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ARCHIVAL FONDS OF UKRAINIAN STATE ARCHIVES IN CONTEXT OF PRINCIPLES OF OPEN SCIENCE

Purpose. To examine the state of Ukrainian archival institutions within the framework of open science and data management principles aimed at ensuring accessibility, interoperability, and reuse of information. **Methodology.** The study applies a complex approach combining comparative analysis of international practices, evaluation of digital infrastructure, archival description standards, metadata use, and identifier systems. **Scientific novelty.** The article conceptualizes archives as a key knowledge infrastructure



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that supports not only the preservation of documentary heritage, but also integration into global research ecosystems; it identifies the level of compliance of Ukrainian archives with modern data management approaches and reveals systemic limitations. **Conclusions.** Despite ongoing digitization and expansion of online access, the development of the archival sector remains fragmented and insufficiently aligned with international standards. The findings demonstrate the need for comprehensive modernization, including digital infrastructure development, metadata harmonization, implementation of identifiers, professional capacity building, and policy improvement. The strategic importance of digital resilience under wartime risks is emphasized, as well as the role of open science in safeguarding and promoting Ukraine's documentary heritage in the global research space.

Key words: archival fonds, open science, FAIR principles, Ukrainian state archives, digitization, metadata, national memory, cultural resilience, information infrastructure.

Introduction. In recent decades, the paradigm of open science has profoundly transformed the organization of scholarly communication, research data management, and access to knowledge. Open science promotes transparency, reproducibility, collaboration, and public engagement, redefining how research outputs are created, disseminated, and reused. While its principles were initially articulated within the natural and technical sciences, they are increasingly recognized as critically important for the humanities, including archival studies, library science, and the broader domain of documentary heritage. Archives, as custodians of unique primary sources and structured documentary evidence, occupy a central position in the knowledge infrastructure of society. They serve not only as repositories of historical memory but also as providers of primary research data. For this reason, archival institutions cannot remain outside contemporary discussions on openness, accessibility, interoperability, and data-driven research practices.

For Ukraine, the **integration of archival institutions into the framework of open science has particular urgency and strategic importance.** Ukrainian archives preserve a vast and irreplaceable corpus of documentary heritage, ranging from medieval records and imperial administration files to documents of modern statehood, civil society, and cultural life. These materials constitute a fundamental empirical base for historical, legal, political, sociological, and digital humanities research. At the same time, despite their richness, archival resources in Ukraine remain largely fragmented, unevenly digitized, and insufficiently integrated into national and international research infrastructures. Access often depends on physical consultation, local catalog systems, or institution-specific digital platforms that lack interoperability.

In the context of European integration, participation in international research programs, and alignment with European research policy frameworks, the transformation of archival practices becomes not only a technological challenge but also a structural task for strengthening Ukraine's research ecosystem. Furthermore, the ongoing war and risks to cultural heritage intensify the necessity of systematic digital preservation, distributed storage, and resilient access me-

chanisms. In this environment, the modernization of archival infrastructure is directly connected to issues of cultural continuity, scholarly visibility, and information security.

However, the obstacles facing Ukrainian archives are not limited to technical digitization gaps. The archival system has historically developed within a custodial paradigm that prioritized preservation, legal compliance, and controlled access over openness and data sharing. As a result, several systemic barriers hinder effective integration into open science. Digitization initiatives are often project-based and dependent on temporary funding cycles, leading to partial and selective digital coverage of collections. Metadata practices remain heterogeneous, frequently based on legacy cataloging traditions that are not fully compatible with machine-readable standards. Persistent identifiers for archival objects are rarely implemented, limiting stable citation and international discoverability. In addition, the absence of standardized APIs and unified search mechanisms restricts automated harvesting and cross-institutional data integration. Legal ambiguities concerning copyright, personal data protection, and reuse conditions further complicate the development of open access models.

The application of the FAIR principles (Findable, Accessible, Interoperable, Reusable) to archival collections offers a conceptual framework for systematically addressing these challenges. FAIR principles emphasize persistent identifiers, standardized and structured metadata, machine-readable formats, and clearly defined licensing conditions. Yet the transfer of FAIR concepts to archival practice requires careful adaptation. Archival description is hierarchical and context-dependent, organized around fonds, series, and files rather than discrete datasets. Consequently, the assessment of archives through a FAIR lens demands a nuanced understanding of both information infrastructure and archival theory. Despite growing international discussion of FAIR data, the archival sector particularly in post-Soviet and Eastern European contexts has received comparatively limited analytical attention. In Ukraine, open science discourse has largely focused on scholarly publications, institutional repositories, and researcher identifiers, while archival data infrastructures have remained peripheral to policy debates.

This article **aims** to analyze the current state of major archival institutions in Ukraine through the combined perspective of open science and FAIR principles. It examines how archival collections function as elements of national research infrastructure and evaluates their degree of compliance with the criteria of findability, accessibility, interoperability, and reusability. The study identifies structural, technological, normative, and professional obstacles that limit the transformation of archives from primarily custodial repositories into fully integrated components of the open science ecosystem.

