

Performing a Systematic Literature Review on the Implementation of the CIDOC CRM in Cultural Heritage

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This article examines the implementation of the Conceptual Reference Model of the International Committee for Documentation (CIDOC CRM) in cultural heritage by performing a systematic review of the literature. We have analysed publications that describe one or more case studies, collections, archives and so on concerning the implementation of the CIDOC CRM. Among other aims, the review sought to identify the heritage categories in which the CIDOC CRM is usually implemented; the degree to which the studies are accessible to humanist readers; whether extensions or new ontologies models have been proposed; whether new tools have had to be created for the implementation; and whether the published studies have included a quantitative or qualitative analysis of the implementation. The results suggest a much greater degree of implementation in movable heritage and low application in intangible heritage. They also suggest that most of the published studies demand an advanced level of computer literacy from readers, which somewhat hinders access by humanist professionals and researchers, thus deterring their collaboration and/or interest. Furthermore, the results indicate that one-third of the studies developed a full or complete extension to the CIDOC CRM and that in approximately half of the studies a new tool was developed and created for the purpose pursued in a specific project or by a specific institution. Following a review of the literature, the article presents a series of considerations and recommendations for future lines of work with a view to extending the implementation of the CIDOC CRM in the cultural heritage sector and contributing to the construction of a more integrated information infrastructure ecosystem.

CCS Concepts: • **Applied computing** → **Arts and humanities**; **Computers in other domains**; • **Information systems** → **Graph-based database models**; **Information systems applications**;

Additional Key Words and Phrases: CIDOC CRM, cultural heritage, ontology, knowledge graph, data integration, semantic model

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1 Introduction

Sharing information and giving feedback have always been a primary concern in the cultural heritage sector as the crucial pillar for innovation and knowledge generation and dissemination. However, the pressing need to digitalise cultural heritage has led to individual and short-term actions which, in many cases, have omitted to consider the ecosystem of the required information system. Furthermore, cultural heritage data present a major challenge due to their heterogeneity, formats and possible relations and interrelations.

During the course of this digitalisation process, the different scientific communities have produced—and continue to produce—databases with different descriptors, metadata, methodologies and structures. Nevertheless, despite the advances and innovations achieved, most of the knowledge generated is isolated and hardly ever reused. In addition, each research community has used its own standards, leading to a lack of standardisation and uniformity. The establishment of an integrated ecosystem for managing heritage information is therefore essential for creating an interdisciplinary framework to share data and generated knowledge and thus permit feedback, access, use, reuse and sustainability: in short, interoperability and sustainability.

Among the various tools for the handling and semantic modelling of heritage data, such as the Dublin Core Metadata Elements [1], Europeana Data Model [2] and Simple Knowledge Organisation System [3], the **Conceptual Reference Model of the International Committee for Documentation (CIDOC CRM)** [4] is one of the most widely implemented and has also been an **International Organisation for Standardisation (ISO)** standard (ISO 21127:2023) since 2006 [5]. Unlike non-semantic standards, which tend to focus on describing data through a set of predefined elements and their structure, semantic standards, such as CIDOC CRM, allow for the creation of more flexible models.

The CIDOC CRM was developed with the purpose of being applicable to the documentation of all types of cultural heritage assets, which extends its scope beyond the exclusively collectable objects in museums and archives. This approach allows the standard to encompass a greater diversity of entities and relationships than other metadata schemas. Another virtue of this standard is its ability to be complemented and expanded by extensions, such as CRMarchaeo, CRMdig, CRMba and so on [4], and other compatible models (Table 1), such as LRMoo, PRESSoo and so on. These extensions seek to address more specific aspects of cultural heritage that often involve disciplines that require more precise technical language or specific methodological procedures. Indeed, the versatility of CIDOC CRM stems from its ontological conception. By defining concepts and relationships through formal propositions and constraints, this ontology not only organises the available data but also allows further inferences or assessments to be made about that data. In addition, unlike other standards, CIDOC CRM does not focus on any specific type of entity within this broad domain. As a consequence, it does not set strict minimum requirements for the structure or content of the data managed by these institutions. This flexibility allows the model to be adapted to different circumstances depending on the specificities of the object being represented.

The primary aim of the CIDOC CRM ontology model is to promote the standardisation of a structure that facilitates the integration and sharing of data related to cultural heritage. In short, it is a model with the capacity not only to handle the variability and complexity of heritage data, but also to describe them in relation to real concepts and events instead of rigid, hierarchical schemes. The CIDOC CRM is a standard semantic model developed to describe, connect and share cultural heritage information between multiple institutions [6, 7].

