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Article

From Manuscript to Cloud: Digital Approaches to Preserving Cultural and Religious Inheritance

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Abstract

The study analyzes the transformation of methods of preserving cultural and religious heritage in the context of digital development. The aim of the work was to identify the features of digital archiving of monuments and develop recommendations for improving the efficiency of their preservation. The study used a comprehensive approach that included an analysis of international experience, an expert survey of cultural institution employees, and an evaluation of existing digital heritage preservation platforms. Authors analyzed 45 international projects of digitalization of cultural heritage, interviewed 40 experts from 8 countries, and studied 23 innovative preservation technologies. The results showed that digital archiving increases the accessibility of cultural monuments by 73%, ensures the long-term preservation of materials in 89% of cases, and promotes intercultural dialogue. It was found that hybrid preservation models that combine traditional and digital methods were the most effective. The key challenges are identified: technical limitations (43% of respondents), financial difficulties (38%), and the need for professional training (52%). A conceptual model for the sustainable development of the digital ecosystem of cultural heritage preservation has been developed and practical recommendations for cultural institutions have been proposed.

Keywords: *archiving, digital preservation, cultural memory, religious heritage, cultural institutions, preservation methods, Ukrainian musical folklore, sustainable development of historical and cultural heritage, digital ecosystem of monuments, cultural values.*

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Introduction

Modern society is experiencing an era of profound digital transformation, which is radically changing approaches to preserving and transmitting cultural memory. Traditional methods of archiving cultural and religious heritage, which have been based on the physical storage of artifacts for centuries, are now being supplemented and partially replaced by innovative digital technologies. This transformation actualizes the need to rethink the conceptual foundations of cultural memory preservation and develop new methodological approaches to digital archiving.

Modern cultural institutions actively implement innovative preservation methods that combine traditional archiving practices with advanced digital technologies to ensure comprehensive protection of cultural and religious heritage for future generations.

The issue of digital preservation of cultural heritage has become particularly acute in the context of the global challenges of our time. The world order is under threat as people live in danger of natural calamities, warfare, urbanization, and climatic changes, endangering the physical existence of the cultural monuments.

This is particularly relevant for preserving Ukrainian musical folklore, which faces additional challenges due to ongoing military conflicts that threaten both tangible artifacts and the continuity of oral traditions passed down through generations.

Meanwhile, it can be noted that due to the high dynamics of information technology development, nowadays unprecedented prospects emerge to develop computerized archives capable of guaranteeing the survivability of information about a culture and heritage over decades and making it available to future generations. A review of the scientific literature will prove that scholars' concern for the digital preservation of cultural heritage is increasing. The work by Dubrovina et al. (2021) researched the possible role of digital humanitarian activities in the perpetuation of documentary heritage, which, among other aspects, lies in the necessity to form dense databases of cultural objects.

Their article indicated that the combination of conventional archival methods and contemporary digital technologies is indeed effective. Still, it did not immediately resolve the problem of the consistency of the digitalization process and long-term accessibility to digital records. Dobrovolska (2020) provides a comprehensive analysis of information and documentation support for cultural development, highlighting the critical role of systematic approaches in preserving cultural heritage in digital environments. Botticelli (2021) analyzed the interdisciplinary nature of cultural heritage within the information

space and explained the necessity of working out special competencies in the digital archiving sphere. In the study, the researcher also pointed out a close relationship between technical expertise and knowledge about the cultural situation, which cannot be avoided in preserving religious and cultural works of art.

Choi (2020) examined the merger among libraries, archives, and museums due to digital change and suggested using a competency-based approach to developing educational programs. The study concluded that new professional standards should be implemented to professionals dealing with the digital cultural heritage. This requirement is particularly welcome in light of the increased complexity of the technological solutions.

It is a research work on the relationship between information science and digital humanities in Spain; the authors found particular methodological approaches and sets of standards to conserve cultural collections. This was brought to light in their work, where they emphasized collaboration and internationalization of the digital archiving process.

Skild et al. (2021) examined the explanation of the digital age's cultural memory, taking into account the semiotics of cultural information preservation. The authors concentrated on the changes in the frameworks of how cultural meanings are inscribed and conveyed within the digital space, which is of particular significance in ensuring the preservation of the religious tradition with its unique system of symbols.

Marty (2014) researched the topic of digital convergence at cultural heritage organizations and discussed the problem of fitting the internal requirements of an institution with users and their needs. According to the study outcomes, it was necessary to create flexible digital turnover strategies and consider the peculiarities of various cultural institutions. Adrian and Kurniawan (2020) saw the idea of smart heritage as a way to preserve cultural heritage in the context of smart cities.

The authors justified the prospect of combining IoT and artificial intelligence technologies to develop new solutions in monitoring and preserving cultural monuments. The article by Niziaieva et al. (2022), which is indirectly concerned with the problem of tourism promotion and maintenance of cultural heritage by means of a tourism digital platform, analyzed the use of digital marketing tools to reconcile the tourism industry's interests.

Even though a lot of work has been carried out, there are lacunae in the scientific literature concerning the issue of integrated approaches to digital archiving of cultural and religious heritage. More specifically, the question of merging the different technological solutions, the unification of the process of digitizing the religious artifacts, and the cultural sensitivity of the digital preservation procedures have not been studied extensively enough.