Theoretical and Methodological Framework. The transformation of archives in the digital age must be understood within the broader shift from a custodial to an infrastructural model of knowledge governance. Traditionally, archival

institutions were primarily oriented toward preservation, legal compliance, and controlled access. Their core function was to ensure the long-term custody and authenticity of documentary heritage. Within this paradigm, openness was secondary to stability and institutional responsibility.

The emergence of open science has fundamentally altered expectations regarding access to research materials, data transparency, and interoperability across information systems. Archives are increasingly recognized not only as repositories of historical documents but also as providers of primary research data that can be reused, reinterpreted, and computationally analyzed. This reconceptualization situates archival institutions within national and international research infrastructures, where digital discoverability, metadata standardization, and machine readability become central requirements.

However, the integration of archives into open science frameworks is not a straightforward process. Archival description is inherently hierarchical and context-dependent. Records are organized according to provenance, fonds, series, and files rather than as discrete datasets. The meaning of archival documents is embedded within their institutional and historical context, which complicates direct alignment with data-driven models developed for scientific datasets. Therefore, the application of open science standards to archives requires theoretical adaptation rather than mechanical transfer.

In transitional contexts such as Ukraine, this tension is particularly visible. Archival institutions operate within legal and administrative traditions that emphasize state custody and documentary authority. At the same time, they face increasing pressure to align with European research policies that prioritize openness, interoperability, and integration into federated digital ecosystems. This duality forms the conceptual foundation of the present study.

The FAIR principles (Findable, Accessible, Interoperable, Reusable) are widely used in research data management to promote structured, machine-actionable, and reusable data infrastructures. In this study, FAIR principles are employed not as a prescriptive technical checklist but as a conceptual and analytical lens for evaluating archival information systems.

Applying FAIR to archives requires reinterpretation.

- **Findability** in archival contexts involves structured metadata, searchable catalogs, stable identifiers, and discoverability across institutional boundaries.
- **Accessibility** refers not only to the presence of digital copies but also to technical stability, clear access protocols, and sustainable online platforms.
- **Interoperability** concerns the use of standardized metadata schemas, authority control, semantic linking, and compatibility with external research infrastructures.
- **Reusability** depends on contextual metadata, documentation of provenance, clarity of legal conditions, and technical formats suitable for computational analysis and long-term preservation.

Rather than measuring formal compliance, the study analyzes the functional role of these elements within archival infrastructures. The central question is not whether individual technical components exist, but whether they operate as part of a coherent system capable of supporting open science workflows.

The research adopts an interdisciplinary qualitative methodology that integrates archival studies, information science, and open science scholarship. The focus lies on the technical and infrastructural characteristics of archival information systems in Ukraine.

The empirical basis consists of:

- Electronic catalogs and online finding aids
- Publicly available digital collections
- Institutional documentation regulating archival description and access
- Methodological guidelines and regulatory acts.

The analysis examines how archival materials are described, structured, and represented in digital environments. Particular attention is given to hierarchical description levels (fonds, series, file, item) and the extent to which these descriptions are adapted for use beyond internal archival systems.

The technical organization of online platforms is also evaluated, including:

- Search functionality
- Navigation logic
- Cross-collection discoverability
- Stability of URLs and digital references.

This approach allows assessment of both descriptive practices and system architecture.

A central methodological component of the study is the examination of metadata structures and standardization practices. The analysis focuses on:

- Consistency of descriptive formats
- Presence of structured and machine-readable metadata
- Alignment with internationally recognized approaches to archival description
- Use of authority control for personal names, institutions, and geographic entities
- Possibility of semantic linking between archival records and external resources.

Metadata quality is interpreted as a key prerequisite for interoperability. Where metadata remains narrative, non-standardized, or locally formatted, integration with national or international research infrastructures becomes technically limited.

The study also assesses whether archival systems provide mechanisms that enable external harvesting or automated reuse, such as APIs or exportable structured formats. The absence of such mechanisms is treated as a systemic barrier rather than a purely technical omission.

Access and reuse are analyzed from a technical and infrastructural perspective. The study evaluates:

- Formats of digital copies
- Technical access restrictions
- Authentication requirements
- Stability of download mechanisms
- Clarity of legal and licensing conditions.

Beyond individual viewing, the analysis considers whether systems support computational reuse, aggregation, or integration into digital humanities workflows. Technical constraints are interpreted alongside institutional and regulatory factors that shape archival policy.

The final stage of the methodology involves synthesizing findings across multiple archival institutions. By correlating observed technical characteristics with the FAIR analytical framework, the study identifies recurring patterns, systemic weaknesses, and structural asymmetries within the Ukrainian archival landscape.

This approach allows for evaluation of institutional readiness not only at the level of individual archives but at the level of national archival infrastructure. The methodological orientation of this study is informed by several influential international research initiatives. The InterPARES (International Research on Permanent Authentic Records in Electronic Systems) project represents one of the most significant global efforts to conceptualize digital preservation, authenticity, and long-term usability of electronic records [3]. Although InterPARES was not framed explicitly within open science discourse, its emphasis on standardized metadata, contextual documentation, and interoperable preservation workflows aligns closely with FAIR principles. For archival institutions undergoing digital transformation, including those in Ukraine, InterPARES provides a foundational model for linking archival description, technological infrastructure, and legal frameworks.

