# When Art meets Computer Science: a systematic review about technologies and user interaction in adaptive digital museums and archives

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## ABSTRACT

The digitization of artistic productions, or their creation in a natively digital format, has expanded their scope beyond original intentions, bringing them into close interaction with software-related aspects. In this context, the dissemination, preservation, and access to such works, especially within digital museums and digital archives, are inevitably influenced by the quality of the underlying software. Considering the inherent challenges at the intersection of Digital Humanities and Computing, particularly the need for user-centered and customizable experiences to effectively manage large, heterogeneous collections, this article presents a systematic literature review focused on adaptive, personalized, and customizable digital museums and archives. The review aims to identify the main purposes of these systems, the technologies employed in their construction and maintenance, and the interaction approaches proposed for users. Using a systematic protocol, searches were conducted across ACM Digital Library, IEEE Xplore, Science Direct, and Scopus, resulting in the analysis of 21 studies. Based on the analysis of studies, we discuss trends, challenges, and opportunities for the design and development of adaptive digital museums and archives, such as the limited incorporation of Human-Computer Interaction and Software Engineering principles and the need for greater standardization in the development of adaptive digital archives.

## KEYWORDS

adaptive systems, digital museums, digital archives

## 1 INTRODUCTION

Digital transformation has brought diverse impacts across different sectors of society. In the field of the Humanities, artistic production stands out as one of the domains affected by digital technologies. As evidence, it can be observed that, while efforts to preserve physical materials have intensified, ranging from manuscripts and paintings

to audiovisual records stored on videotapes, there has also been an increase in the production of digital-born content on platforms such as social media [5].

Although these digital platforms facilitate the dissemination of arts, the ephemeral nature of online materials poses a potential risk to the preservation of cultural and artistic products. Works published as posts on social networks such as Instagram and X, for example, tend to be dispersed amid the large volume of new content continually posted [4]. Furthermore, the discontinuation of certain platforms, as the social network Orkut, can lead to the permanent loss of digital materials. Preservation is also threatened when artistic works rely on specific technologies that become obsolete, as occurred with creations developed in Flash, which ceased to be supported by major web browsers at the end of 2020 [36].

Without proper care for the preservation and cataloging of these digital works, they are subject to disappearance, technological obsolescence, or even simple dispersal across the web [24]. The deterioration process, although generally not caused by humidity, temperature, or light – as is the case with physical works – also applies to digital creations, since they are subject to data corruption and loss, as well as technological lag or discontinuation of proprietary technologies. Therefore, far from being a topic of exclusive interest to the Digital Humanities, the preservation of digital art is also an inherent subject of Computer Science.

In this challenging context, the creation of digital archives represents an effective conservation strategy for these works and has become an increasingly frequent endeavor in the field of Digital Humanities [15]. These platforms, which combine archival, museological, and sometimes even educational purposes, may help overcome both geographical distances and certain socioeconomic barriers to accessing archived cultural products. Although they share some goals and purposes with traditional museums, these platforms do not necessarily replicate the experience of visiting a physical space, and may instead employ different interaction resources.

In the preservation of digital-born or digitized works, several projects have sought to provide solutions for the field. One such example is Tainacan, a free software platform aimed at building collaborative digital archives [32], developed by the University of

Brasília, with support from the Federal University of Goiás, the Brazilian Institute of Information in Science and Technology, and the Brazilian Institute of Museums. Digital archives developed using Tainacan generally present works to visitors through traditional web pages, as in the Museu da Casa de Benjamin Constant[1]. However, this is not the only approach adopted by such platforms. Other initiatives, such as the Museu do Ipiranga Virtual[2] and the Museum of Life[3] maintained by Fiocruz, use Virtual Reality (VR) to create immersive experiences with digitally preserved works or even environments.

Given the interdisciplinary nature of the topic and its foundation in digital technologies, it is essential to examine key aspects from fields such as Human-Computer Interaction (HCI), Multimedia and Software Engineering (SE) in digital archives or museums. In the field of HCI, there is room not only for improving the resources employed, but also for customizing and evaluating these tools from the users' perspective, in order to offer a better user experience while interacting with the digital archive or museum. This includes analyzing how the modes of interaction with these platforms, such as through web pages or VR environments, can influence user interest, exploration of the archive, and overall experience quality. With regard to SE, it is necessary to observe the development of techniques that ensure the efficient implementation of digital archives, with particular attention to the evolution of both the archives and the digital-born works over time.

Given the interdisciplinary nature of digital archives and the fragmented treatment they often receive across the Digital Humanities and Computer Science, this systematic literature review examines 21 studies to identify the primary purposes of such platforms, the technological strategies employed in their development, and the interaction modalities made available to users. By articulating perspectives from both fields, the study contributes to a deeper understanding of current practices while also revealing critical gaps, such as the limited incorporation of Human-Computer Interaction and Software Engineering principles, the lack of standardization in development methodologies, and the insufficient attention to accessibility and long-term software evolution.

## 2 FUNDAMENTAL CONCEPTS

Given the interdisciplinary nature of this work, involving both the Humanities and Computer Science, we present in this section some fundamental definitions for the discussions addressed in this study.

### 2.1 Digital Archives

In this work, we use the term "archives" to refer to institutions that collect, systematize, preserve, and present cultural products to the public. Within this scope, different types of institutions are included, such as museums, archives, and libraries. Their functions may differ for specialists, but for the general public (and for the purposes of this study) they can all be understood as memory institutions.

Digital archives can be broadly defined as organized collections of cultural products that are either originally digital (such as ebooks or images produced by generative algorithms) or digitized (such as images of books and photographs of oil paintings, among others). According to Owens and Padilla [33], a digitized collection may be a copy of a partial or complete collection of a physical archive, as in the case of the *BNB Digital*[4], or the *Centro Digital de Documentação e Pesquisa Memórias do Sul da Bahia*[5]. Both in digitized and digital archives, each collected item is described by metadata and, in general, the collections are accessed by the public through an online interface.

The importance of digital archives for the construction of a memory of our present time is directly proportional to the challenges they face. In addition to issues of funding, infrastructure, and archival methodology, which also affect physical collections, digital archives face issues such as technological obsolescence [42], archival instability, and the potential for infinite data accumulation [21].

### 2.2 Digital Culture

Digital culture can be defined as the set of cultural practices that emerge from contexts in which interactions between two or more humans, between humans and the world, and between humans and their ideas are mediated by computational technologies. In his analysis of the language of new media, [31] defines five characteristics of this language, which can also define the structural elements of digital culture: numerical representation, modularity, automation, variability, and cultural transcoding.

Other proposals for the semiotic characterization of digital culture, such as that of [13], highlight features such as digitality, mobility, impermanence, disruption, connectivity, editability, combinatorics, duplicability, exponentiality, and virtuality, among others. Describing how we relate to information and communication technologies (ICT), these features are hallmarks of a culture in which data is transformed into information and gains prominence in economic, political, and social processes, in a dynamic that Castells [11] called informationalism. Generating data that multiply and circulate in accelerated global flows, the complexification of digital culture requires a complexification and evolution of digital archives as memory devices for the growing mass of data.

