One Ontology to Rule Them All—CIDOC CRM in the Humanities and Its Use in OpenAtlas

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Abstract
The CIDOC Concept Reference Model (CRM, https://www.cidoc-crm.org), developed by the International Council of Museums' International Committee for Documentation (CIDOC), is a widespread ontology in the field of digital humanities. Its version 7.1.1, used within OpenAtlas (https://www.cidoc-crm.org/version/version-7.1.1), consists of classes that can be connected via properties to structure data in a standardised way and create entity-relationship models.
Mapping one's research data using an ontology that is accepted and widely used in the community is consistent with the FAIR Principles (https://www.go-fair.org/fair-principles). Using CIDOC CRM on the INDIGO dataset enables the recombination with already existing research data in this structure as well as the contentious use in new projects is easily possible. This significantly extends the life cycle of the data and prevents the laboriously collected data from remaining unused after the end of the project.
However, the use of ontologies including the CIDOC CRM, requires a certain training period and the time and resources to learn how to use it. OpenAtlas (https://openatlas.eu), as an open-source database system, allows for easy input of research data without prior knowledge of ontologies or other digital humanities applications. The stored data are mapped to the CIDOC CRM model in the background of the application without the user needing to engage with it.

Keywords
CIDOC CRM; cultural heritage; digital humanities; FAIR principles; ontologies; open source software

1. Introduction

This article aims to give a short introduction to ontologies in general and CICOC CRM (https://www.cidoc-crm.org) in particular. It will be presented how the use of an ontology can help to fulfil the requirements of the FAIR Principles (https://www.go-fair.org/fair-principles). In addition, arguments will be given why the use of ontologies is important when dealing with topics in the context of cultural heritage sciences and especially in the scientific research on graffiti. In the second part of this article, the database system Open-Atlas (https://openatlas.eu) will be discussed. It allows the easy input of relevant data from the broad field of humanities and cultural heritage without further knowledge in the field of digital humanities. For this purpose, the application offers a user-friendly interface that can be freely adapted to the respective project.

2. CIDOC CRM—On the Importance of Ontologies

2.1. An Ontology in the Scope of Digital Humanities

The term "ontology" has different meanings in different fields of (academic) research. In philosophy, for example, ontology refers to the study of the nature and structure of all things-real or imaginary (Guarino et al., 2009). It is concerned with the study of being or existing (Stuart, 2016).

On the other hand—in the scope of computer science and digital humanities—ontologies are defined as "explicit specification of a conceptualization" (Gruber, 1993, p. 199)[1]. They are formal representations of knowledge (Merrill, 2011) and are meant to uniformly model the structure of a system (Guarino et al., 2009). By providing such a structure, information becomes automatically and unambiguously readable for humans and machines (Guarino et al., 2009; Stuart, 2016). Thus, ontologies are an important element of the semantic web.

Ontologies are composed of two basic elements: classes and properties. Classes are sets of things with shared properties (Stuart, 2016) and define unambiguously which data belong to a certain class and which do not. For example, an "actor" class comprises everyone in a dataset taking part in the research or creation of graffiti. These classes can further be divided into subclasses (Stuart, 2016), e.g. the aforementioned "actor" class could have the subclasses "graffiti researcher" and "graffiti creator".
Properties are attributes associated with certain classes (Stuart, 2016). They enable the linkage of classes via relations. Clear rules determine which class (referred to as domain) can be linked to which other class (range) via which property or properties (Figure 1) (Stuart, 2016).

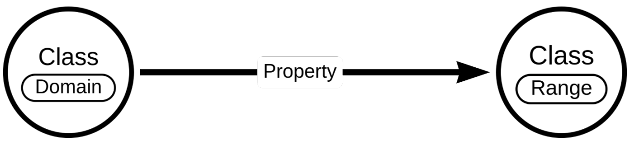

Figure 1. Classes and properties as basic components of an ontology (Graph: Nina Richards via https://arrows.app).

A class can be linked to any number of other classes via any number of properties. In this way, a dense network of information is created that can be interpreted by humans as well as machines—since the data are unambiguous. A single class can act as a domain for one connection as well as a range for another link (Figure 2).

