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Herbarium Digitisation as a Platform for Scientific Knowledge Accessibility: The Case of Herbarium Pomeranicum

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Abstract:

Purpose: *The paper sets out to explore the digitisation of the Herbarium Pomeranicum as a case study illustrating how the digital transformation of natural history collections facilitates the dissemination of scientific knowledge. The study shows how digital access enhances visibility, accessibility, and international recognition of Polish botanical heritage and research achievements.*
Design/Methodology/Approach: *The research is based on a qualitative case study of the Herbarium Pomeranicum project, supported by quantitative data from web analytics reflecting the number of external visits since the platform's launch. Institutional documentation and descriptive analyses of the tree core herbaria collections – the University of Szczecin Herbarium Stetinensis, the University of Gdańsk Herbarium Universitatis Gedanensis and The Herbarium Slupensis of the Pomeranian University in Słupsk – were used to identify their scope, structure, and scientific relevance.*
Findings: *The digitisation of the Herbarium Pomeranicum has substantially enhanced access to scientific resources and exceeded initial expectations regarding user engagement. The platform's continued use indicates its growing role in promoting Polish botanical research, fostering international collaboration, and strengthening knowledge exchange in taxonomy and biodiversity studies. However, as a newly developed infrastructure, its long-term scientific and educational impacts remain to be systematically assessed.*
Originality/value: *This paper demonstrates how the digitisation of regional herbaria not only preserves and disseminates historical collections but also serves as a tool for the internationalisation of research and integration of Polish biodiversity studies into global scientific networks.*

Keywords: *Herbarium, digitisation, knowledge transfer, accessibility, biodiversity data.*

JEL codes: *O32, Q57, I23.*

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1. Introduction

The accelerating process of digital transformation is strongly reshaping the way scientific knowledge is created, stored, and disseminated. In the era of Industry 4.0 and the emerging concept of Society 5.0, the use of digital tools and artificial intelligence (AI) has become a central issue of scientific practice.

Digitalisation not only facilitates data management and interdisciplinary collaboration but also plays a crucial role in enabling open access to scientific information and the long-term preservation of research outputs. This transition supports the principles of open science, where data transparency, reproducibility, and global accessibility are recognised as fundamental values of modern scholarship.

Within this context, the digitisation of natural history collections—particularly herbaria—represents a significant step toward boosting the accessibility and usability of scientific resources.

Herbaria, which have historically served as archives of plant biodiversity, are now being transformed into interactive digital repositories. By converting traditional specimen collections into structured, searchable, and interoperable datasets, digitised herbaria facilitate wide access to verified scientific information for researchers, educators, students, and policy-makers. They also create opportunities for applying AI-based image analysis, automated species identification, and data integration with other biological and environmental databases.

The purpose of this article is to examine how digital tools contribute to enhancing the accessibility of scientific information through the process of herbarium digitisation.

The discussion combines theoretical perspectives on digital transformation and data openness with practical insights derived from the case study of Herbarium Pomeranicum—an integrated digital platform uniting the collections of four herbaria located at three Pomeranian universities.

The project explores how digitisation initiatives can strengthen scientific networks, promote data sharing, and ensure that heritage collections become an active part of the global digital knowledge ecosystem.

2. Literature Review

Scientific knowledge, as a structured and validated form of understanding, constitutes the base of social and technological progress. It is characterised by systematisation, verification, and reproducibility, forming a self-correcting system through which theories evolve and collective understanding expands. Within the knowledge-based economy, this intellectual resource has become a strategic factor of development, not only driving innovation but also determining the global competitiveness of nations and institutions (Ma and Li, 2022; Ma and Zhang, 2025).

The circulation and utilisation of knowledge thus represent key processes in contemporary science and society. In the past knowledge was limited and geographically constrained—printed publications, specialised archives, or conferences. Now is is undergoing a profound transformation driven by digitalisation.

Digital technologies redefine how knowledge is produced, stored, and shared, significantly increasing the efficiency and reach of scientific knowledge dissemination across disciplines and borders. Recent studies emphasise that digital technologies facilitate not only the storage and dissemination of knowledge, but also its transformation into digital innovation through processes of knowledge digitisation and inter-organisational sharing (Cheng, Peng, Wan, Dai, and Zhang, 2025).