The purpose of the study is to analyze current trends in digital archiving of cultural and religious heritage and to develop recommendations for improving the efficiency of cultural memory preservation in the digital environment. To achieve this goal, the following tasks are envisaged: to analyze international experience in the digital preservation of cultural and religious heritage and identify the most effective practices and technological solutions, to assess the challenges and opportunities of modern digital archiving methods in the context of cultural memory preservation, and to develop practical recommendations for cultural institutions on the implementation of effective digital heritage preservation systems.

Literature review

Recent scholarship demonstrates growing interest in digital preservation methodologies for cultural heritage. Dubrovina et al. (2020) examined digital humanities and databases of documentary cultural heritage in Ukrainian libraries, while their subsequent work (Dubrovina et al., 2021) emphasized the integration of traditional archival practices with digital technologies, while Botticelli (2021) highlighted the interdisciplinary nature of cultural heritage informatics. Choi (2020) examined institutional convergence in digital environments, advocating competency-based educational approaches. The convergence of libraries, archives, and museums (LAM) represents a fundamental shift in how cultural heritage institutions approach digitalization, requiring new conceptual frameworks for understanding their interconnected roles (Derstuhanova, 2018, 2019; Kachappilly, 2024). Alvite-Díez and Barrionuevo (2021) analyzed methodological frameworks for digital collections in Spain, emphasizing international collaboration standards. Marty (2014) investigated digital convergence challenges in cultural organizations, focusing on balancing institutional requirements with user needs. Cameron and Kenderdine (2022) provide a comprehensive theoretical framework for understanding digital cultural heritage as a complex socio-technical phenomenon that requires critical examination of power structures and representation practices. Adrian and Kurniawan (2020) explored smart heritage concepts within urban contexts, proposing IoT and AI integration. However, the existing literature lacks comprehensive frameworks combining technological solutions with cultural sensitivity protocols, particularly for religious heritage preservation, which creates a research gap that this study addresses.

Methodology

This study employed a mixed-methods approach combining quantitative and qualitative research techniques. International project analysis utilized systematic sampling of 45 digitalization initiatives (2019-2024) selected through UNESCO, Europeana, and academic database searches using predefined criteria: implementation period, budget thresholds, and international recognition.

Expert assessment involved structured interviews with 40 professionals across eight countries using five-point Likert scales and open-ended questions. Data collection included online surveys, documentation analysis, and case study methodology applied to the Nenets heritage digitization project. SWOT analysis framework guided stakeholder interaction modeling.

Statistical analysis employed correlation coefficients and cluster analysis for expert response categorization. Model validation utilized expert evaluation (n=15) with relevance scoring. Quality assurance included triangulation of data sources, inter-rater reliability testing, and systematic bias control through geographic and professional diversity of respondents (Appendix A).

Results

Analysis of international practices of digital preservation of cultural and religious heritage

To conduct a comparative analysis of international experience, the authors created their own database of 45 cultural heritage digitalization projects selected by the following criteria: 1) implementation in the period of 2019-2024; 2) availability of publicly available documentation; 3) budget over 50,000 euros; 4) international recognition or awards. The projects were identified by analyzing reports from UNESCO, Europeana, the Digital Public Library of America, as well as scientific publications in Scopus and Web of Science using the keywords "digital heritage preservation," "cultural digitization," and "digital archives." Each project was evaluated according to a five-point scale of effectiveness developed by the authors, including technical parameters, social impact, economic sustainability, and cultural sensitivity.

Each analyzed project demonstrated unique approaches to integrating digital technologies into traditional archiving systems, with particular attention to the sensitive handling of religious heritage and the development of sustainable preservation methods.

The results of the geographical distribution of the analyzed projects are presented in Table 1. The largest concentration of initiatives was observed in the European region (53.3% of the total), which is explained by the presence of a developed

digital technology infrastructure and the European Union's active policy on cultural heritage preservation. The North American region demonstrated a high level of technological innovation in projects (31.1%), while Asian initiatives were characterized by unique approaches to the preservation of intangible cultural heritage (15.6%).

Table 1. Geographical distribution of the analyzed cultural heritage digitalization projects

Region	Number of projects	Percentage of the total number	Average efficiency score	Preferred type of technology
Europe	24	53.3%	4.2	3D modeling, VR technologies
North America	14	31.1%	4.5	Artificial intelligence, machine learning
Asia	7	15.6%	3.8	Augmented reality, mobile applications
Overall	45	100%	4.2	Hybrid technological solutions

Source: compiled by the authors based on an analysis of international projects for the digitalization of cultural heritage (2019-2024)

An analysis of the typological structure of projects revealed the dominance of initiatives aimed at preserving tangible cultural heritage (68.9%) over intangible heritage projects (31.1%). This ratio reflects the traditional approach to understanding cultural memory, but recent trends show a growing focus on digital documentation of rituals, traditions, and oral history.

The technological analysis of the projects identified seven main categories of digital solutions used to preserve cultural heritage (Table 2). The most widespread were 3D scanning and modeling technologies (42.2% of projects), which provide a highly accurate reproduction of the physical characteristics of cultural objects. A high level of effectiveness (4.7 points) was demonstrated by projects using virtual reality technologies that create an immersive experience of interaction with cultural heritage.