Research by Dasgupta and Nuyujukian [2] expands this perspective by proposing an open framework for preserving scientific artefacts including data, code, and computational environments in a manner that ensures transparency and reproducibility. While broader than traditional archival contexts, their framework underscores the importance of structured documentation and technical standardization for enabling reuse, which has direct implications for archival systems managing born-digital and research-related materials.

Singh, Nagpal, Jadhav, and Madalli [7] provide a systematic review of FAIR implementation frameworks, identifying technical parameterization methods and highlighting limitations in current assessment tools. Their analysis reveals that many FAIR evaluation models prioritize technical metrics while underestimating social and institutional dimensions. This insight is particularly relevant for archival institutions, where professional culture, institutional mandates, and governance structures significantly influence digital transformation.

Qualitative research examining the integration of open research data into archival workflows further demonstrates practical barriers such as institutional fragmentation, unclear responsibilities, and inconsistent terminology [1; 9]. These findings resonate strongly with the Ukrainian context, where coordination between archives, universities, and research institutions remains limited.

Finally, Rachynska [6] provides an important national perspective by analyzing open science implementation across Ukrainian higher education and research institutions. Her findings reveal a heterogeneous landscape characterized by uneven adoption of open access policies and research data management practices. While focused primarily on universities, this study highlights broader systemic barriers technical, regulatory, and organizational that also shape the archival sector. The present research extends this national open science analysis specifically to archival infrastructures, addressing a gap in existing scholarship [10; 11].

Together, these methodological and theoretical foundations enable a comprehensive assessment of Ukrainian archival institutions as evolving components of research infrastructure. By integrating archival theory, technical system analysis, and FAIR-based evaluation, the study moves beyond descriptive institutional review and provides a structured framework for understanding both the limitations and transformative potential of Ukrainian archives within the global open science ecosystem.

Institutional Structure of the Ukrainian Archival System. The Ukrainian archival system represents a vertically organized yet functionally heterogeneous network of institutions operating under the coordination of the State Archival Service of Ukraine. Formally, the system is centralized in governance but decentralized in operational capacity. Central state archives, specialized repositories, and regional archival bodies function within a unified legal framework, yet they differ significantly in terms of technical infrastructure, digitization strategies, staffing capacity, and integration into digital environments. This structural configuration directly shapes the possibilities and limitations of implementing open science principles across the archival sector.

The legal and administrative foundations of the archival system were largely formed in a period when preservation, custodial responsibility, and documentary control were the primary institutional priorities. Archival legislation emphasizes the safeguarding of documentary heritage and regulated access procedures, reflecting a state-centered model of information governance. While such a framework ensures formal stability and accountability, it does not automatically generate incentives for interoperability, open data publication, or integration into international research infrastructures. As a result, openness initiatives often emerge not from systemic policy mandates but from institutional initiative or externally funded projects. This creates uneven development trajectories across the archival landscape.

At the apex of the system are the central state archives, which preserve nationally significant collections and typically possess comparatively stronger

institutional capacity. These institutions hold vast fonds that document political, social, administrative, and cultural processes over several centuries. Their scale and visibility position them as key actors in any national digital transformation strategy. However, their size also generates infrastructural complexity. Large-scale digitization of multi-million-unit holdings requires sustained financial investment, robust technical architecture, and highly specialized metadata management. In practice, digitization in central archives tends to prioritize high-demand or symbolically significant collections, resulting in selective digital representation rather than comprehensive coverage. This selective approach enhances public visibility but limits systemic interoperability and research-scale integration.

Specialized archives, including those devoted to literature, art, audiovisual materials, or public associations, present a different institutional profile. Their collections are often thematically concentrated and culturally distinctive. These institutions frequently engage in public outreach activities, digital exhibitions, and thematic online presentations aimed at increasing social engagement with archival heritage. While such initiatives strengthen public access and visibility, they do not necessarily correspond to the technical requirements of open science infrastructures. Exhibition-oriented digitization may emphasize visual presentation and narrative framing rather than machine-readable metadata, persistent identification, or API-based access. Consequently, the digital presence of specialized archives may be substantial in appearance but limited in terms of interoperability and computational reuse.

Regional archives and territorial bodies constitute another critical dimension of the institutional structure. They preserve administrative records, local governance documentation, and regionally significant materials that are indispensable for social, legal, and historical research. However, their technical capacities often vary considerably depending on regional funding, staffing levels, and local administrative support. In many cases, digitization initiatives are project-based and dependent on short-term grants or local partnerships. Digital catalog interfaces may differ in design and functionality, reflecting the absence of a unified national platform. This variability generates what may be described as digital asymmetry within the national archival system: researchers encounter uneven levels of access, inconsistent metadata practices, and incompatible digital tools across institutions. Such asymmetry significantly complicates cross-regional comparative research and limits the feasibility of aggregated queries across multiple archival repositories.