Digital transformation is often described as a multidimensional process encompassing both technological and cultural change. It affects all stages of the knowledge cycle: data collection, analysis, communication, and reuse (Forman and van Zeebroeck, 2019; Ma and Li, 2022).

Through digitalisation, scientific outputs can be disseminated more rapidly and effectively, facilitating collaborative research and enhancing the transparency of results. This shift assures the broader principles of open science, which promote the idea that knowledge is a global public good and should be accessible to all who can benefit from it.

Open data policies and digital repositories enable researchers to deposit their datasets, protocols, and publications in ways that make them findable, accessible, interoperable, and reusable. As highlighted by Albats, Alexander, and Cunningham (2022) and Schmeling, Al Dakruni, and Mergel (2025), digital transformation reshapes institutional collaboration and data governance, requiring coherent frameworks that balance openness, quality assurance, and organisational rationality.

Consequently, digitalisation functions not only as a technological facilitator but also as a mechanism for democratising science and maximising the societal value of research.

Academics emphasises that the digital environment expands both the efficiency and reach of knowledge dissemination. Efficiency arises from automation, intelligent indexing, and enhanced searchability, which reduce time and cost barriers in data discovery. Reach, in turn, extends to new audiences, institutions and individuals worldwide gain access to previously restricted materials, breaking down geographical and economic inequalities (Freshwater, Sherwood, and Drury, 2006).

As digital platforms integrate large datasets and support real-time collaboration, the boundary between producers and users of scientific knowledge becomes increasingly porous. This has led to the emergence of networked research ecosystems, where the flow of information is continuous, multidirectional, and often interdisciplinary (Leong, Hua, Xiao, Yu, and Zhou, 2026; Schmeling *et al.,* 2025). Digital ecosystems further enable autonomous value co-creation, where users actively participate in the circulation, refinement, and reinterpretation of knowledge (Leong *et al.,* 2026).

At the micro level, digitalisation enhances the organisation and accessibility of explicit knowledge—data, publications, images, and models—by enabling codification and standardised storage (Moeini, Rahrovani, and Chan, 2019). Search engines, metadata standards, and digital curation tools ensure that research outputs can be located and reused efficiently (Baykoucheva, 2022). The improved discoverability of scientific information increases the speed of learning, fosters innovation, and shortens the time between discovery and application (Ma and Li, 2022).

This pace is particularly visible in fields that rely on extensive datasets, such as environmental sciences or biomedicine, where digital infrastructures enable real-time data exchange and comparative analysis. As Deist, McDowell, and Bouncken (2023) suggest, the creation and conversion of "sticky knowledge" within digital units depend on maintaining a balance between fluid knowledge exchange and structural stability—a condition equally relevant for digital repositories.

The efficiency and reach of scientific knowledge dissemination depend strongly on interoperability. Without shared technical standards and semantic frameworks, the potential of digitalisation remains underutilised (Niedzielski and Markiewicz, 2023).

Interoperability allows different systems to communicate, enabling aggregation of datasets and integration across disciplines. In practice, this means that metadata must be structured and machine-readable, while access policies should be harmonised to permit legitimate reuse. As Schmeling *et al.* (2025) indicate, data collaboration demands institutional frameworks that ensure both interoperability and ethical governance.

Therefore digitalisation creates a multi-layered infrastructure of knowledge—linking repositories, data services, and collaborative tools—that supports cumulative scientific advancement. The resulting digital ecosystem not only preserves the products of research but also accelerates innovation through continuous circulation and recombination of information (Ma and Zhang, 2025).

From the perspective of epistemology, the shift from physical to digital formats also changes the nature of scientific objects. Digital representations, unlike physical artefacts, can be copied infinitely, combined algorithmically, and analysed by computers. This enhances scalability and assures new forms of knowledge creation, such as predictive modelling, data mining, and artificial intelligence-assisted discovery (Walker, Tucker, and Nicolson, 2021; Davis *et al.,* 2022).

Machine learning algorithms, for example, allow scientists to process large image datasets or identify patterns that would be impossible to detect manually. As a result, digitalisation not only disseminates existing knowledge more effectively but also generates new knowledge through computational synthesis.

What is more, the literature notes that digitalisation influences both explicit and tacit dimensions of knowledge. While explicit knowledge—documents, datasets, algorithms—can be fully digitised, tacit knowledge, rooted in personal experience and social interaction, remains partly dependent on human mediation (Deist *et al.,* 2023).