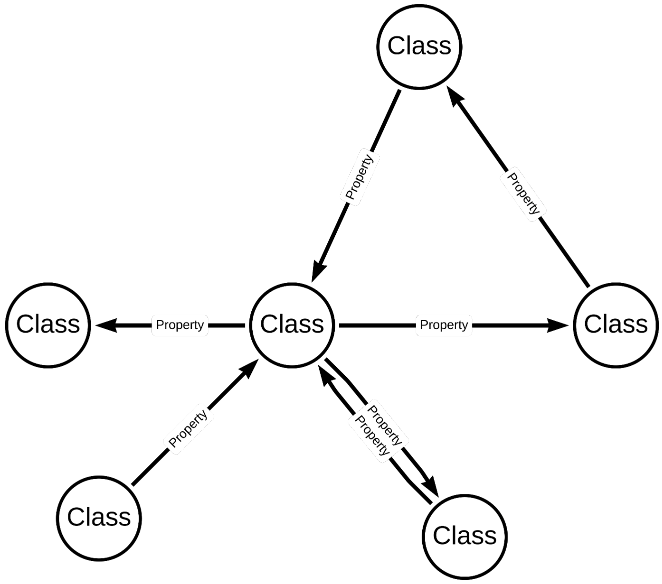

Figure 2. Network constructed by linking the classes via properties (Graph: Nina Richards via https://arrows.app).

This can be well explained with a simple example. For this purpose, the INDIGO graffito will be used, which was created jointly by the participants under expert guidance in the workshop of the project's kick-off meeting at the Danube Canal (Figure 3 and 4).

Of course, an infinite number of other classes and properties could be added—for example, with information about colours or used utensils, but for a rough overview of the functionality of classes and properties within ontologies, this should suffice.

One last thing to note about classes and properties. A distinctive feature of an ontology is its richness in tracking relationships via properties (Hedden, 2010; Stuart, 2016). However, to make the content that is mapped within an ontology more comprehensible, the usage of (controlled) vocabularies and/or gazetteers is highly recommended. They define terms, taxa, places, persons etc. with a unique identifier and make the content comparable with other datasets, especially against the background of linked open data and the semantic web.

Figure 3. INDIGO graffito, created 2021 at Danube Canal during the INDIGO kick-off meeting (Photo: Geert Verhoeven).

