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Domain question-driven Linked Data modeling
The case study of iconological studies

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Abstract

Currently, there is an increasing interest in experimenting with applications of computer science to humanistic disciplines. Although some domains successfully integrated some digital tools and techniques into their methods, other domains had a slower, narrower integration. This paper addresses the challenge of experimenting with the translation of qualitative research into a quantitative one by presenting the experience of the creation of a domain-specific Linked Open Data (LOD) dataset of iconographic and iconological art studies, namely, the Iconology Dataset. The peculiarity of the process adopted lies in its strong grounding in the theoretical framework of the domain, as it followed an ontological modeling according to the key theories proposed and a modeling and analysis through the scholars' key research questions. For the sake of enhancing the transfer of the approach to other studies, we refined it in 5 phases and presented a general description of them. Due to its characteristics of lack of formalization and interdisciplinary nature, we argue that the approach developed for the iconographical-iconological research field can be relevant for the methodological transfer to other domains.

Keywords: AIUCD2023, domain knowledge representation, iconological studies, question-driven approach, LOD

Attualmente, la sperimentazione di applicazioni computazionali alle discipline umanistiche è oggetto di grande interesse. Sebbene in alcuni ambiti umanistici strumenti e tecniche digitali siano stati integrati con successo nei loro metodi, altre discipline hanno registrato un'integrazione minore. Questo articolo affronta la sfida di sperimentare la traduzione di una ricerca qualitativa in una quantitativa, presentando l'esperienza della creazione di un dataset Linked Open Data (LOD), the Iconology Dataset, specifico per il dominio degli studi artistici iconografici e iconologici. La peculiarità del processo adottato risiede nel suo forte radicamento nel quadro teorico del dominio, in quanto ha seguito una modellazione ontologica secondo le teorie chiave proposte e una modellazione e analisi attraverso le domande di ricerca poste dagli studiosi. Per migliorare il trasferimento dell'approccio ad altri studi, abbiamo affinato l'approccio in 5 fasi e ne abbiamo presentato una descrizione generale. Per le sue caratteristiche di mancanza di formalizzazione e natura interdisciplinare, sosteniamo che l'approccio sviluppato per il campo di ricerca iconografico-iconologico può essere rilevante per il trasferimento metodologico ad altri ambiti.

Keywords: AIUCD2023, rappresentazione di conoscenza di dominio, studi di iconologia, approccio guidato da domande, LOD

Introduction[1]

Since the invention of computers, humanistic disciplines have been, to different degrees, experimenting with new computational approaches to push domain research forward by exploiting the latest advancements in computer capabilities. Nevertheless, some humanistic fields (e.g., art history) have not registered systematic attempts in the foundation of shared computational methods to be integrated into the discipline, even if some studies have highlighted the benefits that using computational capabilities and database design thinking would have [65].

Whereas, in the semantic web domain, the development of formal ontologies already provides methodologies to include domain expertise, to the author's knowledge, few guidelines are provided to define competency questions (CQs) that are representative of a domain and can quantitatively express traditional questions. Although the practice of identifying the core interests of the domain through literature reviews is extensively adopted by humanistic disciplines, there is a lack of systematic guidelines to enhance its transfer to computer scientists and database practitioners. The use of insights that can be provided by the output of research (articles, books) is therefore not brought to its full potential.

This paper addresses the issue of how to facilitate the computational turn of a humanistic domain of knowledge, proposing an approach to translate core qualitative research questions into quantitative ones. Specifically, it tackles the difficulty of creating structured data in the humanities field, often characterized by a range of different, sometimes incompatible theoretical frameworks, and in which the result of analysis is expressed in the form of a questionable, uncertain interpretation. The study delves into the details and generalises the approach adopted in the context of a project in the field of Digital Art History, which explored the application of semantic web technologies to the branch of study of iconology and iconography [3].

In particular, iconology aims at understanding the subject of images and interpreting deeper meanings [43]. Grounded in the research by Aby Warburg, it has an interdisciplinary nature, as it includes socio-cultural understandings of the society in which the artwork was created. Due to its complex nature, iconographical and iconological knowledge in artwork catalog entries is

[1] Sofia Baroncini is responsible for the text of the current article. Marilena Daquino and Francesca Tomasi are the scientific supervisors of the research presented.

usually expressed in free text fields according to standards, making thematic information retrieval challenging. The aim of the project consisted of advancing the state of the art through creating domain-specific, authoritative data described with the accuracy and flexibility of a newly created ontology, to allow us not only to explore the art history scholarly discourse through quantitative analysis but also to furnish a new way to access cultural heritage objects described in the network of Linked Open Data (LOD) through the narratives of experts' interpretations.

Hence, an ontology (ICON [59]) based on Erwin Panofsky's theory [47] was created, according to which a corpus of interpretations manually extracted from a selection of his books [47, 48, 49, 50] was described in compliance with the RDF standard. The resulting dataset was used as a proof-of-concept to showcase the improvement in information retrieval (e.g., what are all the artworks in which the character "Cupid" with the meaning of "luxury" appears?) and domain analysis that such a curated dataset can allow for the analysis of iconography and its meaning (e.g., does the interpretation of a symbol vary, if a specific textual source is used for its recognition?).

In the context of the project, the core domain questions were formulated through the hypothesis that the scholarly literature produced by a domain can furnish insights into the interests of the domain itself. A bottom-up approach could allow for identifying the shared typologies of domain-specific research questions pursued by the community, enriching the views provided by the available theoretical frameworks, and guiding both the ontological modeling phase and the dataset construction and analysis. In this paper, we aim to further define the approach adopted in the development of the Iconology dataset[2] to favor its transfer to other disciplines in the area of Digital Humanities (DH). The approach consists of the definition of phases to be applied from the examination of the domain to the analysis conducted in the resulting dataset.

The case study of iconology is considered relevant for transferring the approach to other domains for two main reasons. First, as only a few quantitative approaches were applied to this domain, and no unique theoretical approach is shared by the discipline, it constitutes an exemplar of humanistic domains for which formalization is a challenging task. Second, its interdisciplinary nature can favor the transfer of the method to further related disciplines, including history, anthropology, visual studies, cultural history, and related ones.

Iconography and Iconology

Whereas the term iconography refers to that branch of art history studying the subjects of the artworks (i.e., iconographies), their attributes, meaning, and evolution over time, the current meaning of the term *iconology* has its roots in the research activity of Aby Warburg [43, 71]. His approach considered the content and forms of the artworks as witnesses of social memory, conducting his analysis in an interdisciplinary way to include religion, culture, and the recurrence of visual patterns through different ages [31, 54, 71]. The first systematic attempt to define a theory of the iconographical and iconological method was made by Warburg's scholar Erwin Panofsky [31, 43].

[2] Raw data are available at: https://w3id.org/icon/data/ . An exploratory analysis and a SPARQL endpoint are provided at: https://iconology-dataset.streamlit.app/ . The scripts to create the dataset are available in [4]. The dataset creation, features, and analysis are extensively described in [3].

According to Panofsky, the interpretation act, divided into three layers, is made by an interpreter, who, on the basis of his knowledge, further documentary sources, and characteristics of the artwork examined, can understand the meaning expressed by the artwork. The depth to which the artwork can be understood depends on the background knowledge of the observer, going from a more superficial understanding to a deeper, culture-related one (see Table 1). In the first level (Pre-iconographical description), forms are recognized as carriers of primary subjects, i.e., subjects that are possible to know from everyday experience, reaching the identification of *artistic motifs* and *compositions*. They include natural elements (e.g., people, objects, actions) and expressional qualities (emotions). If the observer has sufficient background knowledge about the subject types and themes that may be represented in the time period considered, s/he can interpret the first-level subjects as second-level ones (e.g., a woman is recognized as Venus). In this phase, the artistic motifs or compositions recognized at the previous level are linked to secondary meanings, therefore identifying *images* and combinations of them, namely, *invenzioni*. Finally, if s/he is aware of the sociocultural context or the artist's personality, s/he can recognize symptoms of such topics in the artwork under examination, identifying symbolic values. The validity of the interpretation can be verified by relating it to the history of the conventions regulating art-making at every level, namely, the history of style, iconographic types, and cultural symptoms. Although three layers can be identified, the actual interpretation is simultaneous, and it doesn't require a description at every level, as the context makes clear implicit knowledge [49].