### 2.3 Folksonomy

Folksonomy is a term that blends the words "folk" and "taxonomy" to describe the process of collaboratively tagging content. In this process, users evaluate the content and define tags that represent it, creating a form of categorization that evolves organically [43]. This can be done in two ways: if the tags are stored only once, we have a narrow folksonomy; however, if each new instance of the tag is recorded, it is considered a broad folksonomy. In the latter approach, it is possible to conduct an in-depth analysis of the number of tags and the exposed content, ensuring greater fidelity to the tag [37]. By reflecting the way users organize and categorize information on the internet, folksonomy is deeply related to digital culture and digital archives.

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[1]https://museucasabenjaminconstant.acervos.museus.gov.br/pagina-acervo-museologico/
[2]https://museudoipirangavirtual.com.br/
[3]https://eravirtual.org/parque-da-ciencia/

[4]http://bnbdigital.cultura.df.gov.br/
[5]https://memoriasulbahia.com.br/

## 3 STATE OF THE ART

Due to its interdisciplinary nature, research involving the creation of digital works, museums, or archives may present different perspectives on the artifacts produced and their use. Thus, this section discusses works that represent the state of the art in digital archives from the perspective of each area.

### 3.1 Digital Humanities

From the perspective of Digital Humanities, publications usually discuss aspects related to the definition of digital archives and their main characteristics. "Anarchive", for example, is a term used by Rocha [41] to recognize the instability, ephemerality, and variability of digital media, which define the characteristics of digital works. With the advancement of digital technologies, it is increasingly common for works to exist exclusively in digital archives. A central issue, therefore, is to find an effective means of preserving these works while respecting their unique characteristics.

Other studies discuss the effective preservation of digital works, which requires not only protecting them from obsolescence but also maintaining their unique characteristics, including their ephemerality and technological dependence. Rocha [41] argues that the intrinsic obsolescence of digital works also needs to be preserved. This ephemeral existence demands the preservation not only of the works themselves but also of their interaction with the reader.

Gobira and Corrêa [20] describe the creation and development of the PO.EX Digital Archive, focusing on the preservation of digital poems. Their preservation efforts ensured that the interactive features of the works were maintained. Since these works were created through programming, they required servers for distribution. To address this issue, the works were reimplemented on the platform's own servers. Alternatively, the implementation could be made available on multiple platforms, reinforcing the idea that dissemination itself is a form of preservation.

While the PO.EX Digital Archive focuses on preserving the interactivity of the works, Pereira [36] discuss the decentralization of digital preservation and the valorization of works from Mato Grosso, while cataloging and disseminating regional literary productions. In the Digital Literature Collection of Mato Grosso, works published on websites or social media platforms (Instagram, Wattpad, Twitter, Facebook, etc.) by artists born or residing in the state of Mato Grosso, Brazil, are showcased. This collection serves as a refuge space for lesser-known works and proposes a means for the dissemination and conservation of regional works in a tool conceived in Brazil: the open-source WordPress plugin Tainacan. Thus, according to Pereira [36], the project fosters the independence of research and literary production delinked from Eurocentric technological and aesthetic standards.

### 3.2 Computer Science

From the perspective of Computer Science, many studies focus on the development of methodologies and technical guidelines aimed at digital preservation. In this line, Formenton and Gracioso [18] propose guidelines for the preservation of digital works, considering the ephemerality of dissemination and storage media, for both digital-born and digitized works. Their work outlines challenges of managerial, technical, legal, political, economic, and social nature.

Ahmad and Rafiq [1] highlight that many organizations already have or are trying to develop digital preservation policies. However, they argue that the development of such policies is generally considered an intrinsic responsibility of organizations, rather than an outsourced or globalized task.

Aspects related to HCI, in turn, have been less explored in the context of digital museums and archives. Tong et al. [47] propose visual interface design strategies for digital museums of intangible heritage based on user experience principles, focusing on color, typography, and layout, but without conducting user evaluations. Similarly, Lee et al. [28] analyze the Google Art & Culture platform through the lens of remediation theory, identifying interface elements that foster both information delivery and user engagement. Their study provides conceptual insights, but does not include empirical testing with users. On the other hand, a broader and complementary perspective is provided by Drivas and Vraimaki [17], who evaluate 234 museum websites based on accessibility, usability, SEO, and speed. The authors emphasized the relevance of user-centered metrics and highlighted disparities in user experience between mobile and desktop platforms. The proposed framework promotes inclusive design and supports non-technical staff in improving digital interfaces, reinforcing key HCI principles such as usability, accessibility, and equity.

### 3.3 Contributions of this paper

The scientific literature presents reviews discussing the use of digital technologies, such as Artificial Intelligence (AI) and VR, within the scope of exhibitions, archives, and museums. For instance, [51] and [22] focus on visitor behavior and user experience with immersive technologies such as VR and Augmented Reality (AR) in museum contexts. Their analyses, however, are predominantly limited to physical or hybrid exhibitions. Li et al. [29] offers a comprehensive overview of Digital Transformation Technologies (DTTs), including AI, Internet of Things (IoT), robotics, and 3D printing, but does not examine how these technologies relate to the communicative or functional objectives of digital collections.

Complementarily, studies such as [52] and [16] are more aligned with institutional and preservation-oriented concerns and do not explore user interaction in depth. Pavlović [34] in contrast, discusses digital tools for learning in museums but remains grounded in pedagogical theory without analyzing digital archives as platforms for broader cultural participation. However, these reviews consider the role of such technologies as part of an experience that is predominantly analog and often guided by professionals or instructions within the physical environment. With this literature review, we aim to investigate the technological decisions and interaction approaches that have been adopted in exclusively digital collections and museums with adaptation, personalization or customization. This investigation is important because, in such cases, the user's entire interaction with artistic productions is mediated by interfaces, which may influence their experience, interest and appreciation of these works.

## 4 METHODOLOGY

In order to identify the characteristics, user interaction methods, and digital technologies used in digital museums and archives with

adaptation, we conducted a Systematic Literature Review (SLR). This review was organized into three main stages, as presented in [26]: *Planning*, *Conducting*, and *Reporting*. The first stage (*Planning*) involves defining the scope and the review protocol. The protocol adopted was PICOC, which is detailed in Table 1. Through this protocol, the area and object of study were defined (*Population*, *Intervention*, *Comparison*), along with the expected objectives (*Outcome*) and the groups affected by this review (*Context*). Our research questions (RQs) are the following:

- **RQ1:** For what purpose are digital archives developed?
- **RQ2:** What computational technologies can be observed in digital archives? How do these characteristics relate to the purpose of the archives?
- **RQ3:** How do users of digital archives interact with the platform and the works available there?

