

Cultural Heritage Semantic Portals: a Systematic Literature Review

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Abstract. This work provides a systematic analysis of cultural heritage (CH) semantic portals as a representative application domain for knowledge graphs and Semantic Web technologies. The paper presents a PRISMA-based systematic literature review of 77 academic papers published in the last 10 years describing 68 cultural heritage semantic portals through five key research dimensions. First, we examine the semantic layer, documenting the adoption of ontologies (CIDOC-CRM, EDM) and controlled vocabularies (Getty AAT, GeoNames). Second, we investigate resource integration workflows, from data acquisition methods to preprocessing formats. Third, we catalog presentation paradigms across web, mobile, and immersive (AR/VR) platforms, while evaluating framework usage (Omeka S, ResearchSpace) and the presence of advanced research features. Fourth, we examine the technical systems used, such as database tools and ontology software. Finally, we look at organizational factors including project motivation, participating institutions, and how portals are evaluated. Our findings demonstrate uneven adoption of Semantic Web standards, with 20% of portals using non-interoperable ontologies and 41% lacking vocabulary links. While human-centric interfaces dominate, only 24% support machine-readable access via SPARQL. Furthermore, Over 50% of the surveyed portals are inaccessible—either due to missing links in the publications or because the provided URLs lead to broken/non-existent pages. The study highlights the need for: (1) improved documentation of implementation practices, (2) reusable open-source tools for data harmonization, and (3) strategies to bridge the gap between large-scale and smaller CH projects. By identifying common practices and persistent challenges, this work contributes not only to the development of interoperable CH applications but also to the broader understanding of challenges in designing and deploying knowledge graph-based systems. Future work will investigate the publication of the collected survey results as a structured, semantically described dataset.

Keywords. Cultural Heritage, Semantic Web, Linked Data, Semantic Portals, GLAM, Ontologies

1. Introduction

The design and implementation of systems for representing, integrating, and providing access to semantically enriched data has been a central endeavor since the early development of the Semantic Web (SW) [11, 42, 107]. With the maturation of SW technolo-

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gies and the emergence of standards and methodologies for knowledge representation and Linked Data (LD) publication, knowledge graphs (KGs) have become an important approach for integrating heterogeneous information sources and enabling richer forms of data exploration, reuse, and analysis. However, realizing the full potential of KGs requires addressing persistent challenges related to semantic modeling, interoperability, data integration, and the development of interfaces that support both human and machine interaction with connected resources.

Semantic portals represent one approach to addressing these challenges by providing interfaces for accessing and exploring semantically enriched data. As discussed by Hitzler, Krotzsch, and Rudolph [45], semantic portals provide human- and machine-readable information through the use of ontologies, enabling integration with other SW applications while enhancing management, browsing, and search functionalities over LD resources. Since the early days of the SW, the design and implementation of such portals have been an important area of research, as they constitute the point of interaction between structured knowledge representations and their users.

Cultural heritage (CH) represents one of the most prominent and challenging application domains for SW and KG technologies. CH resources are typically distributed among diverse institutions, described according to different practices, and enriched by complex contextual relationships involving people, places, events, and concepts. These characteristics make interoperability and semantic modeling particularly valuable, as LD enables the integration and sharing of resources across institutional and disciplinary boundaries. Furthermore, the explicit representation of relationships between CH resources supports enhanced analysis, interpretation, and cross-disciplinary connections, facilitating more comprehensive computer-assisted research [70]. Consequently, CH provides not only a domain in which KG technologies can deliver significant benefits, but also a valuable environment for investigating broader challenges related to the development and adoption of knowledge-based systems.

This relevance is also reflected in current international initiatives concerned with the publication, computational access, and reuse of digital collections [110]. For example, AI4LAM² and GLAM labs³ have promoted experimentation with data-intensive and AI-based methods in libraries, archives, and museums, while the Collections as Data movement [13] has emphasized making collections available in forms suitable for computational use and scholarly reuse. Finally, the CARE principles have highlighted the importance of responsible, ethically grounded, and transparent data practices [16].

A crucial aspect of projects researching and implementing LD in CH is the development of platforms for publishing, presenting, and exploring the resulting knowledge bases. The author of [48] identified semantic portals as a key interface for CH-LD endeavors, arguing that such portals enable access, aggregation, and reuse of content from multiple providers, while supporting dissemination of the created knowledge bases. Furthermore, by exploiting LD structures, semantic portals can provide additional services such as semantic search, browsing, and personalized recommendations. In a more recent discussion on the evolution of CH semantic portals, the author of [50] argues that research focus has gradually shifted from data harmonization, aggregation, search, and browsing toward integrated research environments offering advanced functionalities such as network analysis [116] and knowledge discovery [77]. These developments aim to

²<https://ai4lam.org/>

³<https://www.glamlabs.io/>

support humanities researchers in addressing increasingly complex questions through computational methods.

While the author of [50] highlights the increasing availability of harmonized and aggregated CH linked datasets as a foundation for this shift, the broader review of the SW field presented by Hitzler [44] argues that further consolidation is still needed across its subfields, resulting in “application-oriented processes that are well-documented as to their goals and pros and cons, and which are accompanied by easy-to-use and well-integrated tools supporting the whole process” [44, p. 82]. Such consolidation is essential for guiding new adopters through the diversity of available approaches and technologies and for enabling wider adoption of KG-based solutions.

As a response to this challenge, Hyvönen [51] provides a set of reusable design principles and guidelines for creating state-of-the-art semantic portals based on extensive experimentation with the so-called *Sampo Model*⁴. While such principles and their corresponding application examples provide valuable knowledge for the research and implementation of CH semantic portals, they do not exhaust the range of approaches, technologies, and implementation choices involved in developing such systems.

This paper presents a Systematic Literature Review (SLR) of the standards, methods, technologies, and motivations involved in the research and implementation of CH semantic portals. By analyzing existing approaches, this study aims to provide insights not only into the current state of CH applications of LD, but also into broader practices and challenges relevant to the development of knowledge graph-based systems. The survey covers different aspects of SW for CH, including ontological modeling practices, LD integration, publishing and accessing CH resources, browsing, searching and querying CH data on the web, architectures and infrastructures for CH, and the exploitation of existing solutions. This survey has a twofold goal:

1. Offer a comprehensive overview of the principles, technologies, and methodologies guiding the development of semantic portals, with CH as a case study;
2. Analyze trends on how existing CH portals employing LD align with, extend, or diverge from the principles of the SW and knowledge graph development.

The work intends to be informative to both researchers and practitioners involved in KGs, SW technologies, and digital CH. It aims to support CH institutions and projects developing LD-based applications, as well as researchers studying the adoption, implementation, and evaluation of KG-based systems more broadly.

2. Related Works

2.1. Implementing semantic portals

A common approach for providing access to a structured body of information about a specific domain is through the creation of information portals. These portals serve as platforms designed to aggregate, organize, and present information resources in a coherent and accessible manner for both human users and, in some cases, machine agents. Information portals typically offer functionalities such as browsing, search, and data visualization tools that facilitate interaction with complex datasets.

⁴<https://seco.cs.aalto.fi/applications/sampo/>

As described by [98], the use of SW standards for information portal design introduces significant advantages in terms of data interoperability, integration, and semantic enrichment. By adopting technologies such as RDF⁵, OWL⁶, and SPARQL⁷, these portals are able to represent information in a machine-readable and semantically meaningful format, allowing heterogeneous data sources to be connected and queried in a unified way. Additionally, this approach enables decentralized portal updates, supports multiple aggregations and views of the same data and allows for reusability of data across portals. In this work, we use the term semantic portal to denote any platform that structures and presents information in an interface while using LD in its technology stack.

Several steps are involved in the implementation of an appropriate infrastructure of a semantic portal. [67] present a portal infrastructure consisting of 5 layers. First is the source data layer, that is, a collection of both structured and unstructured data sources powering the portal. Such sources can potentially be distributed and heterogeneous. Second is the extraction layer, a series of human or machine-based semantic-processing actions and workflows that provides and ensures high-quality LD. Third is the semantic data layer, containing domain ontologies and semantic data repositories storing extracted LD. Fourth is the semantic service layer containing a series of services for efficient information retrieval techniques over LD. Finally, the fifth is the presentation layer containing user interfaces offering LD-based visualizations of the underlying heterogeneous data. Furthermore, [67] stresses the need of an evaluation of the features made available by the portal. A similar 5-layered framework is also presented in [43].

The choice of methods, tools, and workflows for implementing each layer of the portal is highly application- and domain-dependent and must align with the portal's objectives and scale. [49] presents an overview of the design considerations and technical frameworks for semantic portals in CH. For instance, common data formats in the source data layer include JSON⁸, CSV⁹, and XML¹⁰, widely used ontologies in the semantic data layer include CIDOC-CRM¹¹, EDM¹², and Dublin Core¹³, while tools used in the semantic service layer include RDF stores like Blazegraph¹⁴, Apache Jena¹⁵, RDF4J¹⁶ (formerly known as Sesame), Virtuoso¹⁷ and GraphDB¹⁸, as well as platforms such as Wikibase and Wikibase Cloud¹⁹ for publishing and enriching digital collections. The study also highlights transformation pipelines of local content into RDF and CH-relevant semantic services.

Moreover, [49] highlights that CH semantic portals can be distilled to three fundamental components:

⁵<https://www.w3.org/RDF/>

⁶<https://www.w3.org/OWL/>

⁷<https://www.w3.org/TR/sparql11-query/>

⁸<https://www.json.org/json-en.html>

⁹<https://tools.ietf.org/html/rfc4180>

¹⁰<https://www.w3.org/XML/>

¹¹<http://www.cidoc-crm.org/>

¹²<http://pro.europeana.eu/web/guest/edm-documentation/>

¹³<https://www.dublincore.org/specifications/>

¹⁴<https://blazegraph.com/>

¹⁵<http://jena.apache.org/>

¹⁶<https://rdf4j.org/>

¹⁷<http://virtuoso.openlinksw.com/>

¹⁸<https://graphdb.ontotext.com/>

¹⁹<https://www.wikibase.cloud/>

1. **Content Infrastructure:** The domain ontologies and vocabularies.
2. **Content Production System:** Methods and protocols used to harvest or create LD.
3. **Semantic Portal System:** The web services and user interfaces available for presenting and analyzing data.

These three components form an analytical framework that guides the formulation of our research questions.

2.2. *Related surveys*

Several surveys on related topics have informed the current work. A survey by Lausen et al. [66] examines nine semantic portal platforms and compares the portals derived from them in terms of the tools used (e.g., databases, ontology editors, and UI technologies), workflows for information extraction and maintenance, and the interfaces and features offered for user interaction. Barbosa et al. [8] conducted an SLR identifying 80 relevant publications on software tools for LD publication and consumption. Their findings show that the initial stages of LD publication, such as data extraction and RDF conversion, are well supported, whereas later stages, such as quality assessment and interlinking, still lack robust solutions. This perspective is complemented by Klímek, Škoda, and Nečaský [59], who provide a focused survey of LD consumption tools by evaluating 110 tools against 34 functional requirements related to LD discovery, processing, and visualization.

Feitosa et al. [28] present a survey of best practices for LD publishing, with the aim of identifying guidelines for publishing, sharing, and connecting data. Their study identifies the types of institutions that have published LD, the motivations behind these efforts, and the extent to which well-defined guidelines influenced them. Since only two CH projects appeared in that review, Davis and Heravi [23] surveyed 43 papers to examine which organizations are involved in the implementation of LD-based CH projects, which motivational factors drive such projects, and to what extent collaboration occurs between institutions.

Recent studies have also examined LD adoption challenges in digital libraries from complementary perspectives. Gaona-Garcia and colleagues [32] analyzed 142 publications to identify key challenges in integrating visual search interfaces into digital libraries. Ali and Warraich [2] investigated the motivating factors and challenges involved in initiating LD initiatives in such institutions. Gaitanou et al. [30] review LD implementations in libraries from 2008 to 2019, documenting widely used models, concepts, projects, approaches, methodologies, guidelines, and tools for publishing library data according to LD principles. Focusing specifically on interface design, Bernasconi et al. [10] conducted a comprehensive survey of 47 SW interfaces, aiming to categorize the available tools and provide useful comparisons among them. That study also discusses the role of such interfaces in the context of digital libraries.