Lev.	**Interpretive act**	**Object of interpretation**	**Subject identified**	**Necessary knowledge**	**Regulating principle**
1	Pre-iconographical description	Artistic motifs and their combinations (compositions): pure forms recognized as carriers of primary meanings	Natural or primary meanings: factual and expressional meanings	Practical experience	History of style
2	Iconographical description	Images and their combinations (invenzioni, i.e., stories and allegories): artistic motifs and their combinations recognized as carriers of a secondary meaning	Secondary or conventional meanings: themes and concepts	Literary sources describing themes and concepts familiar to the artist	History of types
3	Iconological interpretation	Symbolic values: artistic motifs, images, stories, and allegories are recognized as manifestations of underlying principles of a cultural context	Intrinsic meaning or Content: underlying principles that identify the attitude of a nation, a class, a religion, or a philosophy; "a unifying principle which underlies and	Familiarity with cultural phenomena, tendencies, attitudes	History of cultural symptoms

			explains both the visible event and its intelligible significance, and which determines even the form in which the visible event takes shape" [47, p. 28]		

Table 1. Levels of interpretation according to Panofsky

Other art historians referred to Panofsky's framework proposing alternatives or changes. Wittkower [75] proposes alternative 4 levels of understanding, in which the deepest level concerns the understanding of the artist's personality. Van Straten [69] subdivides the last layer in two, distinguishing intentional (e.g., moral messages) from unintentional (e..g, cultural meanings) deeper meanings. Imdahl [33] agrees with Panofsky's levels, but he proposes the addition of a parallel level of understanding which considers the iconic language of visual images. Taylor [66] argues that three levels are not enough to tackle the complexity of iconographies and their meanings, proposing 10 levels distinguishing among resemblance, depiction, and representation. Gombrich [32] refuses the idea of layers, but rather he identifies steps to be followed to correctly interpret the subject of artworks, starting from the identification of its genre.

Although Panofsky's work has been debated, and other scholars have proposed further valuable insights, his work is still a central reference for the description[3], didactic and study of figurative art [10, 41].

Related works

Database and ontology design

The process of modeling consists of the definition of a conceptual representation of data objects and their relations. It concerns every type of data collection, from relational or graph databases to knowledge graphs (KGs) and ontology design, in the case of LOD.

In the context of database modeling, a domain is every field of application of database design (e.g., the business for which the database is implemented). In this sense, the indications provided by Evans [24, 25] underline the importance of mutual communication between domain experts and developers, setting not only a shared vocabulary but also a clear identification of the context of the application and its boundaries. In the context of the current work, we assign to "domain" a narrower meaning, namely a field of knowledge in a research context (e.g., mathematics, art history).

[3] e.g., the CCO and CDWA international catalog standards for cultural objects are based on the three layers of Panofsky's theory

Although key considerations of data model development are always relevant [22, 73], the practices adopted in creating a database are deeply affected not only by the domain of application but also by the intended uses and the type of objects collected. On the one hand, datasets as those created by institutions seek to grasp the interests of potential users, whereas researchers shape the dataset according to their research question. A database can be an extremely valuable part of one's research, and sometimes "the model itself is arguably an equally important outcome in the sense that it offers both an expression of method [...] and also an insight into the deeper patterns that inhabit the modeled instances, taken as a set." [28].

The definition of a structure, being a selection of reality from a single perspective [67], may prevent a wider answer to further research questions. In some cases, it led to the narrowing of the scope of objects collected to create an effective and sustainable dataset (e.g., the exhibition database created in the context of the Artl@s project[4] [36]). In the context of experimenting with computational capabilities applied to the humanities field, the choice of creating a data model that reflects the theoretical approaches of the discipline has been criticized by some scholars [40], as it limits the computational capabilities to (sometimes old) classifications.

Although computational methods applied to primary sources are extremely valuable and require ad-hoc definitions of methods, the importance of defining a relevant database structure to organize data collected in the context of a DH study, leveraging the core theories of the discipline, is widely recognized. In particular, Szabo [65] acknowledges the potential that art history studies would benefit from database design techniques. Art history started using datasets for conducting a wide range of analyses from the study of the art market [27, 35] to provenance studies [55, 61].

Extensive literature on database construction for humanistic research is provided for linguistic corpora [22], from which some indications, such as sampling criteria, can be applied to the context of non-linguistic datasets. As the branch of historical psychology, like the humanities, deals with historical data, the characteristics of this type of inquiry are valuable for a humanistic analysis [62]. Although research on historical facts often tends to rely on incomplete data, it offers advantages, such as examining the past, which would otherwise be impossible [62].

The historian doing quantitative research creates his/her dataset, which answers the defined research question [2]. In this sense, a dataset is "a coherent selection of data from the whole range of historical data available to the historian, and it is selected because it relates closely to the questions that the historian wishes to consider" [29]. Oberbichler and Pfanzelter [45] propose a method to create research-driven corpora thematically oriented, in the context of automatic information extraction. Although the approach is extremely suitable for the development of specific research, the resulting dataset does not include core questions of the domain.

The majority of literature considering domain-specific graph creation deals with methods of automatic information extraction and conversion rather than proposing a reflection on domain knowledge construction [1, 34, 39, 44].

Further experiences of RDF graph creation in the art history domain concerned the conversion of pre-existing databases in the desired format, therefore not affording a general reflection about data collection, modeling and graph creation as a unity (e.g., datasets for the Rijksmuseum [19],

[4] https://artlas.huma-num.fr/en/artlas-bases-de-donnees-en-acces-public/

the Zeri photographic archive [18], the KG for the Italian cultural heritage [14], the Golden Agents project [9]).

The modeling of LOD datasets implies the use of ontologies, namely formal representations of a specific domain of knowledge, in the form of concepts and relations. In the context of LOD creation, literature about ontology design and development proposes a structured definition of domain requirements and the formalization of CQs, under a narrow collaboration with domain experts. Among the existing approaches, the top-down one particularly leverages the characteristics proper of a domain, as it formalizes the core concepts of the suitable domain theoretical frameworks [13]. Furthermore, the most widely adopted development approaches include the test of ontology over real case studies, fostering adherence to the actual characteristics of the domain. Although the definitions of CQs and ontology requirements deeply rely on the domain expert's evaluation, the literature provides some studies on the use [42], classification, and recurrent patterns [74] of CQs in ontology engineering. In particular, Keet and Kahn [37, 38] provide a taxonomy of types of CQs based on the structure and function of CQs, discussing the types of questions that ontologies may or may not be able to answer.

To the best of the authors' knowledge, the literature scarcely provides guidelines and approaches for the development of a domain-specific research LOD dataset, which is intended to address the potential interests of multiple users from the same research community.

Digital humanities (DH) and iconography and iconology

Currently, several ontologies, vocabularies, and KGs describing art-related topics are available. Among them, CIDOC-CRM is the standard for describing cultural heritage (CH) objects [20, 21]. Since it doesn't address domain-specific modeling, it was extended by VIR ontology to include iconographical content, the act of interpretation, and additional information about it [11]. The authors have made the first attempt to extend VIR to include iconological interpretations [6]. Other related ontologies are HiCO,[5] allowing express interpretation acts with their context [17], and Simulation ontology [60], which concerns the description of symbols and their symbolic meanings. Besides ontologies, fundamental for expressing complex relations, controlled vocabularies are essential tools for information retrieval. Getty Vocabularies[6] (in particular AAT and IA) and ICONCLASS[7] provide identifiers for expressing iconographical subjects and terms for describing what is represented by an artwork. Recently, the potential for the Digital Art History sector of Beeldleer, another classification system provided by Henri van de Waal, has been brought to the attention of the community [68]. The Warburg Institute Iconographic Database is the online resource providing the most complete corpus of images related to the discipline [23]. Although it follows an iconographic index based on a classification provided by Wittkower, the categories designed by the historian to classify images often result in blurred groupings that are difficult to understand or replicate without knowing the underlying iconological studies on which they are based.

Among available KGs, artwork subject matter description is afforded by both domain-specific and generic datasets. The study by [8] provides an overview of the extent to which iconographical and iconological content is available in RDF datasets accessible through an online SPARQL endpoint, showing that this content is generally poorly represented and limited to a generic

[5] https://marilenadaquino.github.io/hico/

[6] https://www.getty.edu/research/tools/vocabularies/

[7] https://iconclass.org/

subject identification. Another domain KG, not included in the study, ArtGraph[8] [15], is in line with the survey results. Some further research worked on the creation of domain-specific KGs from free texts, including a wide variety of art historical texts (e.g., art books, exhibition catalogs) as in the case considered by Jain et. al. [34], or ancient historiographical books, as done in the Viewsari project, in which a KG has been created by extracting entities from Vasari's *Vite* text [46, 56]. It's also worth mentioning HyperReal [60], a KG expressing encyclopedic knowledge about symbols and their symbolical meaning in various contexts.

