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A Review of Ontologies for Augmented Reality Cultural Heritage Applications

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Abstract

Purpose - The purpose of this paper is to review ontologies and data models currently in use for augmented reality applications, in the cultural heritage domain, specifically in an urban environment. The aim is to see the current trends in ontologies and data models used and investigate their applications in real world scenarios. Some special cases of applications or ontologies are also discussed, as being interesting enough to merit special consideration.

Design/methodology/approach – A search using google scholar and scopus was done, for articles that describe ontologies and data models in urban environment augmented reality applications. We identified the articles that analyze the use of ontologies and/or data models, as well as articles that were deemed to be of special interest.

Findings - The work shows that a combination of current ontologies seems to be the most complete way to fully describe a cultural heritage object or site. A layered ontology model is suggested, which can be expanded according to the project.

Originality - This study is aimed at reviewing the ontologies and data models in a very narrow field of augmented reality applications. There are many ontologies currently in use in the cultural heritage domain, with none having been universally adopted, while new ontologies or extensions to existing ones are being created, in the attempt to fully describe a cultural heritage object or site. Reviewing and discussing the combinations of these ontologies, and suggesting a model can be very impactful in the design of such applications.

Keywords Augmented Reality, Cultural Heritage, Data Models, Applications, Ontologies

Paper type Research paper

1 Introduction

The Cultural Heritage (CH) domain has received a lot of attention in recent times. The rapid advancement of technology has offered new ways in displaying exhibitions and collections, scholarly cooperating and reconstructing the past in digital form. Augmented Reality (AR) is in the center of this discourse, due to its three main advantages: portability, ease of access, and ease of use (Azuma, 1997). The improvements in wearable technology indicates that such devices will be commonplace in the not-too-distant future.

AR can be generally described as an interactive multimedia experience which incorporates elements from the real world via the camera on a user's device and enhances them with multimedia information or digital objects (Wu et al., 2012). The user sees the combination of the multimedia information and the real-time camera view.

In mixed reality (MR) the digital objects also interact directly with the real world (Milgram & Kishino, 1994). In Virtual Reality (VR), the user is completely disconnected from his/her environment visually and can only see and interact with the digital one.

While VR still has a place in the field, AR offers many distinct advantages over it. On one hand, VR can definitely be more immersive and requires no physical presence. AR shines in its portability and low entry cost. An AR application requires, for at least basic use, a mid-range contemporary smartphone. This seems to have shifted the discussion of post-COVID tourism towards AR, since it can even offer a touchless experience, without a tour guide and in less crowded groups. Many institutions, such as museums and CH sites, are interested in creating more engaging and expansive exhibitions, and AR is being discussed as the main tool of choice, while some are already invested in embracing the new technological advantages offered (Liritzis et al., 2021).

In this new collaboration between the fields of CH and Computer Science, the focus has been on how the cultural data are gathered, classified and eventually presented to the user, as it is investigated in the publications reviewed below. For this purpose, the use of ontologies has become common in the field. Ontologies can be very adaptable and tend to be easier to connect with other ontologies in the same domain, as long as they are standardized properly. They provide increased quality of analysis about an entity, interconnection between various entities and can be reused for multiple projects in the same domain or even project, with little to no modification. However, there is no standard ontology to describe CH data as of yet, and they can be difficult to maintain, as they grow and become more complex (Ben Mahria et al., 2020).

Ontologies are becoming the standard in most AR CH applications, since they offer software developers a way to create a contextual data model that can effectively describe a CH entity and whose parts can be intricately interconnected and easily reused, even across the same project. From the developers' point of view, one such application could become a framework for them to expand and create even more, separate projects, while retaining the ability to link the information from one project to another. An ontology-based AR application is also easier to adapt to various target groups, which makes it ideal as a framework for a software developer. From a stakeholders' perspective, this in turn leads to a higher quality application, since the data is contextually complete, thus offering more accurate AR tours. Standardization of a framework for a software developer also leads to a lower cost application, which allows smaller organizations to create AR tours.

This review focuses on the ontologies and data models most commonly used to describe CH sites for AR applications in urban environments, as opposed to sparsely populated areas or natural environs. In the second case, an CH site might remain unchanged or with very little modification since the time it was built (barring erosion from natural sources), depending on how far from a population center it is. In an urban environment, any CH site will change and be modified, due to the people living in it and any cultural shifts in that population or even accidental damage, things that would not occur away from a population center. Cities are, essentially, spaces of memory with several zones, with some form of relation to their history or cultural events (Guimaraes et al., 2016). A city is also an ever-changing entity, that can include many diverse culture groups, which might change over time but always have an effect on their surroundings. A street can have its name changed, for example, to honor a prominent athlete over the historical figure of the past it was named after. That constant change creates the need for more descriptors, more updated data input and more end-user input.

