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ONTOLOGIES FOR AR IN CULTURAL EDUCATION: STATE OF THE ART AND PERSPECTIVES

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Abstract

Augmented Reality promises to revolutionize the visit and exploration of Cultural Heritage sites. In order to aggregate and interconnect heterogenous contextual data from multiple sources ontologies can be used in the development of the Augmented Reality applications for Cultural Heritage. This study reviews ontologies and data models used in Augmented Reality applications for Cultural Heritage in urban environments. In most cases, a combination of ontologies was used. The most frequently used ontologies include CIDOC-CRM and HiCO. The most common data model is KCHDM.

Keywords: Augmented Reality, Cultural Education, Cultural Heritage, Cultural Objects, Data Models, Ontologies.

1 INTRODUCTION

The Cultural Heritage (CH) domain has been in the spotlight in recent times. Contemporary technological advancements have offered new ways and ideas on both how to gather information from the end user and also how to present information to the end user. In particular, Augmented Reality (AR) has attracted a lot of attention in the CH domain recently, due to its three main advantages: portability, ease of access, and ease of use [1]. Even before the global lockdown and travel restrictions caused by COVID-19, the studies and projects in the CH domain had seen a significant shift towards AR applications.

The main discussions in this new collaboration between the fields of CH and Computer Science have also been focused on how the cultural data are presented to the user, as it is investigated in the publications reviewed below.

This review focuses on the ontologies and data models used to describe CH sites in cities. The goal is to identify the ontology or ontologies that would be best used for AR CH applications in urban environments. The next section presents the methodology used. Section III presents an overview of data models and ontologies currently used, while section IV presents ontologies and data models proposed or implemented. Section V presents case studies of using CH data in AR applications. Finally, section VI concludes.

2 METHODOLOGY

In order to find articles that describe ontologies and data models for AR applications for cultural heritage sites in urban environments, an exhaustive search was done using scholar google and scopus. Searching the string (“Augmented Reality” AND “Cultural Heritage” AND Ontology) in the titles of articles in google scholar gave three results, while searching in the titles, abstract and keywords of documents in scopus gave 12 results. Broadening the search string to (“Cultural Heritage” AND Ontology) gave 120 results in google scholar and 655 results in scopus. Looking at the abstracts of these documents, we tried to identify articles that analyze the use of ontologies and data models in CH applications that would be also suitable for AR CH applications. Next, this study reviews such articles and presents the findings.

3 CULTURAL HERITAGE DATA AND ONTOLOGIES

Cultural Heritage Data includes a wide spectrum of both tangible and intangible legacies. It can include virtually anything handed down from previous generations, from a building or artifact to a song or cooking recipe, and from a dance or legend to a tradition and a myth. The exploitation of such data has many applications, from preservation and facilitating access, to exploration and creation of links for the discovery of other information. 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 [2].

The very first problem encountered, when working with such a large amount and types of entities and relevant information, has been how to effectively classify data. It is possible to describe most, if not all, archaeological sites or buildings in an area via a standard framework, but there will still be a few that require more descriptors. Even so, it will then be impossible to use the exact same data ruleset to describe oral tradition or works of art. This issue becomes even bigger for CH sites embedded in an urban environment.

Classifying such data is, obviously, a challenge. There should be an established framework for storing the data properly before collecting it. This framework has to be efficiently planned having in mind its presentation to the end user. So, the data model is possibly the first vital milestone in such a project. In the case of urban environments, this becomes an even larger issue, simply due to the amount of data related to existing CH sites.

Researchers have recently developed ontologies specifically for CH data. Reference [3] listed the following ontologies that have been used in the CH domain:

- CIDOC CRM: CIDOC Conceptual Reference Model (CRM) is an ontology for concepts and information in CH and museum documentation. It is an event centered ontology that contains temporal entities and a set of entities on those events [4].
- AAT ontology: Art & Architecture Thesaurus (AAT) uses a standardized and controlled vocabulary for users, for information management in art and architecture [5].
- BIBO ontology: 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 [6].
- FRBR ontology: 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 [7].
- CiTO ontology: Citation Typing Ontology (CiTO) characterizes the nature or type of citations. It is restricted to works that cite or are being cited [8].
- FaBiO ontology: FRBR-aligned Bibliographic Ontology (FaBiO) concerns primarily publishable elements that employ or are referenced by bibliographic references or entities used to define such bibliographic references [8].
- HiCO ontology: Historical Context Ontology (HiCO) describes the historical context of CH objects [9].
- BCO ontology: Biological Collections Ontology (BCO) aims to improve interoperability of biodiversity data, including data on museum collections, environmental/metagenomic samples and ecological surveys [10].

Out of the aforementioned ontologies, the ones most recently updated were CIDOC CRM, HiCO and BCO. Table 1 below lists these ontologies and the date when they were last updated.

Table 1. Updated Ontologies.