The breadth of open questions surrounding the adoption of SW technologies in CH is further reflected in the surveys reported by Moraitou et al. [80], Siqueira et al. [105], and Mendoza et al. [78]. Moraitou et al. [80] examine semantic models for conservation and restoration, analyzing their scope, conceptualization, and deployment in SW systems. Siqueira et al. [105] conduct a workflow-oriented review of 12 CH aggregation projects in order to systematically analyze their implementation approaches. Mendoza et al. [78]

explore technologies for the preservation, promotion, and dissemination of CH during the period from 2018 to 2022, highlighting 3D digitization and AR/VR as two of the most prominently used solutions.

Although no SLR has explicitly focused on implemented CH semantic portals, important aspects of their development and associated challenges have been addressed in the studies discussed above. The tools, methodologies, and conceptual frameworks identified in these works informed both the formulation of the research questions in the present study and the interpretation of the findings. Where relevant, our results are also contextualized through comparison with those of existing surveys.

3. Methodology

3.1. Review reporting framework

Different frameworks can be used to structure and report SLRs, depending on the objectives of the study. Among the most common are the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), which emphasizes transparent reporting of the review process, SALSA, which organizes the review into the phases of Search, Appraisal, Synthesis, and Analysis, and TCCM, which is primarily used to analyze literature through the dimensions of Theory, Context, Characteristics, and Methodology [39, 88, 90]. While these approaches are complementary, they serve different purposes. PRISMA is particularly suitable when the aim is to document the identification, screening, eligibility, and inclusion of studies in a transparent and reproducible way, whereas SALSA offers a simpler procedural structure and TCCM provides a framework for interpreting and categorizing prior research [39, 88, 90].

The planning and reporting of the SLR contained in this article is therefore inspired by the PRISMA 2020 guidelines [88]. PRISMA 2020 consists of a 27-item checklist addressing key elements such as search strategy transparency, study selection criteria, and results presentation, thereby offering a structured framework for enhancing the methodological rigor and reproducibility of the review.

3.2. Research questions

This systematic overview of CH semantic portals is structured around a defined set of research questions that guide both the identification and analysis of relevant articles. The theoretical foundation for these questions derives from the framework of portal components in [49], which provides an established basis for examining semantic portals in the CH domain. Although the three components cover a significant portion of CH portals features, there are other aspects worth examining, such as the tools involved in the portal implementation (c.f. [10, 78]) and organization factors involved in such projects (c.f. [2, 23, 28]). Based on these considerations, we formulate the following research questions:

- RQ1: What are the main interoperable standards used in CH semantic portals?

- RQ2: How are resources integrated into the portal?
- RQ3: What interfaces and research features does the portal offer?
- RQ4: What technical infrastructure supports the portal’s implementation?
- RQ5: What are other important non-technical characteristics of the portals?

The main objective of RQ1 is to analyze the semantic layer of CH portals by identifying: which ontologies (e.g., CIDOC-CRM, EDM) are employed and what controlled vocabularies or thesauri (such as Getty AAT²⁰ or GeoNames²¹) are utilized. RQ2 investigates how resources are incorporated into CH semantic portals, focusing on two aspects of the workflow: (1) data acquisition methods and (2) data formats before content import.

RQ3 elicits an exploration of the basis for data presentation in CH portals, first focusing on the delivery platform (web, mobile applications or AR/VR environments) then examining the underlying frameworks (e.g., Omeka-S²², ResearchSpace²³) that enable these presentations, and finally analyzing the inclusion of specialized research features such as interactive maps, temporal visualizations, and 3D models. RQ4 investigates the tools underlying the implementation of the portals, focusing on database systems and ontology development tools. Finally, RQ5 analyzes organizational influences on CH portals, including institutional motivations (e.g., preservation, dissemination), participating organizations (museums, libraries), the public availability of the portal, and the performed evaluation framework towards the portal.

3.3. Sources, Search and selection criteria

This study builds upon a comprehensive collection of scholarly articles retrieved from four major academic databases²⁴: ACM Digital Library, IEEE Xplore, Scopus, and Web of Science. These databases were selected due to their broad coverage of peer-reviewed literature in computer science and digital humanities, their high indexing quality, and their widespread use in SLRs, ensuring both reproducibility and academic rigor (see [40,57]).

The retrieval process employed a systematic keyword strategy encompassing three fundamental categories: (1) Linked Data, (2) Cultural Heritage, and (3) Portal Implementation. As detailed in Table 1, each category was represented by a carefully selected set of search terms. Our inclusion criteria required articles to contain at least one matching term from each category, appearing in either the title, abstract, or author-specified keywords. This tripartite intersection ensures the relevance of retrieved publications to

²⁰<https://www.getty.edu/research/tools/vocabularies/aat/>

²¹<https://www.geonames.org/>

²²<https://omeka.org/s/modules/Sparql/>

²³<https://researchspace.org/>

²⁴While other databases such as Google Scholar and DBLP also index computer-science literature, they did not fit our intended reproducibility and academic rigor. Google Scholar was excluded due to its heterogeneous source quality and less reliable metadata for SLR procedures, and DBLP due to its primarily bibliographic focus and limited access to abstracts and full texts required for screening and data extraction.

our core research focus. The string below represents the query adapted to each database according to their respective search syntax:

(linked data OR ... OR linked open data) AND (digital library OR ... OR exhibition design) AND (portal OR ... OR infrastructure)

Category	Keywords
Linked Data	linked data; semantic web; ontology engineering; ontology; metadata standards; semantic interoperability; linked open data
Cultural Heritage	digital library; galleries, libraries, archives, and museums; museum; digital archives; art gallery; archives management; CH resources; heritage institutions; cultural heritage; digital collections; museum studies; exhibition design
Portal Implementation	portal; prototype; interface; platform; data integration; implemented; infrastructure

Table 1. The complete list of keywords used in the search procedure according to category

Moreover, the search results were filtered to include only publications from the last 10 years (2015–2025) and restricted to English-language sources, fulfilling the criteria C1 and C2 present in Table 2. The search was conducted in January 2025. Metadata such as abstract, title, year, DOI, authors, among others, were readily retrieved from the academic databases, and merged into one list containing 908 papers. Next, duplicates were removed either based on DOI or on title. The list of 875 unique articles was loaded onto Zotero bibliography management platform by the help of which the article screening process was conducted. The screening was conducted manually by the authors, each possessing experience in participating at CH-LD projects, both from a technical and organizational perspective. In every stage of evaluation, the articles were read by at least one of the authors. In case of disagreement, a round of discussion was conducted towards achieving mutual consensus.

The screening process was conducted in two stages. First, title and abstract were read for each paper, where the information was assessed given the full eligibility criteria present in Table 2. While in some cases the relevance of a paper was obvious from the abstract, it also happened that some abstracts did not contain enough information for a relevance decision. In both cases the papers were marked as *sought for retrieval*, summing 148 papers. Given the availability of resources at the university’s database, only 139 articles were successfully retrieved. In possession of the full text, another round of evaluation according to the eligibility criteria was conducted, finally returning the list of 79 selected papers for the survey. Figure 1 presents a PRISMA-inspired diagram showing the number of articles retrieved and excluded at each stage of the selection process.

Every article has been read, appropriate information was collected, and shared in Tables 3–4 present in Appendix A. While it was expected that an article corresponds to one semantic portal, it was not unusual for multiple articles report on the advancements of a single system. In this case, information was accumulated and updated according to the latest article, and all the articles related to the given portal are here reported. The information presented in this SLR is limited to what is described in the articles.

Before moving on to the analysis of articles included in the survey, we present the analysis of five cases to clarify the eligibility criteria. First, a significant number of articles unrelated to CH were retrieved given the keyword *digital library*, for example, [61]. In these cases the abstracts generally mention the field of application, such as *legal doc-*

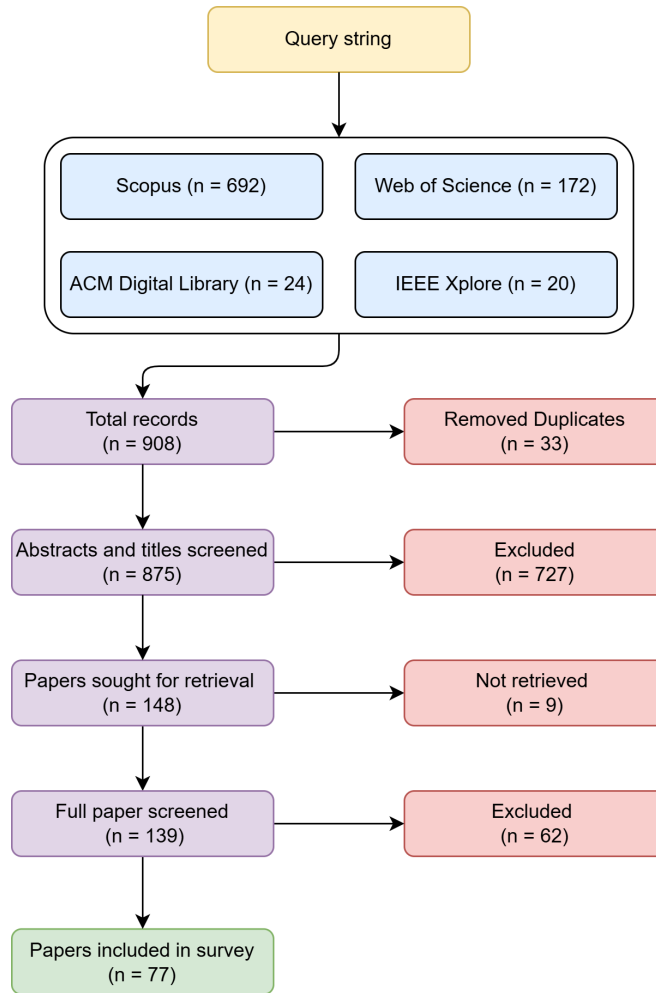


Figure 1. PRISMA inspired diagram containing number of papers in different stages of the survey.

ument management platform in the case of [61], thus clearly showing a failure to criterion C5. Second, keywords such as *implemented* and *infrastructure* led to the retrieval of articles describing other systems that are not portals. [6], for example, describes an ontology-based information retrieval system for digital library, failing criterion C4.

A more difficult case is [51], in which the *Sampo Model* for CH semantic portal implementation is discussed. Even though it refers to semantic portals and CH, it is a review of many portals implemented according to this model, and thus not presenting a specific implemented portal, thus failing criteria C3 and C4. Similar deliberation was required for [29], which describes the National Library of the Netherlands' data aggregation workflow. While technically sophisticated, the system's end product feeds into the Europeana portal rather than constituting a standalone implemented portal as required by criterion C4.

Another case worth mentioning is [41], which presents the development of a digital library for Ethiopia's ancient manuscripts and describes the use of the Dublin Core

	Inclusion Criteria	Exclusion Criteria
C1	The paper is published in 2015 or after.	The paper is published before 2015.
C2	The paper is written in English.	The paper is written in a language different from English.
C3	The paper is a primary study.	The paper is a secondary study (e.g., review, survey).
C4	The paper presents an implemented or proto-typed portal.	The paper presents the outline of a planned portal, or no portal at all
C5	The paper presents a system applied in the field of CH.	The paper presents a system applied in a field different from CH.
C6	LD is present in the technological stack of the presented system.	LD is not present in the technological stack of the presented system.

Table 2. Eligibility criteria for the survey

metadata standard for the description of manuscript metadata. At first, the article appears to meet the inclusion criteria. However, it is important to highlight that the adoption of this interoperable standard was primarily driven by the capabilities and constraints of the selected digital library software, Greenstone²⁵. No explicit goals related to interoperability were stated, nor were any concrete steps taken to enable integration with external systems. In this case, after deliberation we decided to classify [41] as failing criterion C6.