An ontological approach can help with this increased number of properties needed to help describe CH objects.

The goal was to identify the ontology or ontologies that would be best used for such applications. The next section defines some important terms that will be used in this study. Then section 3 presents the methodology followed. Section 4 is an overview of the data that can be used to describe CH sites and the most common ontologies, while section 5 presents interconnected ontologies case studies. Section 6 then presents case studies of ontologies in use specifically for CH. Finally, section 7 discusses the findings while section 8 concludes.

2 Definitions: CH, Data Models & Ontologies.

CH is defined as the entire corpus of material signs – either artistic or symbolic – handed on by the past to each culture and, therefore, to the whole of humankind (UNESCO, 1989). It is separated into (UNESCO, 2019):

- tangible, which includes works of art, buildings, books, artifacts, etc.
- intangible, such as oral traditions, folklore,
- natural, such as culturally significant landscapes as well as flora and fauna.

A major issue in the effective design AR applications for the CH domain is how to design the data models used for CH objects. When we refer to CH objects, we include the entirety of tangible, intangible and natural CH, anything from a statue to a building to a folklore song. In order to create an application for a specific site, we need to be able to appropriately describe and classify every object in the site that will be presented by the application. The cultural objects' descriptors need to also be properly interlinked and correlated. This requires a proper data model to describe the CH objects in the site.

To define it properly, a data model is an organization of data elements or a standard framework describing how these elements relate to one another. Although a data model is an abstract model (conceptual model), it always directly refers to and represents reality (Princeton University, 2021).

An ontology has been explained as "a specification of a domain's conceptualization" (Gruber, 1993). Ontologies have also been described as" a conceptual model that consists of a finite list of terms and the relationships between these terms" (Antoniou & Van Harmelen, 2004). The relationships between the terms are represented by axioms which add a logic layer to the conceptual model. An ontology has also been defined as "a conceptual data model that is translated through a set language" (Tomasi, 2018). Perhaps the most complete definition is that "an ontology is as an explicit specification of the conceptualization of a domain, formed by concepts and relationships that allow humans and machines to have everything they need to understand and reason about an area of interest or a part of the universe" (Nafis et al., 2019). Essentially, an ontology is a model which includes individuals, classes and properties. Individuals are the elements in a domain, such as a specific building or work of art. Classes are the collections of individuals, such as all buildings that make up a class, and properties describe the relationships between all elements and classes within a certain domain. All ontologies can be said to be data models, while not all data models are ontologies.

One term often cited in the discussion on CH data models is the Semantic Web. It is an extension of the World Wide Web, which can provide software programs with data that can be directly interpreted by the software itself and related to other data, thus adding even more descriptors to available information (W3C, 2021). To put it simply, it gives software the information it needs to understand and correlate data, similar to how the human mind works.

Finally, another term often mentioned is metadata. Metadata is essentially data that provides information about other data. It can contain and provide all sorts of relevant information with regards to a specific entity. In the case of a photo, for example, its metadata can provide information on where, how and when it was taken (Nafis et al., 2019).

3 Methodology

In order to capture a wide overview of ontologies for AR CH applications, an extensive electronic search was done on Google Scholar, Scopus, ScienceDirect, and IEEE Xplore during January 2021. Initially, the authors used the query string ("Augmented Reality" AND "Cultural Heritage" AND Ontology) to search the titles of articles in Google Scholar which gave three results. Then they use the same string to search the titles, abstracts and keywords of documents in Scopus which returned 12 results, while ScienceDirect returned 0 results, and IEEE Xplore returned 4 results. Broadening the search string to ("Cultural Heritage" AND Ontology) Google Scholar returned 120 results, Scopus returned 655 results, ScienceDirect returned 34 results, and IEEE Xplore returned 132 results. During this review, a set of inclusion and exclusion criteria were employed for facilitating the selection of relevant manuscripts. The following inclusion criteria were used: Article presents ontology(ies) for AR CH applications; Article presents sufficient data to identify how ontology(ies) are used in AR CH applications; Article was peer-reviewed; Article was written in English. The following exclusion criteria were used: Article refers to ontologies for AR applications in other domains; Article refers to ontologies for CH applications without any AR characteristics; Article does not provide sufficient information on the ontology(ies) used; Article is written in language other than English.