Nevertheless, virtual collaboration tools, online laboratories, and interactive learning platforms can facilitate the exchange of tacit knowledge by simulating environments for mentorship, experimentation, and dialogue. Such tools extend the reach of academic expertise to global communities of learners and practitioners, assuring the diffusion of best practices.

The preservation aspect of digitalisation also contributes to knowledge accessibility. Digitised scientific resources protect fragile physical collections and ensure their longevity, allowing information to be shared without risking deterioration of the originals (Barnes, Sulé-Suso, Millett, and Roach, 2023). Recent advances such as Fourier-transform infrared spectroscopy provide non-destructive methods for analysing digitised herbarium specimens, reinforcing the preservation value of digital archives (Barnes *et al.,* 2023).

Moreover, digital preservation practices—redundant storage, cloud archiving, and periodic format migration—guarantee the continuity of scientific memory. This aspect is particularly critical for historical datasets, which, once digitised, can inform contemporary analyses of environmental change, public health, or social evolution (Greve *et al.,* 2016; Buldrini *et al.,* 2023). In this sense, digitalisation operates as a temporal extension of knowledge dissemination, linking past research with future discovery.

At the institutional level, the digital shift fosters new governance models for knowledge management. Universities, research institutes, and cultural organisations are increasingly adopting open-access mandates and data-sharing policies. These frameworks encourage transparency and accountability while enhancing the global visibility of institutions (Niedzielski and Markiewicz, 2023).

Digital knowledge management systems integrate administrative, educational, and research data, creating feedback loops that support organisational learning and support decision-making (Cheng *et al.,* 2025). As Albats *et al.* (2022) argue, effective inter-organisational collaboration requires reconciling institutional logics and bounded rationality to foster sustainable digital partnerships. The resulting efficiency in resource allocation and collaboration exemplifies the broader socio-technical benefits of digital transformation.

Despite these advantages, several challenges still exist. The literature underlines that digitalisation does not automatically guarantee equal access. Technological gaps and inequalites, language barriers, and uneven data coverage can disturb fair knowledge production and use (Bucher *et al.,* 2025).

Furthermore, the exponential growth of digital information raises questions about quality control, data validation, and ethical use (Cheng *et al.,* 2025). The abundance of content requires advanced filtering mechanisms and digital literacy to distinguish reliable information from noise. To maintain the efficiency and reach of scientific knowledge dissemination, attention must therefore be paid to infrastructure governance, data management, and user training.

In addition, intellectual property and data privacy remain critical issues. Open access improves visibility but can expose sensitive data to be misused. The challenge lies in balancing between openness with protection—designing systems that promote collaboration while respecting ethical and legal boundaries (Moeini *et al.,* 2019). Another crucial issue is the fragmentation of digital repositories, which limits interoperability and increases duplication of effort (Greve *et al.,* 2016; Bucher *et al.,* 2025). International cooperation and standardisation are therefore necessary to ensure that digitalisation leads to genuine integration rather than parallel silos.

The reviewed literature converges on the idea that digitalisation transforms scientific knowledge into a more accessible, dynamic, and participatory domain. It amplifies both the efficiency and reach of scientific knowledge dissemination by accelerating communication, reducing transaction costs, and expanding global participation in the research process.

By integrating digital tools—repositories, databases, AI analytics, and collaborative platforms—science becomes a shared enterprise rather than an isolated endeavour. The transition from localised archives to interconnected digital ecosystems enables knowledge to circulate seamlessly across disciplines, institutions, and societies.

In doing so, digitalisation not only preserves the heritage of scientific inquiry but also opens new horizons for discovery, inclusivity, and innovation. Ultimately, the digital revolution in science represents a shift from scarcity to abundance, from limited access to open networks, and from static communication to continuous interaction. The efficiency and reach of knowledge dissemination are no longer limited by material constraints but depend on the quality of digital infrastructures, interoperability of systems, and inclusiveness of their design.

Ensuring fair participation in this global knowledge space requires sustained investment in technology, policy, and education. Yet the promise is clear: through digitalisation, scientific knowledge can achieve a level of accessibility and societal impact which we have not come across in human history.