Table 2. Technological solutions in digital cultural heritage preservation projects

Type of technology	Number of projects	Percentage of utilization	Average efficiency score	Main advantages
3D scanning and modeling	19	42,2%	4,3	High-precision playback, archival storage
Virtual reality technologies	12	26,7%	4,7	Immersive experience, educational potential
Digital databases and repositories	11	24,4%	4,1	Systematization, accessibility
Augmented reality technologies	8	17,8%	4,0	Interactivity, mobility

Artificial intelligence and machine learning	6	13,3%	4,6	Automation, pattern recognition
Blockchain technologies	4	8,9%	3,9	Copyright protection, authenticity
Cloud platforms	15	33,3%	4,2	Scalability, cost-effectiveness

Note: the total number exceeds 45 due to the use of combined technological solutions in most projects
Source: compiled by the authors on the basis of their own technological audit "Digital solutions for the preservation of cultural heritage: an international review 2019-2024" (research registration number: UA-DIGI-HERITAGE-2024-001). The audit included an analysis of technical documentation, interviews with project managers, and an assessment of user experience. The full report is available here: [internal research, ARVM Foundation archive]

Projects that integrate artificial intelligence to automate the cataloging and analysis of cultural artifacts deserve special attention. Bentkowska-Kafel et al. (2021) emphasize that integrating digital technologies in art history requires careful consideration of methodological approaches to ensure scholarly rigor while embracing technological innovation. The study by Alazzam et al. (2023) emphasizes the importance of developing information models for e-commerce platforms, which is directly related to the creation of digital markets for cultural heritage. The results showed that the use of machine learning algorithms can reduce the processing time of archival materials by 67% and increase the accuracy of attribution of cultural objects by up to 94%. Alazzam et al. (2023) emphasize the importance of developing information models for e-commerce platforms, which is directly related to the creation of digital markets for cultural heritage.

An analysis of the financial models of the projects revealed three main approaches to ensuring the sustainability of digital initiatives: public funding (48.9% of projects), public-private partnerships (33.3%), and crowdfunding campaigns (17.8%). The highest indicators of long-term sustainability were demonstrated by projects that combined public support with private investment and public engagement.

The analysis of regions showed the peculiarities of approaches to digital preservation. The European projects were typified by inter-institutional collaboration and high standardization secured by Europeana and other pan-European platforms. North American projects were seen to take the lead in the field of technological advancement, particularly in applying the concept of artificial intelligence and machine learning to Cultural data processing.

The Asian projects also revealed a peculiar way of maintaining the intangible cultural heritage based on emphasis on recording the way of practice and knowledge. The study by Sydorov et al. (2020) about descriptive models of software ecosystems

can be used to define the interactions that arise in digital cultural heritage ecosystems where various technological elements are combined to form a complete archival environment.

Specifically, initiatives to help preserve religious heritage were of interest, as the total number of initiatives considered was 28.9% of the initiatives. The most distinctive feature of this type of project was the added sensitivity to cultural concerns and digital preservation ethics. The findings indicated that the effective introduction of such programs presupposes the collaboration with religious societies and the observance of certain procedures to gain access to objects and texts of religion.

Expert assessment of current challenges and opportunities of digital archiving

The systematized expert survey of 40 professionals in 8 countries gave us a full picture of the existing situation and the future of digital archiving. The possibility of quantitative analysis of the opinion of experts through the application of an online survey method with a five-point Likert scale was made possible, and at the same time, free-format questions were used in order to reveal some aspects and specifics of professional activity. Expert character:

- professional specialization: museum directors (12 people), archivists (8 people), IT engineers who previously worked in the cultural segment (7 people), cultural scientists (6 people), digital humanities experts (4 people), digitalization of cultural heritage consultants (3 people);
- work experience: the number of 18 experts with more than 15 years of experience is 18, the number of experts with 10-15 years of experience is 14, and the number of experts with 5-10 years of experience is 8;
- by geographical place: Germany (8 experts), the United States (7 experts), the United Kingdom (6 experts), France (5 experts), Italy (4 experts), Canada (4 experts), the Netherlands (3 experts), Sweden (3 experts);
- by institution type: national museums and archives (22 experts), university centers of digital humanities (10 experts), Private IT companies specializing in cultural heritage (5 experts), international organizations (3 experts).

The demographic segment of respondents was marked by high professional competence: 80% of the specialists (32 respondents) has over 10 years of experience in the sphere of cultural heritage, 95% (38 respondents) were directly engaged in the work in the sphere of digitalization of materials, 55% (22 respondents) took leading positions in the work of cultural institutions. The practical geographical representation focused primarily on the countries of Europe (62.5% – 25 experts) and North-America

(27.5% – 11 experts), and a minor representation of other regions (10.0% – 4 experts). The analysis of the financial models of the projects revealed three main approaches to ensuring the sustainability of digital initiatives: public funding (48.9% of projects), public-private partnerships (33.3%), and crowdfunding campaigns (17.8%). Ridge (2020) demonstrates that crowdsourcing initiatives provide financial support, enhance public engagement, and create sustainable communities around cultural heritage preservation.

An analysis of the main challenges of digital archiving is presented in Table 3. The experts identified the need for professional training as the most critical problem (average score 4.7), reflecting the rapid pace of technological development and the need for constant updating of knowledge. Financial constraints were ranked second in importance (4.5 points), and this problem is particularly acute for regional museums and archives with limited budgets.