Table 1. Compatible Models and Contributions to the CIDOC CRM with Their Latest Versions and Status [16]

Model	Full Name	Semantics Captured and Represented by This Ontology	Latest Version and Status	Release Date	CIDOC CRM-Compatible Version
FRBRoo	Functional Requirements for Bibliographic Records	Bibliographic and museum information	Version 0.9.6 (stable)	October 2023	Version 7.1.2
PRESSoo	Modelling of Bibliographic Information	Bibliographic information about continuing resources (journals, newspapers, magazines, etc.)	Version 1.3 (official)	March 2017	Version 7.1.2
CRMinf	Argumentation Model	Argumentation and inference making in descriptive and empirical sciences	Version 1.0 (draft)	October 2023	Version 7.1.2
CRMarchaeo	Excavation Model	Archaeological excavation process and all the various entities and activities related to it	Version 2.0 (stable)	July 2023	Version 7.1.2
CRMsci	Scientific Observation Model	Scientific observation, measurements and processed data in descriptive and empirical sciences	Version 2.0 (stable)	March 2023	Version 7.1.2
CRMgeo	Spatiotemporal Model	Spatiotemporal properties of temporal entities and persistent items	Version 1.2 (stable)	September 2015	
CRMdig	Model for Provenance Metadata	Metadata about the steps and methods of production ('provenance') of digitisation products and synthetic digital representations	Version 4.0 (draft)	December 2022	Version 7.1.1
CRMba	Model for Archaeological Buildings	Metadata about the documentation of archaeological buildings	Version 1.4 (stable)	December 2016	Version 6.2.2
CRMtex	Model for the Study of Ancient Texts	Process related with the investigation of ancient texts and their features	Version 2.0 (stable)	June 2023	Version 7.1.2
CRMsoc	Model for Social Phenomena	Data about social phenomena and constructs that are of interest in the humanities and social science based on analysis of documentary evidence	Version 0.1 (draft)	May 2019	Version 6.2.5
CRMact	Model for Activity Plan	Documentation records about plans for future activities and future events	Version 0.2 (draft)	March 2022	Version 7.1.1

Specifically, it was developed to semantically model the relationships between objects, activities, events, actors, research data and so on.

The origins of the CIDOC CRM date back to 1996 when the Documentation Standards Working Group of the International Council for Documentation (CIDOC)—itself a committee of the International Council of Museums—formed by professionals with expertise in information and communication technologies applied to cultural heritage, embarked on a project to develop a conceptual model for handling cultural heritage information. Known as a Conceptual Reference Model, the first version was presented in Melbourne in 1998 [8]. The model emerged with the aim of perfecting earlier relational models [9, 10], conceived for a specific representation of information, by aspiring to a higher conceptual level. While the earlier models were designed to capture data, creating a unidirectional workflow (for the input of data) and including numerous simplifications [7], the CIDOC

CRM is built on the premise that cultural data are a living and expanding resource [11], and it aspires to have the necessary objectivity to represent the different perspectives of very diverse disciplines and institutions.

The model was accepted by the ISO (with authority to approve international standards) as an official standard under number ISO 21,127: 2006. However, this approval did not signify the end of the standardisation process because the model is designed to be extensible, and it is therefore constantly updated to include new areas of knowledge. The CIDOC CRM SIG [12] is the special interest group responsible for the standard of this ontology. The group members work through mailing lists, open troubleshooting forums [13] and biannual conferences and meetings of the SIG that are attended by experts from museums and other cultural heritage institutions, universities, research centres and companies [14].

The latest official version of the CIDOC CRM is 7.1.2 [15]. Launched in June 2022, it includes 81 classes and 160 properties. The model was created in English and has currently been translated into five languages (Chinese, French, Greek, German and Persian). Translations into another three languages (Japanese, Russian and Czech) are underway. There are currently 11 extensions or models compatible with the CIDOC CRM, either approved or undergoing approval by the CIDOC CRM SIG, which complement and specialise in the semantics of different disciplines or practices related to cultural heritage (Table 1).

The benefits and relevance of the CIDOC CRM application are evidenced by its implementation in numerous projects and institutions in the cultural heritage sector, such as ARIADNEplus [17], the British Museum Research Space [18], CrossCult [19, 20], Arches [21], the Oxford University CLAROS project [22], the Mingei project [23] and the Craeft project [24, 25]. The implementation of a semantic model promotes the interconnection of different pieces of cultural heritage information, thus enhancing data presentation and management while also facilitating the creation and generation of new interpretations and knowledge.

1.1 Previous Literature Reviews

The search for literature reviews with the terms ‘CIDOC AND heritage AND review’ was carried out in **Web of Science (WOS)** databases without any limit of publication date and without a language restriction. Ten publications were identified, but close reading revealed that none of them had undertaken a systematic review of the literature on the implementation of the CIDOC CRM in the cultural heritage sector (Table 2).