3. Herbaria as Platforms Disseminating Scientific Knowledge

For many years herbaria have served as the physical repositories of plant diversity, conserving millions of specimens that document the botanical history of the planet. In recent decades, however, they have evolved into complex digital ecosystems that not only preserve biodiversity data but also function as global platforms for the dissemination of scientific knowledge.

Through digitisation, standardisation, and interconnectivity, herbaria now bridge research, education, and public engagement, transforming their traditional archival role into one of dynamic knowledge exchange and innovation (Güntsch *et al.,* 2021; Bucher *et al.,* 2025).

The digitisation of herbarium specimens and metadata has revolutionised access to botanical information. International infrastructures such as the Global Biodiversity Information Facility (GBIF), Integrated Digitized Biocollections (iDigBio), and the pan-European Distributed System of Scientific Collections (DiSSCo) provide open, standardised channels through which millions of specimen records can be simultaneously searched and analysed (Güntsch *et al.,* 2021; Hussein *et al.,* 2022; Shi *et al.,* 2025).

These platforms employ community-agreed data standards such as Darwin Core and ABCD, ensuring interoperability and facilitating the integration of datasets from diverse institutions (Bucher *et al.,* 2025). In effect, herbaria have become decentralised yet interconnected components of a global information network, expanding the efficiency and reach of botanical knowledge dissemination.

Digital herbaria democratise scientific participation by removing geographic and institutional barriers. Researchers from regions lacking extensive collections can now analyse specimens from leading institutions worldwide without the logistical and financial constraints of physical loans (Bucher *et al.,* 2025). This shift has addressed, at least partially, the colonial legacy of plant collecting by promoting

more equitable access to biodiversity data and strengthening collaborations across the Global South and North (Jackson, 2024). Nevertheless, only about one-fifth of global herbarium holdings are currently digitised, with visible underrepresentation in areas such as central Africa, Asia, and Amazonia, underscoring persistent inequalities in global data infrastructure (Jackson, 2024).

Online platforms facilitate not only accessibility but also the usability of botanical data. Many major herbaria now maintain searchable databases, application-programming interfaces, and direct electronic links to partner institutions, creating a distributed yet functionally unified network of information (Simpson, 2010; Simpson, 2019).

Data portals such as GBIF and iDigBio aggregate and standardise records from multiple sources, enabling large-scale analyses of plant distributions, species diversity, and environmental change (Glon *et al.,* 2017; Borsch *et al.,* 2015).

Beyond simple data retrieval, these systems allow online annotation, crowd-sourced transcription, and error correction, thereby engaging a broader community of scientists and citizen participants in the co-production of knowledge (Shi *et al.,* 2025; Gianquitto and LaFauci, 2021).

Herbaria also play a very important educational role in training the next generation of taxonomists and biodiversity researchers. The availability of digitised specimens provides students and early-career scientists with remote access to materials and metadata that previously required travel and physical handling.

As Simões *et al.* (2025) note, well-developed digital infrastructure directly supports the success of training programmes in plant taxonomy by integrating traditional expertise with computational and imaging technologies. Digital herbaria thus serve as pedagogical laboratories that strengthen scientific capacity, promote open learning, and foster methodological innovation.

In research, the applications of digitised herbarium data have expanded dramatically. Virtual access to collections enables studies of ecological and evolutionary patterns, climate-change impacts, invasive species modelling, and functional trait analysis (Jackson, 2024; Glon *et al.,* 2017). Integration with artificial-intelligence methods further amplifies the analytical value of digital collections.

Machine-learning and computer-vision approaches are now used to automate species identification, detect morphological traits, and extract information from specimen images, thereby increasing both the speed and accuracy of data processing (Hussein *et al.,* 2022; Han *et al.,* 2026). Such techniques transform static specimen images into dynamic data objects that can be continuously re-evaluated as algorithms and datasets improve.

At the same time, challenges remain in realising the full potential of herbaria as digital knowledge hubs. The sheer scale of collections—often numbering millions of specimens—combined with incomplete metadata and heterogeneous data quality limits interoperability and comprehensive analysis (Bucher *et al.,* 2025; Lughadha and Miller, 2009).

Many specimens lack essential contextual information such as collection locality or date, while others suffer from historical misidentifications that require expert validation (Hallingbäck, 2007). Moreover, the coexistence of multiple data portals can lead to duplication and fragmentation, creating obstacles to efficient data exchange. To overcome these limitations, scholars advocate the development of federated global management systems capable of integrating digital collections across institutional and national boundaries (Bucher *et al.,* 2025).