Each article was carefully screened and information was retrieved related to the article identification, objective, technology and ontology(ies) used, domain and context, conclusions, references and citations. The following sections present the findings of reviewing these articles.

4 Cultural Heritage Data Challenges

CH Data can be extremely varied. As mentioned previously, it can include virtually anything handed down from previous generations, be it a legend or tradition (oral history) to a building or a song. A way to manipulate and exploit such data would have many applications, from tourism to scientific advancement. It is important to point out that the interpretation of CH sites should explore the significance of each site in its multi-faceted historical, political, spiritual, and artistic contexts (Kim et al., 2016).

One of the primary issues while collecting CH data is that such data is typically held by public bodies, which store and organize it in many different ways, mediums, and locations. That creates a need for a system that can effectively collect and combine most, if not all, of the relevant data pertaining to CH sites, as deemed necessary on a case-by-case basis.

The other main problem encountered has been how to effectively classify this large amount of data. While it is certainly possible to describe a set of archaeological sites or artefacts to a very detailed degree, especially if they have some commonality (like being from a specific era), as soon as we enter an object, e.g., from a different, latter era, the framework we have for the first set of items would need modification.

Even after such modifications, any significant change to the entities described, like including a song or legend in the list, would again require further adjustments, if it was at all possible. This effect would be even more pronounced in cities, where the population surrounding it might interact and affect the CH site.

5 Data Models & Ontologies

Classifying such data is a challenge. In the field of CH, no data models are yet established as ideal, yet they are definitively linked to both collection and presentation. As it stands, there is no framework in place for collecting, storing and presenting CH data. So, the data model seems to be the first vital milestone in any such project, while it is even more pronounced in the case of urban environments, simply due to the much larger amount of data that needs to be included.The notion of using an ontology in computer sciences was given birth from the need to have some data model capable of describing such a diverse set of real-world entities and relations. Researchers developed ontologies specifically for CH data. Nafis et al. (2019) listed the following ontologies (alphabetically) that have been previously used in the CH domain:

- AAT: Art & Architecture Thesaurus (ATT) ontology uses a standardized and controlled vocabulary for users, for information management in art and architecture (Soergel, 1995).
- BCO: Biological Collections Ontology (BCO) aims to improve interoperability of biodiversity data, including data on museum collections, environmental/metagenomic samples and ecological surveys (Walls et al., 2014).
- BIBO: Bibliographic Ontology (BIBO) is an ontology for the Semantic Web. It was developed using the Resource Description Framework (RDF) standard and can be used as a citation ontology, document classification or simply to describe any type of document in RDF (Surla et al., 2012).
- CIDOC-CRM: CIDOC Conceptual Reference Model (CRM) is an ontology to facilitate integration, and interchange of heterogeneous cultural heritage information. It is an event centered ontology that contains temporal entities and a set of entities on those events (Doerr, 2003). It was developed by the International Council of Monuments (ICOM) through its International Committee for Documentation (CIDOC).
- CiTO: Citation Typing Ontology (CiTO) characterizes the nature or type of citations. It is restricted to works that cite or are being cited (Peroni and Shotton, 2012).
- FaBiO: FRBR-aligned Bibliographic Ontology (FaBiO) concerns primarily published or potentially publishable elements that employ or are referenced by bibliographic references or entities used to define such bibliographic references (Peroni and Shotton, 2012).
- FRBR: Functional Requirements for Bibliographic Records (FRBR) is a conceptual entity–relationship model developed by the International Federation of Library Associations and Institutions (IFLA). Its purpose is to describe documents and their evolution. It is not associated with any particular metadata schema or implementation (IFLA Study Group, 1998).
- HiCO: Historical Context Ontology (HiCO) describes the historical context of CH objects (Daquino and Tomasi, 2015).

In the study performed by Nafis et al., (2019), these ontologies were catalogued and compared according to their various characteristics, one of which was the date of each ontology's last update. They concluded, among other things, that ontologies with a large number of classes can make them seem complete, others with a large number of concepts are more readily usable, while others focus on the relation between the classes. CIDOC-CRM, HiCO and BCO have since been updated. In the table below we can see the scope or domain of each ontology, as well as the date it was created. It is quite clear that the newer ontologies have also been updated more recently, with the notable exception of CIDOC-CRM which has been updated many times since its first version. Note also that the International Standard ISO 21127 (current version 7.1, 2021) which is based on CIDOC-CRM aims at providing a common reference point for the exchange of information between cultural heritage organizations such as museums, libraries, and archives (ISO, 2021).