Despite the relevance of the CIDOC CRM for systematising heritage information and its enormous potential for generating an interoperable ecosystem, there is currently no systematic literature review that studies aspects related to the implementation of the CIDOC CRM for cultural heritage objects and/or collections. This reinforces the need for an article of this nature to identify the most common uses of the CIDOC CRM in the cultural heritage field and assess the solutions undertaken. The systematic literature review developed in this study seeks to explain whether the implementations of the CIDOC CRM for cultural heritage apply predominantly to a specific category¹ or type of heritage documentation object [36, 37], and to what extent humanist readers can understand the published projects and implementations. This review will also assess the location of each project and object of study and whether a specific tool was created. Lastly, the article presents a set of conclusions and future lines of development for this area. Based on the study, we propose a set of actions required to increase heritage data interoperability, taking into account CIDOC CRM implementation.

In the following, Section 2 discusses the methodology followed to undertake this systematic literature review; Section 3 presents our analysis and results; and Section 4 sets out our conclusions and discussion.

¹In this study we adopted the definition of UNESCO concerning cultural heritage categories. In this sense, movable cultural heritage refers to objects that can be transported, such as paintings, sculptures, furniture and documents, while immovable heritage consists of structures and places that cannot be moved, such as buildings, monuments and archaeological sites. On the other hand, the intangible cultural encompasses a wide range of practices, representations, expressions, knowledge, and skills, such as performing arts, social practices, rituals, knowledge and oral traditions.

Table 2. The 10 Publications with the Corresponding Year and Source

Title	Source	Year	Systematic Literature Review
An Evaluation of Graph Databases and Object-Graph Mappers in CIDOC CRM-Compliant Digital Archives [26]	ACM JOURNAL ON COMPUTING AND CULTURAL HERITAGE	2022	No
A Review of Ontologies for Augmented Reality Cultural Heritage Applications [27]	JOURNAL OF CULTURAL HERITAGE MANAGEMENT AND SUSTAINABLE DEVELOPMENT	2022	No
Semantic Bridging of Cultural Heritage Disciplines and Tasks [28]	HERITAGE	2019	No
Museum Professionals in a Digital World: Insights from a Case Study in Portugal [29]	MUSEUM INTERNATIONAL	2018	No
Implementation of Multiple Interpretation Data Model Concepts in CIDOC CRM and Compatible Models [30]	VIRTUAL ARCHAEOLOGY REVIEW	2018	No
3D Point Clouds in Archaeology: Advances in Acquisition, Processing and Knowledge Integration Applied to Quasi-Planar Objects [31]	GEOSCIENCES	2017	No
Online Event-Based Conservation Documentation: A case study from the IIC Website [32]	STUDIES IN CONSERVATION	2016	No
Safeguarding and Accessing Drama as Intangible Cultural Heritage [33]	ACM JOURNAL ON COMPUTING AND CULTURAL HERITAGE	2016	No
Incorporate Cultural Artifacts Conservation Documentation to Information Exchange Standards—The DOC-CULTURE Case [34]	3RD INTERNATIONAL CONFERENCE ON INTEGRATED INFORMATION (IC-ININFO)	2014	No
Factoid-Based Prosopography and Computer Ontologies: Towards an Integrated Approach [35]	DIGITAL SCHOLARSHIP IN THE HUMANITIES	2015	No

2 Review Method

This systematic literature review was based on the methodology established by Okoli [38], divided into nine phases:

- Verify the need for a systematic review focused on the purpose pursued and define the **Research Questions (RQs)** for which answers are sought after undertaking the systematic review;
- Develop the methodology protocol;
- Define the inclusion criteria for creating the sample of publications;
- Choose the Search Source. In this phase, we chose the database to create the sample;
- Carry out the Second Screening Process. This phase checks if the publications meet the inclusion criteria. We read the publications to decide whether they would continue to be part of the sample or not;
- Extract Data. Coding and selection of the relevant information from the studies to answer the questions defined in Phase 1. This phase consisted of reading the entire remaining sample following the screening performed in Phase 5;
- Appraise Quality. This consisted in determining the quality of the publications and the studies undertaken in them;
- Synthesise Studies. We processed the information from the publications in order to complete Phases 1 and 7. This consisted in synthesising the coded answers and visualising the data in order to answer the questions proposed;
- Write the review in order to share the results.

After verifying that no systematic reviews had been undertaken, as discussed in Section 1 of this article, we proceeded to define the questions for which we sought answers. The study was motivated by the following RQs:

- RQ1: For which heritage categories (immovable, movable and intangible) is the CIDOC CRM model implemented?
- RQ2: What level of information science knowledge and/or computer literacy do readers need to have to understand the publication? What we wanted to know was whether the published studies on the implementation of the CIDOC CRM are accessible to humanist audiences.
- RQ3: Was there a development of any extension of the CIDOC CRM model?
- RQ4: Was a new tool/software application created to implement the CIDOC CRM?
- RQ5: Have the generated models been evaluated quantitatively and/or qualitatively?