Innovations in digitisation processes continue to enhance efficiency. Conveyor-belt and robotic imaging systems have accelerated mass digitisation, with institutions like the South African National Biodiversity Institute (SANBI) aiming to complete millions of scans within a few years (Sebola and Willis, 2025). These large-scale initiatives demonstrate the scalability of digital infrastructure and underscore the commitment to making biodiversity information universally available.

Equally transformative are projects such as *Herbaria 3.0*, which combine scientific and humanistic approaches by curating plant narratives, integrating specimen images with cultural stories, and encouraging public participation in environmental knowledge (Gianquitto and LaFauci, 2021). Such interdisciplinary platforms extend the educational and societal functions of herbaria, reinforcing their role as mediators between scientific research and community awareness.

The continuing value of physical collections remains central to this transformation. While digital substitutes enhance accessibility, the original specimens preserve irreplaceable material evidence necessary for genomic, chemical, and morphological studies (Davis, 2023).

The concept of the "herbarium of the future" therefore embraces both physical conservation and digital expansion, integrating material preservation with open-access data systems. This hybrid model ensures that herbaria sustain their dual mission: safeguarding the tangible heritage of biodiversity while enabling the rapid, open, and collaborative circulation of knowledge.

In summary, herbaria exemplify the convergence of tradition and technology in contemporary science. Through digitisation, they have become not merely archives but active nodes in global knowledge networks, disseminating validated information, training specialists, engaging the public, and stimulating innovation. Their success demonstrates how carefully curated scientific collections can underpin interdisciplinary research and public understanding alike.

Continued investment in data quality, interoperability, and inclusive access will be essential to maintain their role as platforms that translate the world's botanical heritage into shared scientific insight for the future.

4. Herbarium Pomeranicum: An Integrated Platform for Digital Scientific Knowledge

The Herbarium Pomeranicum constitutes one of the most comprehensive and technologically advanced initiatives in Poland aimed at transforming traditional scientific collections into open, interoperable digital knowledge resources.

Conceived as a collaborative project between three major academic institutions in northern Poland—the University of Gdańsk, the Pomeranian University in Słupsk, and the University of Szczecin—it integrates the region's four principal herbaria into a single digital platform.

The project's guiding idea is to make approximately half a million scientifically documented specimens available in open access, supporting both research and education while strengthening the regional ecosystem of innovation. The project bridges the gap between the preservation of natural heritage and the commercialisation of scientific knowledge, in line with global trends of open science and digital transformation.

Each of the participating institutions contributes a distinct scientific profile and historical collection to the Herbarium Pomeranicum platform. The Herbarium Universitatis Gedanensis (UGDA)**,** based at the University of Gdańsk, is the largest of the four, containing over 300,000 specimens representing vascular plants, bryophytes, lichens, and fungi, as well as DNA isolates used in molecular systematics.

The Herbarium Slupensis (SLTC)**,** curated at the Pomeranian University in Słupsk, preserves material that documents nearly two centuries of floristic studies in Central Pomerania. The Herbarium Stetinensis (SZUB), located at the University of Szczecin, includes about 65,000 plant and fungal samples, together with a digital atlas of regional species distribution and photographic documentation of ecological sites.

Complementing these is the Szczecin Diatom Culture Collection, an internationally recognised repository containing more than 1,700 living strains and 26,000 diatom preparations, including several type specimens that have already been referenced in global taxonomic databases. By consolidating these diverse resources, the Herbarium Pomeranicum provides a unified and comprehensive record of Pomeranian biodiversity and its long-term study. The Herbarium Stetinensis of the University of Szczecin, established in 1985, constitutes one of the most comprehensive botanical collections in north-western Poland.

It encompasses several sections representing different groups of organisms. The herbarium of vascular plants includes approximately fifty-five thousand specimens, while the herbarium of lichens contains around eight thousand specimens, among which a unique Armenian collection is particularly noteworthy, as it originates from regions previously unexplored in terms of lichen biodiversity.