Our first research question (RQ1) aims to explore the purpose of digital archives. While many of them were developed to digitalize physical museums, other digital archives were created aiming to enhance the availability of artworks. Considering that the purpose of a digital archive can influence the interaction aspects and the technologies adopted, we addressed this topic in this review. Then, in the second research question (RQ2), we observed the technologies adopted in each digital archived related in the papers, aiming to identify if there is any association between technologies and archives' purposes. Aspects related to users' interaction were discussed in our third research question (RQ3), aiming to identify challenges, limitations and opportunities for this context.

In the second stage (*Conducting*), some control articles were selected through a non-systematic search in the Scielo and CAPES Journal Portal databases, aiming to identify relevant articles that could serve as a basis for the selection of keywords. The resulting search string, derived from these keywords, was: *Title must contain: (personaliz\* OR adapt\* OR customiz\* OR user-center\*); metadata must contain: ("digital archive" OR "digital collection" OR "digital museum" OR "virtual museum" OR "cultural heritage" OR "digital art gallery")*. The string was applied to four academic databases: ACM Digital Library, IEEE Xplore, Science Direct, and Scopus. To ensure robust and comprehensive coverage of the study's interdisciplinary focus, the selection targeted databases prominent in Computer Science (e.g., HCI and Software Engineering) and broader research fields (e.g., Digital Humanities and Cultural Heritage). Table 2 shows all versions of the strings.

The search string was meticulously crafted to maximize the retrieval of interdisciplinary works, combining terms for adaptation (e.g., adapt\*, personaliz\*) with context keywords (e.g., "digital museum", "cultural heritage") to ensure all selected studies remained highly relevant to the review's core focus. After the initial data collection using the search strings, the database filters were deemed insufficiently precise. To ensure the proper selection of articles, a Python script was developed to automatically verify the presence of the correct keywords in the metadata and titles, as specified in the search strings. In order for articles to be selected within the scope defined by the review protocol, the inclusion and exclusion criteria were established and listed below:

**I1:** The study addresses the development, maintenance, or use of a digital collection or digital museum.

**I2:** The study describes technical aspects (interaction methods, technologies used) that support the understanding of computational elements.

**I3:** The study presents a solution focused on a broader collection, rather than on a single (art)work.

**E1:** The study does not discuss the development, maintenance, or use of a digital collection/museum.

**E2:** The study does not describe technical aspects (interaction methods, technology used) that enable understanding of computational aspects.

**E3:** The study presents a solution related to a specific (art)work, without addressing a broader collection.

A study is considered eligible when none of the exclusion criteria apply. Additionally, no restriction was placed on the publication date of the articles. Subsequently, data extraction was divided into two stages: partial and full; and performed by two people. Initially, titles and abstracts of all papers retrieved from the databases were read. Only the articles that met the inclusion criteria were read in full, for detailed information extraction and the extraction was performed by using a structured form briefly described in Table 3. Also, whether or not the study included a user evaluation was taken into account during the extraction. This aspect was considered relevant for identifying works that go beyond technical or theoretical descriptions and provide evidence of practical applications and user experience. At the end of the selection process, 21 articles were accepted. The selection process is shown in Figure 1, while Table 4 presents the data collected from the articles selected during this phase.

## 5 RESULTS AND DISCUSSION

In this section, we present the results obtained in our investigation, based on the data synthesized in Table 4. Next, we answer the previously formulated research questions and perform a critical analysis of the evidence found, highlighting the contributions and limitations.
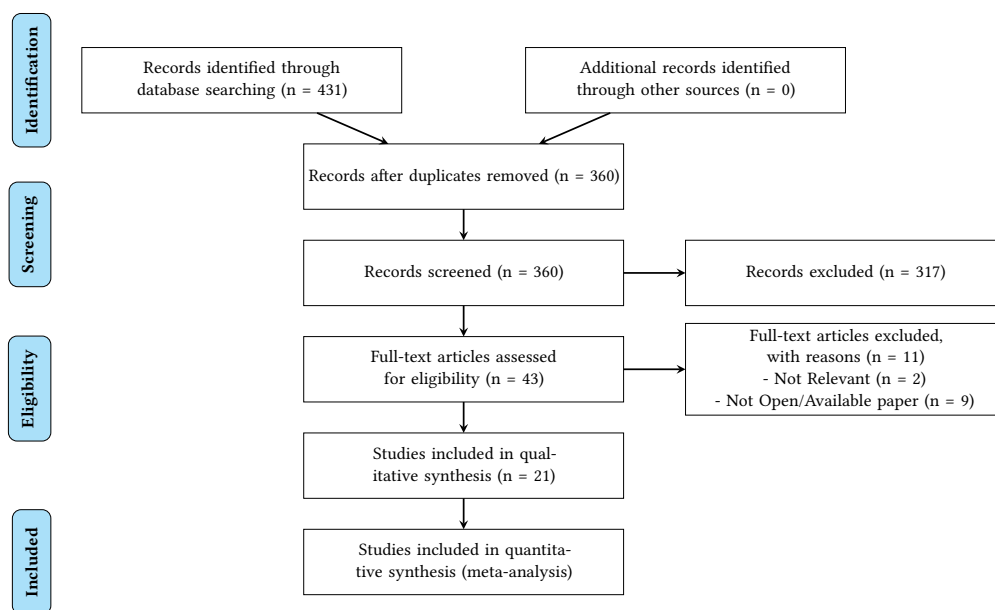
### 5.1 Purpose of Digital Archives

The analysis of the selected articles reveals that the digital archives addressed in these studies are applied in different contexts, also involving different purposes in their conception. In this sense, to support the discussion of **RQ1**, we chose to divide the purposes of the archives into three strands: i) **dissemination**, related to improving visitation; ii) **preservation**, aimed at the maintenance and care of digital works over time; iii) **availability**, related to the facilitation of access to digital works. These categories are not mutually exclusive; therefore, an archive described in a certain study may fall into more than one category, highlighting the multifunctionality of digital archives.

*5.1.1 Dissemination.* Dissemination, which involves the concern with providing a more meaningful experience of exploring the works in the archives, is the most recurring purpose, being observed in 57.14% of the studies. A significant point raised in the works with this purpose is the need to condense the content presented to the user [3, 30, 38, 43], which include, among others, examples that employ recommender systems for this purpose. This stems from

**Table 1: Descriptive table of PICOC protocol elements.**

| PICOC Protocol | |
| --- | --- |
| Population | Studies that describe the development, evaluation, or analysis of digital archives and their impacts. |
| Intervention | "Innovative" approaches to exploring digital archives. |
| Comparison | Digital archives with traditional interaction approaches, such as static web pages. |
| Outcome | Experience with the works, user experience, interest in exploring the digital archive. |
| Context | Academic papers published in conferences or journals, as well as applications made publicly available. |



**Figure 1: PRISMA Flow Diagram illustrating the identification, screening, eligibility, and inclusion of studies according to the defined criteria.**

the fact that many archives have large databases of works and a heterogeneous audience. Thus, the task of presenting appropriate content for a certain user becomes much more complex in this situation. Bonis et al. [9] mention that, due to the large volume of data in these platforms, there is a need for content recommendation to enable user interaction with these extensive data sets. According to this study, a common strategy is to subdivide large data sets, thereby generating subsets. From these subsets, content suggestions are generated for users. To this end, the authors implement semantic graphs to better organize the works.