Since only two researchers conducted this review, we developed the protocol jointly and decided that the following tools would be used: Adobe Acrobat, Excel and Tableau. In Phase 3 we defined the inclusion criteria. Initially, we defined three inclusion criteria to proceed with the analysis of the complete texts:

- (I) The publications had to be accessible through the institutional subscription of the University of Seville or through open access.
- (II) The studies had to describe CIDOC CRM implementation projects.
- (III) The studies had to describe real projects, where one or more case studies, collections, archives and so on were objects for the implementation of the CIDOC CRM.

The empirical corpus was compiled through searches in the WOS databases (Phase 4) with the aim of identifying the publications which dealt specifically with the CIDOC CRM and cultural heritage. In order to obtain the maximum number of publications in the sample, the search term used was 'CIDOC'. The search was carried out by title, abstract and keywords in WOS databases, and the filters used were: (1) works published between 2018 and June 2024²; (2) works written in English, Spanish, Italian and Portuguese; and (3) articles and proceedings papers were included. We identified 133 in this.

We then proceeded to compile the complete texts from the publications. There were nine publications which we could not access (they were not included in the subscriptions of the University of Seville or were not in open access), and the analysis therefore focused on a total sample of 124 publications. After compiling the data from the 124 publications, we generated a database with the EXCEL software, inputting the identification details of the publications (Title, Author, Journal, Year, DOI), and added five columns for the five RQs defined in Phase 2.

Further, when we carefully read the 124 publications, we observed that in six of them the term 'CIDOC' did not refer to CIDOC CRM model (in these publications the term 'CIDOC' refers to 'Centre interculturel de documentation de Cuernavaca', 'Centre for Intercultural Documentation', etc.), leaving us with 118 publications in the sample. We then identified that 85 publications met inclusion criteria II and III (Phase 5). However, the sample contained duplications: i.e., two or three publications dealt with the same study/research and had the same authors, methodology and results. We therefore decided to only include the most detailed version of the study, which reduced the final sample to 74 publications³ [39].

² Although we have detected that there were publications prior to 2018, given that we are at a time when technological advances and CIDOC itself are dizzying, we have decided to limit the period of the study to the last 6 years as a reasonable period to analyse the latest implementations.

³ The Systematic Literature Review presented here has some limitations, as any systematic review because it follows established criteria, limited time and has not made use of artificial intelligence. Among the limitations, as explained in this section, is the use of the WOS database and the search for the term 'CIDOC' in the title, keywords and abstract, which has resulted in a smaller initial sample (133 publications) compared to if we had used other databases such as Google Scholar or if we had searched for the term CIDOC in the body of each paper. Likewise, even if we had used another database to search for publications, we could only access those that were in open access or licensed from our institution to access them.

Next, we embarked on Phase 6, carrying out the coding for the five questions defined in Phase 2. The codes were established as described below.

- RQ1. We established that the possible values would be as follows: Immovable; Movable; Intangible; Intangible and movable; Immovable and intangible; Immovable and movable; Immovable, movable and intangible.
- RQ2. For this specific question we established four levels: Low, Medium, High and Very High. The ‘Low’ level was defined for publications that explain the implementation with graphs and texts for which the reader would not need prior knowledge of XML or any other computer language. The ‘Medium’ level was defined for publications where the reader needs a basic knowledge of RDF and how the CIDOC CRM is structured. The ‘High’ level was used for publications where the reader needs to know how to translate an RDF graph using the XML markup language. For the ‘Very High’ level we included studies that demand familiarisation with the CIDOC CRM and a knowledge of XML, X3ML, RDF, PYTHON, JSON, NLP, HBIM environment, analysis with SPARQL and/or algorithm creation.
- RQ3. This was coded with Yes or No and the name of the new extension or ontology model created.
- RQ4. This was coded with Yes or No. In addition, we added a column to detail what the tools, software and techniques used.
- RQ5. The following values were established: Quantitative; Qualitative; Quantitative and qualitative; None.

Having established the values and codes in Phase 6, we proceeded to Phase 7 to appraise the quality of the studies included in the sample. Next, we analysed the publications and entered the analysis data in the respective columns for each of the questions, organised in an Excel file (Phase 8). Having coded the answers, we embarked on the data visualisation using the tools Excel and Tableau (Figure 1).

3 Analysis and Results

The 74 publications included in the analysis sample of this study date from 2018 to June 2024. Based on the number of publications that appeared in the space of five years, it is reasonable to assume that the implementation of the CIDOC CRM in the cultural heritage sector is of considerable interest. The distribution of the publications during this five-year period is shown in Figure 2. The greatest number of publications appeared with a total of 20 publications in 2018, 2019 and 2020 (Figure 2). In terms of sources, Semantic Web and ACM Journal on Computing and Cultural Heritage account for the largest number of publications: eight each in the last five years (Figure 2).