Approach

To assess the usefulness and capabilities of computational techniques in a humanistic domain, multiple approaches are possible. In this study, we focus on posing traditional qualitative questions in a quantitative fashion through queries to a dataset. In particular, we focus on the creation of LOD data, as it has been demonstrated to be particularly effective in formally describing the complexity that characterizes humanistic fields.

To quantify a research question, it is necessary to create structured data on which information retrieval can be performed. Therefore, this section focuses on the phases that interested the dataset modeling, creation, and analysis, specifically highlighting the role played by domain knowledge in each phase.

The major aim of the approach is to ground the creation of the Iconology dataset, chosen as a case study, and the related modeling in the domain of iconography and iconology, so that it reflects its main vocabulary, object of study, and research questions, aimed at creating a resource relevant to the community, and reusable and extendable by further scholars. Rather than proposing a completely novel methodology, it integrates practices of ontology and database design from the literature.

Phase	**Research question**	**Application in the Iconology Dataset creation**
1. Examining the domain and defining its main characteristics	*What types of information should a domain dataset have? How should they be related?*	Study of theory expressed in the field of iconology and iconography; identification of the main characteristics of the domain
2. Extract core domain questions	*What questions a domain dataset should be able to answer about the identified objects?*	Study of the core scholar's literature and extraction of typological questions they were answering
3. Create an ontological framework	*How can the knowledge collected in the previous phases be formalized in an ontological model?*	Ontology development on the basis of the results obtained in phase 1, following available methodologies (SAMOD, eXtreme Design)
4. Create a dataset	*On the basis of the previous phases, how can a domain LOD dataset be created?*	As no data previously existed, the dataset had to be manually created. The selection focused on the major works of the art historian Erwin Panofsky. Data were collected in a

[8] https://zenodo.org/record/6337958

		spreadsheet, and converted to an RDF graph through a Python script
5. Query the dataset	*How can the questions expressed in phase 2 be meaningfully quantitatively addressed over the created dataset?* *What new further questions can be performed over the dataset that could give new insights into the domain?*	Identification of sub-questions that could be expressed as SPARQL queries and performed over the dataset and the percentage of questions that could be successfully addressed was calculated. Set further meaningful questions to analyze the data (e.g., overview of art historian's method)

Table 2. Translate domain inquiry in a quantitative approach. Overview of the phases adopted in the development of the Iconology dataset

This methodology follows a structured process that begins with examining the domain of knowledge and advances through the extraction of questions the discipline seeks to answer from the literature, which guides the creation of an ontology and a dataset, on which an analysis is finally conducted. In total, it includes five phases.

To the aim of fostering its reuse by other projects, we provide an overview of the approach, followed by the illustration of the actual implementation of the dataset development, as resumed in Table 2. Translate domain inquiry in a quantitative approach. Overview of the phases adopted in the development of the Iconology dataset Figure 1 shows the workflow adopted during the development of the Iconology Dataset.

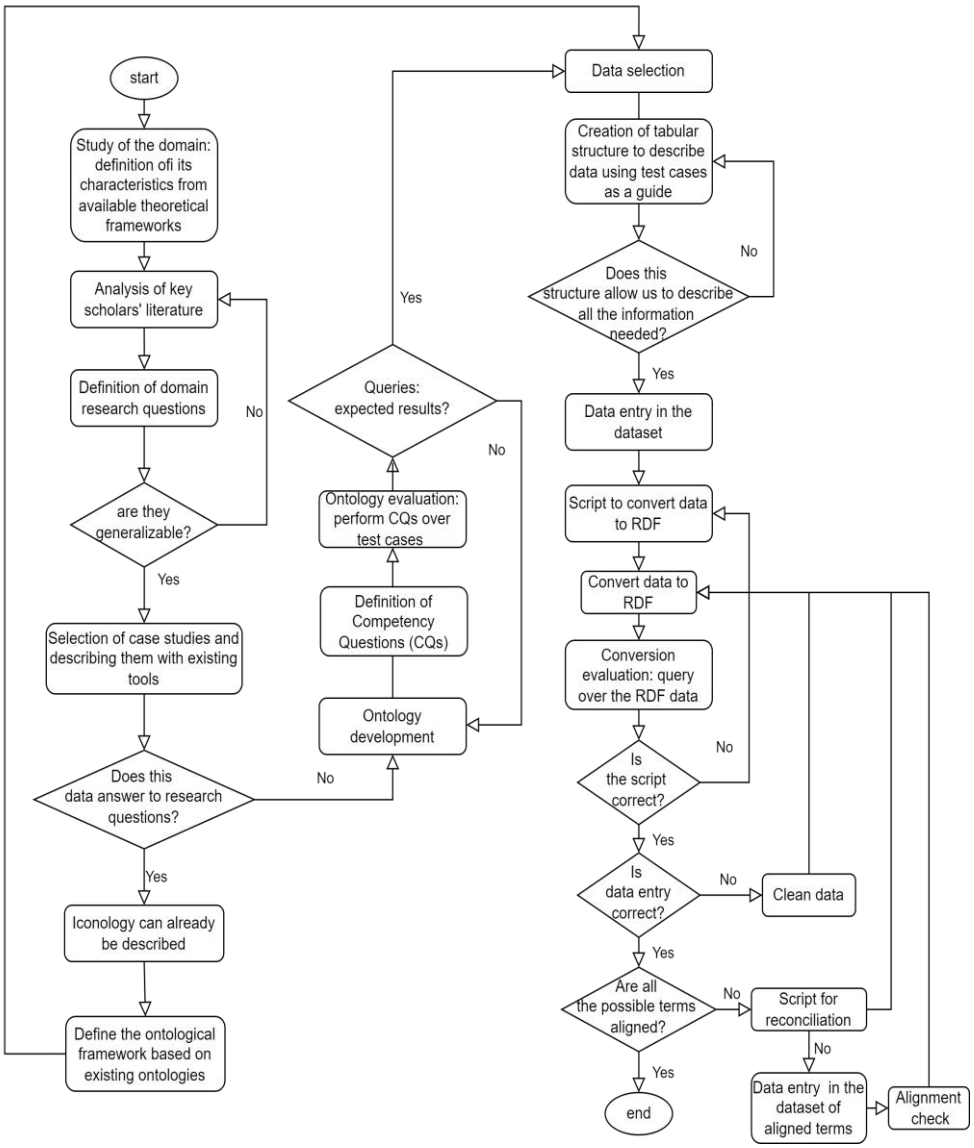

Figure 1. Workflow adopted during the creation of the Iconology Dataset

Phase 1: Examining the domain and defining its main characteristics

The first phase of the approach consists of analyzing the domain of knowledge to identify those theoretical frameworks defined by scholars that would be useful for guiding ontological development. It seeks to answer the research question: *What types of information should a domain dataset have? How should they be related?* Therefore, the relevant framework should elaborate on the nature of objects involved in the field and their nature. It corresponds to the top-down approach

discussed in ontology development methods [13]. The theoretical approaches considered should help the modeler in defining the types of entities involved in the domain and their definition. When more theories are available, a comparison and a possible alignment among them would be beneficial for identifying recurring concepts, addressing possible ambiguities and discrepancies, and guaranteeing that the theory considered can widely represent the domain. In case multiple, incompatible theories are present, selection criteria can be 1) a shared preference of the expert community for a theory, 2) the level of formalization present in the theory itself, which may foster its translation into a semantic model, and 3) the capability of the theory to describe the core characteristics of the domain, and address the research objectives.

Therefore, the objectives of this phase are:

- Verifying if one or multiple domain theories are useful to formally define the types of information that characterize the domain
- Identifying the key terms of the single or multiple theories and the respective definitions provided
- Providing, based on a single or multiple theories, a first modeling prototype

In the project, the comparison of theoretical frameworks of iconology and iconography was conducted among the major scholars proposing a definition of the interpretation act and the nature of the iconographical subjects [3, 6]. The work focused on comparing the theories of those scholars who provided a schematic representation of the discipline. Starting from the early study of Panofsky, who significantly divided the interpretation act into three levels of understanding, many of the following scholars provided their variation of the model. Therefore, the work compared the levels proposed by such historians, namely, Wittkower, Gombrich, Imdahl, Taylor, and van Straten, as described above. Although less formalized than the proposals of the historians just cited, other key studies were considered, such as the description of the evidence-based method by Ginzburg [31] and the foundational writings of Warburg [71].

The final choice lay in selecting the framework proposed by Panofsky as a reference for modeling, enriched with relevant insights provided by other scholars, although the latter are described using the above framework. As it resulted in being central for the theorization of the domain and being adopted by the cultural cataloging standards (CDWA,[9] CCO[10]), an ontology following the same tripartite structure would allow an easier conversion of natural language catalog descriptions into data.