Since archives also play an active role in mediating knowledge, those designed with this purpose often adopt various strategies to encourage user interaction and the discovery of new cultural products, making the experience more immersive and engaging. Our review found works involving catalog personalization according to user characteristics ([3, 38]), encouragement of users' active participation in exploring the collections ([39]), and the creation of more intuitive environments ([19]).

Geng Yang [19] evaluated what design characteristics are most important to users of these tools. A form was used to collect data on which factors influence user comprehension while navigating the page of a digital archive. In the case of [53], implementation efficiency was evaluated through experimental testing. The authors

developed an automatic path search algorithm and applied it to a digital collection. Then, they incorporated the obstacle avoidance technique and compared the performance before and after the implementation. The result revealed improvements not only in more natural movement but also in processing performance and use of memory space.

Another approach adopted by researchers involved improving how additional information about the works is communicated to users. Studies such as [2, 14] investigate more natural means of communication between the user and the collection, promoting greater familiarity and, consequently, better learning. To evaluate communication, [14] led an experiment in which, after interacting with the tool, the users responded to a survey assessing mixed reality experiences, as proposed in [50]. The results of this study will be discussed in more detail in Section 5.3.2. Also from a social perspective, [9] developed a method to create communities with similar interests, thus increasing engagement and encouraging collaborative exploration of digital archives. Once the user modeling is established, it was possible to compare different users, and thus create groups with similar interests. Personalized rooms were created and assigned to users with similar preferences, so that users could meet and communicate.

**Table 2: Database search strings.**

| Database | Search String |
|---|---|
| ACM Digital Library | [[Title: personaliz*] OR [Title: adapt*] OR [Title: customiz*] OR [Title: user-center*]] AND [[All: "digital archive"] OR [All: "digital collection"] OR [All: "digital museum"] OR [All: "virtual museum"] OR [All: "cultural heritage"] OR [All: "digital art gallery"]] |
| ScienceDirect | Title, abstract, keywords: "digital archive" OR "digital collection" OR "digital museum" OR "virtual museum" OR "cultural heritage" OR "digital art gallery" Title: personalization OR personalized OR adaptation OR adaptive OR customization OR customized OR user-centered |
| Scopus | TITLE ( personaliz* OR adapt* OR customiz* OR user-center* ) AND TITLE ( "digital archive" OR "digital collection" OR "digital museum" OR "virtual museum" OR "cultural heritage" OR "digital art gallery" ) |
| IEEE Xplore | ("Document Title":personaliz* OR "Document Title":adapt* OR "Document Title":customiz* OR "Document Title":user-center*) AND ("All Metadata":"digital archive" OR "All Metadata":"digital collection" OR "All Metadata":"digital museum" OR "All Metadata":"virtual museum" OR "All Metadata":"cultural heritage" OR "All Metadata":"digital art gallery") |

**Note:** Each string was adapted to each platform's search syntax.

**Table 3: Summary of key categories extracted from the analyzed articles.**

| Question | Main Answers |
|---|---|
| Purpose of the Archive | Availability, Dissemination, Preservation |
| Interaction Techniques and their improvement | Recommendation Systems, Personalized 3D Environment Generation, Software Quality (A, Folksonomy, Chatbot, Realistic Environments, Data Organization |
| Interaction Resources | Virtual Reality, Traditional Page, Voice, Mixed Reality, Social Network |
| Creation Tools | Unity, Python, JavaScript, XML, WordPress |
| Media Formats of the Artwork | Images, Text, 3D Models, Audio, Video |
| User Evaluation? | Yes, No, Not Informed |
| Reported Challenges | Lack of Funding, Technical Problems, User Education, Hardware Limitations, Interdisciplinary Integration |

*5.1.2 Preservation.* The preservation of works, whether digitized or digital-born, is a central motivation for the development of several digital archives. However, within the scope of this review, few articles have focused on preservation; instead, this concern arose secondarily. For this reason, only 9.52% of the articles fall into this category. In [10], the goal of conserving digital cultural products [44] in digital archives is explicit. The researchers aimed at creating a digital collection of Indonesian customs, arts, and traditions to ensure these are not lost over time. The "e-Dayaknese" framework developed by the authors allows for the creation of entirely new cultural products or the association of new items with existing ones. It leverages a semantic structure based on the relationships between items, which facilitates the discovery of related content. In the proposed architecture, the digital organization of cultural data improves the consultation time and registration of new items. In addition to that, one of its modules is responsible for collecting user

**Table 4: Articles included in this Systematic Review.**

| # | Citation | Year | RQ1 | RQ2 | RQ3 |
|---|---|---|---|---|---|
| 1 | [7] | 2007 | DIS | RS, PEG | VR |
| 2 | [9] | 2009 | DIS | RS, PEG | VR |
| 3 | [35] | 2009 | DIS | SQ | TP |
| 4 | [19] | 2009 | AVA | SQ | TP |
| 5 | [30] | 2009 | DIS | RS, FOLK | TP |
| 6 | [12] | 2010 | AVA | DO | TP, VR |
| 7 | [2] | 2010 | DIS | CHAT | TP |
| 8 | [43] | 2012 | DIS | RS, FOLK | TP |
| 9 | [3] | 2013 | DIS | PEG | VR |
| 10 | [27] | 2018 | DIS | PEG | VR |
| 11 | [38] | 2019 | DIS | RS, PEG | VR |
| 12 | [39] | 2019 | DIS | RS, EYE | TP |
| 13 | [10] | 2019 | PRE | RS | TP |
| 14 | [6] | 2019 | DIS | SQ | TP |
| 15 | [48] | 2022 | PRE | RS | TP, VR |
| 16 | [49] | 2023 | DIS | RS, PEG | VR |
| 17 | [53] | 2023 | DIS | RE | VR |
| 18 | [23] | 2023 | DIS | RE, EYE, CHAT | VR, VOI |
| 19 | [45] | 2023 | DIS | RS, SQ | TP |
| 20 | [25] | 2024 | AVA | PEG | VR |
| 21 | [14] | 2024 | DIS | CHAT | MR, VOI |

**Caption:** AVA: Availability, DIS: Dissemination, PRE: Preservation, RS: Recommendation Systems, PEG: Personalized 3D Environment Generation, FOLK: Folksonomy, CHAT: Chatbot, EYE: Eye-tracking, RE: Realistic Environments, SQ: Software Quality Analysis, DO: Data Organization, VR: Virtual Reality, TP: Traditional Page, MR: Mixed Reality, VOI: Voice Interaction.

information, enabling personalized recommendations. The information is collected following the proposed 5R Adaptation Framework. The acronym 5R stands for Right Timing, Right Location, Right Device, Right Learner, and Right Contents, meaning that the recommendation is made based on the user's context. In the validation process, a functional prototype of the proposed framework was implemented, but user surveys, scalability tests, or discussions on software evolution were not conducted.