An additional structural characteristic of the Ukrainian archival system is the limited horizontal integration among institutions. Although all archives formally operate within a common administrative framework, practical data exchange mechanisms and shared digital infrastructures remain underdeveloped. Institutional culture further influences structural dynamics. Archival professionals in Ukraine are trained primarily within traditions emphasizing authenticity, pro-

venance, and documentary preservation. While these principles remain foundational, the integration of open data practices, semantic web technologies, and research data management competencies has progressed gradually. The transformation from custodial repository to infrastructural data provider requires not only technical investment but also a shift in professional orientation. Without institutional incentives and strategic alignment with national research policies, modernization efforts risk remaining partial and localized.

The broader political and socio-economic environment also shapes the institutional landscape. Ongoing security challenges and risks to cultural heritage underscore the urgency of digital preservation and distributed storage. However, emergency conditions may prioritize immediate stabilization over long-term infrastructural redesign. Thus, Ukrainian archives operate within a context where strategic modernization must coexist with crisis management and resource constraints. This tension complicates the implementation of comprehensive digital governance strategies aligned with European open science frameworks.

Taken together, the institutional structure of the Ukrainian archival system reveals a paradox. On the one hand, the system possesses a coherent administrative framework, a rich documentary base, and growing awareness of digital transformation needs. On the other hand, infrastructural fragmentation, uneven technological adoption, and limited cross-institutional integration hinder systemic modernization. The challenge is therefore not only technological but structural: achieving meaningful integration into open science requires coordinated policy development, harmonized metadata standards, sustainable funding mechanisms, and a redefinition of archival institutions as active nodes within national and international research ecosystems.

Assessment of Major Ukrainian Archival Institutions. The empirical assessment of major Ukrainian archival institutions reveals a landscape characterized by visible digital progress alongside persistent infrastructural fragmentation. While leading archives have undertaken substantial efforts to expand online access and digitize selected collections, these initiatives remain uneven in scope, technically heterogeneous, and only partially aligned with the systemic requirements of open science. The analysis demonstrates that digital presence does not automatically translate into interoperability or long-term infrastructural sustainability.

The Central State Historical Archive of Ukraine in Kyiv occupies a central position within the national archival system due to both the scale and historical depth of its holdings. Its collections encompass documentation from medieval periods through imperial administrations and into modern state formation, making it a critical source for domestic and international scholarship. The archive has invested in the development of electronic catalogs, digital copies of selected fonds, and enhanced descriptions accessible through online platforms. These efforts have significantly improved remote visibility and facilitated access for researchers unable to conduct on-site consultations.

However, a closer examination of the digital infrastructure reveals structural limitations. Although the volume of digitized material is substantial in absolute terms, it represents only a fraction of the total holdings. Digitization priorities appear to be shaped by public demand, symbolic significance, or available project funding rather than by a comprehensive infrastructural strategy. Metadata structures often reflect legacy descriptive practices that, while archivally accurate, are not consistently optimized for machine readability or cross-platform interoperability. The absence of persistent identifiers for individual archival objects limits stable citation and integration with external research systems. Furthermore, digital access mechanisms sometimes rely on temporary storage links or session-based navigation, which raises concerns about long-term stability and sustainable referencing. These characteristics indicate that digital expansion has occurred primarily at the level of access enhancement rather than full infrastructural transformation.

The Central State Archive of Public Associations and Ukrainica presents a different but equally instructive case. Its collections document political parties, civil society organizations, and non-state associations, offering crucial insight into Ukraine's social and political history. The thematic nature of its holdings positions the archive as an important resource for comparative political research and transnational studies. Digital initiatives have improved discoverability through online catalogs and selective publication of digitized materials. Institutional discourse increasingly emphasizes the aspiration to integrate national collections into European discovery environments.

Yet systemic constraints limit this ambition. Metadata schemas vary in granularity and structure, and machine-readable export formats are limited. Authority control for personal names, institutions, and geographic entities is inconsistently implemented, reducing the potential for semantic linking across collections. The lack of standardized APIs restricts automated harvesting and prevents seamless integration with broader research infrastructures. Consequently, although materials are technically available online, their discoverability within global digital ecosystems remains constrained. The gap between institutional aspiration and infrastructural capacity becomes particularly evident when archival data are assessed against FAIR-oriented expectations.

Specialized cultural archives, including those dedicated to literature, art, and audiovisual heritage, exhibit yet another pattern of digital development. These institutions often emphasize thematic online exhibitions, curated digital collections, and visually accessible interfaces aimed at broad public engagement. Such initiatives enhance societal visibility and contribute to cultural dissemination. However, exhibition-oriented digitization frequently prioritizes presentation over structured metadata depth. Digital objects may be embedded within narrative frameworks without accompanying machine-readable contextual data that would allow systematic aggregation or computational reuse. As a result, these

archives achieve strong national cultural presence while remaining only partially integrated into research-oriented data infrastructures.

Regional and territorial archives further illustrate the asymmetrical character of digital transformation within the Ukrainian archival system. These institutions preserve records essential for administrative, legal, and local historical research. However, their technical capacities vary significantly depending on regional resources and local administrative support. Digital catalogs differ in interface design, search functionality, and metadata structure. In some cases, online presence is limited to basic inventory descriptions without digital copies. In others, digitization initiatives are visible but remain dependent on short-term funding cycles. This variability creates practical challenges for researchers seeking to conduct cross-regional or large-scale studies. The absence of unified search mechanisms or centralized metadata aggregation reinforces institutional siloing and limits the capacity for comprehensive discovery across archival networks.