List of common Ontologies				
Ontology	**Domain**	**1st version**	**Last update**	**Language**
AAT http://www.getty.edu/research/tools/vocabularies/aat/index.html	Art, Architecture	1970s	March 2017	English, Chinese, Portuguese
BCO https://purl.obolibrary.org/obo/bco.owl	Biodiversity Data	2013	March 2020	English
BIBO https://bibliontology.com/	Bibliographic	2010	May 2016	English
CIDOC-CRM http://www.cidoc-crm.org/	CH, Museum Documentation	1996	April 2021	English
CiTO http://purl.org/spar/cito	Citations	2008	February 2018	English
FaBiO http://purl.org/spar/fabio	Bibliographic	2012	February 2019	English
FRBR https://sparontologies.github.io/frbr/current/frbr.html	Document	2005	March 2018	English
HiCO https://marilenadaquino.github.io/hico/	Historical Context	2014	March 2020	English

Table 1: List of common ontologies (updated list from Nafis et al., 2019).

Ontologies Compared			
Ontology	**Classes**	**Properties**	**Format**
AAT	37058		RDF/XML, NT3
BCO	157	209	OWL/CSV/RDF-XML
BIBO	69	106	RDF, RDFS, OWL
CIDOC-CRM	86	283	RDFS/OWL
CiTO	9	109	OWL 2 DL
FaBiO	250	94	RDF/XML, OWL, Turtle, N-Triples, Json-LD
FRBR	13	59	RDF/XML, OWL, Turtle, N-Triples, Json-LD
HiCO	25	162	OWL 2 DL

Table 2 : Ontologies Comparison

Each ontology comprises of a set of classes, which in turn have a certain number of properties that define it, as shown in Table 2. To better visualize how these can describe a CH object, Fig. 1 provides a very simple schema of an ontology, that is used to describe a statue and a pottery jar. The 2 CH objects are shown in blue circles, while the classes are in orange and their properties in grey. The green lines display the ways each object connects to a class, and the classes between themselves, while properties remain unique and not interconnected to anything but their parent class. It is obvious how CH objects can be interconnected, as well as share some classes, which would then have separate descriptors that apply to each object. In terms of scalability, this makes an ontology much more agile than a database since the sharing of various classes and interconnectivity make it much easier for the developer to accurately describe an object.