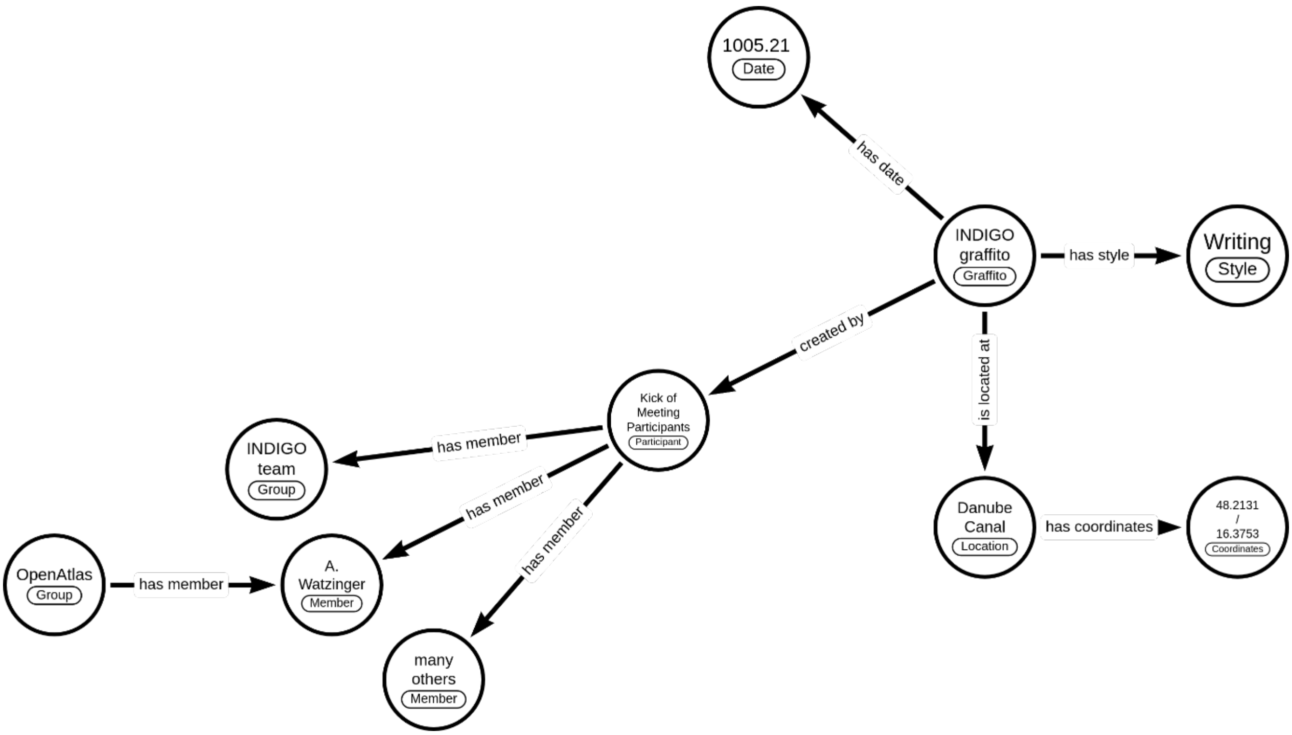

Figure 4. Network of the INDIGO graffito, created with a fictional ontology (Graph: Nina Richards via https://arrows.app).

Ontologies need to constrain what can be expressed by using them (Stuart, 2016), as none of them can represent all research fields with all details and in their entirety. Therefore, ontologies are highly domain-specific, and an ontology used in the medical field will have different properties and classes than one in the scope of heritage science or human resources (Janssen et al., 2010). It is, therefore, up to each team of researchers to identify the ontology best suited for their project and to use it for all data collected as part of the project.

Heritage science, including graffiti research—understood as material evidence of human activities of social relevance in the past—is very interdisciplinary as well as incomplete at some scale (Doerr, 2009). Finding the right ontology for this topic area is, therefore, particularly important.

2.2. Why You Should Use One?

Collecting, organising and using information is not possible without a system of classification. Ontologies can provide this classification and make the collected information manageable, analysable and interpretable (Merrill, 2011).

By providing a standardised way to represent a specific domain with entities and relationships—and thereby structuring data—ontologies allow for semantic interoperability and exchange of knowledge between different projects that use the same ontology (Janssen et al., 2010). A well and efficiently constructed ontology is thus an essential component in the engine of contemporary science (Merrill, 2011). They do so by supporting the indexing of data via the use of uniform terms and by supporting data ontologies which allow for complex queries of the information via their classes and numerous relationships represented by their properties. They also support the findability of information and related concepts by organisation/navigation and browsing rather than searching or querying. Last but not least, they serve as knowledge bases (Stuart, 2016).

So, by using an ontology with agreed-upon meanings and labels, the data become interoperable with other datasets and accessible to all involved parties (Janssen et al., 2010), which allows for data to be widely shared (Stuart, 2016). The unambiguous definition of terms within the ontology enables interoperability with other data sets that use the same structure; this is in accordance with the FAIR Principles, which will be discussed in more detail below. Through interoperability and reusability, the life cycle of the own data is extended, which can be used for further research even after the end of the project.

Sharing data in the research community and with the broader public is not only in accordance with the FAIR principles (see below) but also prolongs the life cycle of said information. Structured data are more likely to be re-used in other projects and for other purposes. Even more so if data are not only readable for humans but machine-readable as well. In that case, it can also become part of the semantic web when two or more computer systems exchange information and can interpret the meaning of the information automatically (Ceusters & Manzoor, 2010).

2.3. CIDOC CRM

A widely used ontology within cultural heritage is CIDOC CRM which is also used in the scope of the INDIGO project. It is a formal ontology developed by the International Council of Museums (ICOM) to ease the integration, mediation, and exchange of heterogeneous information derived from cultural heritage research (Doerr, 2009). While CIDOC stands for the Comité International pour la Documentation (English: International Committee for Documentation), an international committee connected to ICOM CRM is an abbreviation for Conceptual Reference Model (Doerr, 2003, 2009).

CIDOC CRM has been developed since 1996 (Doerr, 2003). Its official version 7.1.1—used in the INDIGO project—was released in April 2021 and consists of classes and properties. While classes are indicated by a preceding "E" followed by a numeric code—e.g. "E29 Actor" or "E67 Birth" —properties are indicated by a combination of "P" and a numerical sequence-think "P26 moved to" or "P52 has current owner" (https://www.cidoc-crm.org/versions-of-the-cidoc-crm). The ontology was developed by a varying team of domain experts to achieve semantic interoperability of museum data but also enable information integration for data derived from related fields as well as their correlation with library and archive information (Doerr, 2003).