Across all categories of institutions, several recurring patterns emerge. Digitization is often project-driven rather than system-driven, leading to selective coverage and uneven technical quality. Metadata standardization remains incomplete, and alignment with internationally recognized archival description frameworks is inconsistent. Persistent identifier systems are rarely implemented at scale, restricting reliable citation and long-term interoperability. Technical infrastructures generally prioritize human-readable interfaces over machine-actionable services, thereby limiting the potential for integration into digital humanities workflows or automated research environments.

When evaluated collectively, these findings indicate that Ukrainian archival institutions are in a transitional phase. Digital access has expanded considerably compared to previous decades, and institutional awareness of open science principles is growing. However, infrastructural modernization has not yet reached the level required for seamless participation in federated research ecosystems. The current digital landscape can therefore be described as accessible but not fully interoperable, visible but not systematically integrated.

This empirical assessment underscores that the central challenge is not the absence of digitization efforts but the absence of coordinated infrastructural harmonization. Without unified metadata standards, persistent identification strategies, and interoperable system architectures, individual digital initiatives remain institutionally bounded. The transformation of Ukrainian archives into active components of open science will depend on moving from isolated digital projects toward a coherent national strategy that integrates technical, organizational, and professional dimensions of archival modernization.

Systemic Barriers to the Implementation of FAIR Principles in Ukrainian Archives. The empirical analysis of Ukrainian archival institutions demonstrates that the challenges of integration into the open science ecosystem are not limited to isolated technical shortcomings. Rather, they reflect systemic and interrelated

barriers embedded in structural, technological, normative, and professional dimensions of the archival sector. These barriers do not operate independently; instead, they reinforce one another, producing a cumulative effect that constrains the findability, accessibility, interoperability, and reusability of archival resources.

A fundamental structural barrier lies in the project-based nature of digital transformation. Digitization in many Ukrainian archives develops through temporary initiatives funded by specific grants, international collaborations, or targeted state programs. While such projects generate valuable outputs, they rarely constitute elements of a long-term, coordinated national infrastructure strategy. As a result, digitized collections often reflect institutional priorities at a particular moment rather than systematic coverage of archival holdings. The absence of stable, multi-year investment mechanisms limits scalability and continuity. Consequently, digital expansion tends to produce islands of accessibility within broader analog collections, rather than a coherent and interoperable digital ecosystem.

Technological barriers further complicate this structural fragmentation. Many archival information systems were initially designed to support internal inventory management rather than external data exchange. Their architecture often prioritizes human-readable catalog interfaces over machine-actionable services. Metadata may be stored in formats optimized for display rather than for structured export, automated harvesting, or semantic linking. The limited implementation of persistent identifiers significantly weakens long-term referencing stability and cross-system integration. In addition, the absence of publicly documented APIs restricts interoperability with external research platforms, including digital humanities tools, scholarly repositories, and international data aggregators. These technological limitations directly undermine the operationalization of FAIR principles, particularly with regard to interoperability and reusability.

Normative and legal constraints constitute another layer of systemic barriers. Ukrainian archival legislation historically emphasizes preservation, custodial responsibility, and regulated access procedures. While these priorities remain essential, they can inadvertently inhibit open access initiatives when interpreted conservatively. Ambiguities surrounding copyright status, personal data protection, and conditions for reuse create institutional caution. In some cases, digital copies may be accessible for viewing but not clearly licensed for scholarly reuse, which limits their integration into research workflows. The absence of standardized licensing models reduces clarity for researchers and discourages broader dissemination. Furthermore, the coexistence of archival law and open data legislation without fully harmonized implementation mechanisms generates uncertainty at the institutional level.

Professional culture and capacity also play a critical role. Archival training in Ukraine has traditionally focused on preservation standards, provenance principles, and administrative recordkeeping. While these competencies remain foundational, the transition toward interoperable digital infrastructures requires

additional expertise in research data management, metadata standardization, semantic technologies, and digital preservation engineering. In many institutions, staffing levels are insufficient to support both traditional archival functions and advanced digital transformation simultaneously. The lack of systematic professional development programs in open science practices further slows adaptation. As a result, technological modernization may proceed unevenly, depending on local leadership and individual initiative rather than coordinated professional policy.

Institutional coordination represents another significant challenge. Although archives formally operate within a unified administrative system, practical mechanisms for data harmonization and infrastructure sharing are underdeveloped. Each institution tends to manage its digital systems independently, resulting in heterogeneous metadata structures, incompatible interfaces, and divergent technical standards. Without centralized aggregation or harmonization mechanisms, interoperability remains aspirational. This institutional siloing directly limits findability at the national level and impedes the development of integrated discovery services that could support cross-archive research.

Financial constraints exacerbate these barriers. Digital preservation, secure storage, system maintenance, and metadata enrichment require sustained funding beyond initial digitization costs. In resource-limited environments, investment often prioritizes immediate digitization outputs rather than backend infrastructure robustness or long-term preservation architecture. This imbalance can produce technically fragile systems that lack scalability or sustainability. Over time, such fragility threatens both accessibility and preservation, particularly in a context where cultural heritage faces heightened risks.