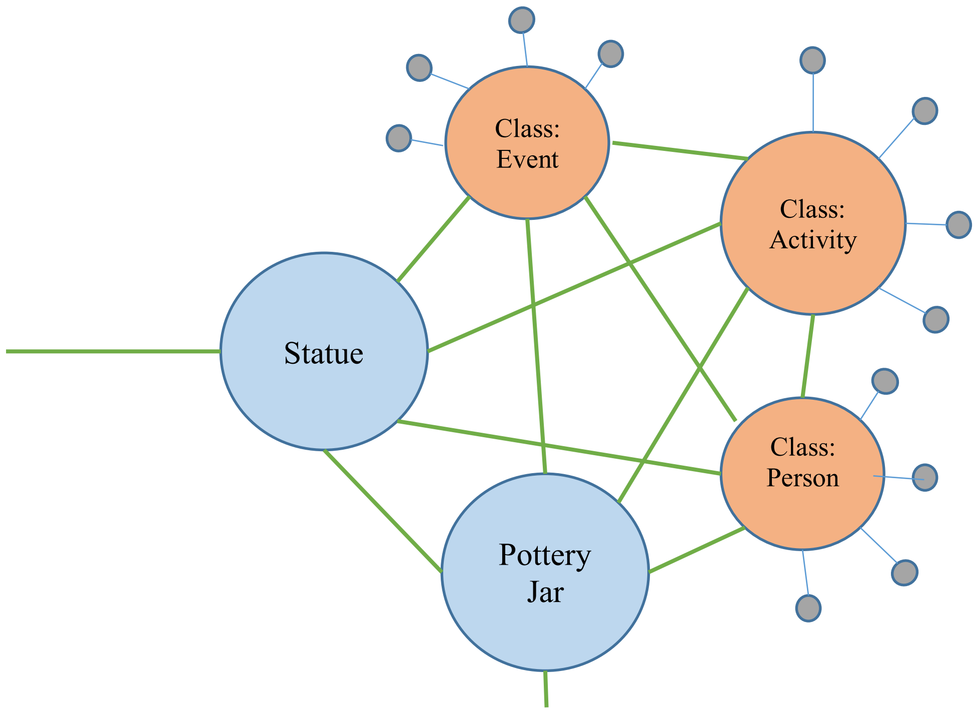

Figure 1: Ontologies and classes

6 Interconnected Ontologies

In order to interconnect different ontologies that were created for different objectives there should be a common language. Ontology Web Language (OWL) has been designed to enable the information processing instead of just the information representation. It is a family of knowledge representation languages for authoring ontologies. Tomasi et al. (2015) investigated interconnected OWL ontologies, in particular GO!, HiCO, and Proles, exploring the semantic content of heterogeneous digital collections in CH. Every one of these ontologies can be used to characterize a CH entity in a different way. GO describes the CH entity's place in a geographical dimension; Proles chronicles the people within a specific time/place period; and HiCO expresses the relationships between CH objects and any entity that is related to an aspect or interpretation of the object. They determined how HiCO can represent a superstructure to describe the way places, events, roles, and relations described in datasets are bound to cultural objects. GO! and Proles can be used to enrich the description of such relations.

Carboni and De Luca (2019) proposed an ontology framework trying to fully describe an object in relation to its context, focusing on iconographical objects. Eventually, they suggested a new ontology called VIR (Visual and Iconographic Representations), which was constructed as an extension of CIDOC-CRM. As part of their study, they also reviewed previous articles. One was by De Luca et al. (2013) who had previously performed an analysis and documentation on the tomb of Emperor Qianlong in China. Another was the Zeri Photo case (Daquino et al., 2017), where two ontologies were developed to map data coming from two different Italian standards. The ontologies were mapped to CIDOC-CRM, HiCO, PRO and FaBiO, and an extension was mapped to PROV ontology. This eventually led to the model described below.

This data model, proposed by Daquino at al. (2020), aims to represent hermeneutical aspects of literary sources, using Semantic Web technologies. Ontologies in hermeneutics focus on questionable statements that are stated and recorded in a source. The requirements were summarized by the authors as follows:

• Type of statement, a classification of the statement.
• Sources, where the statement was recorded as well as cited work.
• Agents, first and second knowledge providers, as well as any software agents involved.
• Motivations, classification of the motivation for the endorsement of a hypothesis.
• Certainty, the degree of precision of the statement.
• Relations, those between sources, between sources and agents, statements and sources etc.

Their final data model had the following four layers (Daquino et al., 2020):

• Layer 0 (SPAR ontologies for bibliographic resources, CIDOC-CRM for cultural objects) includes factual data that were a part of the scholar's background knowledge. This layer essentially determines what is considered a part of this discourse.
• Layer 1 (mostly CIDOC-CRM) describes the scope of the scholars' questionable statement. It basically determines what the examined statement is.
• Layer 2 (HiCO ontology), the context information for hypotheses assessment. This layer describes any information related to the statement itself, such as who made the statement, when did it happen, what is the primary source etc.
• Layer 3 (PROV ontology), the provenance information of the mining processes. This layer traces the machine-readable version of the statement.

The proposed data model, while valuable for hermeneutical sciences, is in essence a very descriptive data model that can be modified and be used extensively in CH in general. The use of multiple ontologies, either singular ones or in combination, is becoming very common, as we see in the case studies below.

7 Ontologies in Cultural Heritage – Case Studies

There are not many AR applications that were created specifically for CH sites in urban environments. Next, this study analyzes such projects with respect to the ontologies or data models used, as well as some particularities of the project itself.

7.1 KCHDM

One of these projects was implemented (Kim et al., 2016) in the Republic of Korea in Injeongjeon, the main hall of the Changdeokgung Palace, a UNESCO World Heritage site. The application proposed and implemented an outdoor AR information browser, that could offer contextual information related to the CH sites. This AR application collects heterogeneous data from five different databases and, using an ontological approach, provides information based on relationships between them. The ontology used in this particular case, was the Korea CH Data Model (KCHDM). KCHDM uses contextual data in text-based descriptions as entities in place of descriptive metadata. The authors considered both CIDOC-CRM and the Europeana Data Model (EDM), but decided on the KCHDM ontology, since it was developed based on sentence patterns in the descriptions of Korean CH (Kim et al., 2017). This model comprises 5 super classes (Actor, Object, Place, Time, and Event) and 78 properties that represent the context of CH entities. The user study was conducted among 30 participants of ages 19 to 39, some of whom had visited the site before. It was indicated that the AR application is educational and new knowledge is gained during its use. Out of the five themes that were chosen to present related CH items to the users, Object was the one chosen most often, and Place being the least often chosen. It is important to note that most of the users answered that the number of related items of CH offered by the application influenced their selections. This indicates the users were more interested in a data-rich option rather than the sparsely populated ones.