At last, it is worth mentioning that from 77 articles, 68 semantic portals were surveyed. Moreover, 59 portals were presented in a single article, while 9 portals were presented in two different, complementary articles. No article presented more than one portal.

4. Results

4.1. Interoperable standards

To answer RQ1 we consider two main approaches for making LD interoperable in CH projects. First, conceptual models can be used for the development of the semantic layer of the portal. Whenever a project reuses some existing ontology, we can affirm that the structure of the knowledge base is to a certain extent semantically interoperable with other bases using such ontology. As mentioned above, some of the widely used CH ontologies are EDM (Europeana Data Model), Dublin Core, and CIDOC-CRM. Besides heritage focused ontologies, CH projects also use more general ontologies, e.g., SKOS²⁶ (Simple Knowledge Organization System) for the representation of classification schemes, concepts, taxonomies, among others, and FOAF²⁷ (Friend of a Friend) for social relationships.

The extent to which data in a certain project is modelled according to a certain standard is variable. Furthermore, multiple standards can be used concomitantly for the creation of a comprehensive conceptual model. An example is the conceptual model

²⁵<https://www.greenstone.org/>

²⁶<https://www.w3.org/TR/skos-reference/>

²⁷<http://xmlns.com/foaf/spec/>

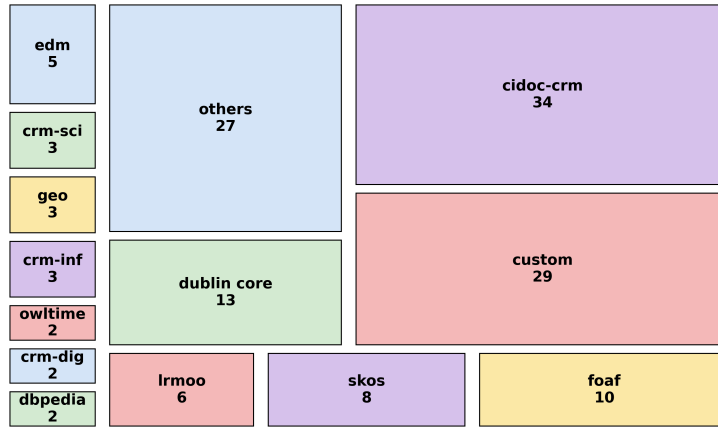


Figure 2. Ontology usage in surveyed semantic portals (n=64).

behind the Museum of the People (see [4]) portal that uses a combination of CIDOC-CRM and SKOS for the data model. While one possible practice is the re-use of existing ontologies, it is not uncommon for custom classes and properties to be created based on data collected in a certain institution or due to project requirements, which attempt to be interoperable with a certain set of ontologies either as extensions of them (e.g., creating sub-classes or sub-properties) or reusing similar ontology design principles. For example, the custom ontology in [106] is described as having several interchangeable attributes with FOAF, Dublin Core and CIDOC-CRM, however it is still a bespoke ontology.

Collecting information from which ontologies are used in a certain project is rather straightforward, as the information is generally explicitly stated. In [4] we can find the following passage “In the referred project, we used CIDOC-CRM, FOAF, and DBpedia nomenclatures” (p. 02). All custom ontologies that were created for a specific project were aggregated into the “Custom” category. Whenever the description of a custom ontology mentioned the reuse or was interoperability with other ontologies (such as the example in [106]), the other ontologies were also counted as part of the portal. Figure 2 presents an overview of ontologies used in surveyed portals, showing every ontology used more than once, the amount of custom ontologies, and the grouping of every ontology used once into the “Others” category.

Aggregating information about ontologies shows that CIDOC-CRM is by a great margin the most widely used ontology in semantic portals. The reason for this predominance is highlighted by Kovalenko et al. [62] who write “The dataset is organized according to CIDOC Conceptual Reference Model to make it interoperable with other cultural heritage data” (p. 15) and further explained by Gehrke et al. [33]:

CIDOC CRM is an accepted ISO standard (ISO 21127). As an event-centric ontology it covers different phenomena in space and time like provenance, copying of texts, creation of works and expressions, as well as the production of information carriers and attribute assignments. (p. 02)

The prominence of CIDOC-CRM is also reflected on the wide use of its extensions, such as LRMoo²⁸ (formerly known as FBRoo), crm-sci²⁹, crm-inf³⁰, among others. The second most widely used CH ontology is Dublin Core. The reasons for adopting this model is generally related to limitations in other areas of the CH project, e.g., in [34] the authors argue that in the case of the “SearchCulture.gr” aggregation portal “most of [the CH institutions] provide their metadata in aggregation schemata that are based on Dublin Core” (p. 04). Furthermore, Rueff [101] mentions limitations related to the choice of a reusable interface, in their case Omeka S, that by default supports Dublin Core. In [3], even though the authors also mention the facility of implementing Dublin Core in the DSpace platform, they double down in their choice by arguing that

The metadata standard adopted to implement and implant the repository herein is the Dublin Core developed from characteristics such as simplicity; semantic interoperability; international agreement; extensibility and modularity of metadata in the Web.(p. 04)

Moreover, FOAF and SKOS were predominantly used as non-CH ontologies. Notably, we observed a high number of custom ontologies and rarely used ontologies (those with only one mention). Only 4 portals did not mention the use of any specific ontology, in these cases they were either aggregation portals, such as in [69] where the National Library of Sweden aggregator portal aiming at “creating interfaces built on top of multiple datasets from the participating organizations”, or portals focused on linking resources to interoperable controlled vocabularies, such as the work mentioned in [99].

A second approach to using interoperable standards in CH projects is by linking specific entities to controlled vocabularies, authority files, or widely recognized thesauri. Vocabularies are generally domain-specific—for example, Getty AAT provides specialized terminology for art and architecture, while GeoNames offers a global gazetteer of geographic features. They can also be country-dependent, such as GND³¹, Germany’s Integrated Authority File, which standardizes personal, corporate, and subject headings in German libraries, or BnF³² the controlled vocabulary used by French national library. Cross-domain knowledge bases like Wikidata and DBpedia can also server as controlled vocabulary for aggregating and reconciling vocabularies into a unified LD ecosystem. Local data can be semantically aligned with these vocabularies through predicates like “owl:sameAs” for identity matching, “skos:closeMatch” for near-equivalent concepts, and “skos:broadMatch” for hierarchical relationships. In practice, links to resources such as Wikidata are often implemented through Wikidata-specific identifiers or properties rather than exclusively through strong identity assertions such as owl:sameAs.

As with used ontologies, information about used controlled vocabularies are also generally explicitly stated. Differently to ontologies, the use of custom vocabularies is rather not practiced or not explicitly stated. The only case of development and use of local vocabulary is described in [113, 114] related to the Dunhuang Grotto portal. Figure 3 shows an overview of controlled vocabulary usage according to similar grouping as

²⁸<https://cidoc-crm.org/lrmoo>

²⁹<https://cidoc-crm.org/crmsci>

³⁰<https://cidoc-crm.org/crminf>

³¹<https://gnd.network>

³²<http://data.bnf.fr>

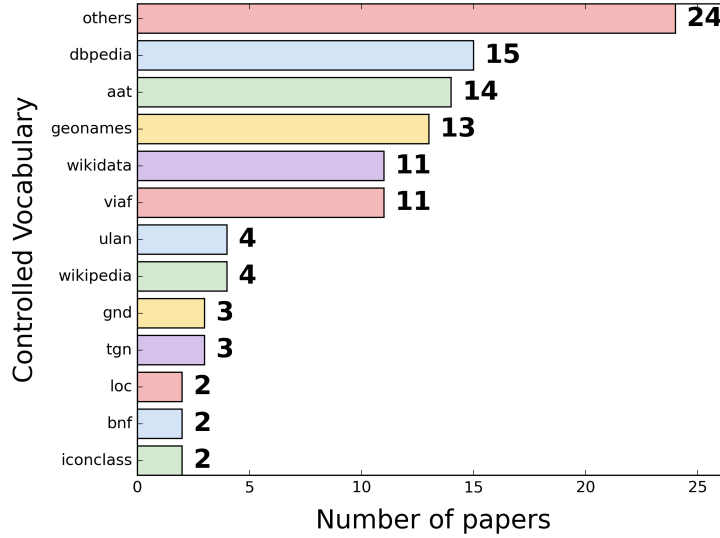


Figure 3. Controlled vocabularies usage in surveyed semantic portals (n=40).

the ontology visualization, although without the “Custom” category. Only 40 portals contained a link to controlled vocabularies.

The prominence of widely adopted standards like DBpedia³³, GeoNames, and Wikidata was expected, as linking to these authoritative resources inherently enhances a portal’s interoperability. These knowledge bases not only provide established conceptual frameworks but also include valuable cross-references to one another and to more specialized thesauri. However, a significant number of portals remain disconnected from such controlled vocabularies, potentially limiting their integration within the broader ecosystem of SW-based CH resources, hindering retrievability and interoperability. Table 3 in Appendix A contains all the data points used for answering RQ1.

4.2. Data Integration

With a defined conceptual model in place, a structured workflow for integrating data points is essential to build the knowledge base for the semantic portal. To answer RQ2, we synthesized four primary workflow categories:

- **Manual:** A curated group of stakeholders (e.g., researchers) manually inputs data points into the portal.
- **Import:** Existing datasets are converted and integrated following the conceptual model.
- **Query:** Data from LD endpoints is queried and displayed in the portal.
- **Crowd:** Data is added through crowdsourcing, leveraging contributions from a broader community.

³³DBpedia appeared as both ontology and vocabulary because it can be used both as, respectively, a shared conceptualization for classes and properties, and as a vocabulary to which instances can be linked.

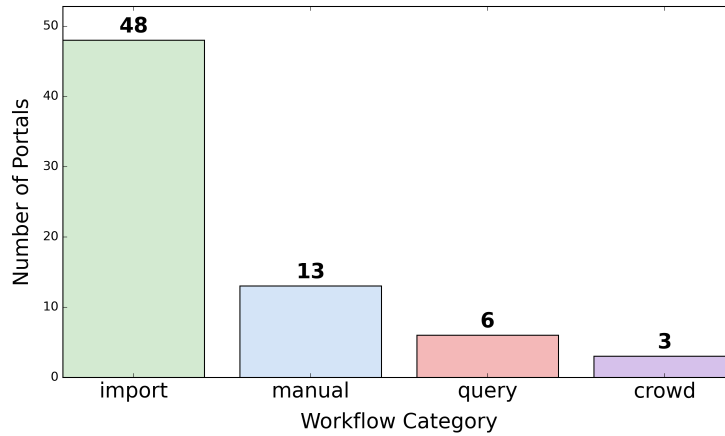


Figure 4. Data integration workflow categories (n=66).

Information about integration workflows could be explicitly collected from the surveyed articles. This information was presented in text, such as in [76] “the InCulture platform is based mostly on user’s contributions in a crowdsourcing form” (p. 2886) or in images, such as in [4]’s figure “Architecture of Ingestion Function” (p. 3). Some portals, such as [24], used more than one workflow category for data integration. Figure 4 presents an overview of used data integration workflow categories.

As shown in the subsection 4.3, one of the ways for interaction with the data in the portal is through 3D visualizations. Out of the 13 cases of manually inserted data, 5 are related to inserting 3D virtual models, such as [31]. This might be due to the complexity of the 3D modeling process, which often requires specialized skills, and significant time investment. A similar situation applies to [22] and the crafted 3D labyrinth as a visual metaphor for knowledge base visualization. A significant majority of workflows are based on the import and eventual conversion of existing datasets to be integrated into the conceptual model. The imported data often originate from CH institutions, such as “Dutch National Library”³⁴ in [24] or the “British Museum”³⁵ in [62]. Other sources are social media, sensors, among others (see [112]). Figure 5 illustrates the type of input data for import workflow.