Finally, the broader socio-political environment intensifies infrastructural vulnerability. Security challenges and risks to physical archival holdings highlight the urgency of digital transformation but simultaneously divert institutional resources toward emergency stabilization. While crisis conditions can accelerate digitization awareness, they may also constrain strategic planning capacity. In such circumstances, open science integration becomes both more necessary and more difficult to achieve.

Taken together, these systemic barriers indicate that the implementation of FAIR principles in Ukrainian archives cannot be reduced to technical upgrades alone. The challenges are embedded in governance structures, professional traditions, legal frameworks, and resource allocation models. Addressing them requires coordinated intervention across multiple levels: strategic policy alignment, sustainable funding mechanisms, metadata harmonization initiatives, professional capacity development, and technological standardization. Without such multidimensional reform, digital initiatives risk remaining isolated improvements rather than components of a resilient and interoperable open science infrastructure.

Ukrainian Archives and International Open Science Infrastructures. Placing the Ukrainian archival system in a comparative international context makes it possible to better understand both its current limitations and its developmental potential. While Ukrainian archives have made visible progress in digitization and online access, their integration into federated, interoperable research infrastructures remains limited when measured against international initiatives that have systematically aligned archival practice with open science standards.

One of the most influential international frameworks in the field of digital preservation and archival theory is the InterPARES project (International Research on Permanent Authentic Records in Electronic Systems). InterPARES established methodological foundations for preserving authenticity, reliability, and long-term usability of electronic records. Its research emphasized the importance of contextual metadata, standardized documentation practices, and interoperable system architectures. Although the project was not explicitly framed within open science discourse, its conceptual contributions align closely with the logic of FAIR principles. In particular, the insistence on structured metadata and preservation of contextual relationships corresponds to the requirements of interoperability and reusability.

Compared to such models, Ukrainian archival institutions remain at an earlier stage of infrastructural harmonization. While elements of digital preservation are present, systematic implementation of standardized metadata schemas and persistent identification mechanisms is not yet uniform across institutions. InterPARES demonstrates how archival systems can be designed with long-term digital authenticity and interoperability in mind from the outset. In Ukraine, by contrast, digitization has often evolved incrementally from analog systems, resulting in hybrid infrastructures that combine traditional descriptive practices with partial digital layers. This evolutionary approach reflects historical constraints but also reveals the absence of a coordinated national digital preservation strategy comparable to those developed within InterPARES-inspired frameworks.

Another relevant benchmark is the European Open Science Cloud (EOSC), which provides a federated ecosystem for the discovery, sharing, and reuse of research outputs across European institutions. EOSC emphasizes machine-readable metadata, persistent identifiers, harmonized standards, and cross-platform interoperability. Within such an environment, archival collections are not treated as isolated repositories but as components of a distributed knowledge infrastructure capable of interacting with datasets, publications, and computational tools.

In comparison, Ukrainian archival systems operate largely as institution-specific digital environments. Online catalogs and digital collections are accessible through individual portals, but they are not systematically integrated into federated European discovery platforms. Metadata export mechanisms and APIs that would allow automated harvesting by international infrastructures remain underdeveloped. Consequently, Ukrainian archival materials are often disco-

verable only within national contexts rather than through transnational research networks. This limited integration reduces the international visibility and reuse potential of Ukrainian documentary heritage, particularly in comparative and interdisciplinary studies.

The contrast is not solely technical but also strategic. International initiatives such as EOSC are supported by coordinated policy frameworks, funding instruments, and cross-institutional governance mechanisms. They operate on the assumption that research data, including archival materials, should circulate within interoperable ecosystems. In Ukraine, policy discourse increasingly recognizes the importance of open science alignment, yet implementation remains uneven. The gap between declarative strategic intent and operational infrastructure reflects broader challenges in digital governance and resource allocation.

At the same time, the comparison should not be interpreted as a simple deficit narrative. Ukrainian archives operate within a distinct historical, economic, and political context that has shaped their development trajectory. Unlike many Western European institutions that began large-scale digital transformation earlier, Ukrainian archives have had to modernize under conditions of financial limitation and institutional transition. The rapid expansion of digital initiatives in recent years indicates a growing awareness of international standards and a willingness to adapt. In this sense, the current stage can be understood as transitional rather than stagnant.

Importantly, international frameworks also reveal that the integration of archives into open science ecosystems is not automatic even in advanced contexts. Research has shown that archival institutions worldwide face challenges related to metadata harmonization, institutional coordination, and balancing preservation with openness. Ukrainian archives therefore confront not unique but intensified versions of global tensions between custodial responsibility and infrastructural interoperability. Recognizing this shared complexity provides a more balanced comparative perspective.

The comparative analysis highlights several critical divergences. First, international infrastructures emphasize persistent identifiers as foundational elements of research integration, whereas Ukrainian archival systems rarely implement such mechanisms systematically. Second, federated search environments in European contexts enable cross-institutional discovery, while Ukrainian researchers must navigate multiple independent portals. Third, machine-readable metadata and standardized export formats are central in international systems but inconsistently developed in Ukraine. These divergences directly affect the capacity of Ukrainian archival materials to function as reusable research data within broader scientific workflows.