An interesting case in Korea, the K-Culture Time Machine (Park et al., 2018) is an attempt to create a system for collecting cultural content with spatial and temporal information, creating semantic correlation and visualizing them on AR and VR platforms. The system is based on the AR reference model, an ISO standard that provides a standardized workflow for interoperability with other AR applications. It is effectively an extension of the project previously implemented in Changdeokgung Palace. It uses the AR framework used in the case of Injeongjeon. This framework had previously been suggested as a solution for outdoor AR tours in CH sites (Park et al., 2016). The AR application uses 6-DOF camera tracking and an ORB key point-based SFM pipeline to reconstruct key points and camera pose of keyframes. A multithreading technique was applied, where the foreground thread calculates the camera pose by solving 3d-2d correspondences, while the background thread collects new candidate key-points. The KCHDM model was used again in this instance, to collect data from the same five databases. The information model was also redesigned for mobile application users, so that they could access it without unnecessary steps or duplicated contents. The aim was to systematically manage spatial and temporal information of video in the AR system. As in the previous project, a SPARQL query was implemented for the KCTM application, to retrieve CH information from the ontology and relational database. User evaluation was in this case focused on the VR part of the application.

7.2 Knowledge Cube

An ontology, named Knowledge Cube (Elrawi, 2017) was proposed in a different project. The idea behind the project was to create a way that the multitude of complex data that are related to Islamic CH objects can be described and presented to a user through a storytelling approach. The AR aspect in this case, was in the goal of presenting 3d models of CH objects, both outdoors and through the use of portable devices or wearables, and indoors using non movable devices. A layered ontology, that uses a taxonomy development method to identify the various characteristics of CH objects (such as dimension) was proposed. This ontology also registers any available relevant metadata for each object. The application has to then use the ontology to gain access to the entirety of CH objects included. It is, however, necessary for the content creator to define all characteristics and related content for each object upon creation. This does allow all content creators to later access all the data related to an object, as identified by the ontology, making the reuse of content much easier.

7.3 City GML

A problem that occurs in the case of AR applications in urban environments would be the 3d modelling aspect. Accurate 3d modelling is a very time-consuming process when there are many 3d objects. In cases where there are multiple buildings in a certain area, an application might be considered incomplete until all, or at least most of the buildings, are presented and displayed in it. One way to overcome this obstacle, in a way, was suggested by Adao et al. (2019). Procedural modelling is, to put it simply, when the software receives input related to an object or building, such as dimensions, height, angle etc., and creates a 3d model using that data. This model might not be entirely accurate, but it would match the intended target to a degree (which is determined by the accuracy of the data and complexity of the software among other factors). The proposed methodology for procedural modelling of buildings included an ontology that relied on the City Geography Markup Language (CityGML) specification. It categorizes parts of a building according to their geometry. These parts are considered separate entities in the ontology, but still retain the connection to the overall building in its full form. Therefore, a door will be considered a rectangular object, a window with a semicircle on the top will be considered a square, and so on. All these objects, even when broken down further in geometry (the latter window would be broken down to two pieces, one large rectangle and a semicircle that is related to the rectangle by being attached to its top, for example), are separate entities. However, they are still considered parts of the overall building. In a three-dimensional space, the previously mentioned window, for example, would get such axis values that would place it on a specific wall on the building. Generally speaking, procedural modelling can be slow, depending on circumstances, accuracy and processing power used. This proposed ontology, in this case, can help alleviate that stress and perform faster and more accurate modeling of buildings. As another benefit of this approach, a database created for such a project could be used in a retrieval comparison method. To follow the previous example, the model of the window with the semicircle on top could be compared directly to a different one that was created for some other project, with the same method, and allow direct comparison between the two models. Even if the models are not 100% accurate, the general shape and geometry could still provide interesting scientific insights.

7.4 CIDOC-CRM

In the case of Anfiteatro Campano, in Santa Maria Capua Vetere, Italy, iJADE Free-Walker was presented (Renda et al., 2012). iJADE is a framework that integrates GPS, ontology and agent technologies, in order to provide location awareness and, effectively, more accurate touristic information and navigation. In this particular case, the ontology used was based on CIDOC. The authors defined 10 superclasses, which were split into three thematic areas, archaeological records, monuments and objects found in archaeological sites. The concepts of the ontology are directly visible to the user, allowing them to select and search relevant information. This gives the user much more freedom into customizing the tour to his own preference.

