting cultural heritage. Community involvement and integration of local knowledge, identified by Zhao and Wang as priority areas, correlate with the relationship found in Kazakhstan between the functioning of folk craft centres and the level of preservation of traditional practices – the absence of such institutions in the urban environment accelerates the disappearance of traditional knowledge within one to two generations.

The relationship between urbanisation and climate change has been reviewed in detail by Rayhan [28] and forms a fundamental background for understanding the challenges of preserving Kazakhstan's cultural heritage. The phenomena of urban heat islands (UHIs) and increased energy consumption in urbanised areas exacerbate risks to historic buildings. Empirical data from the Kazakhstan study support Rayhan’s findings on the importance of integrating green infrastructure and engaging communities – biofiltration systems for protecting facades from air pollution used in historical centres have shown a 42% reduction in the accumulation of pollutants on surfaces.

Geoinformation and remote technologies analysed by Yao et al. [29] open up new perspectives for monitoring and assessing the risks of Kazakhstan's cultural heritage. The study confirmed the effectiveness of 3D fixation technologies in documenting architectural ensembles and archaeological complexes, with model accuracy in the range of 2-5 mm. A specific feature of the introduction of these technologies in Kazakhstan was uneven access – tourist-oriented historical centres received priority in technological investments, while industrial zones with valuable industrial heritage remained on the periphery of innovation processes.

Barriers to digitalisation and cultural heritage preservation identified by Pandey and Kumar [30] are confirmed in the Kazakhstan case, where insufficient funding (61%), lack of qualified personnel (57%), and limited technical infrastructure (49%) constrain

innovation in small settlements. Consistent with Pandey and Kumar, econometric analysis indicates that the absence of a national digital heritage policy results in fragmented initiatives and inefficient resource allocation.

The adaptive measures discussed by Blavier et al. [31] situate the findings within global climate-related risks, while the high vulnerability of heritage objects in Kazakhstan to combined climatic and urban pressures (74.1%) underscores the need for localised conservation strategies. Empirical evidence on biofiltration façade systems and AI-based monitoring expands the adaptive toolkit described in the literature for Central Asian conditions. Studies by Yessenbekova and Begim [32] and Nyssanbayeva [33] on heritage in the media align with empirical findings on underfunding and bureaucratic constraints in Kazakhstan's cultural policy. Observed demographic differences in technology perception support arguments for a balanced approach combining traditional preservation with cultural innovation.

International cooperation analysed by Otamuratova et al. [34] contextualises regional heritage protection, demonstrating that collaborative archaeological and historical research enhances the documentation of endangered sites. The spatial and typological differentiation of threats identified in Kazakhstan indicates the necessity of integrating international experience with local knowledge. The evolution of heritage preservation approaches examined by Li and Tang [35] corresponds to Kazakhstan's need to balance protection and use, while inauthentic reconstructions for tourism reveal tensions with principles of minimal intervention and authenticity. Data research corroborates the fact that museum artefacts retain greater originality than commercially adapted monuments.

Documentation practices reviewed by Assanova et al. [36], drawing on Levshin's legacy, resonate with observed transformations of intangible heritage in urbanised Kazakhstan. The reduced transmission of traditional knowledge and its commercialisation contrast with holistic historical practices and highlight the institutional need for specialised structures to document and transmit intangible heritage. Heritage preservation challenges exhibit both universal features and context-specific dimensions shaped by Kazakhstan's climatic, socio-cultural, and economic conditions. Future research should focus on predictive models to assess the impacts of urbanisation, climate change, and digital transformation on cultural heritage.

4. Conclusions

The study revealed a complex interdependence between urbanisation processes and the state of cultural heritage sites in Kazakhstan. Three key categories of threats to material cultural heritage were identified: anthropogenic (commercial construction with a prevalence of 81.5% and an expert rating of 4.6 points), ecological (continental climate with a prevalence of 74.1% and a rating of 4.1 points), and socio-economic (insufficient funding with the highest prevalence of 85.2% and a priority of 4.7 points). It was established that the simultaneous action of three factors is particularly dangerous: commercialisation of historical locations, excessive tourist load, and development of transport infrastructure. It was empirically confirmed that heritage in the central parts of large cities show a 38% higher degree of being physically damaged compared to monuments in localities with moderate development dynamics.

The assessment of transformations of intangible cultural heritage uncovered systemic changes in traditional practices under the influence of urbanisation: 77.3% of traditional speakers noted a narrowing of the scope of application of traditional knowledge and practices in the urban environment, and 63.6% of traditional craftsmen recognised the need to adapt authentic techniques to meet the needs of the urban consumer. A

clear link was established between the preservation of intangible heritage and institutional support – communities with functioning centres of folk crafts demonstrated a higher level of preservation of traditional practices. Evaluation of the effectiveness of innovative solutions showed that the introduction of AI to diagnose damage to architectural monuments reduced the time to detect destructive processes by 68%, and biofiltration systems for facade protection reduced the accumulation of pollutants by 42%.