The fungal herbarium comprises about six thousand specimens of both macroscopic and microscopic fungi, collected since 1989, mainly from the Pomeranian region and other areas of Poland. It contains extensive collections of macrofungi from the beech forests of the Ińsko and Wolin Landscape Parks, as well as the largest national collection of fungi inhabiting raised and transitional peat bogs, primarily from north-western Poland.

The herbarium also preserves historical German collections dating from 1837 to 1939, consisting of one thousand four hundred and one sheets. Among them are the collections of Baenitz, E. Ćwikliński, S. Kownas, and M. Ciaciura, which are of significant taxonomic importance. These include scientifically valuable and rare specimens representing sedges of the group Carex flava, the family Elatinaceae, peatland species, macrofungi and microfungi, as well as xerothermic lichens from Pomerania and various protected forest areas such as the Bukowa, Drawieńska, Wolińska, Goleniowska, and Wkrzańska forests.

Approximately eighty percent of the entire collection originates from Western Pomerania, while the remaining part represents specimens from other regions of Poland, Scandinavia, the Mediterranean Basin, Armenia, and Russia. Since 2006, the collection has been systematically expanded with records of vascular plants and fungi from Western Pomerania, which are integrated into the Flora and Funga Pomeranica Occidentalis database containing around six hundred thousand entries.

A distinctive part of the resources of the University of Szczecin is the Szczecin Diatom Culture Collection, founded in 1990. It comprises approximately twenty-six thousand environmental samples and microscope slides, as well as about one thousand eight hundred living diatom strains representing over one thousand seven hundred marine taxa originating from littoral and pelagic oceanic zones.

The cultures were collected from a wide range of environments, including sandy and rocky coasts, estuaries, coral reefs, as well as extreme habitats such as hot springs, saline lakes, and desert oases. They come from various regions of the world, including Europe, Asia, Africa, both Americas, Australia, and New Zealand.

From the collected samples, more than fifty thousand microscope preparations were produced, many of which serve as holotypes and isotypes for species newly described by science. These materials were developed within national and international research projects implemented between 1990 and 2018. Many specimens have been cited as reference material in scientific publications,

confirming the global relevance of this collection for diatom taxonomy and biodiversity studies.

The Herbarium Universitatis Gedanensis of the University of Gdańsk, established in 1970, is among the largest and most significant botanical repositories in Poland, encompassing over three hundred thousand specimens of vascular plants, bryophytes, lichens, and fungi, as well as preserved floral samples, DNA isolates, and living specimens.

The herbarium of vascular plants contains approximately two hundred and twenty thousand specimens from the Pomeranian region, extending from the Odra River to the Vistula estuary, with a special emphasis on areas of the Słowiński and Wolin National Parks.

Within this collection is the notable compilation created by Professor Hanna Piotrowska in the 1960s and 1970s, documenting the flora of the Polish parts of Wolin and Uznam Islands, consisting of around four thousand five hundred specimens. The bryophyte herbarium includes about twelve thousand specimens, primarily from northern Poland, with a focus on the Gdańsk Pomerania region.

The lichen herbarium, encompassing approximately sixty thousand specimens, gathers both Polish and international material, including significant collections from South America. Another major collection, created by Professor Dariusz Szlachetko since the early 1990s, contains around ten thousand orchid specimens. The herbarium also maintains a collection of genetic material, consisting of more than one thousand records of tissues and DNA extracts, and a collection of liquid-preserved orchid flowers used for studies of complex morphological and ultrastructural features.

Additionally, the herbarium holds about ten thousand such preparations, enabling precise taxonomic analyses of orchids. A unique part of the collection comprises fifteen thousand analytical drawings made during international botanical research in major herbaria worldwide, depicting reference specimens studied by eminent taxonomists such as Lindley, Reichenbach, Schlechter, Kraenzlin, and Garay.

The Herbarium Universitatis Gedanensis holds the certificate of a scientific institution authorized under the Convention on International Trade in Endangered Species of Wild Fauna and Flora and constitutes an essential center for research on biodiversity and floristic diversity in temperate, tropical, and polar regions.

From an infrastructural perspective, the Herbarium Pomeranicum is a model of a high-performance virtualised information system designed to ensure stability, redundancy, and scalability. The architecture comprises three mirrored data centres located in Szczecin, Słupsk, and Gdańsk, each equipped with a 260-terabyte storage array, providing both physical and logical redundancy.