The analysis reveals a clear predominance of structured data formats, with XML (n=18), tabular data (n=14), and relational data (n=12) constituting the majority of import workflows. Library-specific standards are notably represented by MARC21³⁶, appearing in four cases. A significant portion of systems (n=10) directly ingest LD compatible formats, primarily implementing established semantic frameworks such as Dublin Core [9] and CIDOC-CRM [35]. The dataset further demonstrates the heterogeneity of digital heritage sources through unstructured content (text: n=6; images: n=1) and web-derived inputs (scraping: n=1). Notably, five XML-based workflows specifically employed the

³⁴<http://www.kb.nl>

³⁵<https://www.britishmuseum.org/>

³⁶<https://www.loc.gov/marc/bibliographic/>

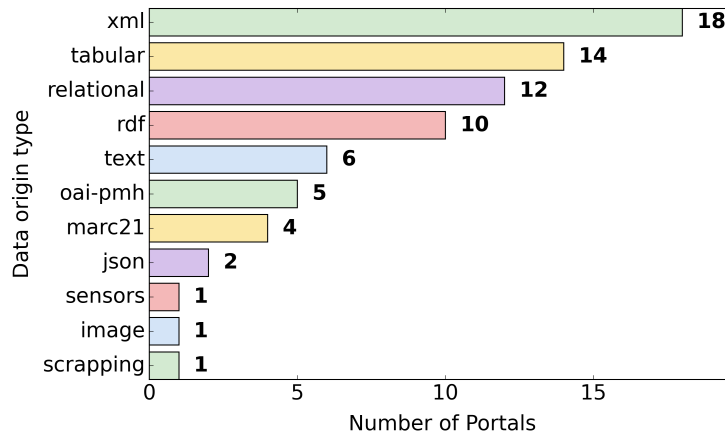


Figure 5. Origin data type for import workflows (n=41).

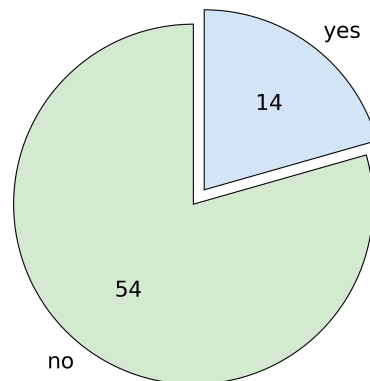


Figure 6. Proportion of portals mentioning community feedback feature (n=68).

OAI-PMH protocol³⁷ for metadata harvesting, highlighting its continued presence in CH data exchange.

While only three portals had crowdsourcing as a main workflow for data integration, 14 portals mentioned offering the possibility of community feedback (including the crowdsourced portals). Figure 6 illustrate such a division. In [1] the authors highlight the advantages of having such a feature:

Making the portal available for public use opens up the possibility of gathering feedback from end-users on how the portal and its functionalities can be improved or changed to better accommodate the end-users' needs (p. 04)

Table 3 in Appendix A contains all the data points used for answering RQ2.

³⁷<https://www.openarchives.org/pmh/>

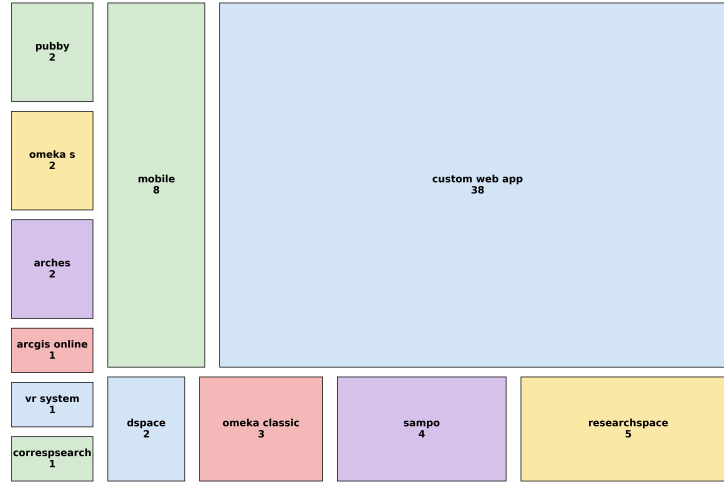


Figure 7. Types of application of the surveyed portals (n=68).

4.3. Interfaces

The basis for answering RQ3 is understanding the type of application that constitutes the portal. While the most common approach to developing semantic portals is the creation of a web application, other platforms, such as mobile applications, embedded museum kiosks, or immersive devices (e.g., VR/AR interfaces) can also be deployed for such portals. Moreover, even when opting for a web application, there is a variety of reusable frameworks and content management systems specifically designed for CH data, such as Omeka S and ResearchSpace. These tools significantly reduce development overhead while ensuring standards compliance, though they impose specific architectural constraints. Figure 7 presents the overview of the type of application of each semantic portal.

Every described portal has one application type, except the portal “InCulture” described by Mathioudakis et al. [76], which can be accessed both as a web application and a mobile application. Each of the existing reusable systems are web applications, what makes the total of 59 portals that are only web applications, 7 portals that are mobile applications and one VR-based portal.

Each portal contains a different combination of interfaces for accessing the integrated resources. Figure 8 presents a synthesis of the usage of different access interfaces. The most common offered approach of interacting with CH data in semantic portals is by browsing, followed by search. Although in the majority of cases (n=45) an application offer both browse and search functionalities, they also appear separately. It is worth noting that browsing without search capabilities often appear in the case of mobile applications (n=6). Furthermore, all Augmented Reality (AR) interfaces are based on mobile applications. A notable limitation is the modest adoption of SPARQL endpoints, with only 24 portals offering this feature.

Besides the above-mentioned interfaces for accessing data, some portals offered more advanced features for resources exploration and visualization, in pair with the description of a second or even third generation portal according to Hyvönen [50]. Figure 9 presents an overview of these features present in surveyed portals. 24 portals did not

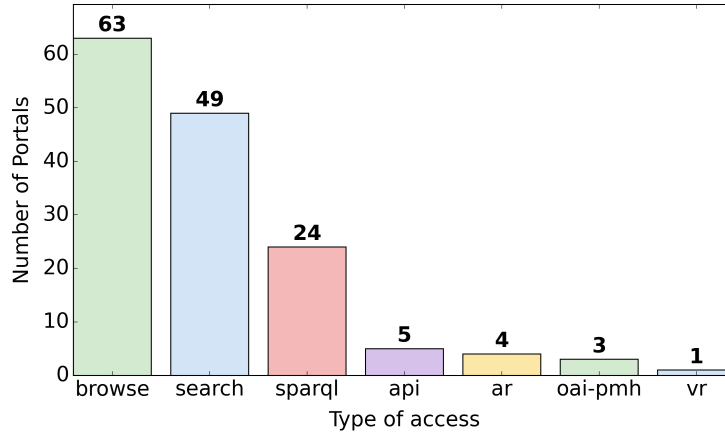


Figure 8. Types of resource access in the surveyed portals (n=68).

contain any additional feature. The most common features are maps, 3D visualization, timelines and graph visualization. Different kinds of graph-based representations were grouped as the category “graph visualization” including sunburst charts, dependency wheel, nodes and edges plot, among others. Three tools used for graph visualization were LodView³⁸, LodLive³⁹ in [46] and Ontodia⁴⁰ in [47, 81]. Another recurrent feature was narrative, that is, the grouping of a set of objects into a semantically meaningful exhibition (see [100]). Table 3 in Appendix A contains all the data points used for answering RQ3.

4.4. Technical infrastructure

To answer RQ4 we investigated the technical infrastructure for storing, modelling and converting LD. Only 37 portals contained information about the infrastructure used for storing the available resources. Figure 10 presents an overview of the usage of different tools and their classification as triplestore, SQL databases or NoSQL databases. The majority of projects used triplestores for data storage, primarily relying on solutions under the Apache Jena framework⁴¹, often combining multiple Jena-based components. Cliopatria⁴², a logic-based SW server that bridges reasoning with RDF data management, was also used given its support for a SPARQL endpoint.

SQL and NoSQL databases, though not natively designed for RDF, were occasionally used by pairing with middleware or custom adapters to bridge the gap with LD standards—a pragmatic choice for projects prioritizing scalability or accommodating non-triple data alongside semantic annotations. One example is the use of PostgreSQL in [93]

³⁸<https://lodview.it/>

³⁹<http://en.lodlive.it/>

⁴⁰<https://github.com/metaphacts/ontodia>

⁴¹Apache Jena is an open-source Java framework for building SW and LD applications. It provides tools for RDF data management, including storage (e.g., TDB, Fuseki), querying (SPARQL), and ontology processing.

⁴²Cliopatria is a SWI-Prolog-based SW server, designed for querying and managing RDF data. Though not a triplestore in the conventional sense, it provides similar functionalities. See <https://github.com/CLIOpatria/CLIOpatria>.

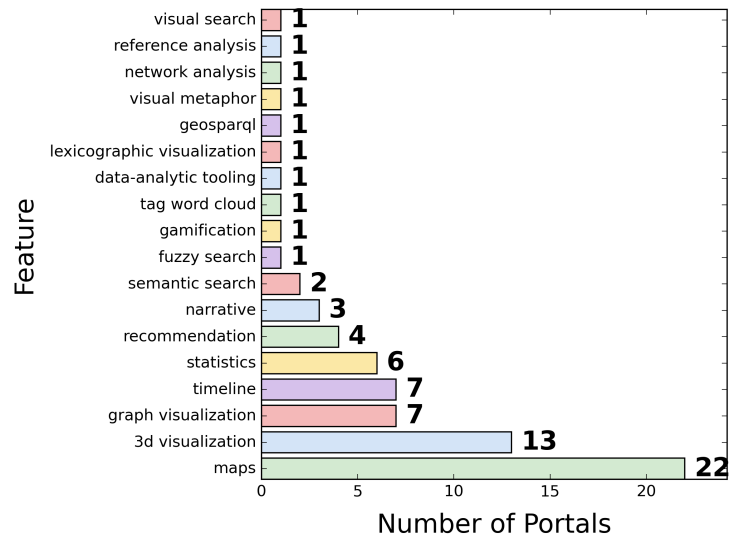


Figure 9. Presence of visualization and research features among the surveyed portals (n=44).

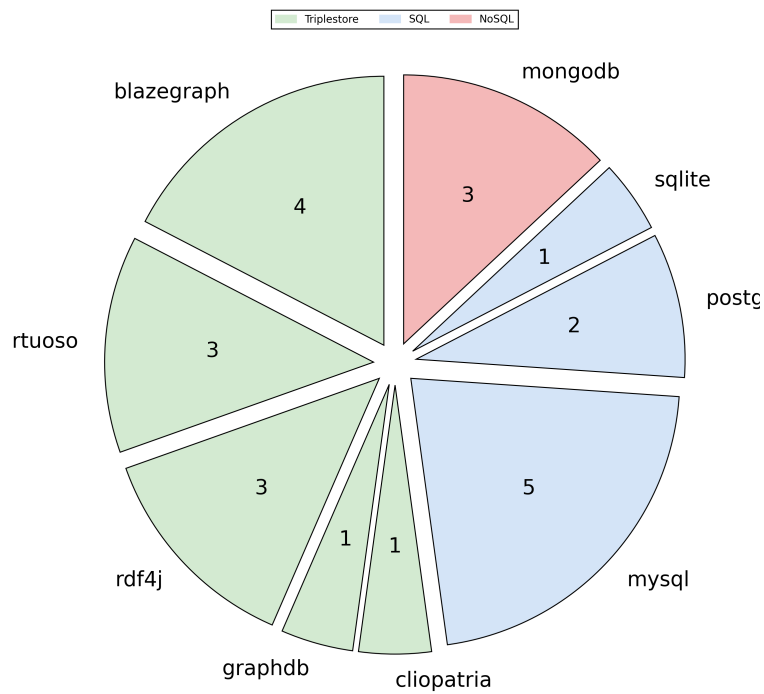


Figure 10. Data storage infrastructure (n=37).