An ontological model for buildings for buildings was suggested (Zalamea Patino et al., 2018) specifically for preventive heritage conservation as defined by the ICOMOS charter (ICOMOS, 2003). As seen in the previous cases, the proposed solution included a combination of ontologies. In this case, the CIDOC-CRM, CityGML and the Monument Damage Ontology (Mondis) were combined into the BCH ontology. Overall, the BCH ontology included 143 classes, out of which 30 were new, while the rest originated from the other three ontologies. The ontology could possibly be used effectively in the CH domain for designing AR tours, since it can be effectively used to describe a CH object. CIDOC-CRM includes the contextual historical data, spatial information and possibly 3d models can be handled by CityGML and damages by Mondis. Even though the use of Mondis might seem inappropriate for tourism purposes, it can serve as a way to record past and possible future conservation work that might alter a specific CH site. This new ontology still needs to be validated and tested further, but the authors suggest it can be a promising new tool for both the preventive conservation field, as well as tourism and education.

In a proposal of a dissemination framework that could benefit smaller stakeholders in the CH domain, an ontology-based integration mechanism was used (Valtolina, 2016). The concept of the framework was based around digital storytelling, aiming to increase the participation of experts in the domain in disseminating information about CH objects across various physical locations, in order to promote cultural knowledge and growth rather that single museum collections. As an example, an implementation of this framework was performed for a project focusing on an information system for the Etruscan civilization. The experts on this field could use the Narration Builder tool, to create a story that focused on one particular area. The ontology-driven data access would help in classifying and linking that particular story to other relevant stories and cultural objects. The ontology used in this project was CIDOC-CRM.

Two extensions to CIDOC-CRM were proposed, with a focus on structuring knowledge about historical objects and events (Van Ruymbeke et al., 2018). Although their approach started with a conceptual data model, the Multiple Interpretation Data Model (MIDM), it was translated, to an extent, and added to CIDOC-CRM. The main reason behind this suggestion was that the authors wanted to find a way to incorporate information about the entire lifecycle of a CH item, be it past, present or future. Past restoration work, for example, could be relevant and offer insights into similar future work of a CH building, even when performed in a different area of said building. This approach certainly holds merit as way to complete the information knowledge base concerning a CH entity.

7.5 DMO

An ontology aimed primarily at museums, named Digital Museum Ontology (DMO), was suggested in 2019 (Chiarenza et al., 2019). As of this writing, it is a work in progress but, according to the authors, their tests have been encouraging. DMO can incorporate 3d digital models and museum exhibition projects with semantic relationships. These models, along with other relevant information, like documents, can be accessed when using various tours in a virtual museum. These tours can also be modified by the user, effectively offering a custom-made experience. This ontology could possibly be used in city tours if modified appropriately.

7.6 BIM

In a case that was not directly related to CH, an ontology that aimed to improve the use of Building Information Modelling (BIM) models was proposed in 2019 (Dris et al., 2019). This new ontology is based on OWL, was created by combining existing ontologies such as IFC or Conceptual BIM, and was focused on VR applications. It was created for and applied in the construction sector. This implementation offers a way to create a bidirectional link between the 3d model building database and the VR application. This link then allows for the automatic generation of object specific functions, according to the building's classification. This could potentially be of use in the development of AR applications for CH sites, if it can be applied to existing CH ontologies.

8 Metrics

An analysis of metrics concerning various ontologies was presented by Ben Mahria et al. (2020). They analyzed various characteristics of the most commonly used ontologies, with a focus on their complexity. Specifically, they investigated the Size of the Vocabulary, Average Path Length, Average Numbers of Paths per Concept, Tree Impurity and Coupling. They concluded, among other things, that ontologies can have great variations in application according to their complexity. Most CH ontologies are highly complex, making them difficult to maintain after a certain point. This complexity would also largely increase in the case of combined ontologies. The authors' suggestion is that it might be better to share and reuse current ontologies, rather than attempt to create entirely new ones.

9 Discussions and Implications

From all the case studies mentioned above, we can come to certain conclusions. To start with, we look at Table 2 for the most commonly used ontologies.