In 2006 the model was accepted as an ISO standard (Doerr, 2009) and renewed in 2014 as ISO21127:2014 (https://www.iso.org/standard/57832.html). CIDOC CRM, as a middle-level ontology, is not designed to be universal but

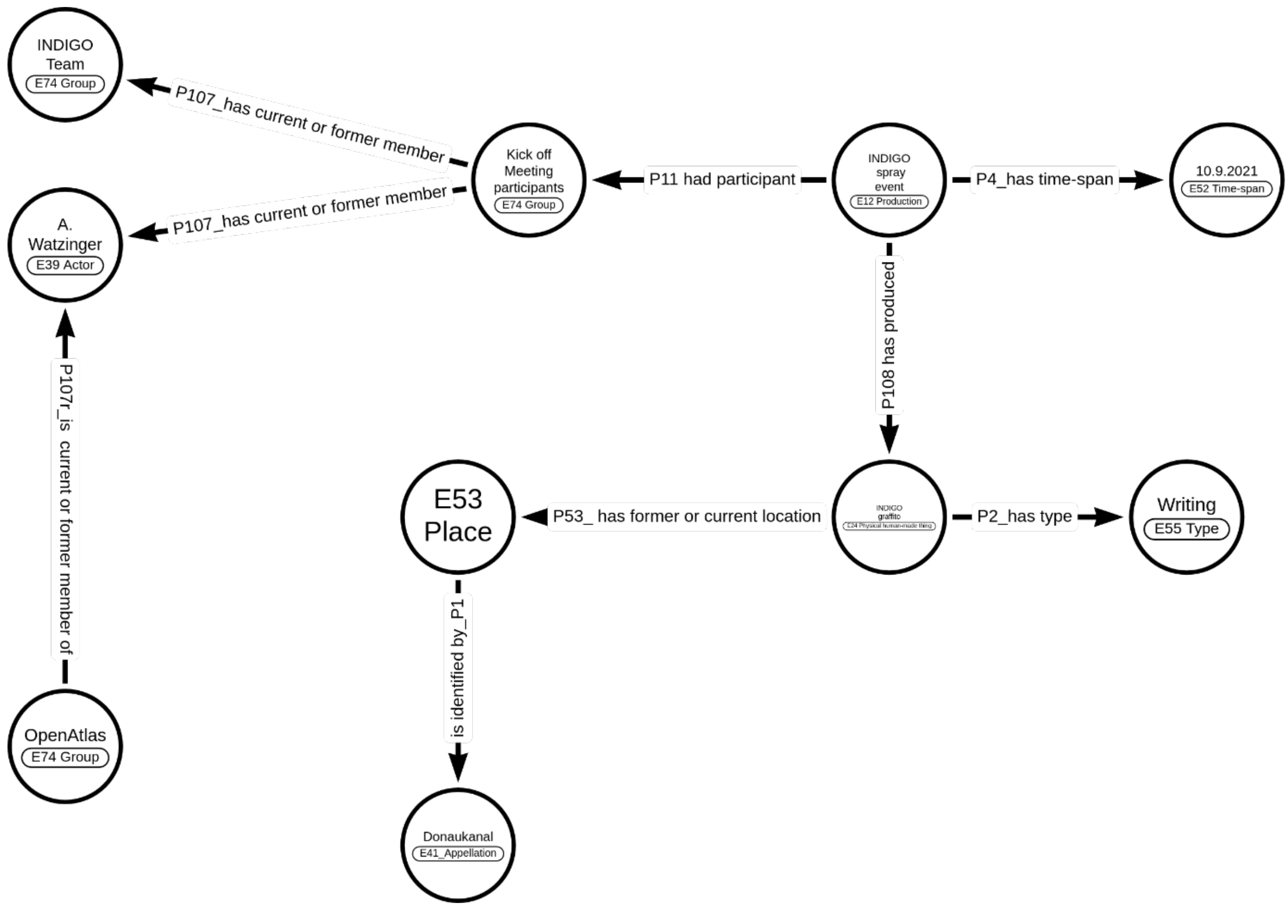

Figure 5. Model of INDIGO graffito following the CIDOC CRM specifications (Graph: Nina Richards via https://arrows.app).

to accommodate data from a large number of domains. While other ontologies are commonly designed to encode resources of one specific domain, in the scope of cultural heritage ontologies such as CIDOC CRM deal with a wider range of topics due to the interdisciplinarity of the field and are designed to be extensible to accommodate new developments (Stuart, 2016). If one takes up the model discussed before to the INDIGO graffito again, it can be modelled according to the constraints and rules stated in the CIDOC CRM by using some of their predefined classes and properties (see Figure 5).