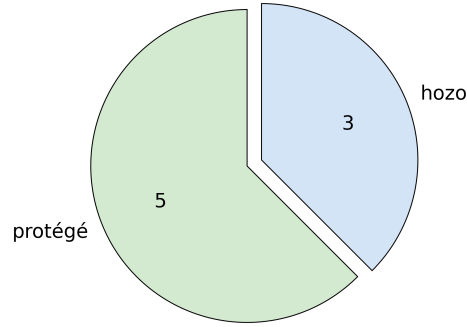


Figure 11. Usage of ontology editors (n=8).

based on the possibility of using plugins for geospatial and point cloud extensions (PostGIS and pgPointCloud) to manage 3D CH data. In [31] Blazegraph was used as the main storage for linked resource, however they supplemented it with PostgreSQL for more advanced geospatial querying (in the chart, this portal was counted only as using Blazegraph).

It is common to use ontology editors for modelling custom ontologies. Even though, as already mentioned, there were 29 custom ontologies in the surveyed portals, there were only 8 mentions to ontology editors. Figure 11 shows the division between the usage of Protégé⁴³ and Hozo⁴⁴. Furthermore, Yen and Yang [117] highlight that the use of such software is not based only in the development of a new ontology (as no custom ontology was developed in this project), but rather to visualize, and communicate existing ontological structures to both technical and non-technical stakeholders.

Figure 12 presents a summary of other LD-related tools that were used in the processing of setting up the technical infrastructure of the surveyed semantic portals. The most prominent tools included D2RQ⁴⁵, an open-source framework for creating virtual RDF graphs from relational databases through customizable mapping languages, OpenRefine⁴⁶, a powerful data cleaning tool with dedicated RDF extensions that facilitates both structural normalization (through facet-based filtering and clustering) and semantic enrichment (via reconciliation services like Wikidata) and 3M Mapping Memory Manager⁴⁷, a vocabulary alignment platform that supported complex transformation rules between heterogeneous schemas. Furthermore, specialized RDF and OWL processing libraries for different programming languages were used, including dotNetRDF⁴⁸ for .NET environments, RDFLib⁴⁹ and OWLReady2⁵⁰ for Python applications, EasyRDF⁵¹ for PHP-based implementation. Table 4 in Appendix A contains all the data points used for answering RQ4.

⁴³<https://protege.stanford.edu/>

⁴⁴<https://www.hozo.jp/>

⁴⁵<https://d2rq.org/>

⁴⁶<https://openrefine.org/>

⁴⁷<https://github.com/is1/Mapping-Memory-Manager>

⁴⁸<https://github.com/dotnetrdf/dotnetrdf>

⁴⁹<https://rdflib.readthedocs.io/>

⁵⁰<https://owlready2.readthedocs.io/>

⁵¹<https://www.easyrdf.org/>

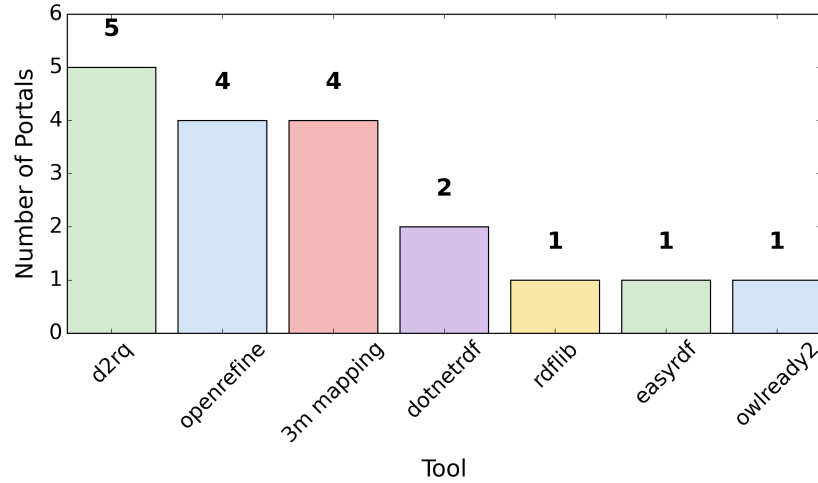


Figure 12. Usage of other LD-related tools (n=15).

4.5. Organizational factors

RQ5 was designed as the amalgamation of several topics connected with semantic portals in general, and not with its specific components. A first general question worth asking is which kind of CH institutions was involved in the development of the project that lead into the development of the surveyed portal. Figure 13 presents the collected information about the type of CH institution involved in the CH project. The information about the presence of the institution was collected either from the author affiliation, explicit mention in the text of the collaboration, or the origin of the data. All papers presented maximum one affiliated CH institution, except for [35] where both a library and an archive was involved in the project. Davis and Heravi [23] present a chart with similar data, however they did not limit to the presentation of involved CH institutions, and they did not limit the collected information to what was stated in the paper.

Another similar point of comparison with [23] are the motivational factors for conducting LD-CH projects. While they described 8 categories—research needs, exploration of LD, user needs, discoverability, interoperability, education, CH institution needs and preservation—we chose those 6 categories:

- **Dissemination:** Enhance the access and engagement of a broader audience with CH data.
- **Visualization:** Using interactive and user-friendly visual tools for the exploration and engagement with CH resources.
- **Interoperability:** Ensuring integration and exchange of data across different systems and institutions by adopting standardized LD models.
- **Research:** Supporting scholarly investigations by providing structured, inter-linked, and machine-actionable datasets for analysis and discovery.
- **Aggregation:** Combining dispersed CH resources into unified datasets accessible in a given portal enabling cross-collection search and analysis.
- **Preservation:** Safeguarding CH data in a sustainable, reusable, and long-term accessible format using shared formalized conceptualizations.

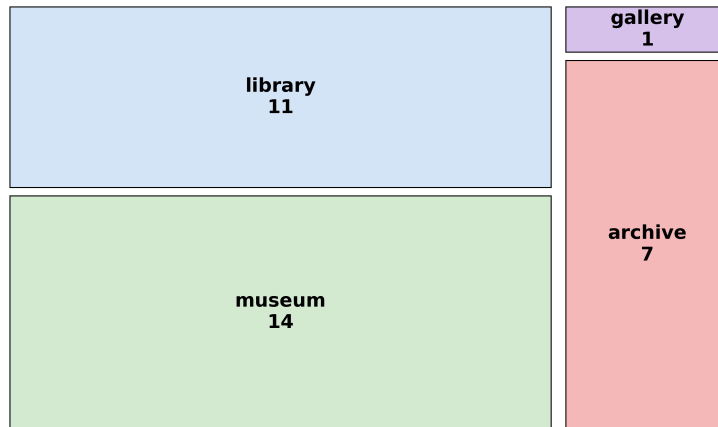


Figure 13. CH institution participating in LD project (n=68).

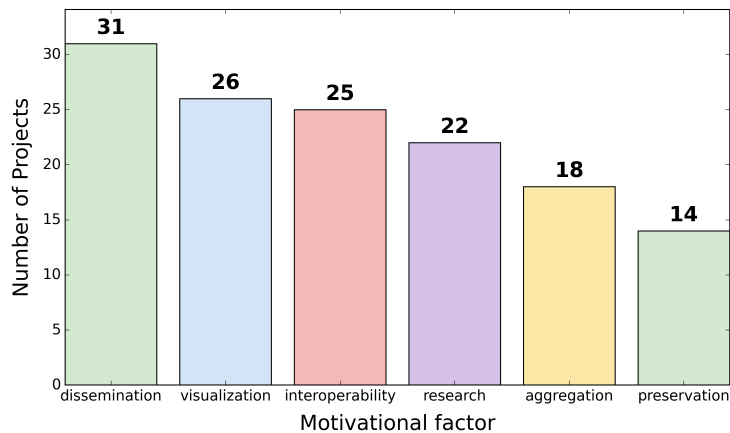


Figure 14. Motivational factors of CH-LD projects (n=68).

Figure 14 presents an overview of such motivational factors according to the surveyed articles. While the majority of articles mentioned a variety of factors, we limited the collection to the two most predominant factors. The motivational factor in some cases was explicitly stated as in [21]

The current focus of this monument by the ITN-DCH project is to design a single holistic framework in order to best document and disseminate its heterogeneous data for both future academic research and the public. (p. 48)

However, there were many cases where such factors had to be inferred from the context, such as in [71] where a museum strategy for improving engagement was based in gamification according to LD. The aim of improving engagement was categorized as dissemination. Finally, the only similarity to the results in [23] is the position of preservation as the least common motivational factor.

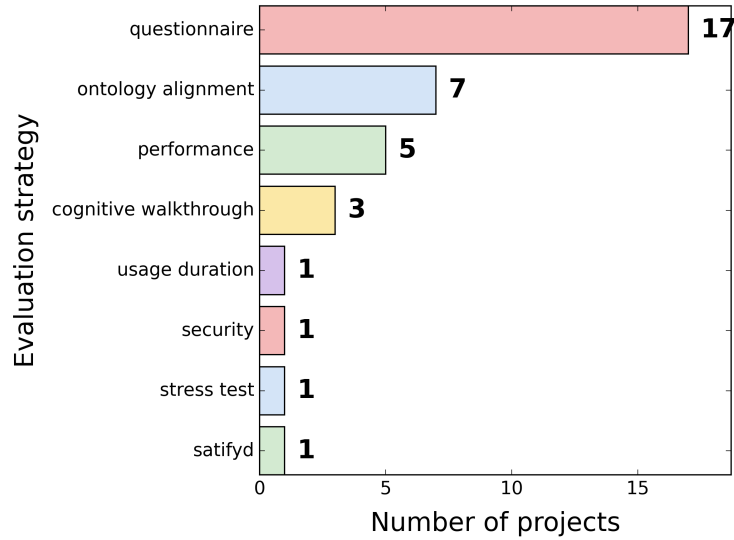


Figure 15. Evaluation strategies for CH portal (n=25).

We also gathered information about the evaluation strategy for each portal. Only papers related to 25 portals contained information about evaluative strategies, and they are presented in Figure 15. The evaluation methods refer to different components of the created portal, e.g., about the interface in questionnaires, on the content infrastructure with ontology alignment, with the underlying technical infrastructure with stress test and performance test, among others. It is worth highlighting the SATIFYD⁵² tool, a framework designed to assess the FAIRness (Findability, Accessibility, Interoperability, and Reusability) of digital resources, that has, however, been discontinued.

At last, we assessed the availability of each surveyed portal to the general public. The basis for such assessment was the presence of a link to the portal shared in the article. In the case of the existence of such a link, a connection was attempted⁵³. If the page was available, we considered the portal as available, otherwise we considered it as not available⁵⁴. Figure 16 illustrates the synthesis of the different availability status of the surveyed portals. Surprisingly, a significant amount of papers about semantic portals do not present any link for public access. Moreover, the majority of portals mentioned in surveyed papers cannot be currently accessed, either given a lack of link or the inexistence of the resource. Table 4 in Appendix A contains all the data points used for answering RQ5.

4.6. Bibliometric overview

We used two steps for a bibliometric analysis of the 77 selected publications. First, we aggregated the articles according to publication type, i.e. conference paper, journal paper

⁵²<https://dans.knaw.nl/en/satifyd/>

⁵³All access attempts were performed on April 23rd, 2025

⁵⁴We did not exhaustively explore the available pages to ensure that the content corresponded to what was described in the articles

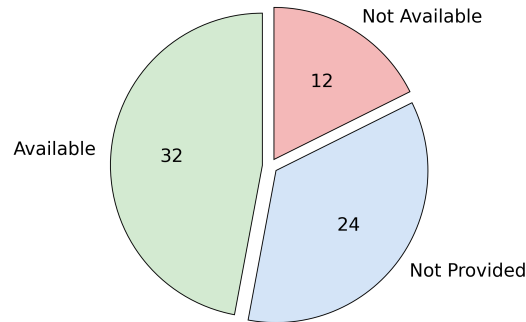


Figure 16. Availability of surveyed semantic portals (n=68).