Following, Panofsky's text was examined to identify the key concepts and relative terms used and the respective definitions. The rigorousness of his definitions favored the translation of its framework in a computational model and the identification of key terms. A first conceptual draft was drawn out of them, enriched with important additions from other scholars, for each level of interpretation (e.g., the relevance of the iconic language of images underlined by Imdahl [33]).

Phase 2: extract core domain questions

The second phase concerned the study of the domain to understand its interests, namely, the core questions that the branch of study pursues. It seeks to answer the research question: *what questions a domain dataset should be able to answer about the identified objects?*

[9] https://www.getty.edu/publications/categories-description-works-art/

[10] https://www.vraweb.org/cco

The essential interests of a discipline are usually provided in the encyclopedic definitions of the domain and by the experience of domain experts. Nevertheless, the actual scholars' research can provide more detailed examples and applications of the interests defined in the previous sources. For this reason, a selection of the core literature can be examined to understand which typological questions the scholars sought to answer. We suggest that the criteria for the selection of such literature occur according to sampling or relevance criteria and that the inquiry follows a typological perspective (e.g., what types of objects do the research question consider?).

In the case of iconography and iconology, a selection of the core literature of the domain, including studies by the main scholars Panofsky, Warburg, Gombrich, and Wittkower, was made. In total, circa 50 articles from the core scholars' writings were examined [6]. As a result, we obtained 12 questions, which were further thematically grouped according to the type of object treated [7]. Research questions have been designed by a team belonging to diverse disciplines, including Digital Humanists with a strong background in Art History. Table 2 provides an overview of the questions.

Phase 3: create an ontological framework

The thorough definition of the characteristics and interests of the domain specified in the previous phases plays a key role in the transfer of domain knowledge to the model adopted (phase 3). Before the ontology development begins, it is useful to test, through the description of case studies, if the available ontologies can describe the identified domain requirements (see Figure 1). In case the answer is positive, the ontologies can be integrated into a descriptive framework that is adopted for the data creation, without creating a new ontology.

It is relevant to remember that, although valuable, the theoretical frameworks expressed in the domain were not intended to be implemented as a computational framework. Consequently, it may be necessary to select or change some parts of the theory to adapt it to practical requirements. Similarly, core theories may not be suitable for providing a computable representation of a domain, as they may lack characteristics of formalization.

In case the available tools are not sufficient, the knowledge previously gathered can be integrated into the ontological modeling approaches proposed in the literature [13]. The majorly used ones in the DH domain (e.g., SAMOD [51], eXtreme design [52], Neon [63]) adopt a modular, iterative approach in which a model is proposed for every iteration, tested through CQs, and real-world test cases. The outcomes of phase 1 should be used to create the proposed model of every iteration, and the CQs to develop and test the ontology should be expressed considering how the identified objects modeled can address the domain interests identified in phase 2.

In our case study, the outcomes of phases 1 and 2 were fundamental for the OWL 2 DL ontology development phase. The requirements were defined with the help of the Ontology Requirements Specification Document [64]. Having adopted the agile methodologies of SAMOD [51] and eXtreme design [52], the designed scheme drafts were combined with the identified terminological definitions to create a model for each level of interpretation, plus a further iteration for the overall definition of the structure of a recognition. Questions developed in phase 2 guided the definition of the CQs that the ontology should be able to address, expressed according to the objects defined by the model. The CQs were divided per level of interpretation and performed over a portion of the dataset as part of the evaluation. Further evaluation of the ontology included a check of its formal requirements through the FOOPS tool [30].

The resulting domain ontology,[11] which top-classes are illustrated in Figure 2, expresses the artistic interpretations as a collection of subject recognitions, for which provenance can be provided (e.g., the author of the recognition, the text in which they are expressed) along with further details (e.g., support among recognitions, citation of evidence, connection with the interpreted artwork). The ontology is aligned with the DOLCE+ DnS Ultralite foundational ontology, in which the Description and Situation pattern describe the context used to provide a view on an observed Situation.[12] The class `:Recognition`, subclass of `dul:Situation`, represents the observation made by an interpreter of the subjects depicted in the artwork. Each `:Recognition` identifies a subject as manifested in the artwork, namely, a `:VisualSubject` (e.g., the specific Cupid depicted in that particular artwork), which is in turn related to a subject as described by common vocabularies (e.g., the ICONCLASS term for Cupid). The Recognitions comply with an `:InterpretationDescription`, subclass of `dul:Despription`, which represents the outcome of the interpretation according to the adopted iconographical-iconological observational approach. The `:InterpretationDescription` class collects all the `:Recognitions` that are performed in the same interpretation act. This structure allows a granular description of the appearance and meanings of subjects as depicted in a specific artwork. Each level of interpretation is further specialized through sub-classes of Recognition named after Panofsky's theory, namely, `:PreiconographicalRecognition` (level 1), `:IconographicalRecognition` (level 2), and `:IconologicalRecognition` (level 3), which recognize subjects at each level (`:ArtisticMotif`, `:Composition`, `:Image`, and `:IntrinsicMeaning`) that can be further enriched with level-specific details. For example, at the first level of interpretation it is possible to express qualities of recognized subjects (e.g., colors, poses), the structure of a group of subjects (e.g., the fact that three people are depicted in a pyramidal arrangement), and visual patterns citations between different artworks (i.e., the fact that the compositional structure of an artwork derives from another artwork). Whereas such information pertains to the Visual Subject and its subclasses, further classes represent the generic terms to identify the same subject across multiple artworks, namely :`Preiconographical`, :`Iconographical`, and :`Iconological Subjects`.

[11] A domain ontology is a formalization of a specific domain of knowledge, such as, in this case, the branch of study of iconography and iconology. On the contrary, upper or foundational ontologies formalize general relations between concepts that can be applied in multiple domains (e.g., the ontology DOLCE).
The ICON ontology was presented in Sartini et. al. [59]. We refer to this paper for a full description of it, along with the ontology documentation, available at https://w3id.org/icon/docs/

[12] "A Description represents a conceptualization, and it can be read as a descriptive context "that uses or defines concepts in order to create a view on a 'relational context' (cf. Situation) out of a set of data or observations. For example, [...] a Diagnosis is a Description that provides an interpretation for a set of observed entities"
http://www.ontologydesignpatterns.org/ont/dul/DUL.owl

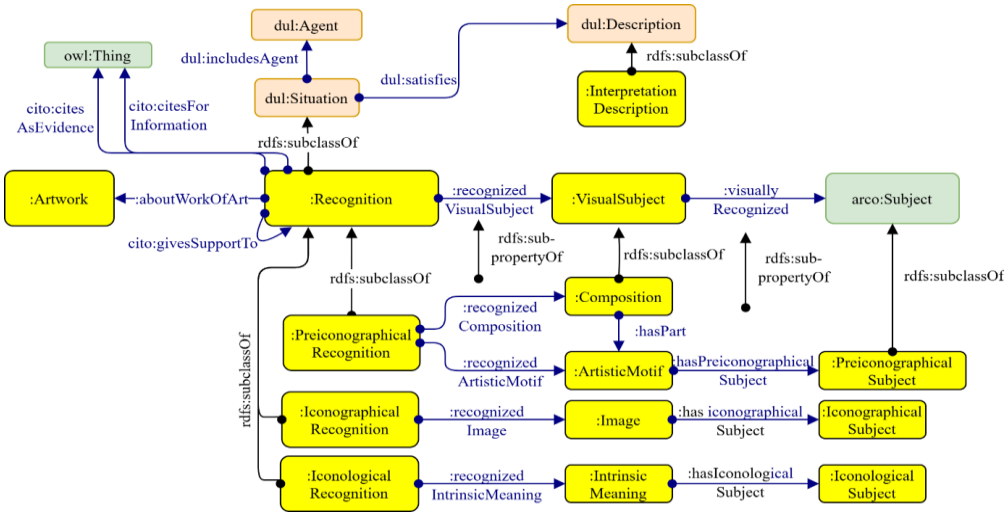

Figure 2. Overview of the main classes of the ICON ontology

Prefix	URL
:	https://w3id.org/icon/ontology/
dul:	http://www.ontologydesignpatterns.org/ont/dul/DUL.owl#
owl:	http://www.w3.org/2002/07/owl#

Table 3. List of prefixes

Phase 4: Create a dataset

To effectively tackle research questions specific to a particular domain, it is essential to create a KG tailored to that domain. According to the needs, data can be collected in different types of datasets (e.g., a spreadsheet, a relational, or a graph database) and later converted into a graph format. When applicable, data collection should follow the rules of database creation and sampling to create a representative dataset. It should also be considered whether the dataset can be automatically or manually created, and if data currently exists, as it may affect the database design decisions and creation workflow. Appropriate ontologies and controlled vocabularies should be adopted for the description of every relevant type of information.