3. Being FAIR and Being Open

3.1. FAIR Principles

In the digital humanities, FAIR principles (Wilkinson et al., 2016, https://www.go-fair.org/fair-principles) take an important role as it is not enough that data and code are being published open and available to everyone. The information has to be findable and reusable by those who want to keep working with them (Stuart, 2016) (Figure 6).

With the increasing popularity of the digital humanities in the field of the humanities, funding agencies are also placing increasing emphasis on data management and publish-

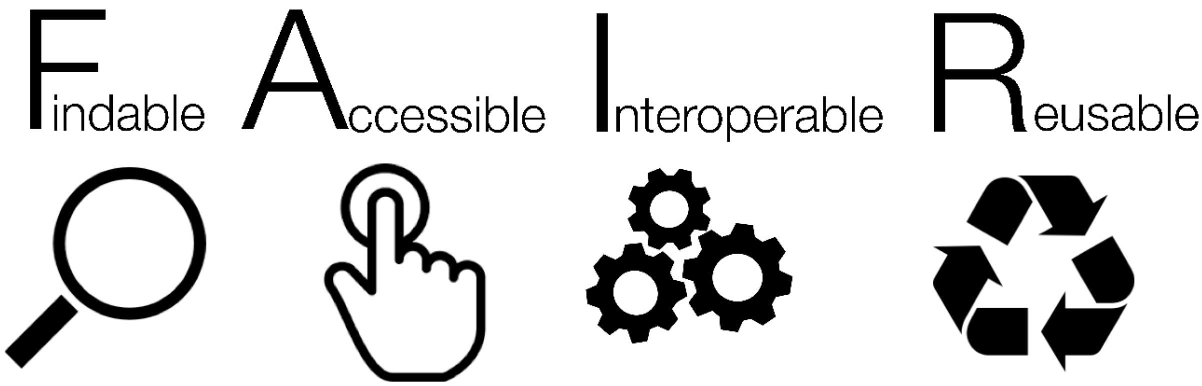

Figure 6. Fair Principles (Graphic by SangyaPundir published under a CC-BY 4.0 licence, see also https://creativecommons.org/licenses/by-sa/4.0).

ing project data in accordance with these principles.
More specifically, the FAIR principles state:

- Findable: data and metadata should be easily findable for humans and computers.
- Accessible: the conditions under which data are accessible should be provided in a way that humans and computers understand.
- Interoperable: data and metadata should be based on standardised vocabularies, ontologies, thesauri, etc. to be able to integrate them into already existing applications and workflows.
- Reusable: data and metadata should be well described so that they can be replicated and/or combined with other research data

This again illustrates the important role ontologies have in creating FAIR data.

3.2. Linked Open Data
Linked Open Data and the use of external (controlled) vocabularies also play an important role in fulfilling the aforementioned FAIR principles. Linked data are essential for building the semantic web (Tim Berners-Lee, 2006) and a best practice to publish structured data online (Stuart, 2016). It is an approach to making data interoperable (Murdock et al., 2012) by following the four rules of linked data principles as stated by Berners-Lee (2006, see also Stuart (2016), https://www.w3.org/wiki/LinkedData):

- Use URIs as names for things.
- Use HTTPS URIs so that people can look up those names.
- When someone looks up a URI, provide useful information.
- Include links to other URIs. so that they can discover more things.

Linking information to external sources creates a web of interconnected data-the semantic web-and makes it, therefore, possible for humans and machines to explore said web (Tim Berners-Lee, 2006; T. Berners-Lee & Hendler, 2001).