In turn, [45] presents a tool that stores digital and digitized sculptures from artists representing various cultures around the world. The tool uses fuzzy logic-based resources to improve recommendations by taking into account user profiles and the experience of accessing cultural heritage. The architecture created for Sculpt-Mate contains three layers: the *User Interface Layer*, which allows button configuration and 3D model visualization; the *Application Logic Layer*, which includes the implementation of content management and personalization with fuzzy logic; and finally, the *Data Storage Layer*, which stores user information and structures. The article mentions that the focus during development was on usability, adaptability, and performance, allowing for future evolution of the framework due to its modular implementation. The main improvements discussed in the article are the implementation of more sophisticated machine learning algorithms and techniques for more accurate recommendations. The paper also proposes the migration from local storage to a cloud server, with integration with APIs to access external resources and models. Furthermore, the authors discuss the possibility of implementing social functionalities, such as sharing preferences among users, promoting a more connected community.

*5.1.3 Availability.* Another purpose of digital archives is to make content available to the public, facilitating access to digital cultural products, as discussed in 33% of the analyzed studies. Some studies

present models that address the heterogeneity of digital resources, proposing strategies for making content available in a way that improves user experience , whether by developing user-centered and enjoyable interfaces [19], or by implementing recommendation systems to guide access [12, 53]. These approaches aim to make access to heritage more inclusive, adapted to individual needs and, at the same time, increase interactivity and visitor engagement, providing a richer and more personalized experience. Budiman et al. [10] and Strousopoulos et al. [45] state that, in addition to acting as preservation tools, collections play a crucial role in democratizing access to the heritage of socioethnic entities with limited visibility on the global stage. These tools not only ensure digital preservation but also expand access to the represented cultures.

Similarly, Bollini [6] proposes the centralization of information on cultural heritage, aiming to make content available both to natives and to the non-specialized public in the Milan region. That strategy is intended to preserve the relationships between documents during the process of organizing and digitizing the works. This model aims to broaden access to cultural resources, promoting greater understanding among diverse audiences and encouraging engagement with local history. In the evaluation process, a survey was conducted with 24 participants, and the data were analyzed according to Norman's guidelines. Based on the findings, a second design cycle was launched to implement the necessary improvements. The collection was evaluated within the field of HCI, aiming to verify usability and user-centered design. However, no effort was made to analyze the collection's potential for popularization; that is, metrics of reach or social impact were not taken into consideration.

## 5.2 Techniques and Technologies

Digital archives and museums are driven by a variety of technologies aimed at providing immersive and personalized experiences for users. This section discusses the main technological approaches and their relation to the archive purposes identified in the literature, seeking to answer the research question **RQ2**.

*5.2.1 Virtual Environments.* In digital museum studies, virtual environments can take on various forms and characteristics. In this article, virtual environments are considered as 3D interfaces, which may or may not resemble the physical spaces of real museums, allowing users to navigate, interact with, and explore exhibitions. This type of system often uses 3D modeling and supports specific equipment, such as VR headsets.

Svanaes [46] argues that the meaning of something is generated from the physical interactions we establish with the environment. Thus, perception and interaction are directly linked to how we see an artifact and what it represents – not statically, but dynamically and generated at the moment of interaction. VR provides the environment through which the user can interact and, consequently, create new meanings and perceptions of the surrounding objects. Therefore, it has become one of the most common resources in digital museums, providing immersive experiences that allow users to explore exhibitions intuitively. 3D virtual environments have been widely adopted in studies focusing on adaptive enhancements to conventional museums. For example, Komianos and Oikonomou [27], Rajaonarivo et al. [38], Bonis et al. [9], Yang et al. [49], Zhao

[53], and Kim et al. [25] present solutions that adapt the user experience to the context of traditional museums through personalization and interaction enhancements within 3D virtual environments. These studies represent approximately 28% of the publications in our SLR.

These studies focus on different characteristics of virtual environments. For example, in [49] the development of the environment reflects a concern with realism in the rendering of 3D models. The article describes the steps used for gamma correction, color, and tone adjustments of images to create a more realistic and therefore more immersive environment. Zhao [53] also address this concern by discussing the following modeling methods: geometric modeling, based on mathematical models and computer graphics; and image-based modeling, using real image capture. While the former offers many details in the 3D model, it is computationally expensive for complex environments such as a digital museum. The latter offers many visual details but has limitations regarding the interactivity of the 3D model. Therefore, the authors propose a hybrid modeling approach, leveraging the interactivity of the first method and the realism of the second.

In addition to the visual realism of 3D models in the virtual environment, Zhao [53] also discusses more natural forms of navigation. For example, algorithms are developed, to ensure that movement occurs naturally, smoothly avoiding objects rather than passing through them. Other works discuss the effective arrangement of artworks within the space, considering artistic categories [9], user preferences [38], and immersion time within the virtual environment [27].

*5.2.2 Traditional Interfaces.* While several adaptive works highlight a preference for 3D virtual environments, in which the user is directly immersed in the exhibition context, studies such as [2] propose an alternative approach. In this study, artworks are brought closer to the user through simplified interfaces focused on prioritizing direct interaction with displayed items, without the need for full immersion in a virtual environment. In this case, the user interacts directly with the model of the artwork and does not navigate through a virtual environment. This interaction is performed through traditional visual commands, by clicking buttons on the archive's interface.

Studies such as [12] and [6] also favor the use of traditional web pages due to the diversity of resources available to users. This approach is common in contexts where resource heterogeneity demands a more conventional interface, focused on user-centered curation. On the other hand, studies aiming to enhance the user experience through interface adaptations, such as [35] and [19], opt for simplified and conventional traditional pages. This is because the inclusion of external elements, such as excessive menus, disconnected functionalities, or redundant information, would compromise the immersiveness of the archive.

In a context where immersion is not a priority, several studies are dedicated to gathering and adapting artworks based on cultural and ethnic characteristics, without the intention of replicating a real-world exhibition in a virtual environment. Examples can be found in studies such as [10, 30, 43, 48], which adopt traditional page structures. These works focus on curating and organizing artworks based on cultural and ethnic categories.

*5.2.3 Recommendation Algorithms.* The literature highlights the growing adoption of recommendation algorithms in different types of digital archives, both in 3D virtual environments and traditional pages, aiming to enhance the personalization of the user experience.

In 3D environments, recommendation involves various techniques. Javdani Rikhtehgar et al. [23] and Raptis et al. [39] use eye-tracking to assist in analyzing user behavior and enable suggestions based on their points of interest. For instance, in [23], users' eye movements were tracked to determine which elements within paintings most attracted their attention (buildings, faces, and details). This information was used to make personalized recommendations. The study also reveals that gaze duration can serve as an indicator of user preference, but this correlation comes with certain limitations. User surveys showed that the display order of artworks, how detailed the artwork is, or whether it has a more or less interesting description also impact gaze duration, but they do not necessarily define a user profile.