Ontologies used in reviewed articles	
Case Study	**Data model used**
Anfiteatro Campano (Renda et al., 2012)	CIDOC
Built CH (Zalamea Patino et al., 2018)	BCH - CIDOC-CRM, City GML, Monument Damage
Custom Museum Tours (Chiarenza et al., 2019)	DMO
Hermeneutics (Daquino et al., 2020)	SPAR, CIDOC-CRM, HiCO, PROV
Injeongjeon (Kim et al., 2016)	KCHDM
Interconnected OWL Ontologies (Tomasi et al., 2015)	GO!, HiCO, Proles
K-Culture Time Machine (Park et al., 2018)	KCHDM
Knowledge Cube (Elrawi, 2017)	Proposed new ontology
Multiple Interpretation Data Model (Van Ruymbeke et al., 2018)	CIDOC-CRM extensions
Procedural Model Generation (Adao et al., 2019)	Proposed new ontology, based on City GML
Storytelling Driven Framework (Valtolina, 2016)	CIDOC-CRM
Tomb of Emperor Qianlong (De Luca et al., 2013)	CIDOC-CRM
Visual and Iconographical Representations (Carboni and De Luca, 2019)	VIR, extension of CIDOC-CRM
Zeri Photo Archive (Daquino et al., 2017)	CIDOC-CRM, HiCO, PRO, FaBiO, PROV

Table 3: Ontologies used in reviewed articles.

It is obvious that CIDOC-CRM is the most common ontology, though usually in combination with others, with HiCO a close second. KCHDM is the most common data model, that is used on its own, but it applies specifically to Korean CH. It could, potentially, be modified and expanded to include other CH objects. It generally seems, however, that the combination of ontologies might be the most complete and fully descriptive way to catalogue a CH object.

Instances of Ontologies	
Ontology	**Instances**
CIDOC-CRM	8
HiCO	3
CIDOC-CRM Extensions	2
PROV	2
City GML	2
KCHDM	2
Other	8
New Ontology	2

Table 4: Instances of Ontologies used in reviewed articles

The overall varied use of ontologies does suggest that, as of yet, there is no standard set for use in the CH domain. Ontologies are varied and this variation leads to incompatibilities across projects. That essentially means data from one project cannot be easily incorporated into another, effectively cancelling out a benefit that ontologies could potentially offer to the field as a whole, which is interconnectivity across projects.

10 Suggestions for CH Data

It seems that a model similar to the one suggested in 2020 (Daquino et al., 2020) will be more than adequate to describe urban CH. This new ontology would be a modified 3-layer (or perhaps even 4-layer) data model with CIDOC-CRM as layer 0, that can handle the descriptors and basic information of the object. A supplementary layer could potentially be inserted here, that would capture any related background information. Layer 1 would consist of a HiCO ontology that would include relevant context and relations. Finally, layer 2 can possibly be a BCO ontology that includes relations to museum collections specifically. Another possible supplementary layer could include the modified City GML ontology, that could work both for fully and not digitized buildings, in order to record their geometry. This could help alleviate the stress and technological limitations on an AR device, not to mention the scientific benefits such a database could provide.

One could suggest designing a completely new ontology, similar to what was done in the case of BCH, DMO and KCHDM. In those instances, the authors found the ontologies that already existed as insufficient in some way and created new ones. This could lead to an ontology that could potentially describe all aspects of CH entities. An issue that could arise in that case, would be the complexity of such an ontology, which is also true in the case of combining multiple ontologies. It seems that, while both proposals have their merits, it really comes down to the less complex and more elegant solution.

11 Conclusions, Limitations and Future Research

This paper attempted to look at ontologies in AR CH applications over the last few years. The overview could benefit researchers, by showing the variation in methodology and data models that exists. It could potentially lead to a framework that encompasses various ideas and ontologies, into a set standard that can effectively describe CH entities and can be used in multiple projects, ensuring compatibility of data across various applications. The suggested ontology or modification to existing ontologies, based on previous research, can offer an effective way of dealing with CH data and the interconnection that needs to be achieved, to effectively describe them.

This review could benefit stakeholders in the CH domain, since it shows an overall preference in the ontologies used to CIDOC-CRM. It is important to note that it is commonly used in combination with other ontologies or extensions. Therefore, an organization designing such a project could look to some of the solutions in the articles previously reviewed or even develop a model appropriate for their specific project.

Future research could focus on the ontologies themselves, as to determining if there is indeed a single one that could potentially become the standard. That could either be an existing ontology, or even a completely new one. Or it could even be a layered data model that contains a combination of ontologies, as mentioned previously. The specifics of each ontology, in depth, would need to be examined and compared, to determine their adequacy. The need for a completely new ontology is yet undetermined at this stage. Existing ones might still be able to completely describe some CH objects, though the question remains if they can describe all types to a satisfactory degree. They could reach that stage in combination, though they will become very complex. Further research into the complexity of each case would then be necessary, as they grow within a project by data input. This issue might not be as important, however, depending on technological advancement, as more powerful computers could offset the need for simpler ontologies.

In our opinion, the best choices would be either a standard framework that guides the use of each ontology to specific use cases, or a completely new ontology, as discussed before, made specifically to encompass the entirety of CH object types.

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