3.1 RQs Analysis

To answer our first research question (RQ1), we analysed each publication and its respective heritage objects. This revealed that some of the publications did not offer a detailed description of the object(s) of study, which slowed down the analysis because we had to conduct searches using the references provided in the publication (mostly websites of collections, archives or projects) in order to generate reliable codes. Analysis of the publications also revealed a prevalence of movable heritage (textual documents, paintings, artworks, etc.), half of the publications deal with the implementation of the CIDOC CRM in movable heritage (37 of the 74 analysed), followed by immovable heritage, with 19, and 13 publications that dealt with both categories. This clearly demonstrates the predominance of the movable category, which is justified by the nature of the CIDOC CRM since it was initially created to register and manage museum objects. The other salient aspect to note is the small number of publications in the intangible heritage category: one in intangible heritage [40] and 2 publications in Intangible and movable heritage [41, 42] (Figure 3).

In relation to the level of information science knowledge and computer literacy required of readers, 14 publications demand a very high level, 16 demand a high level, 26 a medium level, and 18 a low level. As such, most of the publications demand a high or very high level (30 publications in total). Also, we observed that most of the publications that demand a low level are related to the immovable category (Figure 4).

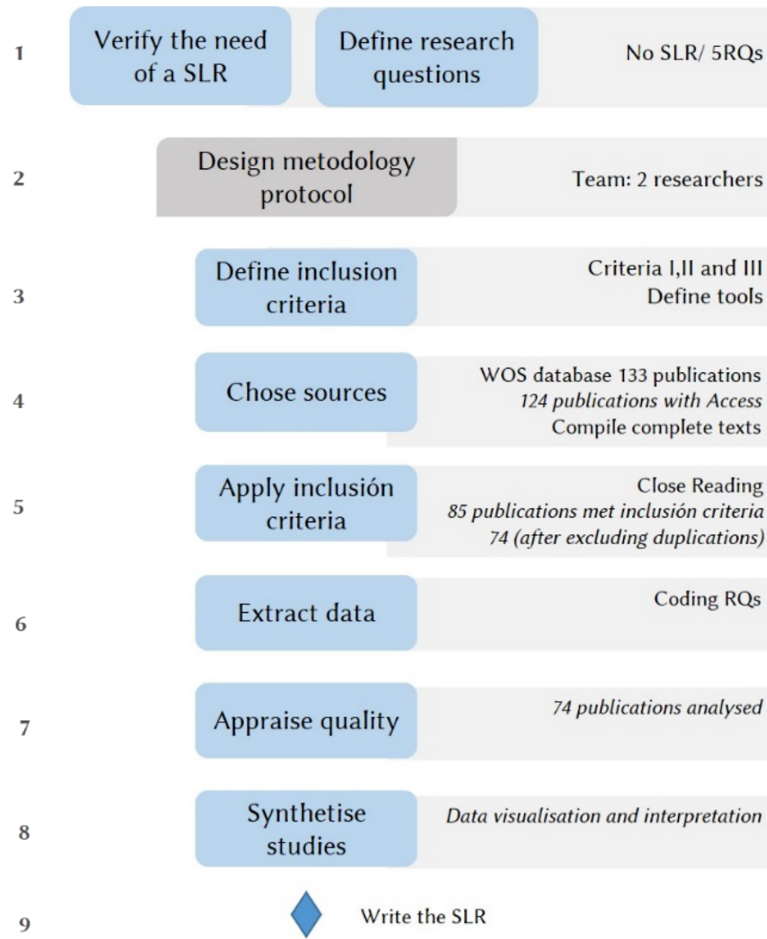


Fig. 1. Methodology workflow.

Our analysis about the creation or not of new extensions of CIDOC CRM (RQ3) reveals that only 23 studies created new extensions and, in some, new ontology models (Figure 5) which indicate the good adoption of CIDOC CRM in a wide diversity of cultural objects. Among the proposed extensions are, for example, the SeaLiT Ontology [43], which is a formal ontology developed to facilitate the integration, mediation and interchange of heterogeneous information related to maritime history; the ArchOnto [44] which is an ontology-based model for archives; and DOREMUS [45], which extends the CIDOC CRM and FRBRoo models for representing bibliographic information, adapting it to the domain of music.

We also wanted to analyse the matter of tools needed to implement the CIDOC CRM (RQ4). Our analysis revealed that 35 of the publications did create or generate new tools or platforms—of which 24 deal only with movable heritage. Accordingly, of the 14 publications that deal with an immovable heritage developed a new platform or tool, which once again demonstrates the interest in—and possibly a greater need for—the use of the CIDOC CRM for the movable heritage category (Figure 6). Among the various tools most commonly used, the following are worth mentioning: X3ML [46–49], Protégé [50–54] and Arches [6, 54].

Lastly, in relation to RQ5 (Have the generated models been evaluated quantitatively and/or qualitatively?), the vast majority of the publications in the sample (58 out of a total of 74) do not offer a qualitative or quantitative

Source and number of publication(s) per year



Fig. 2. Source and number of publication(s) per year.

analysis. Of the ones that do offer some form of analysis, the majority (10 publications) are qualitative analyses that examine the model and/or tool created. Those studies consider filter queries, thematic queries, relationship queries, patterns and data visualisation. On the other hand, the publications that have only quantitative analysis show tables with the numbers of instances, classes, properties and objects. Only one publication includes a joint qualitative and quantitative analysis [55].