In contrast, folksonomy-based approaches, as seen in [43] and [30], involve organizing content through collaboratively defined categories, and traditional pages provide users with a familiar interface to perform this task. In [30], users rated paintings (from 1 to 5) and added tags they deemed appropriate. The interface provided access to the painting image, title, description, and other popular tags created by users. A data collection process was carried out with 40 individuals (30 general users and 10 experts) to gather tags for training a multivariable Poisson model. Tags were classified as (i) PersonalTags, provided by a specific user for a specific artwork; and (ii) SocialTags, assigned to the artwork by various users. The results showed a general improvement in filtering accuracy with tags created by users. Based on this, the authors proposed a hybrid system that incorporates folksonomy into content-based recommendation. To evaluate this framework, K-fold cross-validation and metrics such as precision and recall were used, tied to different experimental combinations (permutations between static content implementation, personal tags, and social tags). The inclusion of SocialTags produced lower results than PersonalTags, and combining static information (artwork descriptions) with PersonalTags achieved the highest filtering precision. The main results of this study show that personal preferences are more relevant than general consensus when making recommendations.

Moreover, models that adapt to user preferences are present in both immersive environments and traditional pages. Examples include the use of machine learning for personalization, as in [49] and [25], as well as genetic algorithms and fuzzy logic for more accurate recommendations, as previously addressed in [45].

The dynamic generation of 3D virtual spaces can also be tailored to user characteristics and the curated selection of artworks to be displayed. In [8, 9, 38], semantic graphs grouped artworks for users, optimizing the recommendation process. In [53], recommendations are generated based on user profile, which includes demographic attributes collected to associate new cases with similar past ones, using the Case-Based Reasoning technique. Recommendations are generated in a ranked list of the best visitation routes. Likewise, in [49] demographic data (age, profession, gender, education level) are collected to serve as input for a deep learning model that can infer user preferences.

In addition to these approaches, other methods also deserve mention, such as calculating the proximity between clusters of artworks and users, as described in [25]. In this case, artworks are divided into thematic clusters, based on similarity in color, material, description, artist, and creation date. Once the groups are defined, distances between them are calculated, representing how different they are from one another. This information is then used to generate more coherent thematic exhibitions.

*5.2.4 Chatbots.* [2, 14, 23] implement chatbots and voice interaction to improve communication between users and the archive systems. Those systems are complementary to the standard ways of interaction, like mouse and keyboard, and so not mandatory to the user. In [2], speech recognition is limited by the grammar that the system can recognize, which restricts interaction with the user. In this type of approach, questions outside the system's predefined pattern are not understood, which could frustrate users. Through this system, users can obtain specific information about artworks and also use specific voice commands for navigation. Voice-guided navigation adds an accessibility layer to the software, enabling use by people with motor or visual impairments, in addition to offering a different form of interaction for users to acquire knowledge of the artworks. Nonetheless, this feature should be regarded as a complementary interaction method, as reliance on voice guidance alone may pose accessibility barriers for deaf users.

## 5.3 Interaction Features

Interaction features play a fundamental role in user engagement and satisfaction. From this perspective, the studies revealed different forms of interactivity with digital archives, which will be presented in the following topics, allowing us to address **RQ3**.

*5.3.1 Interaction in Virtual and Augmented Reality Environments.* VR is one of the technologies that enables the creation of 3D virtual environments, where interaction can be either immersive (through the use of VR headsets or haptic gloves) or non-immersive (typically via conventional screens). In [9], VR allows the development of a more immersive and realistic experience for the user, as it also enables more natural navigation. The construction of VR spaces involves several stages, such as the arrangement of objects in the environment, texturing, lighting, and, in some cases, animation.

The works of [7, 9, 38, 49, 53] seek ways to facilitate the construction of VR environments and represent 25% of the articles we analyzed. In these studies, methods were developed to automate and simplify the creation of VR environments through algorithms capable of arranging the items across the available space, given a set of artworks – an otherwise time-consuming and repetitive manual task. In [27], this arrangement also aims to optimize the user's time by ensuring that artworks are placed in appropriate locations with dynamically calculated spacing, minimizing unnecessary time spent during exploration. Likewise, [53] also develops an algorithm to find more natural paths that avoid obstacles in exhibitions, thereby improving the user's navigation experience.

In [53], interaction occurred in an intuitive and immersive manner, allowing users to explore the digital archive through different modalities. Sensors captured movements, voice commands, and

gestures to enable fluid navigation through the virtual environment, while an intelligent roaming system automatically adjusted the trajectory to avoid obstacles, making navigation faster. Various media formats (text, image, animation, sound, and video) were also integrated into the systems to find more user-friendly ways to convey information.

Other articles, such as [53], [9], and [38], do not explicitly describe how user interaction takes place – whether through mouse, keyboard, or any special equipment. In contrast, [49] details how interaction occurs: the WASD keys are used to navigate the environment, the R key activates automatic navigation to a user-defined point, the mouse sets the viewing direction, and the right-click allows the user to rotate objects. Strousopoulos et al. [45] describe an alternative to standard devices: headsets compatible with 3D vision, which provides greater immersion.

An important point is that articles concerning archives using VR demonstrate a concern with navigation through space, emphasizing naturalness and user's freedom. Among the works analyzed, users were not suggested specific routes to follow; guidance occurred through the museum's construction based on artwork selection during curation and automatic space creation. The only exception was [3], in which a route is suggested to the user and adapted not only to their preferences but also to their reactions while navigating the exhibition. It is worth noting that navigation is a key challenge in any VR environment, particularly immersive ones requiring headsets, and not an issue exclusive to virtual archives, so that solutions and challenges in VR from other domains might apply to digital archives as well. Surprisingly, the analyzed studies do not address motion sickness, a common concern in immersive VR experiences. Although most works include some form of user evaluation, these are often limited to assessing curatorial aspects. They analyze, for example, the positioning and distribution of artworks, or the quality of the rendering and lighting, rather than comfort or discomfort during navigation.

*5.3.2 Voice Interaction.* From another perspective, in [2, 14, 23], representing 14% of the studies, voice resources permit a more personalized and natural user interaction. With advancements in the development of LLMs (Large Language Models), such as LLaMa or GPT, text generation has become significantly more sophisticated and complex, allowing for advancements in voice system implementation for digital archives, as done in [14]. In this project, an application was developed for Microsoft HoloLens (1st generation) to present artworks to visitors, integrated with a system using the GPT-3.5 model, which received the user's audio recording and generated the desired responses. In the application evaluation tests, a mixed reality approach was used, displaying images of the artworks to users through the headset. The results of the study indicated that this technology has the potential to captivate users. Two metrics showed lower performance in the empirical test: immersion and response credibility. Although the metrics and tests that indicated the model's responses were accurate, users reported that they would not trust the information provided in awkward responses. Furthermore, they mentioned that the interaction with the conversational agent did not seem natural or realistic in the archive.