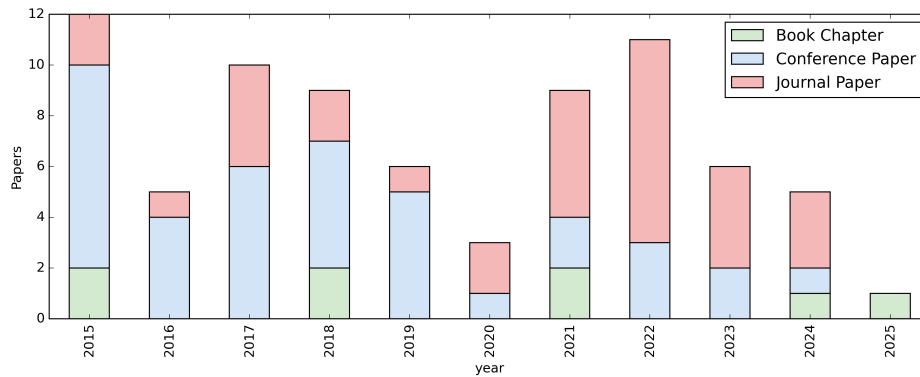


Figure 17. Distribution of selected papers according to publication year and type.

and book chapter, and plotted as Figure 17 a temporal distribution of the papers over the publication years included in the survey. Second, we identified the journals and conferences where at least two of the papers were published, and presented it respectively in Figure 18 and Figure 19. Proceedings of workshops happening within a conference were classified as part of the conference total. The full list of papers, publication type, source and year are presented in Table 5 present in appendix B.

Papers were predominantly published in conference proceedings (n=37) and in journals (n=32), while the number of book chapters presenting semantic portals are rather limited (n=8). A significant amount of articles was published in journals dedicated to the application of information technologies to CH-related disciplines, such as “Journal on Computing and Cultural Heritage” and “ISPRS International Journal of Geo-Information”. Journals focusing on applied computer science were also frequent publication targets, including “Semantic Web” and “Information”. A smaller number of articles were published in CH-centered journals, such as “Museum Management and Curatorship” and “Heritage”.

A similar trend was observed for conference proceedings, where some of the most popular conferences are in the intersection of CH and computer science, including “CIPA

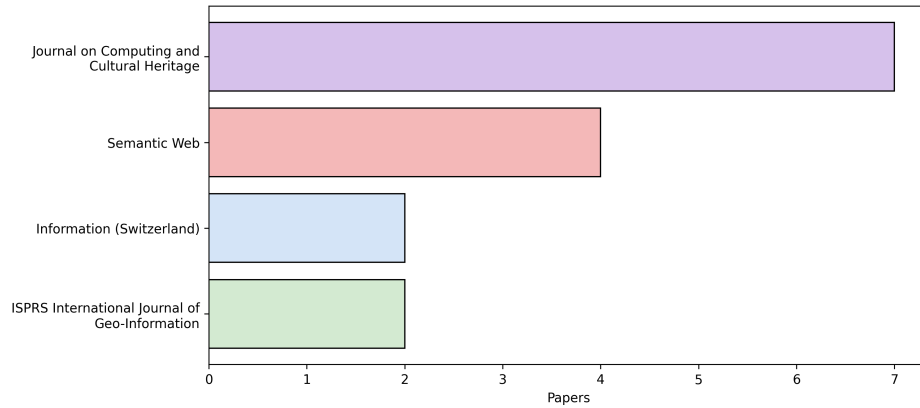


Figure 18. Journals where at least 2 papers were published.

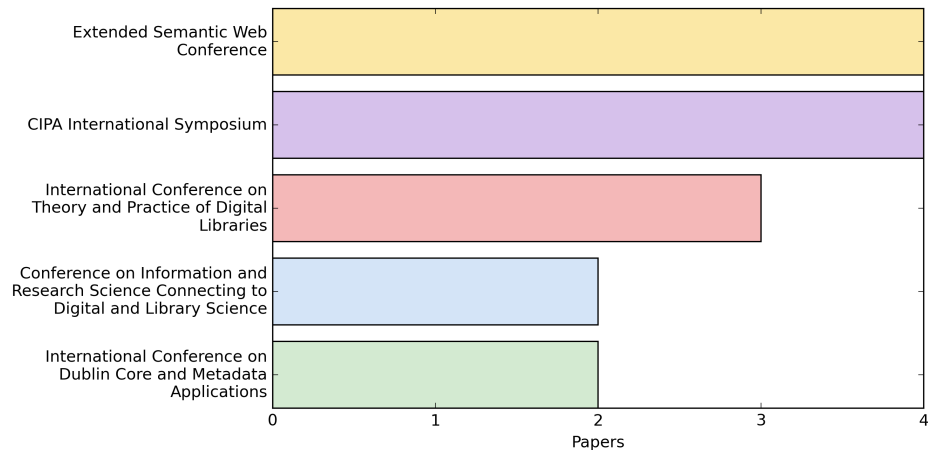


Figure 19. Conferences in whose proceedings at least two papers were published.

International Symposium” and “International Conference on Theory and Practice of Digital Libraries”, while information technology-centered conferences such as “Extended Semantic Web Conference” and “International Database Engineering and Applications Symposium” were also present in the list.

5. Discussion

The analysis of existing LD-based portals for presenting and exploring CH resources reveals several implementation trends. We highlight and discuss four key observations.

First, there is a notable lack in the implementation of reusable solutions in two dimensions of these projects. As shown in Figure 2, 29 portals employed custom ontologies, while 27 relied on rarely used ones. However, most supplemented these with widely adopted standards. More concerning is that 13 portals depended exclusively on a com-

bination of custom and rarely used ontologies without integrating any established ontology, raising long-term interoperability concerns. This suggests that a significant fraction (around 20%) of the surveyed CH semantic portals face interoperability challenges due to the absence of shared conceptualizations⁵⁵.

The situation is even more pronounced in the reuse of existing systems for portal interfaces. Only 22 portals were built on existing platforms, while 46 were custom-developed from scratch⁵⁶. Although reusing interfaces is less critical than reusing ontologies, the limited adoption of existing systems hinders the development of CH portals, particularly where resources for custom software development are scarce.

Second, machine-readability remains a challenge in many portals. A core principle of SW applications is enabling algorithmic access to semantically structured data. The most common approach is providing a SPARQL endpoint for querying LD. Alternatively, lightweight semantic annotations—such as microformats or RDFa⁵⁷—can embed machine-readable metadata directly into human-readable web content, bypassing the need for dedicated query services.

However, only 24 portals in the survey offered a SPARQL endpoint, and none mentioned alternative machine-readability strategies. This gap suggests that many CH portals prioritize human consumption over structured data access, limiting their interoperability and potential for automated reuse.

Another trend worth discussing is the usage of the concept of a “semantic portal.” Although the surveyed applications are often labeled as such, only a few authors explicitly define or align their work with this concept (e.g., [53, 91, 109]). While the surveyed portals attempt at applying LD principles for organizing and presenting CH resources, rarely do these efforts engage with established literature on design, implementation, or evaluation of semantic portals.

Descriptively, many surveyed applications fall short of qualifying as semantic portals—for instance, due to lacking machine-readability. Nevertheless, the concept retains normative value by setting clear expectations for what such portals should achieve (e.g., structured data access, interoperability, and semantic exploration). We advocate for retaining this term, as it fosters interdisciplinary alignment and encourages the adoption of LD solutions beyond CH, ultimately advancing the broader SW vision.

Finally, we can refer back to the assertion by Hyvönen [50] that research on CH semantic portals has shifted from developing an interface for harmonized LD towards the integration of more advanced research features. The basis for this shift is claimed to be the availability of massive resources in repositories such as Europeana, and the increasing number of harmonized aggregated linked datasets. While our survey confirms that many portals now offer an extensive range of advanced research functionalities, it also reveals persistent limitations in data harmonization and aggregation. Notably, 20% of portals lack widely interoperable ontologies, and 41% do not link to standardized controlled vocabularies. These findings suggest that, although the field has progressed toward richer forms of resource exploration, the underlying foundations required for interoperability remain incomplete.

⁵⁵No working links were provided for any of the custom ontologies.

⁵⁶[101] presents a strong case for using reusable systems (e.g., Omeka S), emphasizing benefits such as data longevity and reduced need for specialized interface development skills. For a comparison of CH content management systems, see [75].

⁵⁷See [79] for an in-depth discussion of microformats and RDFa.

The push to develop advanced tools for processing CH datasets—such as those employing machine learning—is undoubtedly valuable. However, such innovations remain feasible primarily for well-resourced institutions with established expertise in LD and CH, as demonstrated in [53]. For smaller institutions or lower-budget projects, research prioritizing foundational work—such as improving data harmonization, integration, and the adoption of reusable solutions (challenges for first-generation systems according to [50])—remains critical. These efforts continue to play a pivotal role in building an interoperable SW of CH resources. At the same time, the analysis of portal features (Figure 9) demonstrates that semantic portals are increasingly moving beyond basic search and browsing functionalities by incorporating advanced approaches for knowledge exploration, including maps, timelines, graph-based visualizations, 3D representations, and narrative-driven interfaces. This evolution creates new opportunities for integrating AI-based approaches, such as semantic search, question answering, automatic metadata enrichment, entity linking, and AI-assisted interpretation of cultural resources. However, the effectiveness of such approaches depends strongly on the availability of structured, interoperable, and machine-readable data.

This observation is also relevant in the context of emerging research infrastructures and data ecosystems, such as the European Cultural Heritage Data Space and the European Collaborative Cloud for Cultural Heritage (ECCCH)⁵⁸. Although these initiatives are still under development and are therefore not yet reflected in the surveyed portals, they represent an important direction for the future evolution of CH semantic portals by enabling distributed access, enrichment, and reuse of cultural heritage resources. Participation in such ecosystems will require the same foundational capabilities identified throughout our analysis: the adoption of reusable semantic models, the use of shared vocabularies, and the provision of machine-readable access mechanisms. Therefore, while AI-driven tools and integration with large-scale research infrastructures represent promising next steps for CH semantic portals, continued investment in interoperability and data harmonization remains essential to ensure that these developments benefit the broader CH community rather than only institutions with substantial technical resources.

In sum, the analysis of the semantic portals has shown the following challenges:

- **Incomplete data harmonization and integration:** Despite progress, significant portions of portals lack interoperable ontologies (20%) or connections to standardized vocabularies (41%), hindering aggregation and cross-portal discovery.
- **Low adoption of existing platforms:** A majority of portals (46 out of 68) are custom-developed rather than built on reusable systems, which increases development costs and hinders sustainability.
- **Insufficient machine-readability:** Only 24 portals provide a SPARQL endpoint, and none implement alternative methods (e.g., RDFa, microformats), limiting structured data access and algorithmic reuse.
- **Limited adoption of advanced research features:** While many portals provide advanced functionalities such as maps, timelines, graph visualizations, and 3D representations, further integration of AI-based approaches still depend on improved data interoperability and machine-readability.

⁵⁸<https://www.echoes-ecch.eu/>

6. Conclusion

This article reports on the conducted SLR of 77 selected academic papers presenting 68 different prototyped or deployed CH semantic portals, i.e., applications using LD to present CH resources. Cultural heritage represents a particularly relevant use case for knowledge graphs, as it brings together heterogeneous, multilingual, and context-rich information sources that require semantic modeling, integration, and exploration. As such, CH provides a valuable setting for studying not only the challenges of representing and accessing cultural resources, but also broader issues related to the design, implementation, and adoption of knowledge graph-based applications. The survey covers a range of aspects of SW for CH, including architectures and infrastructures, interfaces for the exploitation of linked CH data, and the reuse of ontologies, controlled vocabularies, and other supporting tools. The main motivation for this survey was therefore not only to provide a comprehensive overview of existing approaches for CH semantic portals, but also to identify common practices, challenges, and opportunities relevant to the wider knowledge graph community. Existing literature on semantic portal development and on LD standards in the CH domain served as the basis for defining the overarching research questions that guided the extraction, synthesis, and presentation of relevant information from the surveyed articles.