4 Conclusions and Future Lines of Work

This article provides an in-depth study of the implementation of the CIDOC CRM in the cultural heritage sector through a systematic literature review. This review demonstrates that the CIDOC CRM does not extend to and/or has not been implemented in all heritage categories. In the field of immovable heritage, research tends to be long-term, and statements, analyses and interpretations emerge over time, which means that a ‘reality state’ can change as time passes. As such, the ontological model must not allow the loss of previous information and must be capable of recording all changes that occur. On the other hand, it is important to encourage contextualisation—connecting the data from different categories—because we understand the relevance of the close and broad context for generating correct knowledge and interpretations of heritage objects and preserving their dynamism.

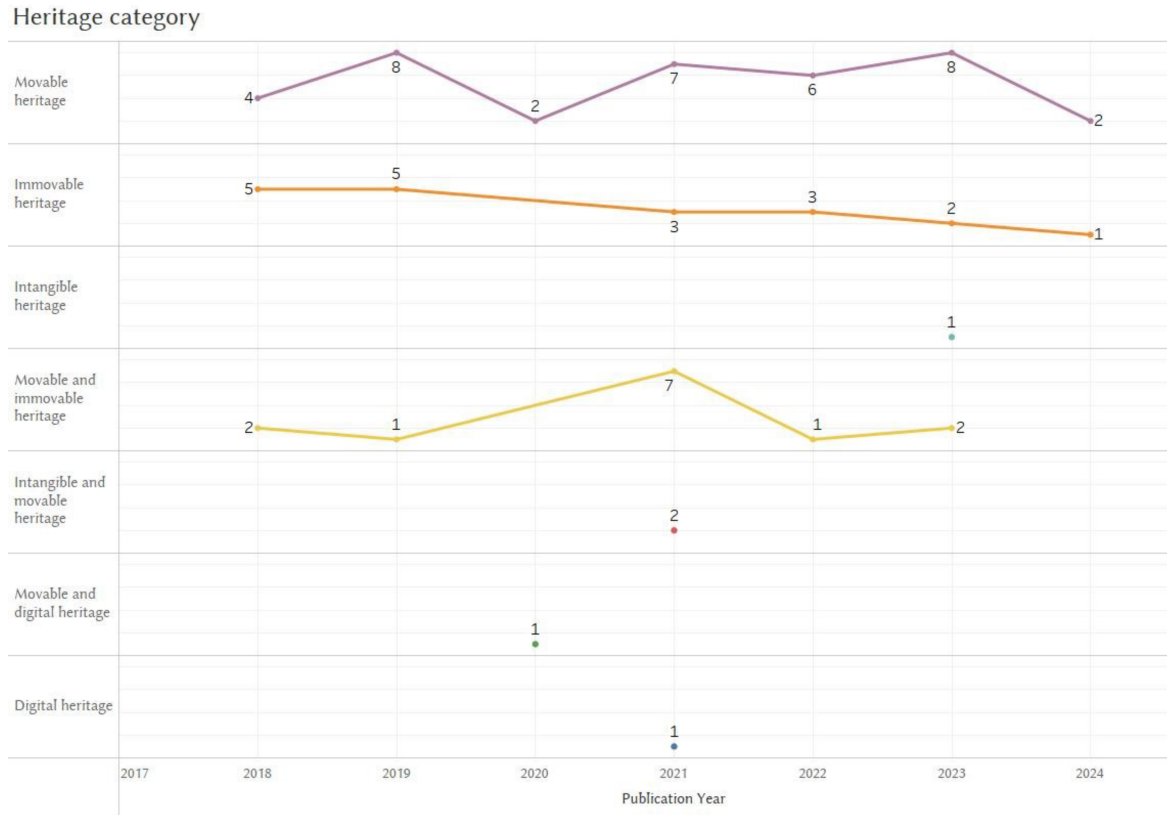


Fig. 3. Number of publications per heritage category.

Although the study also suggests that there is great interest in creating new tools and platforms, it appears that the style and knowledge indicated in the publications are still not fully accessible to humanist professionals and researchers. The great obstacle confronting us is that most implementations of the CIDOC CRM in specific projects and institutions have been carried out by specialists from the field of information science and computing, offering very limited resources to enable experts from the humanities to understand and/or even propose models and improvements in the semantic model. In the domain of cultural heritage data management, some experiences, such as the collaborative system FAST CAT, have achieved significant progress, particularly in addressing the common challenges of data management in descriptive and empirical disciplines such as history [56]. Other experiences improved in the development of tools and platforms, such as the 3D annotation platform, [57] and in archaeological and anthropological description [58]. We can therefore conclude that there is a need for greater collaboration between disciplines, institutions and companies, as well as for the integration of innovation from the intersection of the humanities and IT in order to generate discussion about historical events and heritage data.