*5.3.3 Web Pages.* Web pages are widely used today as a solution for digital archives. Considering that one of the goals of such collections is to make archived material available, web pages offer broad compatibility with current devices, ease of use through elements such as menus and hyperlinks, and high scalability for large audiences. This form of interaction was employed in [6, 10, 12, 19, 30, 35, 39, 43, 45], which represent 43% of the articles.

Some studies implemented traditional-format web pages without incorporating any unconventional interaction element. One noteworthy example is [19] which presents a study and heuristic analysis of the interfaces of three different digital museums, aiming to identify the design elements that are most important for creating effective interfaces of this kind. The factors deemed most important were the *user model* and the *interpreter*. This emphasizes that the interface must have high usability and communicability, easily conveying its purpose and content to the user and responding satisfactorily to user interactions. Aesthetics, although relevant, was not prioritized; the main aspects mentioned were typography (font size and family choice) and the alignment of page elements.

In [6], a different form of user interaction is addressed. Their framework features a map-based visualization that can be freely explored by the user. For each point on the map, historical information is provided by the various communities that lived there.

## 6 QUANTITATIVE ANALYSIS

Figure 2 presents the temporal evolution of publications related to the adaptation of digital archives and museums. The graph shows that, despite a reduction in the number of publications in the years 2012, 2013, and 2018, the topic has been regaining prominence, indicating a renewed interest in the field. VR is the most widely adopted technology in the studies, followed by traditional web interfaces. Other technologies, such as voice interaction and chatbots, appeared in 2010 but only resurfaced in 2023, likely due to recent advancements in AI. The word cloud presented in Figure 3 underscores the terms most frequently used in the analyzed studies, revealing a prominent interest in personalization, VR, and immersive experiences.

Complementing this discussion, Figure 4, generated with the support of the *Bibliometrix* and *Highcharts* tools, shows the number of publications by country. Greece is the country with the highest number of publications, totaling 12 articles, followed by China, which appears in 7 publications. The results highlight the absence of publications from North or South American countries, revealing the need for broader discussions on interaction aspects in digital archives and museums.

Figure 5 emphasizes the relationship between the main interaction features employed in the papers analyzed and the purposes of the archives, categorized into three strands: dissemination, preservation, and availability. The strong interest in the use of VR stands out, as evidenced by its widespread adoption in 50% of the works included in the figure. One example is the study by [38], which proposes a model capable of generating a 3D virtual environment with the user's works of interest. Moreover, VR shows a similarly significant presence in archives aimed both at availability and dissemination. A scarcity of works exploring other approaches, such as AR, is also noticeable, suggesting that technological barriers or the need for specific infrastructure may limit its application for navigation in digital archives. Additionally, although the number
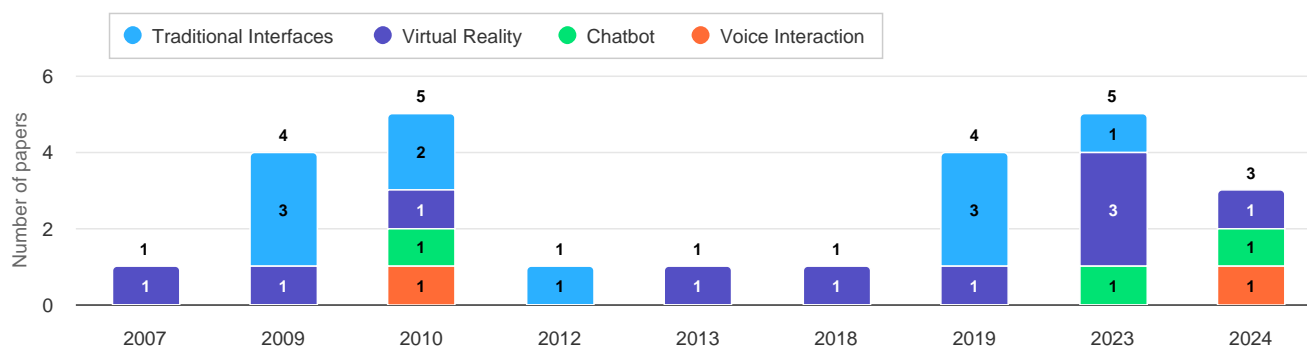
**Figure 2: Trends in the use of interaction features in works on digital archive adaptation.**



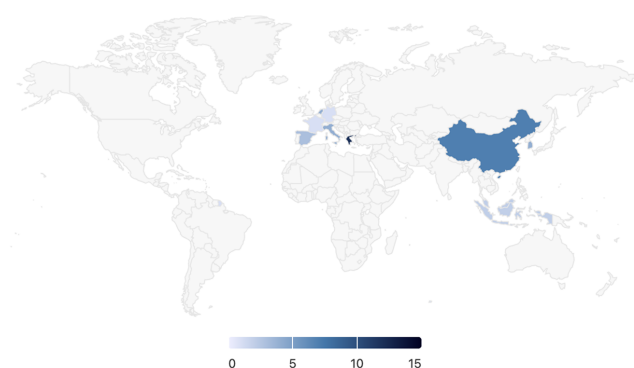**Figure 3: Word cloud with terms used in the studies.**



**Figure 4: Publications by Country.**

of studies implementing conversational agents and voice interaction is limited, these technologies appear to be more present in

studies focused on archive availability, suggesting a possible relationship between their adoption and the facilitation of access to digital cultural products.

With regard to evaluation, 71% of the studies conducted experiments with users. Notably, 100% of these works aimed at dissemination or availability, suggesting a significant focus on aspects of user interaction and access to archived materials. Furthermore, there is a recurrence of studies seeking to empirically validate their proposals. User participation in this process is essential, as many of the developed solutions aim to meet individual preferences and interests, making the experience more engaging and personalized. In summary, by observing the focus on dissemination and availability as purposes, the analyzed data reveal that digital archives and museums perform the role of active agents in the mediation of knowledge and collective memory in digital culture. The emphasis on VR highlights the concern with user immersion in the virtual environment; however, the low application of AR indicates an opportunity to be explored. Ultimately, empirical evaluations involving users are essential to validate the proposed approaches.

One of the recurring issues in the realm of the arts concerns copyright. Despite its relevance, only two studies explicitly address this matter in a significant way. In [45], the quality of 3D digitization of artworks is limited by the difficulty of accessing artifacts protected by copyright. In [12], copyright-related issues are discussed from a different perspective: the protection of digital artworks. One of the features proposed for the environment described in that study is the integration of a content management system equipped with security mechanisms capable of efficiently protecting various digital artworks in their multiple multimedia formats (text, image, 3D model, among others). This type of technology is particularly important in digital collections, which aim not only to provide access to content but also to ensure the preservation and respect of intellectual property rights. Thus, tools designed to prevent the misuse of images, unauthorized copies, or non-consensual modifications contribute not only to legal compliance but also to the consolidation of digital preservation initiatives.