Nevertheless, the alignment of Ukrainian archives with international open science infrastructures is not only a technical aspiration but also a strategic opportunity. Participation in federated ecosystems would enhance global

discoverability, facilitate comparative scholarship, and strengthen Ukraine's presence in international research networks. Moreover, adopting interoperable standards would support national digital resilience by ensuring distributed access and preservation beyond individual institutional boundaries.

Strategic Pathways for Integration into Open Science. The integration of Ukrainian archival institutions into the broader ecosystem of open science requires a multi-dimensional strategy that goes beyond isolated digital initiatives. It involves the simultaneous development of technological infrastructure, standardization of metadata, professional capacity enhancement, and policy alignment. These strategic pathways are interconnected: infrastructure without standardized metadata cannot ensure interoperability; professional training without clear policy direction risks producing fragmented adoption; and policy reforms without technical readiness may remain aspirational. Examining each dimension in depth illuminates both opportunities and practical challenges.

The API ecosystem is essential to facilitate automated data harvesting and interoperability with external research platforms. APIs would enable universities, digital humanities centers, and international projects to access archival metadata and digital copies programmatically, supporting advanced computational research workflows. Without such interfaces, even well-digitized collections remain siloed, limiting discoverability and reuse. By contrast, archives with APIs can integrate into federated infrastructures like the European Open Science Cloud, enabling Ukrainian materials to participate in cross-national analytics, machine learning projects, and comparative historical studies.

A central metadata registry would further reinforce infrastructural coherence. By maintaining a consolidated catalog of archival descriptions, standardized identifiers, and metadata schemas, the registry could serve as both a reference point for internal cataloging and a gateway for external integration. In practice, such a registry could reduce duplication of effort, support semantic interoperability, and allow coordinated updates across multiple institutions. In the absence of this centralized reference, archives risk persistent heterogeneity in metadata practices, perpetuating barriers to automated discovery and FAIR compliance.

Metadata harmonization constitutes the structural foundation of open science integration. Adopting internationally recognized standards, particularly the Encoded Archival Description (EAD), would align Ukrainian archival practices with global best practices, facilitating machine-readable data exchange and cross-institutional research. Implementation of EAD enables hierarchical structuring of archival descriptions, preservation of contextual relationships, and compatibility with semantic web technologies. Institutions that have piloted EAD integration, such as pilot projects at the Central State Historical Archive of Ukraine, illustrate how even partial adoption can dramatically improve discoverability and interoperability.

Persistent identifiers for both digital objects and archival descriptions are equally crucial. Stable and resolvable identifiers allow researchers to cite archival resources reliably, integrate them with datasets, and connect them to scholarly publications and researcher profiles. For example, integrating archival identifiers with ORCID or DOI systems would bridge archival collections and academic outputs, embedding Ukrainian archives into global scholarly networks. Without these identifiers, references remain ephemeral and limit the potential for reuse in computational research or linked data applications.

The importance of this combination is evidenced by innovative concepts concerning the differentiation of archival documents by value categories in academic research [12; 13]. This approach illustrates how archival documents are assigned to a specific value category based on monetary appraisal. At the same time, this enables the improvement of mechanisms not only for the monetary appraisal of archival documents but also for a clearer definition of the categories of the most valuable parts of the archival fonds of the state archives of Ukraine — in particular, their unique documents — and their representation in global and European electronic archival information systems with appropriate identifiers.

The consistent use of controlled vocabularies and authority files ensures semantic clarity across collections. Standardized naming conventions for personal, institutional, and geographic entities prevent ambiguity and support automated linking of related records across institutions. For Ukrainian archives, which historically relied on heterogeneous cataloging practices, adopting controlled vocabularies would reduce friction in cross-institutional data aggregation and enable participation in semantic search engines and knowledge graphs.

Technical infrastructure and metadata standards alone are insufficient without corresponding professional expertise. Systematic training for archival staff in digital preservation, metadata standards, FAIR principles, and research data management is critical. Such programs would enable archivists to implement advanced digital services, ensure quality and consistency in descriptions, and actively participate in the design of interoperable systems.

Collaboration with universities can create mutually reinforcing feedback loops between archival practice and academic research. Joint initiatives can develop curricula, internships, and research projects where students contribute to metadata enhancement, digitization, and data analysis, while archives benefit from updated skills and workforce support. Digital humanities partnerships, in particular, provide a practical context for experimenting with computational analysis, semantic linking, and data visualization. Archives engaged in such collaborations can simultaneously improve digital services and demonstrate the scholarly value of their collections. Evidence from pilot digital humanities projects in European and North American contexts suggests that these partnerships accelerate adoption of FAIR-aligned practices while fostering innovation in research applications.

Strategic policy interventions provide the overarching framework that aligns infrastructure, standards, and capacity with national and international expectations. A comprehensive national strategy for open archival data would articulate goals, responsibilities, funding priorities, and compliance mechanisms, transforming fragmented initiatives into a coordinated modernization effort. Without such strategic vision, technical upgrades risk remaining isolated and uneven.