Ontology	**Last updated**
AAT: http://www.getty.edu/research/tools/vocabularies/aat/index.html	March 2017
BCO: https://purl.obolibrary.org/obo/bco.owl	March 2020
BIBO: https://bibliontology.com/	April 2009
CIDOC CRM: http://www.cidoc-crm.org/	March 2021
CiTO: http://purl.org/spar/cito	February 2018

FaBiO: http://purl.org/spar/fabio	February 2019
FRBR: http://kcoyle.net/beforeAndAfter/index.html	September 2015
HiCO: http://hico.sourceforge.net/	March 2020

The following Table 2 provides a comparison on some of these ontologies [3]. Each ontology is presented as a set of linked classes, while each class has a certain number of properties that describe its structure.

Table 2. Ontologies Comparison.

Ontology	Application Domain	Classes Concepts	Properties	Format
AAT	Art, Architecture	37058	-	RDF/XML, NT3
BCO	Biodiversity Data	157	209	OWL/CSV/RDF-XML
BIBO	Bibliographic	69	106	RDF, RDFS, OWL
CIDOC CRM	Cultural Heritage, Museum Documentation	86	283	RDFS/OWL
CiTO	Citations	9	109	OWL 2 DL
FaBiO	Bibliographic	250	94	RDF/XML, OWL, Turtle, N-Triples, Json-LD
FRBR	Document	13	59	RDF/XML, OWL, Turtle, N-Triples, Json-LD
HiCO	Historical Context	25	162	OWL 2 DL

In Table 2, CSV stands for comma-separated values, OWL for Ontology Web Language and XML for eXtensible Markup Language. OWL 2 DL is a newer version of OWL. N-Triples is a plain text format for encoding an RDF graph. Turtle stands for Terse RDF Triple Language. Json is a data serialization and messaging format, while Json-LD is a Json-based format to serialize linked data [11].

4 ONTOLOGY CASE STUDIES

Ontology Web Language (OWL) is a family of knowledge representation languages for authoring ontologies. Reference [12] investigated interconnected OWL ontologies, in particular GO!, HiCO, and Proles, exploring the semantic content of heterogeneous digital collections in CH. Each one of these ontologies can describe a certain aspect of a CH entity. GO! defines space and places in a geographical dimension; Proles defines people within a role in a space/time-indexed situation; and HiCO manages the relationships between cultural objects and an entity considering an interpretation about the object itself. They found that HiCO can represent a superstructure to describe how places, events, roles, and relations described in datasets are bound to cultural objects. GO! and Proles can be used to enrich description of relations. So, HiCO can be used as an overall ontology that can connect to other ontologies that perform much better in their suited tasks.

Reference [13] proposed an ontology framework trying to fully describe an object in relation to its context. In art history and, in their case, iconography, the object-centric descriptors could not fully describe the entire relation structure of a specific artefact. To solve this problem, the authors extended the CIDOC-CRM model with the Descriptions & Situations extension of DOLCE, developed in another project [14]. Reference [15] performed an analysis and documentation on the tomb of Emperor Qianlong in China, and inserted the information in spatial elements around a 3D model, linked to their referenced items. The authors eventually decided to use CIDOC-CRM along with a new ontology, VIR (Visual and Iconographic Representations) for their particular project. The Zeri Photo case [16] was perhaps the most interesting of the reviewed cases. The solution in this case included two ontologies developed to map data coming from two different Italian standards developed by the Istituto Centrale per il Catalogo e la Documentazione (ICCD). They were mapped with CIDOC-CRM and HiCO in combination, PRO and FaBiO, while also using an extension and mapping to a PROV ontology. This eventually led to the model described below.

This data model aims to represent hermeneutical aspects of literary sources, using Semantic Web technologies [17]. Ontologies in hermeneutics focus on questionable statements that are stated and recorded in a source. A summary of the requirements 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.

The data model used was a 4 layered one, as detailed below:

- Layer 0 (SPAR ontologies for bibliographic resources, CIDOC-CRM for cultural objects) was comprised of factual data that is part of the scholars' background knowledge. This layer answers the questions of what artifacts are part of this discourse and what is the logical organization of their components.
- Layer 1 (mostly CIDOC-CRM) described the scope of the scholars' questionable statement. This layer answers the question of what an agent argues about.
- Layer 2 (HiCO ontology) describes the context information for hypotheses assessment and answers the question of what type of claim is it, who claims it, when and what is the primary source and degree of certainty.
- Layer 3 (PROV ontology) describes the provenance information of the mining processes and answers the question of who is responsible for the machine-readable version of the statement.

The proposed data model is valuable for hermeneutical sciences, as it can formalize aspects that characterize the approach used by most scholars. It also offers a data model that uses multiple ontologies, each suited to a particular task.

5 AR CH ONTOLOGIES

There have been some uses of AR in CH that merit special consideration, especially in relation to the subject of the exploitation of CH sites in urban environments.