Since, to the best of the author's knowledge, structured data about iconological interpretations are currently not available, and the complexity of an iconological text does not allow automatic extraction of the content through automatic techniques, data had to be manually created.

The Iconology Dataset was created by collecting data in a spreadsheet and converted into an RDF graph in a second moment. The choice was motivated by the fact that 1) the spreadsheet offers an in-the-process customizable scheme, that could be adapted and extended in the case of updates to the ontology or the need to annotate new features, and 2) it was possible to customize the creation of classes and specific IDs in the Python script, without manually editing in the spreadsheet the reification classes needed by the ontology structure (e.g., the class Recognition identifying the interpretation itself).

The Iconology Dataset focuses on Erwin Panofsky's key works, chosen for their significance in the field and suitability for conducting further analyses on his method, as his theory was ontologically modeled. His major books concerning the revival of antiquity were selected according to the eminence criterion [62], obtaining a total of three books and an article. Therefore, the dataset offers insights into the work of the art historian and the theme of antiquity in his work. Instead of representing the entire iconographical-iconological discipline, it is a proof-of-concept of the method for the field through the major work of a key art historian.

The dataset creation was structured in phases, namely: database design, database population, cleansing, conversion into RDF, alignment, and evaluation [3]. The database design reflected the ontological structure, therefore including the subject subdivision into levels, relations between levels and (textual) sources, and provenance information. Metadata about the artworks and books were included, too. The insertion of terms was checked with the aid of controlled lists of terms, and the table structure and further conversion were tested through a set of 11 examples.

The database population consisted of the manual identification and structuring of the information present in the source texts, selecting only the information considered relevant for the artwork interpretation. Beyond ICON and the ontologies it reuses, CIDOC-CRM was used for describing item metadata. When possible, the terms were aligned to vocabularies (Getty vocabularies, ICONCLASS, VIAF[13]) and knowledge bases (e.g., Wikidata [70]). The resulting RDF dataset was evaluated according to the applicable measures defined by Färber [26].

Phase 5: Query the dataset

In this phase, the quantitative analysis of traditional questions is afforded. Therefore, the research question is: *how can the questions expressed in phase 2 be meaningfully quantitatively addressed over the created dataset?* In this study, we refer to "quantitative analysis" as the queries that can be performed over structured data. Most likely, the objects that can be queried consist of the type of data stored in the dataset. Therefore, the quantitative expression of the domain questions is dependent on the modeling adopted in the specific dataset used.

To this aim, the 12 questions identified in phase 2 were further specialized in sub-questions, in which the information to be sought was expressed as a categorical variable and such variables could be quantified through frequencies and correlations, corresponding to the constraint-seeking question type [37, 38].

As a result, we obtained 20 sub-questions, performed over the dataset as SPARQL queries (see Table 2). The possibility of quantitatively performing traditional domain questions was evaluated as the percentage of questions that could be answered through such queries.

An interactive dashboard was created to visualize the SPARQL queries performed and the results[14] and host further queries that can be raised. Additional features (e.g., an image search

[13] https://viaf.org/

[14] https://iconology-dataset.streamlit.app/

per subject) and the presence of a SPARQL interface[15] give the possibility to users and art historians to perform custom data explorations.

Theme	**Questions from literature (phase 2)**	**sub-questions (phase 5)**
Cultural Phenomena	Q1.Which cultural phenomena are witnessed by artworks? [71]	SQ1. How many artworks have a cultural phenomenon associated?
	Q2. Which sources and visual aspects motivate their presence? [12, 71]	SQ2. What is the frequency of level 1 and 2 subjects occurring with each cultural phenomenon?
		SQ3. What is the frequency with which a cultural phenomenon recognition is supported by a piece of evidence? Of which type is it? (texts, artworks, etc.)
		SQ4. Is there any co-occurrence between cultural phenomena and other types of subjects?
		SQ5a. What recognitions support the recognition of a cultural phenomenon? SQ5b. What types of subjects are explicitly related to an intrinsic meaning?
	Q3. How does the representational evolution of subjects witness the emergence of cultural changes? [50]	SQ6. What are the artworks having both a cultural phenomenon in common and a different style associated?
Symbols	Q4. How does the usage of symbols evolve? (47, 75]	SQ7. Which and how many symbols express the same concept?
		SQ8. What different symbolical meanings can the same symbol have?
		SQ9. How do symbols evolve over time and in different contexts?
	Q5. Is the symbolic meaning motivated by a specific source? [16]	SQ10. What are all the symbols motivated by a specific source? Do they vary from the corresponding subjects not citing a piece of evidence?
	Q6. Is the deeper conceptual meaning motivated by sources? [32]	SQ11. Do deeper meanings cite as support textual sources?

[15] https://projects.dharc.unibo.it/icondataset/sparql

Iconographies	Q7. How do iconographies, their meaning and attributes evolve over time? [47]	SQ12. Which are the representational variations of iconography? I.e. what are the sets of level 1 subjects composing the recognized level 2 subject in artworks?
		SQ13. What are the attributes having a symbolic meaning?
		SQ14. How does the representation of iconography vary over time? Of which level 1 subjects is it composed?
	Q8. What are the attributes allowing us to recognize a subject?[47, 69]	SQ15. What attributes allow us to identify representations? What is their frequency?
		SQ16. Which are the most common and rare attributes among the ones marked as recognizing?
	Q9. How does the representation of iconography vary? [49]	SQ17. What are the most common level 1 subjects not marked as recognising?
Evidence	Q10. What were the known textual sources to which the artwork refers, and what does this knowledge tell us about the thinking of the time? [71]	SQ18. What were the known textual sources to which the artwork refers? Is the artwork involved in a cultural phenomenon?
Visual citation	Q11. How do visual shapes migrate and re-appear across cultures? [72, 75]	SQ19. What artworks cite the visual pattern of others?
	Q12. Is a visual citation the evidence that documents a cultural phenomenon? [71]	SQ20. In which cases are those artworks involved in a visual citation also associated with a cultural phenomenon?

Table 4. Research questions

Besides the possibility of performing traditional questions, it is important to explore which new insights can the availability of structured data give, that couldn't be explored with qualitative research. To this aim, queries aiming at providing an overview of the data were conducted. Further queries were formulated to computationally explore characteristics of Panofsky's method:

- *Does data show an extensive use of textual sources?*
- *Does Panofsky consistently use the three levels of interpretation in his own studies?*
- *Can data modeled according to his theory fully represent the complexity characterizing an iconological interpretation?*
- *Does the recognition of a deeper phenomenon need a thorough description at the previous levels?*
- *Are the artworks discussed in different books treated with the same level of detail?*

Case study: third level of interpretation

As a way of example, we provide a more detailed description of the phases illustrated above as applied to the third level of interpretation, chosen as the detection of deeper meanings is a central aspect of iconological studies. Although presented separately, the example is narrowly linked to the overall development process.

Phase 1

From the comparison of the major theories identifying levels of interpretation conducted in the first phase, it emerged that only Panofsky and van Straten explicitly talk about the (involuntary) presence of contemporary socio-cultural phenomena in the depicted artworks. Gombrich considers it, although he does not explicitly define deeper levels, and Wittkower expressed it as the manifestation of the personality of the artist.

As the selection focused on the theory by Erwin Panofsky, we manually identified the definitions of the terms relevant to the level and their relations (Figure 3), enriched with pertinent insights from other scholars. In the theory previously discussed in the second section, Panofsky defines the third level of interpretation as the layer in which the *intrinsic meaning or content* is discovered, which is recognized when *motifs* and *images* (recognized at the previous levels) are identified as manifestations of underlying principles governing cultural tendencies. The motifs and images understood are defined as *symbolic values*. Contrarily to the previous levels, the author provided symbolic values and intrinsic meaning with a similar definition. As the former term may be confused with theories of symbols intended more narrowly, we adopted the term *intrinsic meaning* to refer to the cultural symptoms as manifested in the visual work, in line with another definition given by Panofsky, which includes the visual aspect in the identified subject (see Table 1). Furthermore, to complete Panofsky's perspective, we include in the model van Straten's view, who also encloses deeper, voluntary messages (e.g., moral messages) embedded by the artist. Aligning with Wittkower, we extended the definition of cultural symptoms to include also the personality of the artist. Figure 3 shows a first draft of the related items just discussed, which will serve as a basis for the ontological development performed in phase 3.