Table 3. Rating of the main challenges of digital archiving of cultural heritage (according to experts)

Challenge	Average score (1-5)	Percentage of experts who rated it as critical (4-5 points)	Regional peculiarities
The need for professional training	4,7	88% (35 experts)	Most acute in Eastern Europe
Financial constraints	4,5	83% (33 experts)	Critical for regional institutions
Technical limitations of the infrastructure	4,3	75% (30 experts)	Relevant outside the EU and the US
Legal and ethical issues	4,1	68% (27 experts)	Especially important for religious heritage

Source: results of an expert survey of cultural heritage professionals (n=40)

Technical limitations of the infrastructure received high marks (4.3 points), especially from experts from developing countries, where insufficient internet bandwidth and outdated equipment pose serious obstacles to the implementation of ambitious digitalization projects. Brown and Miller (2023) analyze the transformation of cultural institutions during crisis periods, focusing on the significance of digital systems' adaptability and flexibility. Experts also paid a lot of attention to the legal and ethical aspects of digital archiving (4.1 points), particularly to the topic of religious heritage preservation.

The respondents said that special protocols to work with sacred objects should be developed and that indigenous people's cultural tradition should be considered

during the digital documentation of indigenous people's heritage. Table 4 shows the evaluation of the current technological solutions' efficiency.

Cloud storage technologies received the highest scores (4.6 points), which is justified by the fact that they are accessible, scalable, and relatively lower in the cost of implementation. The technologies of artificial intelligence applying automatic cataloging were also tested to be quite efficient (4.4 points) regarding the processing of large archival collections.

Table 4. Expert evaluation of the effectiveness of technological solutions for digital archiving

Technological solution	Average efficiency rating (1-5)	Implementation rate (%)	Development forecast until 2030
Cloud storage technologies	4,6	84%	Mass implementation
AI for automatic cataloging	4,4	31%	Exponential growth
High-resolution 3D scanning	4,3	67%	Steady growth
Blockchain for copyright protection	4,1	12%	Gradual implementation
Virtual reality	4,0	43%	Significant expansion
Augmented reality	3,9	28%	Growth in the education sector
IoT for conservation monitoring	3,7	19%	Niche use
Quantum storage technologies	3,2	2%	Prospective research

Source: expert assessment of technological solutions (n=40)

The analysis of regional differences revealed interesting patterns in approaches to digital archiving. European experts demonstrated the highest level of optimism about the prospects for interinstitutional cooperation (average score of 4.2), which correlates with the successful experience of implementing pan-European digital platforms. North American experts showed the greatest interest in the introduction of artificial intelligence technologies (4.7 points), while Asian experts emphasized the importance of cultural sensitivity in digitalization processes.

Particularly noteworthy are the results of the analysis of the prospects for digital archiving development until 2030. 89% of experts predicted a significant increase in the use of cloud technologies, 76% expected widespread adoption of artificial intelligence solutions, and 64% anticipated the integration of virtual and augmented reality technologies into standard museum practices.

Cook's (2021) study on archives and digital transformation emphasizes the growing importance of technological adaptation in archival practices. Experts noted

that the future of archiving will increasingly depend on the effective integration of traditional archival practices with innovative digital technologies.

The analysis of the experts' open-ended responses revealed several key trends. First is the growing importance of an interdisciplinary approach combining technical knowledge with an understanding of the cultural context. Secondly, there is a need to develop ethical standards for digital preservation, especially for indigenous heritage and religious artifacts. Third is the need to create sustainable financial models to provide long-term support for digital archives.

Cluster analysis of experts' responses allowed us to identify three main groups of approaches to digital archiving: technology-oriented (32% of respondents), humanitarian-oriented (41%), and balanced (27%). Representatives of the technology-oriented approach emphasized the primacy of technical solutions, while supporters of the humanities-oriented approach emphasized the importance of cultural context and ethical aspects. The balanced approach group demonstrated the highest success rates of implemented projects (87% of successful initiatives versus 64% and 71%).

The results of the correlation analysis showed a strong relationship between the level of inter-institutional cooperation and the success of digitalization projects ($r=0.73$, $p<0.001$). There is also a significant relationship between investment in professional training and the long-term sustainability of digital archives ($r=0.68$, $p<0.001$), confirming the human factor's critical importance in the digital transformation of the cultural sphere.

Development of a conceptual model of sustainable development of the digital ecosystem of monuments

System analysis and modeling using the SWOT analysis method allowed us to develop a comprehensive conceptual model for sustainable digital ecosystem development for cultural heritage preservation. The empirical basis for developing the model was a detailed case study of the process of digital preservation of the cultural and religious heritage of the Nenets people, which has been implemented since 2024 at the ARVM Cultural Heritage Preservation Foundation (Kyiv, Ukraine).

The digitization of the Nenets people's heritage covered a significant part of the materials collected by Ukrainian artists Volodymyr Melnychenko and Ada Rybachuk during their expeditions to the Yamalo-Nenets Autonomous Okrug in 1954-1959. Among the preserved artifacts, a special place was occupied by a shamanic tambourine, ritual masks associated with the Ardeev and Varnitsky families from Kolguyev Island, and images of protective spirits known to the Nenets as myadhekhe

and yankata. The pilgrims brought or left these objects to the artists by local people when they worked among the indigenous people of North Asia.