The results indicate that, although established ontologies such as CIDOC-CRM and Dublin Core, and controlled vocabularies such as DBpedia and Getty AAT, are widely adopted in the CH domain, a substantial number of CH LD projects still do not rely on interoperable standards. Similarly, while semantic portals primarily focus on human-oriented access through browsing and search interfaces, the provision of machine-readable data remains limited. A variety of existing tools support the implementation of such portals, including triplestores, semantic enrichment tools, visualization frameworks, and content management systems. Reusing these existing solutions can substantially reduce the resources required for developing and maintaining semantic portals. However, our analysis also shows that, despite progress in providing richer exploration interfaces, the adoption of research-oriented functionalities remains limited. Many portals lack advanced mechanisms for knowledge discovery, such as recommendation systems, semantic exploration, analytical capabilities, or AI-assisted interaction with cultural heritage resources. Furthermore, the application of AI techniques for supporting the creation and enrichment of CH datasets—including entity linking, metadata generation, semantic annotation, and data reconciliation—is still rarely reported. These limitations highlight that the potential of knowledge graphs in CH extends beyond data publication and access, toward supporting intelligent discovery, interpretation, and reuse of cultural resources.

Based on these findings, we advocate for the continued publication of academic reports and papers documenting the implementation of CH semantic portals that adhere to interoperable standards and technologies. Such transparency facilitates knowledge sharing, minimizes redundant development efforts, and promotes the adoption of best practices across the field. We further highlight the critical need for sustained research and development of open-source tools for data harmonization, integration, and enrichment, particularly to enable the growing volume of CH datasets to contribute to the linked open data cloud. Cultural heritage is one of the most prominent application domains for knowledge graphs, as its heterogeneous, multilingual, and context-rich resources provide

a challenging yet valuable environment for demonstrating the benefits of semantic technologies. Therefore, the CH community should continue to serve as a testbed for innovative approaches in knowledge representation, data integration, and AI-assisted resource exploration, while sharing successful strategies and reusable solutions that can advance both CH applications and the broader knowledge graph ecosystem.

One plan for future work is the publication of the collected survey results as a structured dataset by describing them using semantic vocabularies or ontologies. Such a representation would facilitate reuse, integration with other knowledge graphs, and further analysis of trends in the development of CH semantic portals.

Acknowledgements

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A. Complete presentation of survey results

The data presented in the following columns can be accessed in Zenodo under the link <https://zenodo.org/records/22753224>.

Table 3.: Complete information gathered according to RQ1, RQ2 and RQ3

Reference	Ontologies	Vocabularies	Data integration	Data origin	Feed-back	Application type	Access type	Research features
[3]	dublin core	not provided	manual	not applicable	yes	dspace	browse, search, oai-pmh	not provided
[20]	custom	ehraf, ich	not provided	not applicable	no	custom web app	browse, search	semantic search
[21]	dublin core	not provided	manual, import	tabular	no	omeka classic	search, oai-pmh	maps, 3D visualization
[33]	cidoc-crm, lrmoo	rameau, viaf, geonames	import	relational, xml	no	custom web app	search, sparql	timeline, maps
[62]	cidoc-crm, skos	dbpedia	import	rdf	no	mobile	browse	recommendation
[68]	cidoc-crm	not provided	manual	not applicable	no	mobile	ar, browse	recommendation
[69]	not provided	dbpedia, viaf	query	not applicable	yes	custom web app	browse	not provided
[91]	not provided	dbpedia, freebase	import	not specified	no	custom web app	browse, search	timeline, graph visualization, semantic search
[55], [56]	custom, cidoc-crm	not provided	import	not specified	no	mobile	ar, browse	not provided
[4]	cidoc-crm, foaf, dbpedia	dbpedia	import	relational, xml	no	custom web app	browse, search	not provided
[15], [14]	custom, rda	dbpedia, geonames, wikidata	import	marc21	no	custom web app	browse, search, sparql	maps
[36]	cidoc-crm	eol	import	text	no	custom web app	browse, search, sparql	maps, statistics
[65]	cidoc-crm, lrmoo, sioc	not provided	import	rdf	no	custom web app	browse, search	not provided
[95], [94]	custom, cidoc-crm	not provided	crowd	not applicable	yes	custom web app	browse, search	not provided
[111]	cidoc-crm	not provided	import	not specified	no	custom web app	sparql, browse	not provided
[7]	foaf, skos, music ontology, event, geo, custom, relationship, linkedjazz	viaf, bbc music, musicbrainz, wikidata	import	tabular, relational	no	pubby	browse, sparql	not provided
[12]	custom	not provided	import	xml, oai-pmh	no	custom web app	browse, search	not provided

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Table 3 – *Continued from previous page*

Reference	Ontologies	Vocabularies	Data integration	Data origin	Feed-back	Application type	Access type	Research features
[18], [73]	custom	not provided	manual	not applicable	yes	omeka classic	browse, search	maps, 3D visualization
[35]	cidoc-crm, crm-archaeo, crm-sci, lrmoo, geo	zenon, idai.gazetteer, aat, wikidata	import	xml, rdf, oai-pmh	no	custom web app	browse, search, sparql	maps
[64]	skos, geolink	dbpedia, loc, orcid	import	tabular	no	arcgis online	browse, search, sparql	maps
[103]	foaf, culturalis, bibframe	viaf, wikidata, gnd, bnf, sbn, dbi	import	tabular, xml, json	yes	custom web app	browse, search, sparql	not provided
[38]	cidoc-crm, crm-inf	not provided	import	relational	no	custom web app	browse	3D visualization
[99]	not provided	viaf, geonames	import	xml	no	correspsearch	browse, search	not provided
[71]	dbpedia	dbpedia	query	not applicable	no	mobile	browse	gamification
[112]	custom	geonames	import	sensors, scraping	no	mobile	ar, browse	recommendation
[85]	custom	dbpedia, geonames	import	tabular, xml, rdf	no	custom web app	browse	3D visualization, maps
[104]	cidoc-crm, skos, foaf, dublin core, hipla	ysa, koko, ammo	import	tabular, xml, rdf, text	no	sampo	browse, search, sparql	maps
[106]	custom, foaf, dublin core, cidoc-crm	aat, periodo, viaf, geonames, wikidata	import	xml, oai-pmh	yes	custom web app	browse, search, api	not provided
[115]	gvp, skos, dublin core, edm, cidoc-crm	aat	import	text, tabular	no	custom web app	browse, search, api	graph visualization, fuzzy search
[5]	custom	not provided	query	not applicable	no	custom web app	browse, search	tag word cloud, graph visualization
[52], [1]	custom	not provided	import	marc21, xml	yes	sampo	browse, search, sparql	data-analytic tooling, statistics, maps
[76]	cidoc-crm	not provided	crowd	not applicable	yes	custom web app, mobile	browse, search, sparql, ar	narrative, 3D visualization, maps
[102]	cidoc-crm, crm-inf	wikidata	manual	not applicable	no	researchspace	browse, search, sparql	not provided

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Table 3 – *Continued from previous page*

Reference	Ontologies	Vocabularies	Data integration	Data origin	Feed-back	Application type	Access type	Research features
[26]	cidoc-crm	ulan, viaf, aat, tgn, iconclass	import	xml	no	custom web app	browse, search	timeline, maps, lexicographic visualization
[60]	wikibase	wikidata, aat, tgn, fast	import	tabular, xml	no	custom web app	browse, search, sparql	not provided
[72]	custom	not provided	manual	not applicable	no	vr system	vr	3D visualization
[82]	custom	not provided	import	tabular	no	pubby	browse, search, sparql	not provided
[31]	cidoc-crm	not provided	manual	not applicable	no	researchspace	browse, search, sparql	3D visualization
[74]	custom, cidoc-crm	aat, dbpedia	not provided	not applicable	no	mobile	search	recommendation, maps
[108]	custom	aat, dbpedia	import, query	tabular	no	custom web app	browse, search	statistics
[83], [84]	custom, cidoc-crm, crm-sci	data.culture.fr	import	xml, relational	no	custom web app	browse, search, sparql	not provided
[93]	custom, cidoc-crm, crm-geo, crm-ba	not provided	import	image	no	custom web app	browse	3D visualization, geosparql
[96]	custom, edm, cidoc-crm	pactols, viaf, aat, geonames	import, query	oai-pmh, xml, relational	yes	custom web app	browse	3D visualization
[22]	custom	not provided	manual	not applicable	no	custom web app	browse	visual metaphor
[81]	cidoc-crm	dbpedia, british museum	import	relational	no	custom web app	browse, search, sparql	graph visualization, timeline
[24]	sem, dublin core, skos, foaf, openannotation	dbpedia, wikipedia	import, crowd	text, tabular	yes	custom web app	browse, search, sparql	not provided
[25]	custom, dublin core, persona, foaf	not provided	import	relational	no	custom web app	browse, search	not provided
[63]	not provided	gnd, geonames, wikipedia, dbpedia	manual	not applicable	no	dspace	browse, search	not provided
[17]	custom, dolce	not provided	import	not provided	no	custom web app	browse, api	maps
[19]	cidoc-crm	not provided	import	relational	no	custom web app	browse, search, sparql	maps, timeline

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Table 3 – *Continued from previous page*

Reference	Ontologies	Vocabularies	Data integration	Data origin	Feed-back	Application type	Access type	Research features
[46]	cidoc-crm, foaf, geonames	dbpedia, geonames	import	relational	no	custom web app	browse, sparql	maps, graph visualization
[53], [109]	nif, cidoc-crm, dublin core, crm-bio	aat, wikidata, ulan, viaf	import	text, relational, rdf, tabular	no	sampo	browse, search, sparql	statistics, network analysis, reference analysis
[54]	custom, geo	not provided	manual	not applicable	no	custom web app	search, api	3D visualization
[114], [113]	custom, cidoc-crm, foaf, lrmoo	aat, geonames, wikipedia, dmt, cbdb	import	text, xml, rdf, relational	no	arches	browse, search	3D visualization, graph visualization, maps
[34]	dublin core, edm	viaf, wikipedia, semantics.gr	query	not applicable	no	custom web app	browse, search	not provided
[47]	custom, foaf, skos	aat, viaf, ulan, wikidata, dbpedia	import	not specified	no	custom web app	browse, search	graph visualization
[58]	similarity ontology, crm-inf, cidoc-crm	not provided	import	rdf	no	researchspace	browse, search, sparql	visual search
[89], [118]	cidoc-crm, narrative ontology, lrmoo, owltime, dublin core	geonames	manual	not applicable	yes	researchspace	browse, search, sparql	maps, timeline, narrative
[92]	cidoc-crm	cer.es, geonames	import	not specified	no	custom web app	browse	maps, 3D visualization, timeline
[86]	mao/tao, nomisma	not provided	import	not specified	yes	sampo	browse, search, sparql	maps, statistics
[97]	cidoc-crm, crm-dig, dublin core, skos	wikidata, loc, bnf, gnd, aat, ulan, tgn	import	not specified	no	custom web app	browse, search, api	not provided
[101]	custom, dublin core	aat	manual	not applicable	yes	omeka s	browse, search	not provided
[87]	custom, edm, owltime	not provided	import	oai-pmh, xml, json	yes	mobile	browse	not provided
[100]	cidoc-crm, lrmoo	wikidata	import	marc21	no	researchspace	browse	narrative
[9]	custom	not provided	import	marc21, rdf, xml	no	custom web app	browse, search	not provided
[37]	edm	aat, geonames, icon-class	import	tabular, xml	no	omeka classic	browse, search, oai-pmh	maps

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Table 3 – *Continued from previous page*

Reference	Ontologies	Vocabularies	Data integration	Data origin	Feed-back	Application type	Access type	Research features
[117]	cidoc-crm	not provided	manual	not applicable	no	arches	browse, search	maps, statistics
[27]	cidoc-crm, crm-sci, crm-archeo, crm-dig, dublin core, custom	not provided	import	tabular	no	omeka s	browse, search	3D visualization