One such project was implemented in the Republic of Korea [2], in Injeongjeon, the main hall of the Changdeokgung Palace, a UNESCO World Heritage site. The project developed 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 Cultural Heritage Data Model (KCHDM). KCHDM differs from those developed by ICOM and Europeana in that it suggests using data extracted from a description as instances and properties, through an analysis of Korean sentence pattern. KCHDM uses contextual data in text-based descriptions as entities, rather than using descriptive metadata.

Another interesting case in Korea, the K-Culture Time Machine [18], 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. It is, in effect, an extension of the work done in the project previously implemented in Changdeokgung Palace, as it uses and expands on the AR framework proposed for that project. The KCHDM model was used once again, to collect data from the same five databases. In this case, four types of web resources (text, audio, image, and video) were linked to each

CH entity. Three existing metadata sets, “W3C core set of multimedia metadata”, “Metadata Element and Format for Broadcast Content Distribution”, and “Metadata Schema for Visualization and Sharing of the Augmented Reality Concepts” were referred to, for designing the metadata element and schema.

Another ontology, named the Knowledge Cube, was proposed in 2017 [19]. The goal was to present a multitude of complex data regarding Islamic CH objects in a comprehensive manner, using a storytelling approach. Specifically, it aimed to eventually use AR in order to display 3d models of CH objects, either through portable devices or indoor fixed devices. The application has to access the database of cultural objects via the layered ontology proposed. The ontology itself uses a taxonomy development method in order to identify characteristics of CH objects, such as dimensions, while it also includes relevant metadata for each object. During the input of information, the designer has to define the characteristics and related content, making it easier to, later on, access all relevant data identified by the ontology and effectively introduce it into the scenarios through the storytelling editor.

A very interesting idea concerning the procedural modeling of buildings, using ontology-based grammar rules, was presented in 2019 [20]. The proposed methodology included an ontology that relied on the City Geography Markup Language (CityGML) specification. It attempts to create a knowledge-based skeleton to control any procedural operations, by defining the boundaries of any known geometry. To explain it simply, it effectively categorizes buildings’ parts with geometrical aspects, while it still considers them distinct entities. Therefore, while a window is assigned a specific geometry and is then a separate entity, it still retains the connection it has to the building it originated from. This allows for faster and more accurate procedural modeling of buildings, while also subdividing them into separate entities that can be manipulated on their own. For example, the windows of a certain church can be directly compared to others, through the use of this methodology.

An ontological model was suggested [21], concerning built CH, specifically for preventive heritage conservation as defined by the ICOMOS charter [22]. A combination of ontologies was proposed, which included CIDOC-CRM, the Geneva CityGML and the Monument Damage ontology. While the model was proposed specifically for built CH, it shows that combining ontologies seems to be the common approach in recent years.

An analysis of metrics concerning various ontologies was presented in 2020 [23]. By measuring characteristics like size of vocabulary, tree impurity, coupling, average path length and others, the evaluation determined that ontologies can be substantially differentiated according to complexity. It determined that all CH ontologies are highly complex and suggested that it is better to share and reuse these ontologies, rather than create entirely new ones. It was also mentioned, however, that the existing CH ontologies are generally not easy to maintain.

6 DISCUSSION AND CONCLUSIONS

This study reviewed ontologies and/or data models used in various case studies of AR applications in Cultural Heritage. Table 3 summarizes the findings

Table 2. Ontologies and Data Models in Case Studies.

Case Study	Ontology used	Data model used
Interconnected OWL Ontologies	GO!, HiCO, Proles	
Art History and Iconography	CIDOC-CRM with DOLCE DS Extension	
Tomb of Emperor Qianlong	CIDOC-CRM, VIR	
Zeri Photo	CIDOC-CRM, HiCO, PRO, FaBiO, PROV	
Hermeneutics	SPAR, CIDOC-CRM, HiCO, PROV	

Injeongjeon		KCHDM
K-Culture Time Machine		KCHDM
Knowledge Cube	(proposed ontology)	
Built CH	CIDOC-CRM, City GML, Monument Damage	

CIDOC-CRM seems to be the most commonly used ontology, often in combination with other ontologies. Also, HiCO is a frequently used ontology, again in combination with other ontologies. KCHDM is the most common data model, but it is used in very specific cases, since it was designed specifically for Korean CH.

The combination of ontologies appears to be the most complete way to describe a CH object. It would seem that a model similar to the one suggested in 2020 [17] will be a good fit to urban CH projects. Even though the current ontologies are already quite complex, it seems that combining them is the best course of action, in order to completely describe a CH object. A suggestion for an ontology that would fit most CH AR application in urban environments, would be a modified 3-layer data model with CIDOC-CRM as layer 0, that can handle the descriptors and basic information of the object (or even 2 layers in this case, the second layer holding all the 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.

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