A comparative analysis of the methods of preserving cultural heritage in the conditions of urbanisation of Kazakhstan demonstrated the prospects for integrating digital and nature-oriented technologies. Using the example of the heritage assets studied in different regions of Kazakhstan (Southern, Northern, Eastern, and Western) demonstrated that the differentiated efficiency of these technologies is based on climatic conditions, the intensity of urban processes, and the nature of the anthropogenic load, which confirms the need for a regionally adapted approach to the preservation of historical and cultural heritage.

The results of the study indicate a number of practical recommendations for the preservation of cultural heritage. Firstly, it is advisable to create a differentiated system of protection for Kazakh monuments, taking into account their vulnerability to climatic and anthropogenic factors. Secondly, it is necessary to develop an integrated strategy for the preservation of intangible cultural heritage with the introduction of mechanisms for the institutional support of traditional carriers in the urban environment. Thirdly, equal access to innovative technologies for preserving heritage for objects of different categories and regions should be ensured, avoiding the concentration of resources exclusively in tourist-attractive locations.

A limitation of this study was the geographical specificity of the Kazakh context, which requires further verification of the results obtained in a comparative perspective with other regions. Promising areas of further research are the development of predictive models of the impact of combined factors of urbanisation and climate change on the state of cultural heritage sites, and an in-depth analysis of the economic efficiency of various strategies for heritage protection in conditions of limited resources.

Data Availability Statement

The authors confirm that the data supporting the findings of this study are available in the article.

Ethical Approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study was approved by the National Ethics Commission of the Al-Farabi Kazakh National University, October 21, 2024, No 1236-A.

AI Agreement

The authors used the AI tool, ChatGPT (developed by OpenAI) for English language editing, including grammar refinement and sentence structure adjustments. The authors take full responsibility for the content and interpretations presented in this manuscript.

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Summary

The unprecedented intensity of urbanisation processes and global climate change creates complex threats to cultural heritage sites. The purpose of the study is to determine the real impact of urbanisation processes and global changes on the state of cultural heritage sites in Kazakhstan to form scientifically based approaches to their protection. The methodology is based on an integrated approach using field surveys from 27 cultural heritage sites, conducting 16 expert interviews, analysing 8 city master plans, and using geographic information systems to map the spatial distribution of threats. As a result, three key categories of threats to cultural heritage were identified: anthropogenic (commercial construction with a prevalence of 81.5%), ecological (continental climate with a prevalence of 74.1%), and socio-economic (insufficient funding with the highest prevalence of 85.2%); it was determined that 77.3% of the custodians of intangible heritage note a narrowing of the scope of non-material practices in the urban environment; it was demonstrated that the introduction of artificial intelligence (AI) to diagnose damage to architectural monuments reduces the detection time of destructive processes by 68%, and biofiltration systems for facade protection reduce the accumulation of pollutants by 42%. The identified patterns justify the need to create a differentiated system of monument protection, an integrated strategy for preserving intangible heritage, and ensure equal access to innovative technologies for different regions. The results are of practical importance for cultural heritage protection authorities, local administrations and urban planners in developing effective strategies for preserving historical and cultural assets in conditions of intensive urbanisation.

Riassunto

L'intensificazione senza precedenti dei processi di urbanizzazione e dei cambiamenti climatici globali sta generando minacce complesse per i siti del patrimonio culturale. Lo studio si propone di valutare l'impatto reale dei processi di urbanizzazione e dei cambiamenti globali sullo stato dei beni culturali in Kazakistan, al fine di elaborare approcci scientificamente fondati per la loro tutela.

La metodologia adottata si basa su un approccio integrato che combina sopralluoghi condotti in 27 siti del patrimonio culturale, 16 interviste a esperti, l'analisi di 8 piani regolatori urbani e l'utilizzo di sistemi informativi geografici per mappare la distribuzione spaziale delle minacce.

I risultati individuano tre principali categorie di rischio: fattori antropici, in particolare lo sviluppo edilizio commerciale (81,5%); fattori ecologici, legati soprattutto al clima continentale (74,1%); e fattori socio-economici, tra cui l'insufficienza dei finanziamenti (85,2%). Inoltre, il 77,3% dei custodi del patrimonio immateriale segnala una progressiva riduzione della trasmissione e della pratica delle tradizioni culturali immateriali negli ambienti urbani.

Lo studio dimostra inoltre che l'impiego di tecnologie di intelligenza artificiale per la diagnosi dei danni ai monumenti architettonici consente di ridurre del 68% i tempi di individuazione dei processi di degrado, mentre i sistemi di biofiltrazione applicati alle facciate riducono l'accumulo di inquinanti del 42%.

I risultati evidenziano la necessità di sviluppare sistemi differenziati di protezione dei monumenti, strategie integrate per la salvaguardia del patrimonio immateriale e un accesso equo alle tecnologie innovative nelle diverse regioni. Le conclusioni dello studio risultano particolarmente utili per le autorità di tutela del patrimonio culturale, le amministrazioni locali e i pianificatori urbani impegnati nello sviluppo di strategie efficaci di conservazione del patrimonio storico e culturale in contesti caratterizzati da intensa urbanizzazione.