Several hundred photographs and archival records of daily life, rituals practiced, and relations of the artists with the Nenets communities were an important aspect of the digitization project. Those photographs became an invaluable archival photo document of the Soviet-period Nenets' everyday culture, showing the diversity of its local customs, such as dressing, arts, buildings, and methods of transportation, and gave a fascinating foreknowledge of how indigenous people survived and adapted in the North Asian reality.

The methodological approaches developed for this project have proven applicable to similar initiatives, including ongoing efforts to preserve Ukrainian musical folklore, where the integration of audio recordings, musical notation, and ethnographic documentation requires equally careful attention to cultural authenticity and community involvement.

Since 2024, a project has been underway to digitally preserve the cultural and religious heritage of the Nenets people housed in the Cultural Heritage Preservation Fund of ARVM (Kyiv, Ukraine). Ukrainian artists Volodymyr Melnychenko and Ada Rybachuk collected a significant portion of these materials during their expeditions to the Yamalo-Nenets Autonomous Okrug between 1954 and 1959. Among the preserved artifacts are a shamanic drum, ritual masks associated with the Ardeyev and Varnitsyn clans from Kolguyev Island, as well as depictions of protective spirits known to the Nenets as myadhekhe and yankata. These objects were either gifted or entrusted to the artists by local residents during their work among the Indigenous peoples of Northern Asia.

An important component of the digitization effort involves several hundred archival photographs documenting everyday life, ritual practices, and the artists' interactions with Nenets communities. These images serve as a valuable visual record of the Nenets daily culture during the Soviet period. They capture a wide range of traditional practices, including clothing, crafts, housing structures, and means of transportation, offering unique insights into both the persistence and adaptation of Indigenous lifeways in the North Asian context.

The SWOT analysis of the Nenets heritage digitization project revealed the main factors of success and risks, as was summarized in Table 5. The uniqueness and the historical significance of the materials are considered to be one of the project's strengths (importance score of 4.8 points), and experts evaluated the availability of the meticulous documentation of the origin of the artifacts as well. The opportunities were assessed as the most significant, with the possibility of international collaboration and

establishing the precedent of conducting such projects to save the heritage of indigenous states.

Table 5. SWOT analysis of the project of digital preservation of the Nenets heritage

Factor	Description	Rating of importance (1-5)	Strategic recommendations
	Strengths		
Uniqueness of materials	Rare artifacts of the mid-20th century	4,8	Maximizing public access
Professional documentation	Detailed records of research artists	4,6	Creating high quality metadata
Cultural authenticity	Materials donated by the culture bearers themselves	4,7	Involvement of Nenets communities in the project
	Weaknesses		
Fragmentation of the collection	Incompleteness of some series of artifacts	3,9	Search for additional materials
Technical condition of some materials	The need for restoration of certain objects	4,2	Preventive conservation
	Features		
International cooperation	Cooperation with Nenets cultural centers	4,5	Partnership agreements
Educational potential	Use in educational programs	4,3	Development of educational resources
Scientific contribution	Contribution to anthropological and cultural studies	4,4	Publications and conferences
	Threats		
Ethical issues	Sensitivity of religious heritage	4,1	Consultations with communities
Technological risks	Data loss, format obsolescence	3,8	Multiple copies, data migration

Source: SWOT analysis of the project to digitize the heritage of the Nenets people (2024)

In accordance with the analysis, the system of interactions between participants of the digital ecosystem of cultural heritage preservation was created (Table 6). The matrix indicates various actors' degrees of responsibility and interaction in the digital archiving process, from local cultural communities to the international ones. Shevchenko and Kopievska (2019) provide theoretical foundations for socio-cultural management that inform the development of effective stakeholder engagement strategies in cultural heritage preservation. The article by Volynets (2020) focused on the new content and prospects of the virtual museum, underlining the necessity to

realize digital platforms as socio-cultural arenas in which the active involvement of all parties is needed.

Table 6. Matrix of interaction between stakeholders of the digital ecosystem of cultural heritage preservation

Steakholder	**Primary functions**	**Level of involvement**	**Key resources**	**Expected results**
Cultural communities	Carriers of traditions, consultants	High	Knowledge, permissions, authenticity	Preservation and transmission of heritage
Cultural institutions	Storage, cataloging	High	Expertise and infrastructure	Digital collections, research
Technology partners	Development, implementation	Medium	Technologies, innovations	Effective solutions
Educational institutions	Research, training	Medium	Scientific potential	Knowledge and training
Government agencies	Regulation, financing	Medium	Legal framework, funds	Conservation policy
Private sector	Investments, development	Low-medium	Finance, innovation	Commercial applications
International organizations	Coordination, standards	Low-medium	Global networks	International cooperation
Civil society	Advocacy, support	Variable	Activism, connections	Public support

Source: compiled by the authors based on the analysis of the Nenets Heritage Preservation Project

The five key principles on which the conceptual model of sustainable development of the digital ecosystem rests are interoperability of technologies, cultural sensitivity, economic sustainability, social inclusiveness, and sustainability in environmental terms. The implementation mechanisms and indicators are defined in each of the principles.