It allows homonyms to be uniquely assigned to their actual meaning in that specific context. Think, for example, of a data set about graffiti in Vienna, available online. Without further information, the mentioned Vienna could be the capital of Austria. However, the text could also refer to Vienna in Ontario (Canada) or talk about one of the many Viennas in the US—think of Vienna, Alabama, or the eponymous towns in Georgia, Illinois, Maine, or Wisconsin, to only name some of them. Humans might be able to distinguish between those possibilities, but machines, on the other hand, can not. By linking the city of Vienna in this record to the Austrian capital of the same name in another data set—e.g. the GeoNames thesaurus (http://www.geonames.org)—it unambiguously specifies which Vienna is being discussed.

Figure 7. OpenAtlas logo, designed by Jan Belik and released under a CC-BY SA 4.0 licence (https://creativecommons.org/licenses/by-sa/4.0).

4. On OpenAtlas and Its Use in Cultural Heritage

4.1. OpenAtlas in a Nutshell

OpenAtlas (Figure 7) is an open-source database software meant to acquire, edit and manage research data from various fields of the humanities, such as cultural heritage sciences, history, prosopography, and archaeology as well as related fields of the natural sciences. It is developed by a small, interdisciplinary team, which is mainly based at the Austrian Centre for Digital Humanities and Cultural Heritage (ACDH-CH) as part of the Austrian Academy of Sciences in Vienna (ÖAW).

Open Atlas provides a customisable and highly adaptable user interface. Freely selectable types allow the input mask to be adapted to the requirements of each project. Numerical values of any kind, such as length, width and height, can be entered via so-called Value Types. This user interface can be accessed via any standard web browser.

Within the INDIGO project, OpenAtlas is used to record and edit all data connected to each graffito while the images will be stored in the CoreTrustSeal-certified ARCHE repository hosted by the ACDH-CH (https://arche.acdh.oeaw.ac.at). The use of the database application enables the recording of the relevant data in a structured and standardised form throughout the entire project. Creator and graffito-specific information (like location, time of creation, style, colours, and dimensions) is easy to add via the browser-based user interface. Besides entering all information manually, OpenAtlas provides a way to import already existing structured information.

Furthermore, the system gives researchers opportunities to further process and analyse the entered information. For direct visualisation of the entered data, OpenAtlas offers the possibility to display them directly in the application as network graphics (for a representation with example data, see https://demo.openatlas.eu/overview/network). In addition, the OpenAtlas API (short for Application Programming Interface) provides all entered information in a machine-readable format and therefore serves as an interface between the database and a presentation website. On this web application, relevant information can be presented in an understandable, state-of-the-art and appealing way for scientific audiences as well as the general public. The API also allows for numerous other possibilities, such as data analyses. For example, one could run statistical tests with other specialised tools and to answer project-specific research questions.

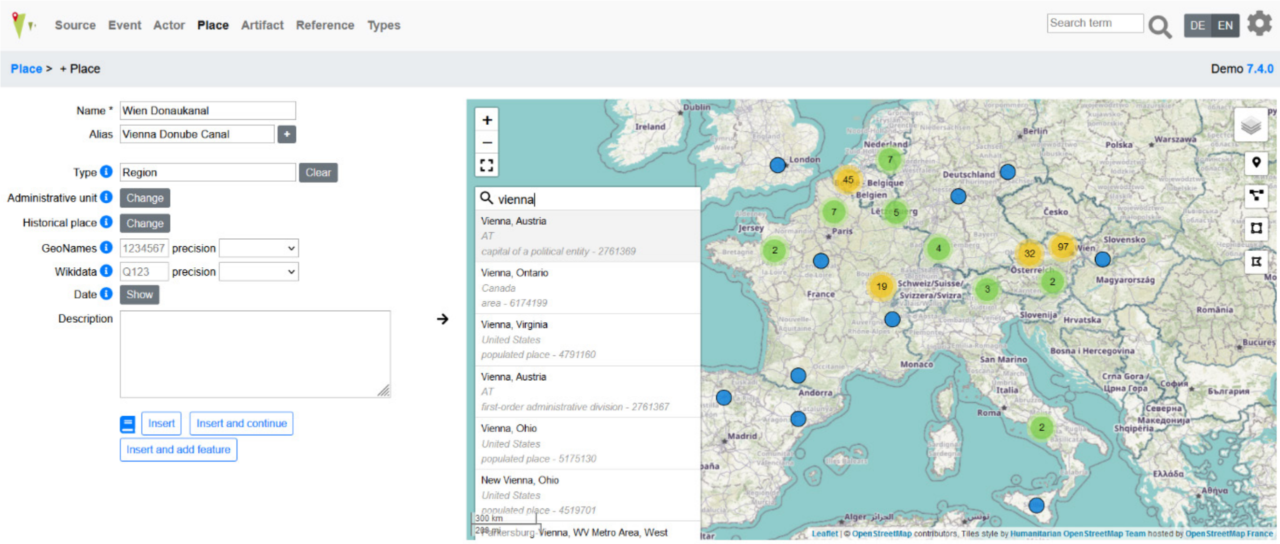

Figure 8. Enter new data about the Danube Canal in Vienna (Austria) via the OpenAtlas user interface.