Data are synchronised in real time through advanced replication protocols, ensuring continuous system operation even in the event of local hardware failures. The software environment is entirely open source, enabling adaptability and long-term sustainability. Multiple application programming interfaces (APIs) manage interactions between subsystems responsible for data collection, metadata management, user authentication, and external integration.

These APIs also allow for export to global biodiversity platforms such as the Global Biodiversity Information Facility (GBIF) using the TAPIR protocol, and to geographic information systems (GIS) through OGC-compliant web services. Data can be shared in several scientific formats—including CSV, XML, and TXT—facilitating reuse in environmental modelling, educational materials, and external analytical systems.

Equally significant is the project's commitment to open data principles and transparent knowledge sharing. All digitised resources are distributed under the Creative Commons CC BY-SA 3.0 license**,** which allows unrestricted reuse, adaptation, and redistribution provided that authorship is properly acknowledged.

This licensing model ensures that data produced within publicly funded research remain accessible for further scientific, educational, and commercial purposes. Such openness enhances both the efficiency and reach of scientific knowledge dissemination, as it enables secondary analyses, innovation in applied environmental studies, and the creation of digital learning tools. In this way, the Herbarium Pomeranicum embodies the principles of open government data and open science promoted by the European Union's Digital Agenda.

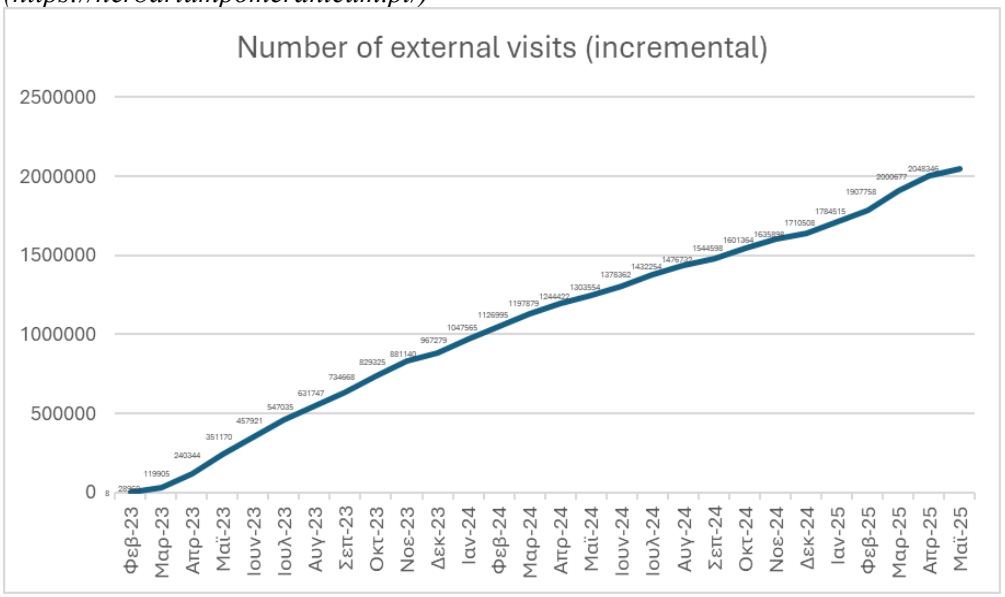
The project's funding under the Digital Poland Operational Programme 2014–2020 situates it within a broader policy framework aimed at expanding the availability of public-sector information and promoting the reuse of scientific data for socio-economic development. By aligning regional academic resources with national and European digitalisation strategies, Herbarium Pomeranicum contributes to strengthening Poland's research infrastructure and international visibility.

The initiative directly supports the European Open Science Cloud (EOSC) principles by enabling data interoperability and cross-institutional collaboration. Furthermore, its scalable architecture allows for future expansion, opening the possibility of integrating additional collections from other Pomeranian or Baltic institutions, thus extending both the geographic and thematic reach of the database.

Since the launch of the Herbarium Pomeranicum platform in February 2023, the number of external visits has demonstrated a steady and substantial upward trend. In the first month, the portal registered only eight visits, followed by a rapid increase to almost thirty thousand in March 2023 and over one hundred thousand in April of the same year.