On the other hand, some of the institutions and researchers that have implemented the CIDOC CRM have drawn attention to its complexity and, in some specific cases, have indicated the need to simplify the model to ensure adequate implementation and use both by the institution's staff and database users [59, 60]. In other cases, they have pointed out that its generic structure of concepts and relationships lacks a controlled vocabulary for types, terms and individuals, so each institution and/or project ends up either choosing a specific thesaurus to use, such as the Getty Arts and Architecture Thesaurus [61], EUROVOC [62], the UNESCO Thesaurus

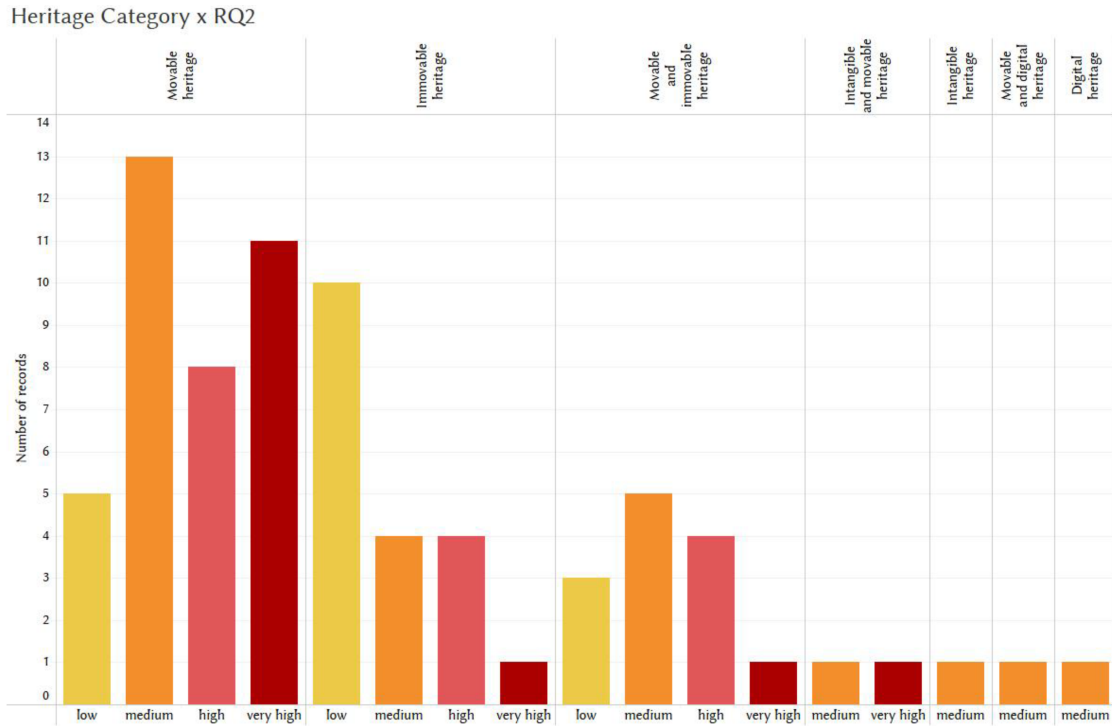


Fig. 4. Level of knowledge and heritage category.

[63] or others [19, 59, 64], or creates its own vocabularies to suit its own needs. To a certain extent, this high degree of abstraction helps to expand the usability of the data in the cultural heritage field, but ultimately it fails to provide a precise or clear definition of the terms and vocabulary required to guarantee the reliability of the documentation and/or description of the objects in the models. By extension, this makes it more difficult to ensure interoperability between institutions and/or projects of the same country [65] or different countries or, in the case of Spain, between different autonomous communities. Furthermore, idiomatic and locative specificities can sometimes give rise to doubts about the use and interpretation of certain entities, and in the medium to long term it will therefore be important to complete the versions in languages other than the original one (English) and embark on new translation projects (e.g., Italian, Spanish, Arabic), not least because the literature clearly shows that these geographical regions are increasingly interested in using the CIDOC CRM.

The systematic literature review has revealed that some of the elements defined in the CIDOC CRM are open to interpretation by the users of the model, which means there is a considerable risk of compromising the model quality and data uniformity and interoperability that was sought precisely through the implementation of the CIDOC CRM. Future studies must therefore encourage greater depth and transparency related to the implementation of the model in the cases carried out [66] in order to progress towards a more specialised data model without diminishing its interoperability. Along these lines, although we have been able to observe a large number of examples of cases that implement CIDOC CRM, we should seek models and databases to be published openly for feedback. In this sense, contributions such as the CIDOC CRM Datasets Portal [67, 68] and the CIDOC Use Cases [69] are relevant for the generation of knowledge and greater reliability and accuracy when implementing CIDOC.