4.2. The OpenAtlas Data Model and Why You Might Not Have to Worry Too Much About Ontologies or being FAIR and Open After All

As discussed earlier, ontologies play an important role in the scope of digital humanities. However, the application of these requires some knowledge and experience. The modelling of the data is not always intuitive and various ontology-specific rules must be followed. OpenAtlas provides a way to collect data and map it to CIDOC CRM through its user-friendly interface (Figure 8) without first becoming familiar with the ontology.

The entered data are mapped according to the CIDOC CRM specifications in the background of the application (Figure 9). The users do not need to be familiar with the complexity of the CIDOC CRM, as the software takes care of the mappings. To ensure data integrity and compatibility, no CRM extensions are used (e.g. CRMsoc https://cidoc-crm.org/crmsoc or CRMarchaeo https://cidoc-crm.org/crmarchaeo; for an overview of all CIDOC CRM extensions see: https://cidoc-crm.org/collaborations). Where possible, the system uses the CRM class that represents the lowest common denominator for the respective entity. However, as mentioned above, the users are most often not familiar with the CIDOC CRM, and therefore, superior classes are used to define the respective entity to guarantee a classification that is not incorrect. Of course, these mappings could be extended later by experts on ontology using the CRM extensions to go deeper into detail (Eichert, 2021).

Being open wherever possible is a key value of OpenAtlas. Therefore, in addition to offering an easy way to map data to CIDOC CRM, OpenAtlas allows for the creation of fair and open data in other ways as well. As already mentioned, OpenAtlas is itself an open-source project. The code developed by the team is freely available on GitHub (https://github.com/craws/OpenAtlas) under GNU General Public Licence Version 2 (GPL2, https://www.gnu.org/licenses/old-licenses/gpl-2.0.html). This allows other researchers and software developers to adapt the code to their needs and guarantees that work on it can continue even if the current key personnel or institutes are not available anymore. If technology developed by a third party is used in OpenAtlas, care is taken to ensure that it is also open source (for an overview, see: https://openatlas.eu/software). Since open source and open access play an important role in the development of the application, care is also taken in collaborations to ensure that the information collected in the projects is subsequently made available to a broad public as open access.

Therefore, OpenAtlas offers the possibility to link each project's data directly with external information of their