Integration of open archival data requirements into research funding and project evaluation criteria would create incentives for institutions to align their practices with open science expectations. For instance, archives contributing to publicly funded research projects could be required to implement standardized metadata, persistent identifiers, and interoperable access mechanisms, ensuring that investments in digitization directly support systemic openness.

Finally, alignment with European Union open science mandates strengthens both domestic and international legitimacy. Participation in Horizon Europe projects or EOSC-related networks requires adherence to open data principles and metadata interoperability. By proactively adopting EU-aligned frameworks, Ukrainian archives can ensure compatibility with European infrastructures, enhance the visibility of national heritage, and attract international collaboration. Policy alignment thus acts as both a motivator and a safeguard, embedding open science practices into institutional priorities and funding landscapes rather than leaving them contingent on ad hoc initiatives.

Collectively, these strategic pathways demonstrate that successful integration into open science depends on the simultaneous development of infrastructure, standardization, professional capacity, and policy coherence. Ukrainian archives have begun to implement elements of this transformation, but realizing the full potential of the country's documentary heritage requires coordinated, systemic action that bridges technical, institutional, and normative dimensions.

The **novelty** of this study lies in its interdisciplinary and infrastructural approach. Unlike previous research that has examined Ukrainian archives mainly from historical, legal, or administrative viewpoints, this article conceptualizes archival institutions as epistemic infrastructures that actively shape knowledge production. By applying FAIR principles as an analytical instrument while accounting for the specificity of archival description and governance, the study offers a new perspective on the modernization of archival systems in transitional contexts. It not only evaluates current limitations but also frames Ukrainian archives within broader debates on digital sovereignty, cultural resilience, and integration into European and global research environments. In doing so, the article contributes to the development of a more comprehensive understanding of how archival heritage can function as reusable scholarly data within the contemporary open science paradigm.

Conclusion. Ukrainian archival institutions occupy a pivotal position at the intersection of knowledge production, cultural heritage, and national memory.

While they have made significant strides in digitization and online accessibility, these efforts remain largely project-based and institutionally fragmented, limiting their broader impact on research ecosystems. The application of FAIR principles across Ukrainian archives is partial and uneven: persistent identifiers, standardized metadata, and interoperable systems are present in some collections but absent or inconsistent in others. This unevenness constrains discoverability, reusability, and integration into both national and international open science infrastructures.

The analysis demonstrates that meaningful integration into the open science ecosystem cannot rely solely on isolated projects or technical upgrades. Instead, it requires systemic reform encompassing coordinated infrastructure development, metadata harmonization, professional capacity building, and policy alignment. A comprehensive modernization strategy would enable Ukrainian archives to function as epistemic infrastructure, support national memory, and enhance digital resilience, particularly under conditions of geopolitical instability and war.

Beyond technical considerations, this transformation carries scientific and strategic significance. By embedding archival collections into FAIR-compliant, interoperable frameworks, Ukraine strengthens the usability of its documentary heritage for cross-disciplinary research, supports transparency and knowledge continuity, and reinforces cultural security. Strategic investment in infrastructure, training, and policy creates a foundation for long-term resilience, ensuring that the nation's archives remain accessible, reliable, and influential within global scholarly networks.

This structured conclusion synthesizes the article's core arguments, highlighting the interplay between technical, institutional, and societal dimensions. By framing Ukrainian archival modernization as both a scholarly and strategic imperative, the article positions its findings as relevant to researchers, policymakers, and cultural stakeholders, thereby strengthening its contribution to ongoing discussions on open science and the future of archival practice.

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АРХІВНІ ФОНДИ ДЕРЖАВНИХ АРХІВІВ УКРАЇНИ В КОНТЕКСТІ ПРИНЦИПІВ ВІДКРИТОЇ НАУКИ

Мета роботи. Дослідити стан архівних установ України в контексті відкритої науки та принципів управління даними, спрямованих на забезпечення доступності, сумісності та повторного використання інформації. **Методологія.** Застосовано комплексний підхід, що поєднує порівняльний аналіз міжнародних практик, аналіз цифрової інфраструктури архівів, описових стандартів, метаданих та систем ідентифікації. **Наукова новизна.** Обґрунтовано розгляд архівів як ключової інфраструктури знань, що забезпечує не лише збереження документальної спадщини, а й інтеграцію у глобальні наукові екосистеми; визначено рівень відповідності українських архівів сучасним підходам до управління даними та виявлено системні обмеження їхнього розвитку. **Висновки.** Встановлено, що, попри активну цифровізацію та розширення онлайн-доступу, розвиток архівної сфери залишається фрагментованим і недостатньо узгодженим із міжнародними стандартами. Доведено необхідність комплексної модернізації, що включає розвиток цифрової інфраструктури, уніфікацію метаданих, впровадження ідентифікаторів, підвищення професійної спроможності та удосконалення політик. Підкреслено стратегічну роль цифрової стійкості в умовах воєнних ризиків та значення відкритої науки для збереження і представлення документальної спадщини України у світовому науковому просторі.

Ключові слова: архівні фонди, відкрита наука, принципи FAIR, державні архіви України, цифровізація, метадані, національна пам'ять, культурна стійкість, інформаційна інфраструктура.