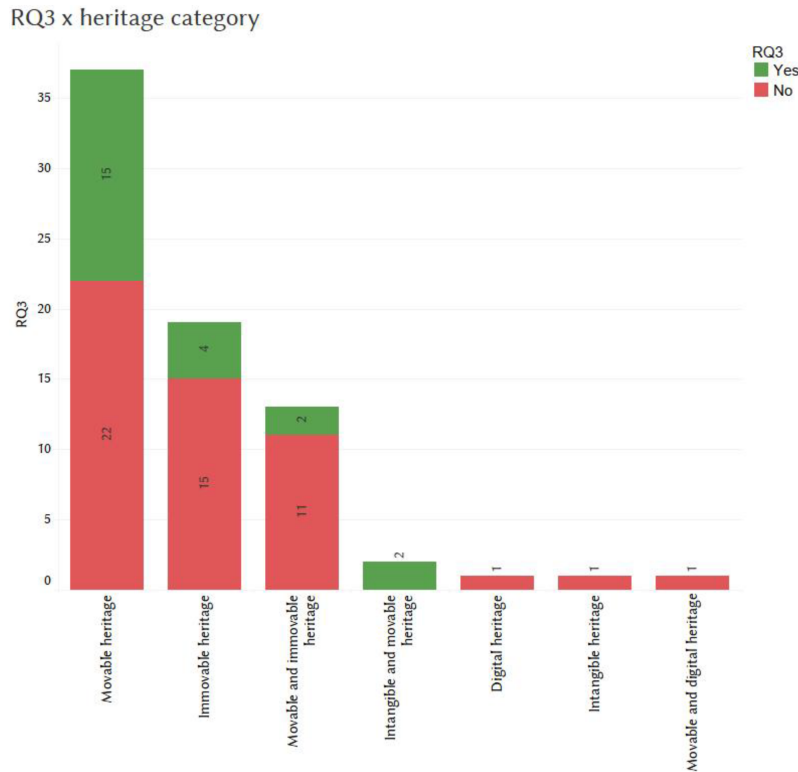


Fig. 5. RQ3 and its relation with the heritage category.

The CIDOC CRM could be a useful element for achieving greater operability and usability of heritage data. However, it is important to bear in mind that various other processes and tasks need to be carried out, such as the design and creation of the scheme and mapping features, the transformation or adaptation of the data, the extraction of the data, and the design of the possible analyses and visualisations. In these core tasks some open sources are being applied (e.g., X3ML tool kit [70], OntoMe [71] or ResearchSpace [72]). As we observed during this Systematic Review, ontologies have provided a shared common language able to facilitate both data integration and information translation. In the image domain the rise of the International Image Interoperability Framework as a standard for viewing and sharing image collections has also made possible the development of some viewers' applications rich in annotation capabilities, such as Mirador [73].

Future lines of work should therefore investigate and study the possibility of automating these processes and tasks in order to make more efficient use of time and resources. For this purpose, there are recent studies that apply machine learning techniques [74] and others that use AI [75], semantic segmentation and metadata enrichment to refine, both qualitatively and quantitatively, the extraction of data in heritage objects [76] and new platforms such as Draw.io [77] that incorporate the CIDOC CRM ontology in its library to facilitate the development of diagrams and its RDF generation [78].

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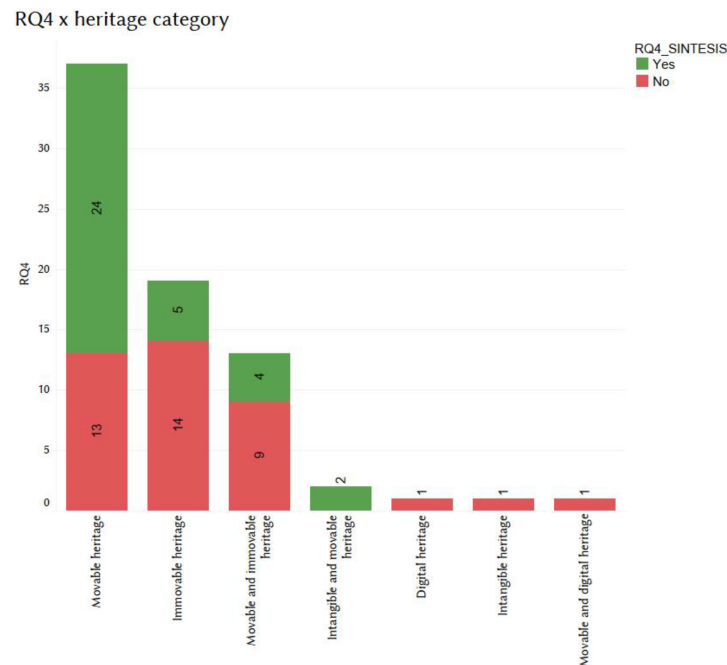


Fig. 6. Number of publications that have or have not created new tools/software to implement the CIDOC CRM.

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