The technological interoperability principle suggests that open standards and formats have to be used to make digital archives available in the long term. The assessment of the Nenets Heritage Project revealed that the selection of the storage formats, the use of TIFF as the storage format of images, and the Dublin Core as the storage format of the metadata was of paramount significance in the ability to meet an international standard and to be available on an international digital platform.

The cultural sensitivity can be achieved by engaging cultural bearers at every phase of digitalization. Ludlow and Malcolm (2023) argue that ethical frameworks for indigenous digital heritage must prioritize community sovereignty and self-

determination, ensuring that digitization processes respect traditional knowledge systems and cultural protocols. Within the framework of the project on the preservation of the Nenets heritage, a mutually beneficial dialogue was also built with representatives of Nenets communities due to remote consultations and professional, discreet estimates. This helped us ensure the culture-sensitive information was presented accordingly, and did not conflict with possible ethical issues.

In the study on the organization of digital collections of Ukrainian literature in the web environment conducted by Lobuzin and Perenesienko (2020), the significance of a systematic approach to the creation of digital resources of manuscript and book funds is evidenced. Their practice reveals the necessity of developing the methodology as integratively as possible, bringing together the technique of digitization and the science of cataloging.

Diversifying the funding sources supports the model, establishing self-sufficiency mechanisms that render it economically sustainable. As the financial structure of the Nenets Heritage Project was analyzed, the success of the mixed model was clear: 40 percent of funds were given due to the government grants, 35 percent comes due to the international funds, 15 percent came because of the private donors, and 10 percent belonged to the educational and commercial initiatives.

Social inclusiveness is realized by creating a multi-level system of access to digital resources. Three levels of access have been developed: public (general materials), limited (sensitive cultural objects), and research (full access for research purposes). This gradation allows balancing the principles of openness and cultural sensitivity.

The principle of environmental responsibility is implemented by optimizing the energy consumption of digital systems and using green cloud storage technologies. Peterson and Wang (2024) provide evidence that sustainable digital preservation practices can reduce the carbon footprint by up to 40% while maintaining long-term accessibility of cultural heritage materials. Cloud service providers were selected based on their commitment to using renewable energy sources.

The developed model was validated through an expert evaluation by 15 international experts in the field of digital humanities. The average relevance score of the model was 4.3 points (out of 5 possible), and 87% of the experts confirmed its potential for replication in other contexts of cultural heritage preservation.

The modeling results showed that successful implementation of the conceptual model requires investment in three key areas: technological infrastructure (35% of the budget), professional training (30%), and cultural interaction (25%). The remaining funds (10%) should be used to ensure the project's long-term sustainability.

The developed model offers specific mechanisms for assessing the effectiveness of digital archiving through a system of key performance indicators (KPIs), including technical metrics (access time, system reliability), social indicators (usage rate, user satisfaction), and cultural parameters (authenticity of representation, level of community involvement).

The study made it possible to comprehensively analyze current trends in digital archiving of cultural and religious heritage and develop practical recommendations for improving the efficiency of cultural memory preservation in the digital environment.

The analysis of 45 international projects for the digitalization of cultural heritage revealed the dominance of European initiatives (53.3%) with high efficiency indicators (4.2 points), due to the developed technological infrastructure and active policy of the European Union. The most common technological solutions were 3D scanning and modeling (42.2% of projects), while virtual reality technologies demonstrated the highest efficiency (4.7 points). It was found that blended finance projects showed the best results in terms of long-term sustainability compared to mono-source funding.

An expert survey of 40 experts from 8 countries identified the key challenges of digital archiving: the need for professional training (4.7 points), financial constraints (4.5 points), and technical infrastructure limitations (4.3 points). Experts identified cloud storage technologies (4.6 points) and artificial intelligence for automatic cataloging (4.4 points) as the most effective technological solutions. The correlation analysis confirmed the critical importance of inter-institutional cooperation ($r=0.73$, $p<0.001$) and professional training ($r=0.68$, $p<0.001$) for the success of digitalization projects.

Based on the case study of the Nenets heritage digitization project, a conceptual model of sustainable development of the digital ecosystem for cultural heritage preservation was developed based on five principles: technological interoperability, cultural sensitivity, economic sustainability, social inclusion, and environmental responsibility. The project's SWOT analysis revealed the materials' uniqueness (4.8 points) as the main strength and the potential for international cooperation (4.5 points) as a key development opportunity.

The developed matrix of stakeholder interaction demonstrated the critical importance of active involvement of cultural communities as bearers of traditions and cultural institutions as centers of professional expertise. Validation of the model by international experts confirmed its relevance (4.3 points) and potential for replication (87% of positive ratings).

The practical significance of the research results is the development of specific recommendations for cultural institutions: prioritizing investments in technological infrastructure (35% of the budget) and professional training (30%), introducing a multi-level system of access to digital resources, and using open standards to ensure interoperability. The cost-effectiveness of projects is increased by diversifying funding sources and creating self-sustaining mechanisms through educational and commercial initiatives.

The scientific novelty of the study is the development of a comprehensive conceptual model that integrates the technological, cultural, and social aspects of digital archiving. A system of key performance indicators for evaluating digital heritage preservation projects is proposed for the first time, including technical metrics, social indicators, and cultural parameters.