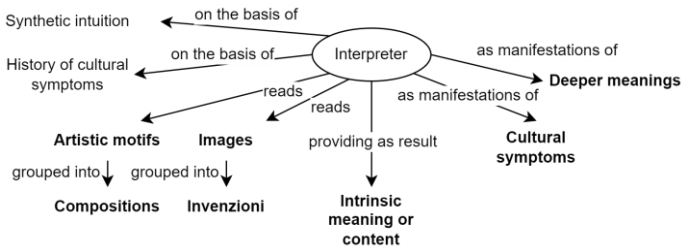

Figure 3. Representation of the main items described by Panofsky as involved in the third level of interpretation, integrated with the perspectives of other scholars. This phase precedes the ontology development

Phase 2

The three questions concerning cultural phenomena defined in phase 2, listed in Table 3, were identified in two studies, namely Warburg's *The Art of Portraiture and the Florentine Bourgeoisie* [71] and Saxl and Panofsky's essay *Classical Mythology in Medieval Art* [50].

The question *which cultural phenomena are witnessed by artworks?* (Q1) is the core of each iconological inquiry. An example from it is provided by Warburg [71], who inquired how the contemporary background influences visual arts in the Renaissance Florentine context by examining the shift in the position occupied by patrons' portraits in the representation of religious scenes. Contrarily to medieval representations, the depicted patrons started sharing the illusionistic sacred space dedicated to the saints. This phenomenon occurs in the painting depicting the *Confirmation of the rule of Saint Francis* in Sassetti Chapel in Santa Trinita. Although it may appear as a profanation of the sacred scene, the pictorial change reveals a votary intention if it is related to the documented practice of the Medici family, who used to place real-size portraits of family members in the churches for votary purposes.

The same example is useful for the definition of the second typological question, namely, *which sources and visual aspects motivate their presence*? (Q2). In his study, Warburg based the interpretation on several sources. In addition to the painting's visual evidence, the study of the letters and documentary sources allowed 1) the reconstruction of the relations of Sassetti with the Medici family, and 2) understanding the role of Lorenzo's real-size portraits located in churches for votive purposes. From this example, it emerges that both visual and textual pieces of evidence were fundamental sources used by the scholar for reconstructing the sociocultural context in which the artwork was realized.

The third, fundamental question reflects the inquiries of scholars who seek traces of a sociocultural cause in changes in representing subjects over time and space: *how does the representational evolution of subjects witness the emergence of cultural changes?* Several studies addressing the topic of reception of classics are based on the assumption that how themes are transmitted and reinterpreted expresses the cultures that assimilate them. Panofsky and Saxl [50] reconstruct the survival of classical themes and their classical visual appearance in the Middle Ages. They observed that classical subjects were depicted in a non-classical manner. According to them, one of the reasons for the phenomenon lies in the fact that the Gothic style, being already in its mature phase, was closer to the sensibility of contemporaries than the classical one.

Phase 3

The ontology development conducted in the third phase corresponds to the fourth and final SAMOD iteration of the overall ontology development. In this phase, the main items of Panofsky's theory concerning the third level of interpretation, previously identified in Phase 1 (see Figure 3), were translated into a model. In Particular, an `:IconologicalRecognition`, a subclass of the class `:Recognition` previously discussed (see Figure 2), represents the act of recognition of a third-level subject made by an observer. The examined artwork identifies the `:IntrinsicMeaning`, intended as the underlying (socio-cultural) principles as described by Panofsky, manifested through the visual features of the artwork. The `:IntrinsicMeaning` is then related to specific parts of the artwork (`:Composition`, `:Image`, `:ArtisticMotif`) which may specifically reveal the underlying meaning. The `:IntrinsicMeaning` is related to the actual `:CulturalPhenomenon` that it documents, or to the deeper meaning voluntarily expressed by the artist, represented here by the class `dul:SocialObject`. All the Iconological Recognitions are collected in an `:InterpretationDescription`, which represents the

overall interpretation, through the level-specific property `:iconologicallyCompliesWith`.

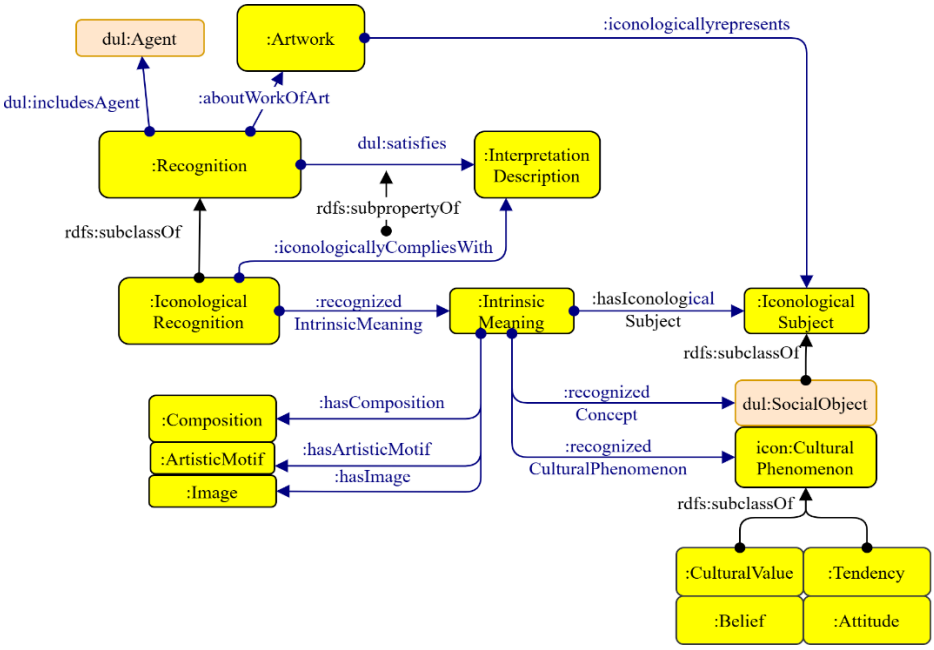

Figure 4. Formalization of the third level of interpretation as represented in the ICON ontology

The CQs formulated during the development aimed to verify if the ontology structure represents the domain as expected and if it can address its interests. Therefore, the defined CQs respond to the ontology requirements and the domain questions identified in phase 2:

CQ 3.1 What meanings are expressed by the artworks?

CQ 3.2 What cultural phenomena are identified?

CQ 3.3 Who identified the cultural phenomena and on which basis?

CQ 3.4 What are the artworks involved in the same cultural phenomenon?

CQ 3.5 To which specific subjects at level 1 and 2 does the level 3 recognition refer?

CQ 3.6 What are the artworks having both a common cultural phenomenon and a common level 2 subject?

In particular, CQs 3.1 and 3.2 verify if the ontology correctly describes the identified third-level subjects, namely cultural phenomena and deeper meanings, reflecting Q1. CQ3.5 verifies whether features of the same artwork are narrowly connected to the understanding of the phenomenon. The formulation of the question is related to Q2 (e.g., in the case of the fresco in the Sassetti chapel, the phenomenon is narrowly connected to the donors, and in particular to their location). CQs 3.3 and 3.6 ensure that a further study of the characteristics of the relation of cultural phenomena and other features can be correctly conducted, as the examples examined

in the literature show that 1) multiple artworks can share the same phenomenon, and 2) the phenomenon is reconstructed through seeing similarities in the characteristics of the artworks.

CQ3.3 corresponds to a functional evaluation, as it verifies whether the ontological requirement of the provenance of the recognition is respected in the third level.

From the modeling, it is possible to see that not all the terms considered relevant in phase 1 were modeled and that further classes were added. Some terms would have required modeling beyond the scope (e.g., the definition of "history of cultural symptoms"). Other terms and definitions were functional to the ontological structure adopted (e.g., the differentiation between recognitions and interpretations).

Phase 4

The database framework for storing third-level recognitions was modeled narrowly to the ontological model. One table was dedicated to the third level, to collect information including: 1) the usual provenance information about the assertion (author, source, evidence), and 2) the necessary identifiers for the artwork and the recognition, and the type of subjects recognized, namely, concepts and cultural phenomena. The phenomena were described in detail. If a broader phenomenon was related to the specific one identified, both the broader and the narrower phenomena were assigned to the artwork. For example, the ivory cover plate of the Pericopes of Henry II, preserved at the Bayerische Staatsbibliothek of Münich,[16] was assigned the specific phenomenon "classical personifications represented with their classical iconography during Carolingian renovatio", but also the more general one "classical subject matter represented in classical form" to allow the retrieval of artworks with shared phenomena. Furthermore, as the high specificity and variety of phenomena prevented further analysis, they were grouped into 20 types of phenomena, based on the instances present in the graph.