Table 4.: Complete information gathered according to RQ4 and RQ5

Reference	Data storage	Ontology Editor	Other tools	Institution	Motivation	Evaluation	Link status
[3]	not provided	not provided	not provided	library	preservation, interoperability	not provided	available
[20]	apache jena framework	hozo	not provided	research	research, dissemination	performance, questionnaire	not provided
[21]	not provided	not provided	not provided	library	preservation, interoperability	not provided	available
[33]	not provided	not provided	not provided	library	preservation, interoperability	not provided	not provided
[62]	apache jena framework	not provided	not provided	museum	interoperability, dissemination	not provided	available
[68]	apache jena framework	not provided	not provided	gallery	dissemination, visualization	cognitive walkthrough	not provided
[69]	not provided	not provided	rdflib	library	aggregation, research	not provided	not provided
[91]	not provided	not provided	not provided	research	visualization, interoperability	not provided	not provided
[55], [56]	not provided	not provided	dotnetrdf	museum	aggregation, visualization	usage duration, questionnaire	not provided
[4]	apache jena framework	not provided	not provided	museum	visualization, research	not provided	available
[15], [14]	rdf4j	not provided	not provided	library	interoperability, research	questionnaire	available
[36]	not provided	not provided	3m mapping	archive	aggregation, preservation	not provided	not available
[65]	not provided	not provided	not provided	museum	interoperability, research	not provided	not available
[95], [94]	apache jena framework	not provided	easyrdf	research	preservation, research	questionnaire	not available
[111]	not provided	not provided	not provided	research	interoperability, research	ontology alignment, performance	not provided
[7]	virtuoso	not provided	d2rq, openrefine	research	interoperability, research	ontology alignment	available
[12]	not provided	hozo	not provided	museum	aggregation, interoperability	questionnaire	available
[18], [73]	not provided	not provided	not provided	archive	aggregation, visualization	not provided	not available
[35]	blazegraph	not provided	3m mapping	museum, archive	aggregation, research	not provided	available
[64]	apache jena framework	not provided	not provided	library	aggregation, research	not provided	available
[103]	not provided	not provided	not provided	library	interoperability, aggregation	not provided	available
[38]	not provided	not provided	not provided	museum	visualization, research	not provided	available
[99]	not provided	not provided	not provided	library	visualization, aggregation	not provided	available
[71]	not provided	not provided	not provided	museum	visualization , dissemination	questionnaire	not available
[112]	not provided	protégé	not provided	museum	visualization, dissemination	questionnaire, performance	not provided
[85]	mongodb	not provided	not provided	research	aggregation, visualization	not provided	not available
[104]	apache jena framework	not provided	not provided	research	aggregation, research	ontology alignment	available
[106]	not provided	not provided	not provided	research	aggregation, research	not provided	available
[115]	not provided	not provided	d2rq, openrefine	research	dissemination, preservation	not provided	not provided

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Table 4 – Continued from previous page

Reference	Data storage	Ontology Editor	Other tools	Institution	Motivation	Evaluation	Link status
[5]	mysql	not provided	not provided	research	aggregation, visualization	not provided	not provided
[52], [1]	not provided	not provided	not provided	research	interoperability, research	not provided	available
[76]	mongodb	not provided	not provided	research	visualization, preservation	cognitive walkthrough, questionnaire	available
[102]	not provided	not provided	not provided	museum	dissemination, research	not provided	available
[26]	virtuoso	not provided	not provided	research	dissemination, preservation	not provided	available
[60]	not provided	not provided	openrefine	library	aggregation, dissemination	ontology alignment	available
[72]	mongodb	protégé	dotnetrdf, owlready2	museum	dissemination, visualization	ontology alignment, questionnaire	not provided
[82]	apache jena framework	hozo	openrefine	research	dissemination, interoperability	questionnaire, ontology alignment	not provided
[31]	blazegraph	not provided	not provided	research	visualization, dissemination	not provided	not provided
[74]	sqlite	not provided	not provided	research	visualization, interoperability	questionnaire, performance, security	available
[108]	apache jena framework	protégé	d2rq	research	aggregation, dissemination	not provided	not provided
[83], [84]	rdf4j	not provided	not provided	research	interoperability, preservation	not provided	not provided
[93]	postgresql	protégé	not provided	research	visualization, dissemination	not provided	not available
[96]	postgresql	not provided	not provided	research	visualization, preservation	not provided	available
[22]	mysql	not provided	not provided	research	visualization, research	questionnaire	not available
[81]	blazegraph	not provided	not provided	museum	dissemination, interoperability	not provided	not available
[24]	cliopatria	not provided	not provided	library	dissemination, interoperability	questionnaire, performance	not available
[25]	apache jena framework	not provided	d2rq	archive	preservation, dissemination	not provided	not available
[63]	not provided	not provided	not provided	archive	visualization, dissemination	not provided	available
[17]	apache jena framework	not provided	not provided	archive	dissemination, visualization	questionnaire	not provided
[19]	not provided	not provided	not provided	museum	dissemination, interoperability	questionnaire	not provided
[46]	virtuoso	not provided	d2rq	research	dissemination, interoperability	not provided	not provided
[53], [109]	apache jena framework	not provided	not provided	research	dissemination, research	ontology alignment	available
[54]	apache jena framework	not provided	not provided	research	visualization, dissemination	not provided	not provided
[114], [113]	not provided	not provided	not provided	research	visualization, research	not provided	not provided
[34]	not provided	not provided	not provided	archive	aggregation, research	not provided	available
[47]	not provided	not provided	not provided	research	aggregation, interoperability	not provided	not provided
[58]	blazegraph	not provided	not provided	research	research, interoperability	not provided	not available
[89], [118]	graphdb	not provided	not provided	research	preservation, dissemination	questionnaire, cognitive walkthrough	available
[92]	not provided	not provided	not provided	research	dissemination, visualization	stress test	available
[86]	not provided	not provided	not provided	research	interoperability, research	not provided	available

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Table 4 – *Continued from previous page*

Reference	Data storage	Ontology Editor	Other tools	Institution	Motivation	Evaluation	Link status
[97]	not provided	not provided	not provided	research	interoperability, dissemination	not provided	available
[101]	mysql	not provided	not provided	research	visualization, research	not provided	available
[87]	rdf4j	not provided	not provided	research	dissemination, interoperability	not provided	not provided
[100]	not provided	not provided	3m mapping	library	visualization, dissemination	not provided	available
[9]	not provided	not provided	3m mapping	museum	dissemination, aggregation	questionnaire	not provided
[37]	mysql	not provided	not provided	research	dissemination, preservation	not provided	available
[117]	not provided	protégé	not provided	research	dissemination, preservation	not provided	not provided
[27]	mysql	not provided	not provided	research	visualization, interoperability	satisfyd	available

Appendix B. Full bibliographic information

Table 5.: Complete bibliometric information

Ref.	Type	Source	Year
[9]	Book Chapter	Linked Data and User Interaction	2015
[69]	Book Chapter	Linked Data and User Interaction	2015
[18]	Book Chapter	Digital Hampi: Preserving Indian Cultural Heritage	2018
[73]	Book Chapter	Digital Hampi: Preserving Indian Cultural Heritage	2018
[115]	Book Chapter	Information and Knowledge Organisation in Digital Humanities: Global Perspectives	2021
[106]	Book Chapter	Information and Knowledge Organisation in Digital Humanities: Global Perspectives	2021
[97]	Book Chapter	Decoding Cultural Heritage: A Critical Dissection and Taxonomy of Human Creativity through Digital Tools	2024
[96]	Book Chapter	Springer Science and Business Media Deutschland GmbH	2025
[62]	Conference Paper	Extended Semantic Web Conference	2015
[81]	Conference Paper	Extended Semantic Web Conference	2015
[91]	Conference Paper	AIUCD Annual Conference on Humanities and Their Methods in the Digital Ecosystem	2015
[3]	Conference Paper	International Conference on Dublin Core and Metadata Applications	2015
[20]	Conference Paper	Joint International Conference on Semantic Technology	2015
[21]	Conference Paper	CIPA International Symposium	2015
[22]	Conference Paper	International Conference on Intelligent Technologies for Interactive Entertainment	2015
[33]	Conference Paper	Extended Semantic Web Conference	2015
[55]	Conference Paper	International Conference on Signal Image Technology and Internet-Based Systems	2016
[63]	Conference Paper	International Conference on Theory and Practice of Digital Libraries	2016
[87]	Conference Paper	International Conference on Management of Digital EcoSystems	2016
[83]	Conference Paper	International Database Engineering and Applications Symposium	2016
[111]	Conference Paper	International Conference on Building and Exploring Web Based Environments	2017
[95]	Conference Paper	Australasian Conference on Information Systems	2017
[4]	Conference Paper	Iberian Conference on Information Systems and Technologies	2017
[15]	Conference Paper	International Conference on Digital Access to Textual Cultural Heritage	2017
[17]	Conference Paper	International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management	2017
[65]	Conference Paper	International Conference on Metadata and Semantic Research	2017
[94]	Conference Paper	International Conference on Digital Heritage	2018
[103]	Conference Paper	Italian Research Conference on Digital Libraries	2018
[7]	Conference Paper	International Conference on Digital Libraries for Musicology	2018
[12]	Conference Paper	International Conference on Knowledge, Information and Creativity Support Systems	2018
[35]	Conference Paper	Conference on Computer Applications and Quantitative Methods in Archaeology	2018
[54]	Conference Paper	International Conference on Transdisciplinary Multispectral Modeling and Cooperation for the Preservation of Cultural Heritage	2019

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Table 5 – Continued from previous page

Ref.	Type	Source	Year
[53]	Conference Paper	International Semantic Web Conference	2019
[99]	Conference Paper	Digital Humanities in the Nordic Countries	2019
[46]	Conference Paper	Association for Information Science and Technology	2019
[38]	Conference Paper	CIPA International Symposium	2019
[71]	Conference Paper	International Conference on Intelligent Environments	2020
[113]	Conference Paper	CIPA International Symposium	2021
[117]	Conference Paper	CIPA International Symposium	2021
[52]	Conference Paper	International Conference on Theory and Practice of Digital Libraries	2022
[47]	Conference Paper	International Conference on Dublin Core and Metadata Applications	2022
[34]	Conference Paper	International Conference on Theory and Practice of Digital Libraries	2022
[1]	Conference Paper	Extended Semantic Web Conference	2023
[26]	Conference Paper	Conference on Information and Research Science Connecting to Digital and Library Science	2023
[31]	Conference Paper	Conference on Information and Research Science Connecting to Digital and Library Science	2024
[24]	Journal Paper	JOURNAL OF WEB SEMANTICS	2015
[68]	Journal Paper	Museum Management and Curatorship	2015
[25]	Journal Paper	International Journal on Digital Libraries	2016
[56]	Journal Paper	Multimedia Tools and Applications	2017
[36]	Journal Paper	Studies in Digital Heritage	2017
[93]	Journal Paper	Geosciences (Switzerland)	2017
[84]	Journal Paper	Journal on Computing and Cultural Heritage	2017
[14]	Journal Paper	Semantic Web	2018
[64]	Journal Paper	Journal of Map and Geography Libraries	2018
[19]	Journal Paper	New Generation Computing	2019
[112]	Journal Paper	Virtual Reality	2020
[114]	Journal Paper	Knowledge Organization	2020
[104]	Journal Paper	Semantic Web	2021
[37]	Journal Paper	Information (Switzerland)	2021
[108]	Journal Paper	Electronic Library	2021
[85]	Journal Paper	ISPRS International Journal of Geo-Information	2021
[74]	Journal Paper	Journal on Computing and Cultural Heritage	2021
[102]	Journal Paper	Digital Studies/ Le Champ Numerique	2022
[109]	Journal Paper	Semantic Web	2022
[5]	Journal Paper	Information (Switzerland)	2022
[58]	Journal Paper	Semantic Web	2022
[92]	Journal Paper	ISPRS International Journal of Geo-Information	2022
[118]	Journal Paper	Journal on Computing and Cultural Heritage	2022
[76]	Journal Paper	Heritage	2022
[89]	Journal Paper	Journal on Computing and Cultural Heritage	2022
[72]	Journal Paper	Heritage Science	2023
[82]	Journal Paper	Emerging Science Journal	2023
[27]	Journal Paper	Journal on Computing and Cultural Heritage	2023
[60]	Journal Paper	Journal on Computing and Cultural Heritage	2023
[100]	Journal Paper	Parergon	2024
[101]	Journal Paper	Peer Community Journal	2024
[86]	Journal Paper	Journal on Computing and Cultural Heritage	2024