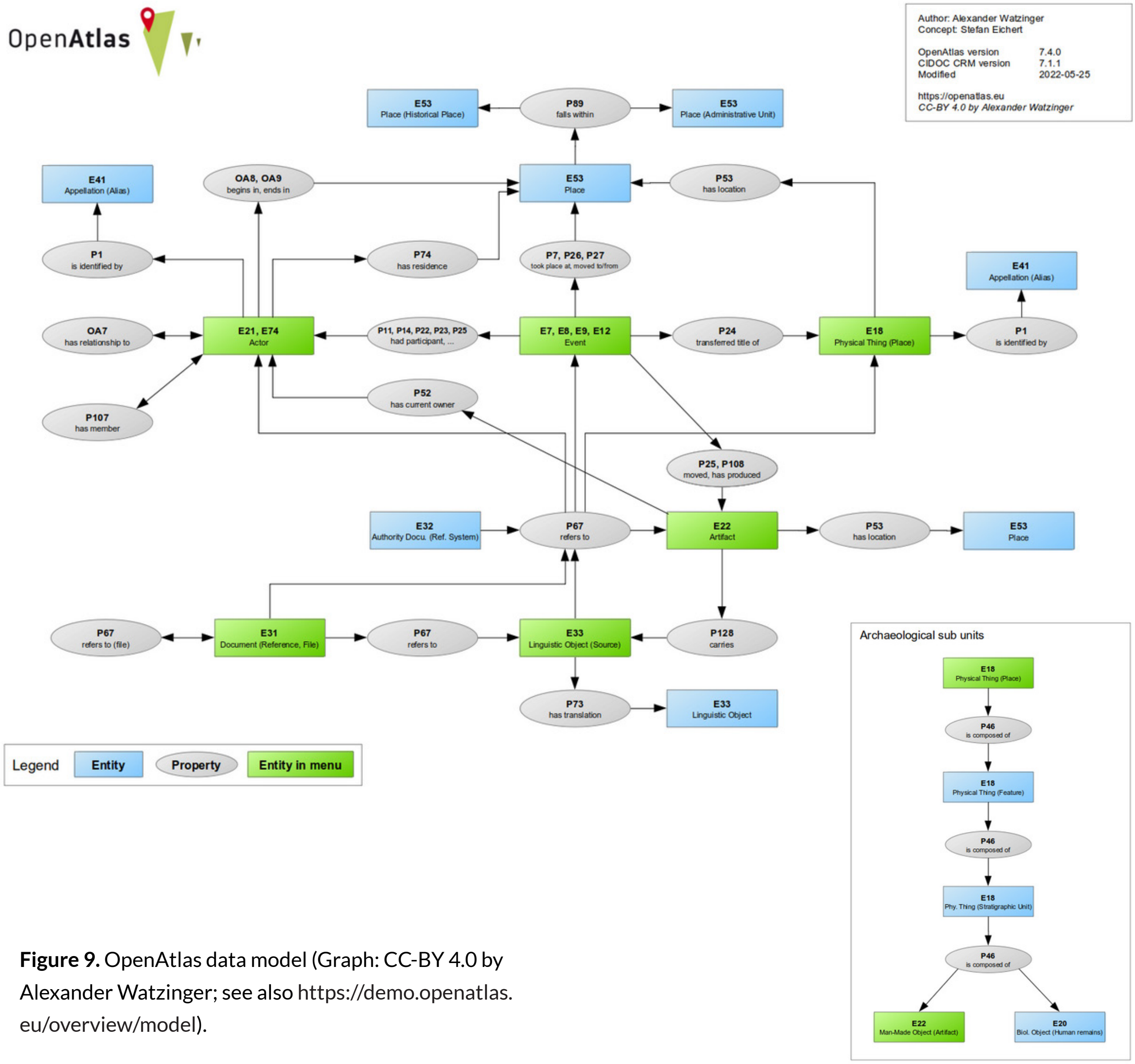

Figure 9. OpenAtlas data model (Graph: CC-BY 4.0 by Alexander Watzinger; see also https://demo.openatlas.eu/overview/model).

choice. This can be gazetteers and controlled vocabularies like Wikidata (https://www.wikidata.org), Getty's Arts and Architecture Thesaurus (https://www.getty.edu/research/tools/vocabularies/aat) or GeoNames (http://www.geonames.org), but also offline sources like inventory numbers of museums or old card catalogues of libraries.

From a technical point of view, the OpenAtlas users, respectively the hosts of the server, have full control over their data and can decide whether or not to provide them open. However, OpenAtlas provides the technical prerequisites to select, e.g. Creative Commons licences for the content, link it to controlled vocabularies and provide machine-readable data and metadata via an open API.

5. Conclusion

Using an ontology for any (research) data has numerous advantages. Ontologies give structure to the collected data and make them easier to re-use—both in their application areas and for other scientists. Structured data can be presented much more easily and coherently in various web applications and can thus be made available to the interested scientific community as well as to the general public. In addition, the use of an ontology that is established and widely used in one's science domain allows easy re-use of the dataset by integrating it into other data pools using the same ontology. Last but not least, this extends the life cycle of the collected data and can ensure that it does not become obsolete after a project is completed. The use of an ontology is thus an important step towards fulfilling the FAIR principles with respect to one's data set.

Conflict of Interests

The authors declare no conflict of interest.

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Special thanks go to the entire INDIGO (https://projectindigo.eu team under PIs Geert Verhoeven and Norbert Pfeifer for their support of OpenAtlas as well as for organising the goINDIGO 2022 conference and this publication.

Endnotes

1 - This most widely used definition was later supplemented by Borst (1997) as "formal specification of a shared conceptualization" and as "a formal, explicit specification of a shared conceptualization" by Studer et al. (1998) (see also Guarino et al., 2009; Stuart, 2016).

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