Phase 5

For the topic of cultural phenomena, six sub-questions were identified and performed in corresponding analyses (see Table 4). SQ1 assessed the possibility of retrieving all the artworks presenting a cultural phenomenon. Second, the interest of Question 2, which seeks to quantitatively express the aspects that suggest the presence of a deeper meaning, was expressed by retrieving 1) correlations of phenomena with other visual aspects, such as the frequency of subject (SQ2) and co-occurrence (SQ4) of the type of subjects depicted, and 2) the support given by other interpretations (SQ5) or the presence of cited pieces of evidence (SQ3). Assuming that artworks with different styles belong to different cultures, we examined whether artworks sharing common phenomena belong to different styles (SQ6)[17] to address Question 3, which concerned the deep understanding of socio-cultural shifts that brought to subjects' evolution.

As a way of example, we provide the SPARQL query expressing SQ6:

```
PREFIX: <https://w3id.org/icon/ontology/>
PREFIX crm: <http://www.cidoc-crm.org/cidoc-crm/>
```

[16] Available at https://www.digitale-sammlungen.de/view/bsb00087481?page=%2C1

[17] Queries, resulting dataframes and their visualizations about cultural phenomena are available at this link: https://iconology-dataset.streamlit.app/Analysis_of_cultural_phenomena

```
SELECT DISTINCT ?phenomenon ?cfLabel ?style
(group_concat(distinct ?styleL;separator=", ") as ?styleLabel)
?artwork  WHERE {
         #Getty term to identify style
        ?style                                  crm:P2_has_type
<http://vocab.getty.edu/aat/300015646>.
         # artworks having both a style and a phenomenon
        ?artwork a :Artwork;
            crm:P2_has_type ?style;
           :iconologicallyRepresents ?phenomenon.
        ?style rdfs:label ?styleL.
        ?phenomenon a :CulturalPhenomenon.
            ?phenomenon rdfs:label ?cfLabel.
    } GROUP BY ?phenomenon ?cfLabel ?style ?artwork
```

The results of the questions are shown in Table 5. From the analysis emerged that the majority of artworks (76%) present a cultural phenomenon (SQ1). Among them, the most represented subject at level 1 is the male figure (SQ2), a result that is reflected at the second level of interpretation, as the majorly represented iconographies per phenomenon type are classical (male) deities. Data seem to suggest that no further correlation emerges between depicted subjects and cultural phenomena types (SQ4). The analyses focusing on evidence and support reported relevant results. Surprisingly, a small number of phenomena recognitions cite as evidence a textual source (SQ3), suggesting that such interpretations are not generally directly motivated by a text. Furthermore, the analysis of the recognitions supporting a third-level one (SQ5a) highlights that, among the other levels, only the recognition of a visual citation (i.e., formal motif recognitions) directly supports the phenomenon understanding. Therefore, no further hints on which other subjects are considered fundamental for the phenomenon of recognition are provided. On the contrary, it seems that other phenomena's recognitions support recognitions of the same type, suggesting a narrow relation among recognized phenomena. SQ6 examined the style in relation to cultural phenomena. Although limited to 18% of the artworks, it showed relevant results. In the network (see Figure 5), clusters of artworks having similar styles, related to the medieval period, and common phenomena emerge, showing the possible coexistence of similar phenomena in related cultural contexts. On the contrary, some clusters included artworks from distant styles (e.g., CF1088, *evolution of the iconography of Saturn*), reflecting diachronic inquiries that trace the evolution of the same subject over time and space.

Query	**Results**	**Description**
SQ1	327 out of 428 described artworks are associated with a cultural phenomenon (76%)	

SQ2	Most frequent level 1 subject per cultural phenomenon type: *man* (highest frequency in 18/20 phenomenon types), followed by *wings* and *woman* Most frequent second-level subject per cultural phenomenon type: classical deities	Extraction of the top-5 subject frequency per cultural phenomenon type, both of the first and second-level subjects
SQ3	14% of Iconological Recognitions identifying a cultural phenomenon cite a piece of evidence. Out of them, 84% cite an artwork, and 11% cite a text	
SQ4	Set of types with higher support:[18] "Natural Element, Reception of Classical Antiquity" (0.54); high support (0.90) between Character, Iconographical evolution, Personification, Reception of classical antiquity, Action (antecedents), and Natural Element (consequent)	Association rules calculated through the Mlxtend Python library[19] over the types of subjects and types of cultural phenomena present in the same artwork
SQ5a	Visual Motif Recognitions and Iconological Recognitions support a phenomenon identification, with, respectively, 57 and 46 recognitions.	
SQ5b	Only 16% of phenomenon recognitions refer to a specific subject. Among them, 45.7% refer to an Artistic Motif, 29.5% to an Image, and 24.8% to a composition	
SQ6	Only 18% of the described artworks have a specific style. By looking at their relations in a network, it emerges that the most interconnected cluster concerns the Medieval styles (Figure 5). Gothic and Byzantine are the nodes with the highest number of edges (37 and 13). Among phenomena, the nodes with the highest degree show relations with contemporary or narrowly related medieval styles (CF1240, CF1242, CF1238) or with styles of different periods (CF1088)	

Table 5. Results of the SQs concerning cultural phenomena

[18] Support identifies the frequency with which a set of items appears together in the data. Confidence indicates in which measure it is likely that an item of the same set (consequent) is present if another element is present (antecedent).

[19] https://rasbt.github.io/mlxtend/

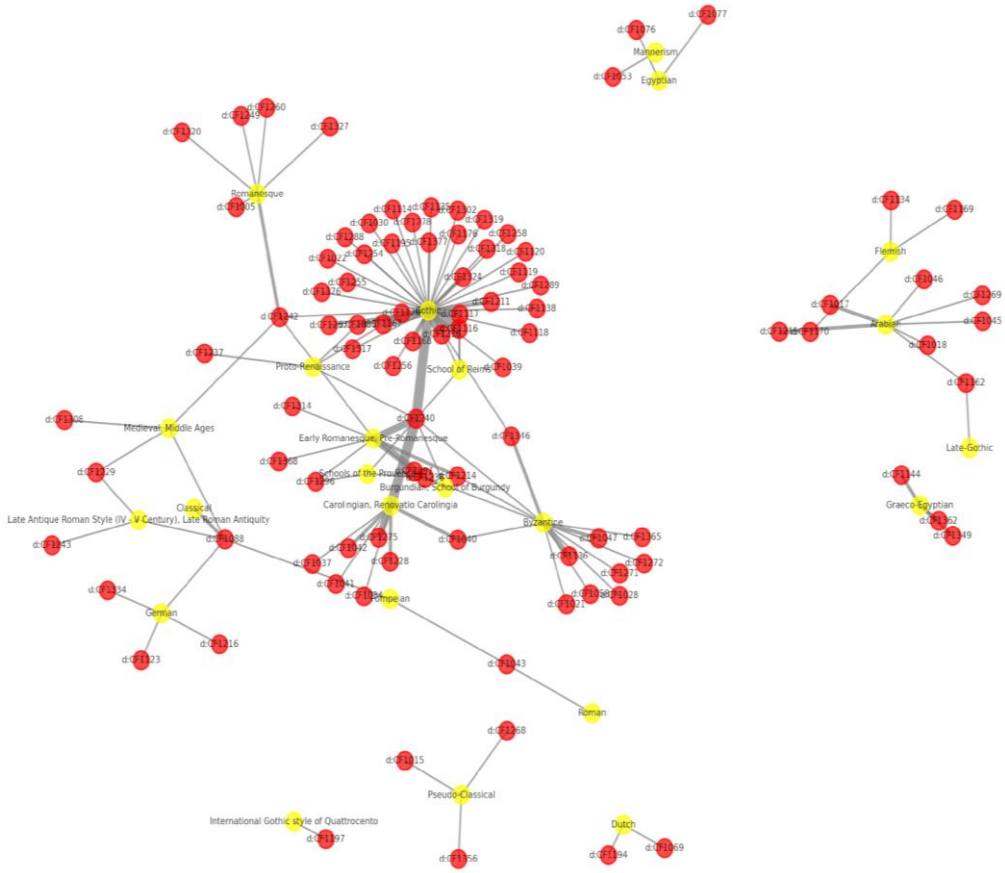

Figure 5. Network of the artwork presenting both a style (yellow) and a cultural phenomenon (red), visualizing the results of SQ6. The thickness of the edges shows the number of artworks presenting the association

Results overview

The proposed approach to embed domain-specific interests and characteristics in the *datification* of a domain resulted in valuable outcomes in its application to the domain of iconography and iconology.