The research demonstrates that successful digital preservation of cultural heritage requires systematic integration of advanced digital technologies with traditional archiving practices, ensuring that cultural memory and religious heritage remain accessible through effective collaboration between cultural institutions and innovative preservation methods.

The study's limitations are related to the geographical concentration of experts (90% from Europe and North America), which may affect the universality of the findings for other regions. The analysis timeframe (2019-2024) does not allow us to assess the long-term effects of introducing digital technologies. Technical aspects of cybersecurity and personal data protection require additional research in the context of cultural heritage.

Prospects for further research include the development of standardized protocols for ethical digital archiving of religious heritage, a study of the impact of artificial intelligence technologies on the authenticity of cultural representation, and an analysis of the cost-effectiveness of various models of financing digital archives. A longitudinal study to evaluate the prospects of long-term changes caused by the digitalization of cultural establishments and create specific training programs to form specialists in the field of digitalizing cultural heritage would be recommended.

Discussions

The results of the study allow us to consider the data obtained in the context of modern scientific research and the practical challenges of digital archiving of cultural heritage. A comprehensive analysis of international experience and expert opinions has revealed both coincidences and significant differences with the findings of previous studies in this area.

The identified dominance of European digitalization projects (53.3%) correlates with the research of Alvite-Díez and Barrionuevo (2021), who analyzed the convergence of library and information science and digital humanities in Spain. However, the results obtained demonstrate a much wider geographical coverage and a more detailed typology of technological solutions than in previous works. In particular, the finding that virtual reality technologies are superior in terms of efficiency (4.7 points) contradicts Marty's (2014) findings on the priority of basic digital repositories, which may be explained by technological progress in the last decade.

The results of the expert survey on the key challenges of digital archiving partially coincide with the findings of Botticelli (2021) regarding the importance of professional training. However, the high score of this factor (4.7 points) and the correlation with project success (r=0.68) indicate a more critical role of the human factor than presented in previous studies. Choi's (2020) study on the convergence of memory institutions confirms the importance of an interdisciplinary approach, which is consistent with the results obtained on the effectiveness of a balanced approach to digitalization.

A significant contribution of the study is the identification of regional differences in approaches to digital archiving. Unlike the research of Dubrovina et al. (2021), which focused on the national context, the results demonstrate global trends, taking into account the specifics of different regions. In particular, the identified advantage of Asian projects in preserving intangible heritage expands the understanding of cultural sensitivity in digital archiving beyond the Western conceptual framework. Milnichenko (2025) and Vargas (2024) emphasize the critical role of libraries, archives and museums in preserving Ukraine's heritage, demonstrating how national contexts shape digital preservation approaches during cultural and political transformation.

The developed conceptual model of sustainable development of the digital ecosystem significantly complements the theoretical work of Haux et al. (2021) on the cultural memory of the digital age. The integration of the five principles (technological interoperability, cultural sensitivity, economic sustainability, social inclusiveness, and environmental responsibility) offers a more comprehensive approach than existing models that usually focus on individual aspects of digitalization.

Particularly noteworthy is the analysis of the case of digitizing the heritage of the Nenets people, which demonstrates the practical application of a culturally sensitive approach to digital archiving. This case expands the understanding of the ethical aspects of the digitalization of indigenous heritage, which was not sufficiently covered in previous studies. The identified need for a multi-level access system

(public, limited, research) offers a practical solution for balancing the principles of openness and cultural sensitivity.

The study's results partially contradict the optimistic predictions of Adrian and Kurniawan (2020) regarding the rapid adoption of smart technologies in the cultural heritage field. The identified technical limitations of infrastructure (4.3 points in terms of importance) and financial challenges (4.5 points) indicate the existence of serious barriers to the mass adoption of innovative solutions, especially in developing countries.

The data obtained on the effectiveness of cloud technologies (4.6 points) confirm the trends noted in Le Deuff's (2018) research, but the low popularity of blockchain technologies (8.9% of projects) contrasts with theoretical expectations of their potential for cultural heritage protection. This may indicate a mismatch between technological capabilities and the practical needs of cultural institutions.

The correlation analysis revealed a strong link between inter-institutional cooperation and project success (r=0.73), which confirms the findings of the American Library Association (2010) on the importance of a network approach in the field of cultural heritage. However, the identified variability in regional approaches to cooperation indicates the need to adapt global strategies to local contexts.

The developed matrix of stakeholder interaction expands the understanding of the complex ecosystem of digital archiving beyond the traditional focus on cultural institutions. The identified critical role of cultural communities as bearers of traditions is consistent with the principles of participatory archiving, but requires additional research into the mechanisms of effective engagement of different stakeholder groups.

Limitations of the study related to the geographical concentration of experts and the timeframe of the analysis point to the need to expand the empirical base of future research. In particular, the underrepresentation of experts from Africa and Latin America may affect the universality of the proposed recommendations for the global context.

The practical implications of the study results include the need to reconsider the priorities for investing in the digital infrastructure of cultural institutions. The identified importance of professional training (30% of the recommended budget) requires the development of specialized educational programs that combine technical skills with an understanding of the cultural context.

The developed conceptual model has the potential to be adapted to different contexts of cultural heritage preservation, but it needs empirical validation through long-term longitudinal studies. Further research on economic models of digital

archives sustainability and the development of standardized metrics for evaluating the effectiveness of digitalization projects deserves special attention.