Throughout the subsequent months, the number of visits grew dynamically, exceeding 880,000 by the end of 2023. In 2024, the platform maintained a consistent growth trajectory, reaching over 1.6 million visits by December. During the first quarter of 2025, the rate of increase remained high, with more than 1.9 million visits recorded in March. By May 2025, the total number of external visits reached approximately 2,048,000, confirming continuous expansion of user engagement and the platform's growing visibility within the scientific community. The data is shown in Figure 1.

Figure 1. *Number of external visits in Herbarium Pomeranicum (https://herbariumpomeranicum.pl/)*



Source: *Website analytics data from https://herbariumpomeranicum.pl (monitored through institutional firewall).*

At the conceptual level, Herbarium Pomeranicum is more than a technological repository—it is an ecosystem for knowledge transfer and innovation. Its digital resources can be used not only by academic researchers but also by public institutions, NGOs, and private companies operating in fields such as environmental monitoring, sustainable development, and eco-innovation.

By providing verified and standardised biodiversity data, the platform supports regional decision-making processes, environmental impact assessments, and educational programmes in natural sciences. The system thus bridges the divide between the scientific and socio-economic spheres, exemplifying how academic data can fuel both research excellence and practical applications. The project's focus on accessibility and standardisation ensures that scientific resources collected over centuries can now be employed in new contexts, creating opportunities for entrepreneurship and technological transfer.

Another important dimension of the project is its role in scientific education and capacity building. The digitisation of herbaria provides students and young researchers with remote access to collections that were previously available only through direct visits. Instructors can now incorporate digital specimens and metadata into university courses, fostering skills in taxonomy, ecology, and digital curation.

The platform also facilitates interdisciplinary teaching, linking life sciences with information technology and data analytics. By promoting these integrative educational models, Herbarium Pomeranicum contributes to the formation of a new generation of researchers equipped for work in digitally driven science.

The implementation of the Herbarium Pomeranicum has also required a redefinition of organisational collaboration among participating universities. It established a shared governance structure based on transparent data standards, common workflows, and joint responsibility for maintenance and development.

This model of distributed yet cooperative management offers a template for other scientific institutions seeking to integrate their resources without sacrificing institutional autonomy. Furthermore, the project demonstrates that digitalisation, when combined with institutional partnership, can serve as a catalyst for regional innovation ecosystems—stimulating interdisciplinary projects, joint publications, and international cooperation.

5. Conclusions

The digitisation of the Herbarium Pomeranicum collections has significantly improved access to scientific resources and facilitated the dissemination of regional botanical knowledge. The implementation of the digital platform has not only met but also exceeded the initial project assumptions concerning the number of users and visits. This achievement confirms the high relevance of open-access digital repositories in the contemporary scientific landscape.

The initial surge in visits following the platform's launch can be interpreted as a result of widespread curiosity and the exploratory use of the newly available database. Over time, the number of visits has stabilised, which may indicate a transition from general public interest to more specialised, targeted searches conducted by researchers and academic users who are familiar with the system.

The continuous use of the platform demonstrates that the digital transformation of herbaria collections plays a crucial role in increasing the visibility of Polish research achievements and integrating them into the broader international scientific community. The online accessibility of the collections has made it possible to recognise and appreciate the scientific legacy accumulated by several generations of researchers, while also promoting new collaborations and comparative studies.

It may be assumed that the digitisation process has indirectly contributed to strengthening research networks, especially in the fields of taxonomy, ecology, and biodiversity studies, where access to verified specimen data is essential.

At the same time, several limitations of this case study should be acknowledged. Firstly, the available analytical data are limited to visit statistics, which do not provide a comprehensive understanding of users' engagement patterns or the qualitative nature of their interactions with the platform. Secondly, as the Herbarium Pomeranicum is a newly developed digital infrastructure, long-term impacts such as citation rates, scientific collaborations, or educational applications have not yet been systematically measured.

Moreover, technical and methodological differences between partner institutions may have influenced the pace and uniformity of digitisation, affecting the comparability of data sets.

Future studies could therefore extend the analysis to include user behaviour patterns, the academic use of the digital collections, and the development of international partnerships resulting from the project. It would also be valuable to explore how the digitisation of herbaria contributes to open science policies, citizen science initiatives, and sustainable management of natural history data.

Overall, the case of the Herbarium Pomeranicum illustrates how digitisation not only preserves historical collections but also transforms them into dynamic instruments for knowledge exchange, visibility enhancement, and international collaboration in contemporary science.

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