The first phase allowed an extensive comparison of the major available theoretical frameworks, which led to the choice of the one proposed by Erwin Panofsky, who provided the most extensive and coherent attempt. On its basis, the characteristics and main items of the domain were identified, namely, the process of recognition, the three levels of interpretation, and the subjects identified at each level. A comparison with further historians led to the integration of important features, such as the description of a visual arrangement. The second phase allowed the identification of meaningful, typological research questions from the literature, which served as guidelines for 1) the creation of CQs needed in the ontology creation phase, and 2) the

questions to perform the quantitative analysis. The ontology development itself was deeply reliant on the domain study, reflecting the modeling framework adopted and the questions. As a result, the ICON ontology allows a granular description of artistic interpretations at three levels of understanding, furnishing means to document provenance and source documents for each subject recognition. The three-layered structure identifies subjects at each level and connections among them. Such a structure is reflected in the Iconological Dataset, containing interpretations about ca. 400 artworks (see Figure 5), mostly from the Middle Ages and Renaissance Western art, mainly interpreted by Panofsky. The subject types recorded include natural elements, actions, and emotions (level 1), characters, events, places, objects with a specific identity (e.g., the Bible), personifications, symbols, stories, allegories (level 2), concepts, and cultural phenomena (level 3). For each subject identification, a provenance of the assertion can be provided, indicating the author, source, and cited evidence, to allow the coexistence of multiple (diverging) interpretations.

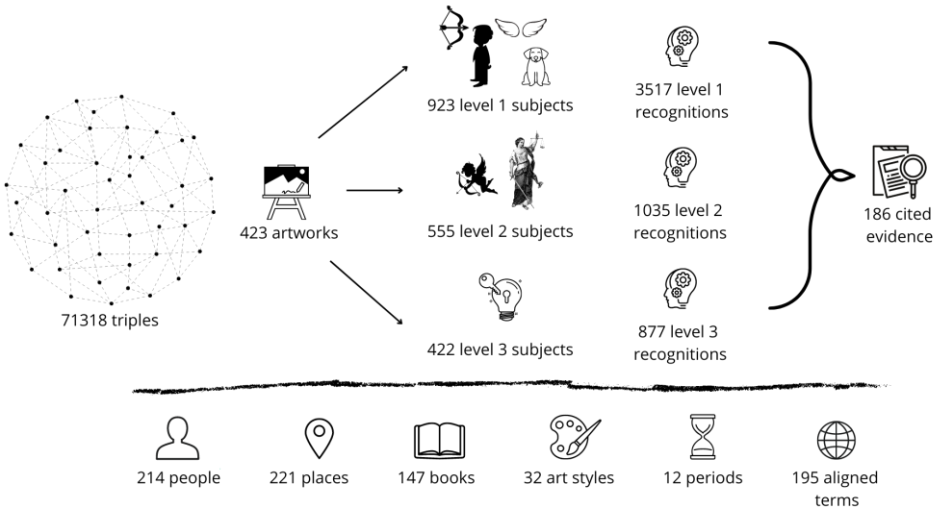

Figure 6. Overview of the Iconology Dataset: main types of entities

The data analysis shows that the art historian focuses on the classical themes, as half of the artworks are involved in the cultural phenomenon "reception of classical antiquity", and the most frequent level 2 subjects are related to Classical mythology. While it was possible to address quantitatively all the RQs, some of them (15%) were only partially addressed due to the lack of data, as the dataset reflects only the selection of artworks performed by the art historian, rather than the representative works of the considered period (see Table 4).

Theme	**Fully addressed**		**Partially addressed**	
	Questions	Percentage	Questions	Percentage
Cultural Phenomena	SQ1, SQ2, SQ3, SQ5, SQ6	83, 34%	SQ4	16,67%
Symbols	SQ7, SQ8, SQ10, SQ11	80%	SQ9	20%

Iconographies	SQ12, SQ13, SQ15, SQ16, SQ17	83, 33%	SQ14	16,67%
Evidence	SQ18, SQ20	100%		0
Visual citations	SQ19, SQ20	100%		0
Total		**85%**		**15%**

Table 5. Overview of addressed queries

The set of questions concerning the methods of the historian led to interesting insights. The scholar seems not to describe all the artworks according to the levels of interpretation, as only 53% of them present a description at all the levels, and only 28% of the interpretations cite a source as evidence. Furthermore, the style and narrative pace adopted by the scholar in the books affect both the number of artworks described and the level of description detail.

Discussion

This paper presented an example of a five-step methodology that can be applied to newly quantitatively examine a humanistic domain, based on the experience of the Iconology Dataset creation in the art historical domain of iconography and iconology. It highlights how domain knowledge can be embedded in every phase of data creation. Following the approach, the project reached consistent results, namely 1) a domain-specific ontology, 2) an authoritative LOD dataset of Panofsky's scholarly interpretations, and 3) iconographical, iconological, and historiographical insights over the created data.

During the project, some limits and challenges were faced. Although deeply grounded in the theoretical framework of the domain, the approach reflects the assumptions of the perspective chosen, in this case, Panofsky's theory. Furthermore, the lack of availability of structured data led to the manual creation of the dataset, which was consequently prone to the subjectivity and interpretation capabilities of the compiler. The time-consuming manual creation also prevented the creation of an extensive dataset representative of multiple art historians, obtaining a dataset focusing on the major works of a single historian, mainly dealing with the topic of the reception of classical antiquity. Whereas the approach sought to cover the core domain questions, a topic-specific analysis can necessitate further, ad-hoc categories. Furthermore, as it is based on the actual interpretations by an art historian, rather than being a discovery of new knowledge through the analysis of primary sources, the dataset created in the project offers insights into the knowledge already detected by the chosen scholar. In this sense, it can be seen as a historiographical analytical tool and a domain-specific information retrieval system for scholarly literature.

Besides these limits, the current paper newly introduces an approach aimed at ensuring the transfer of domain expertise in all the phases of domain-specific LOD dataset creation, from the ontological modeling to the analysis, giving breath to the research questions of the scholars expressed in the domain literature, so far not included in the database and ontology development methodologies. To the best of the authors' knowledge, in the current state of the art, no other studies discuss a similar topic. The definition of the approach into phases, thoroughly illustrated through the application of the approach to a documented and openly published project, can foster its reuse by the community.

Conclusion and future works

The current paper illustrates a novel approach to include valuable insights from a domain in its translation in quantitative form, to explore how computer science can aid in the analysis and information retrieval of domain data. The approach, applied in a Digital Art History project, is further structured into 5 phases. The state-of-the-art methods are combined and integrated with the extraction of research questions from the domain literature, which were not included in previous domain and ontology design approaches. A generic description of each phase is provided, followed by insights on the actual implementation of the project and a more extensive description of the third level of interpretation, presented as a case study. Such description, combined with the rich descriptions of the ontology documentation and dataset, both openly available, constitutes valuable material to foster the method transfer to computational experiments in neighboring humanities disciplines.

The application of the approach to the case study of iconography and iconology led to the creation of a domain-specific ontology (ICON) and dataset (the Iconology Dataset) of the major interpretations by the art historian Erwin Panofsky. The dataset served as a proof-of-concept for quantitatively addressing 20 domain questions and further performing exploratory data analysis of the historian's applied method. Through the extensive reference to the domain literature made in each of the steps, the domain knowledge became a valuable source in the process of inquiring about the domain quantitatively, preserving the scholar's expertise in the new computational approach.

Through the case study, the issue of proposing a formalization of a domain characterized by a lack of a commonly shared theoretical framework and a strong interpretative nature has been addressed, providing an example of application that can be tested in disciplines with similar characteristics. In particular, domains including interpretative and hermeneutical acts, either of textual documents or of visual sources, such as philology, cultural history, and visual semiotics, could particularly benefit from the approach.

Future works include testing the method in other domains and on heterogeneous art descriptions (e.g., catalog entries) to verify its robustness. Furthermore, the capabilities of semi-automatic information extraction from textual sources (e.g., NLP, LLM, Machine Learning) will be explored to partially automate the process of dataset creation, which would allow its extension to other art historians' interpretations. Hence, having such data could allow 1) further data-driven validations of art historiographical methods, and 2) deepen iconographical inquiries on art subjects (e.g., analyses of symbolism in the arts [57, 58]) with studies on the influence of the different scholars' point of view (see [5]).

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