## 7 CHALLENGES AND OPPORTUNITIES

The analysis of research on digital archives reveals both persistent challenges and opportunities to enhance the interaction experience
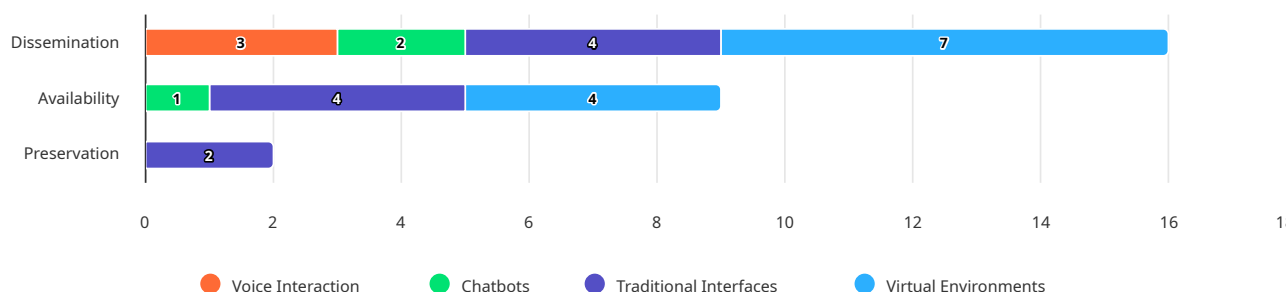
Figure 5: Interaction Features by Digital Archive/Museum Purpose.

within digital repositories. Several studies have explored adaptations and personalizations based on user profiles, as seen in [43] and [23], and have proposed interactive features to improve navigation and content access. However, there is a noticeable lack of effective applications of these approaches in natively digital archives. In many cases, the studies are limited to conceptual development models. For example, in [27], the evaluation is conducted using only a prototype, without implementing the results in an actual digital archive. This lack of a comprehensive evaluation constrains the findings to a non-realistic context.

Moreover, there is a clear scarcity of specific approaches in the construction and exploration of digital archives. For example, no implementations of 2D virtual environments were found. The main argument for implementing 3D virtual environments is that this interaction medium allegedly promotes greater immersion. However, immersion is also present in 2D, albeit to a lesser degree. Furthermore, hybrid adaptations that combine traditional pages with virtual environments tend to be more acceptable in the 2D model, as interaction is typically performed through devices that have become commonplace in users' daily lives. Additionally, the integration of conventional elements is also facilitated, given that 2D interfaces are common to many other applications, making the platform more intuitive and familiar to users.

It is also important to note that 3D virtual environment applications are commonly used in the digitization of physical collections belonging to institutions whose buildings are, in themselves, works of art. This is the case for the Louvre Museum, the Tate Museum, or the Museu da Vida Fiocruz, which are digital archives that preserve not only digitized works but also the physical architecture of the building that houses them. However, in the studies analyzed in this review, 3D virtual environments did not demonstrate the same level of attention to architectural preservation, as they were focused on facilitating the generation of the virtual environments.

Although immersive and adaptive strategies, as seen in [7, 25, 38], offer users greater immersion and more engaging visits, the use of specific devices, such as VR headsets, limits access to digital archives. As such, this should be an optional resource, as proposed in [45], where the use of headsets is not mandatory.

Also concerning the access to digital archives, it is evident that there is a shortage of implementations focused on the availability of works. Javdani Rikhtehgar et al. [23] and Constantinides et al. [14] propose interaction methods that enhance the availability of

content to users; however, these are exceptions among the articles in our sample. The remaining studies do not address this issue, revealing a clear limitation in the potential dissemination and reach of digital archives. Furthermore, most systems are still based on traditional web pages and do not implement innovative solutions. Although this is not necessarily a problem, there is a clear lack of standardization and guidelines for developing digital archives. The studies by Zhao [53], Geng Yang [19], and Pedrero et al. [35] go in this direction; however, there is no clear organizational structure that provides consolidated guidelines for these implementations.

Another relevant aspect is the difficulty to integrate different areas of knowledge. Works such as [10] clearly state that the creation of digital archives is a multidisciplinary project, involving not only the cultural elements to be preserved, but also the techniques and guidelines for building robust software. Studies in the field of Computer Science emphasize technological aspects in the development of archives, neglecting certain unique characteristics of digital works and interactions that arise from the digital world – elements that are, in turn, highlighted and analyzed in case studies from the Humanities. A strong association between both fields is imperative for the development of the area and to meet the expectations for digital archives from both technical system aspects (such as accessibility, usability, interactivity, etc.) and humanistic archival concerns (such as curation, storytelling, and representativeness of the collection, for example).

Additionally, the development and creation of digital archives are intrinsically linked to the preservation of the archived works, meaning that they must endure over time. In this regard, for the development of the software, its evolution in response to changes in technology and social dynamics must be considered. Some alternatives to this problem have already been proposed and could be adapted and implemented, such as Lehman's Laws. In [45], this idea is present; however, it was expected to be more widely adopted in the development of this type of platform.

Finally, it is important to highlight the development of platforms that support the preservation of collections with limited resources. Preservation efforts should not be constrained by the broad availability of personnel, infrastructure, and financial resources – conditions typically found in well-established physical archives, or institutions supported by external funding. Alternatives are explored in works such as [40], which proposes a paradigm of projects that incorporate minimal computing and, therefore, reduce

development costs. In parallel, there are also initiatives involving low-cost implementations that, for example, incorporate social media or tools such as Tainacan to expand access and the sustainability of digital preservation [36].

## 8 FINAL REMARKS

In this study, a systematic review was conducted with the objective of identifying the main technologies and forms of interaction employed in digital archives. From this analysis, it is evident that there is a lack of standardization in the field regarding guidelines and norms for the creation of such platforms. Moreover, our results show that there is limited use of Software Engineering practices for software maintenance and preservation – essential aspects in the field of digital preservation studies. Finally, most of the works did not demonstrate concern with evaluating software quality aspects, which reveals a significant gap as to Human-Computer Interaction.

As a scope limitation, this review included only projects that develop digital archives intended to host multiple works, excluding those focused on building technologies for individual exhibitions or single artworks. Relevant future work could focus on initiatives that aim to standardize the development processes of digital archives or, at the very least, the systematic documentation of such practices.

## 9 ETHICAL CONSIDERATIONS

This work presents a systematic literature review, characterized as secondary research, since it does not involve direct interaction with participants nor the exposure of individuals to technologies or computational systems. Therefore, according to CNS Resolution No. 510/2016 and CNS Resolution No. 674/2022, it is exempt from approval by the Research Ethics Committee involving Human Subjects. The data used refer exclusively to the metadata of the analyzed articles, which are publicly available in the databases selected and described in Section 4.

## ACKNOWLEDGMENTS

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