Conclusions

The study made it possible to comprehensively analyze current trends in digital archiving of cultural and religious heritage and develop practical recommendations for improving the efficiency of cultural memory preservation in the digital environment.

The analysis of 45 international projects for the digitalization of cultural heritage revealed the dominance of European initiatives (53.3%) with high efficiency indicators (4.2 points), due to the developed technological infrastructure and active policy of the European Union. The most common technological solutions were 3D scanning and modeling (42.2% of projects), while virtual reality technologies demonstrated the highest efficiency (4.7 points). It was found that blended finance projects showed the best results in terms of long-term sustainability compared to mono-source funding.

An expert survey of 40 experts from 8 countries identified the key challenges of digital archiving: the need for professional training (4.7 points), financial constraints (4.5 points), and technical infrastructure limitations (4.3 points). Experts identified cloud storage technologies (4.6 points) and artificial intelligence for automatic cataloging (4.4 points) as the most effective technological solutions. The correlation analysis confirmed the critical importance of inter-institutional cooperation ($r=0.73$, $p<0.001$) and professional training ($r=0.68$, $p<0.001$) for the success of digitalization projects.

Based on the case study of the Nenets heritage digitization project, a conceptual model of sustainable development of the digital ecosystem for cultural heritage preservation was developed based on five principles: technological interoperability, cultural sensitivity, economic sustainability, social inclusiveness, and environmental responsibility. The project's SWOT analysis identified the materials' uniqueness (4.8 points) as the main strength and the potential for international cooperation (4.5 points) as a key development opportunity.

The developed matrix of stakeholder interaction demonstrated the critical importance of active involvement of cultural communities as bearers of traditions and cultural institutions as centers of professional expertise. Validation of the model by international experts confirmed its relevance (4.3 points) and potential for replication (87% of positive ratings).

The practical significance of the research results is the development of specific recommendations for cultural institutions: prioritizing investments in technological infrastructure (35% of the budget) and professional training (30%), introducing a multi-level system of access to digital resources, and using open standards to ensure interoperability. The economic efficiency of projects is increased by diversifying funding sources and creating self-sustaining mechanisms through educational and commercial initiatives.

The study's limitations are related to the geographical concentration of experts (90% from Europe and North America), which may affect the universality of the findings for other regions. The period of analysis (2019-2024) is insufficient to measure the long-term impact of implementing digital technologies. Cybersecurity and personal data protection are noted to be more technical areas that also need further investigation on the subject of cultural heritage.

The potential topics of additional studies can be the formulation of a unified ethical approach to the digital archiving of religious heritage, the investigation of the influence of artificial intelligence technologies on the validity of the cultural presentation, and an exploration of the economic viability of different kinds of funding for digital archives. Conducting a longitudinal study to understand the long-term effects of digital transformation of cultural institutions and creating special educational programs to train specialists in the field of digital archiving of cultural heritage will be recommended.

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Conflicts of Interests

The authors declare no conflict of interest.

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Appendix A

Questionnaire of the expert survey "Digital archiving of cultural heritage"

Part 1. General Information about the Respondent

Please specify your country of work: _____

Type of organization where you work:

□ National Museum/Archive

□ Regional museum/archive

□ University/research center

□ IT company

□ Consulting firm

□ International organization

□ Other: _____

Your position: _____

Experience in the field of cultural heritage:

Up to 5 years old

□ 5-10 years

□ 10-15 years

□ Over 15 years of experience

Have you participated in projects to digitalize cultural heritage?

□ Yes, as a project manager

□ Yes, as a team member

□ Yes, as a consultant

□ No.

Part 2. Assessing the Challenges of Digital Archiving

Please rate the importance of the following challenges on a scale of 1-5, where 1 is insignificant and 5 is critical:

The need for professional training: 1 2 3 4 5

Financial constraints: 1 2 3 4 5

Technical limitations of the infrastructure: 1 2 3 4 5

Legal and ethical issues: 1 2 3 4 5

Standardization of processes: 1 2 3 4 5

Long-term data retention: 1 2 3 4 5

Inter-institutional cooperation: 1 2 3 4 5

Part 3. Efficiency of Technological Solutions

Assess the effectiveness of technologies for digital archiving (1-5 points):

Cloud storage technologies: 1 2 3 4 5
AI for automatic cataloging: 1 2 3 4 5
High-resolution 3D scanning: 1 2 3 4 5
Blockchain for copyright protection: 1 2 3 4 5
Virtual reality: 1 2 3 4 5
Augmented reality: 1 2 3 4 5
IoT for conservation monitoring: 1 2 3 4 5

Part 4. Development Prospects

How do you assess the prospects for the development of inter-institutional cooperation in your region? (1-5 points): ____
What technologies do you think will have the greatest impact on digital archiving by 2030?
□ Artificial intelligence
□ Virtual reality
□ Blockchain
□ Quantum technologies
□ Cloud solutions
□ Other: _____

Part 5. Open Questions

What are the main barriers to the implementation of digital technologies in your institution?
What competencies do digital archiving professionals lack the most?
What are the most problematic ethical aspects of the digitalization of cultural heritage?
Additional comments and suggestions:

Thank you for participating in the survey!