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Short Paper

Stratigraphic Units beyond Archaeological Contexts. A Proposal to Enhance Knowledge Management of Heterogeneous Data of Cultural Heritage Sites

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Abstract

This paper introduces BranCO, an ontology tailored for the integration and reconstruction of heterogeneous cultural data, illustrated through the Brancacci Chapel in Florence. Central to this model is the concept of the "interpretative unit," which broadens the application of stratigraphic units (SU) beyond traditional archaeological use. The initial sections provide an overview of existing research, among which the Extended Matrix, and analyses the implementation of SU within semantic models for cultural heritage, as in the CIDOC-CRM standard and its extensions such as CRMarchaeo. On this basis, the paper outlines the main components of the ontology, developed following the SAMOD methodology. The satisfaction of both formal and rhetorical requirements highlights the potential for advancing this research, particularly to later integrate linked data with semantic nodes in 3D models.

CCS Concepts

• ***Computing methodologies*** → ***Ontology engineering;*** • ***Applied computing*** → ***Arts and humanities;***

1. Introduction

Research on audience participation and engagement showed the importance of storytelling for visitors' perception and appreciation of cultural objects or sites (see e.g. [Pal17]). In particular, these narratives should accompany visitors in the exploration of the history of an artwork, its preservation and its state of conservation. Communication of curators, heritage scientists and professionals is therefore of paramount importance in creating both accessible experiences for vast audiences and preserving the rigour and the scientific validity of scholarly research.

To properly document the analysis and reconstruction of a site, archaeology traditionally relies on the "stratigraphic diagram", also known as Harris' Matrix [Har79], through which chronological relationships between the various Stratigraphic Units (SU) may be asserted. These units are a cognitive base for the understanding and examination of the context, as they can integrate chronological information of absolute nature resulting, for example, from the study of finds or from dendrochronological and radiometric dating [Cos19].

This approach encountered also a vast application in the field of *virtual* archaeology to ensure the scientific reliability of the digital reconstruction [FPF*14] [PF21]. An example is the *Extended Matrix* (EM): it translates the stratigraphic approach into a full conceptual model formalised into a visual palette for the diagram editing application yEd which can be integrated in Blender [Dem18]. It includes and defines not only archaeological stratifications (the superimposition of single units of stratigraphy) but also their hypothetical reconstructions (the Virtual Stratigraphic Unit - USV). Furthermore, paradata on the cited sources and the entire interpretation processes can be accounted and directly visualised on a 3D Model, via the integration EMviq for the web framework ATON (see Sect. 2) [DEM*20].

Despite these potentialities, examples of the implementation of EM in non-archaeological contexts are scarce as it fails in capturing processes that are typical in the art-historical research (e.g authorship attribution). In this ongoing research, we therefore investigate whether SUs can succeed in describing scholarly analyses beyond their traditional archaeological applications. We hypothesise a possible solution to this research question with the concept of *interpretative units* (IntUnits), defining their possible applications in an OWL2 ontology, starting from a real case study, i.e. the Brancacci Chapel in Florence. In this contribution, we discuss the current state of the art, the adopted methodology and the main entities of the model. The satisfaction of formal and rhetorical requirements encourages a more structured test with real-data and future research to design visualisation systems able to communicate in 3D semantic annotations the complexity of the hermeneutics process on cultural heritage (CH).

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2. State of the art

Existing ontologies for the description and the reconstruction of cultural sites do not introduce *interpretative* units, whereas the use of *stratigraphic* units is mostly limited to archaeological case studies. Numerous projects indeed rely on CIDOC-CRM [BBC*24], the international standard for metadata description of cultural heritage, and its integration CRMarchaeo, explicitly tailored for archaeological excavations [GPKC21]. This latter model declares a specific class for the stratigraphic unit: A8 Stratigraphic Unit. The asserted axioms indicate that it is generated by an event (A4 Stratigraphic Genesis) and is conceived as subclass of S20 Rigid Physical Feature, i.e. the intersection of a tangible E26 Physical Feature and E53 Place defined in another integration of CIDOC-CRM, CRMsci [GPKC21].

Such a definition of stratigraphic unit in the semantic web is still not unique and other proposals have been put forward. An example is provided by ARCO, a network of ontologies of National Research Council (CNR) and the Istituto centrale per il catalogo e la documentazione (ICCD), which is to become an Italian national standard for the Cultural Heritage domain [CGM*19]. In partial similarity with CRMarchaeo, it defines stratigraphic unit class in the "Context Description Ontology" as subclass of location.

On the other hand, identifying the newly introduced interpretative unit (IntUnit) as specification of a place could be reductive, since it fails in capturing the semantics of the virtual stratigraphic unit at the very core of the Extended Matrix [Dem15], on which this model in part relies. As seen, this conceptual model – which is however not defined as an OWL ontology - distinguishes between the "archaeological remains" (i.e. SU), and their "hypothetical presence", that is "the likelihood of a specific SU having existed in the past" (the VSU).

The stress on the *hypothetical* nature of this latter concept may suggest how the future model could rely on CIDOC-CRM E89 Propositional Object class, i.e. "set of propositions" about cultural heritage. In addition, this latter entity is intimately connected with the concept of "interpretation", which has been deeply scrutinised in ontology design research. Even though a possible solution is provided by the integration CRMinf [Ste23], which translates into RDF the core model for assertions making [DKB11], the Historical Context Ontology (HICO) is a valid alternative which is gaining popularity in semantic web applications to cultural heritage [DT15]. It consists of a light model for the description of interpretation acts in humanities and historical sciences, detailing the provenance of assertions on cultural heritage, for example debated authorship of an artwork (see Figure 1).

Lastly, as already in the Extended Matrix, among the requirements of the new ontology the possibility of expressing a connection between scholarly data and digital objects is of paramount importance. Other projects, in particular the study by Messaoudi and colleagues [MVHDL18], proposes as reference the CIDOC-CRM integration CRMdig [DST16]. This model is particularly helpful because it describes digital acquisition processes and can detail data objects together with semantic annotation. This semantics lays the basis for a full integration of future knowledge graphs built upon this conceptual model with 3D visualisation framework such as ATON (`https://osiris.itabc.cnr.it/aton/`) [FFD*21].

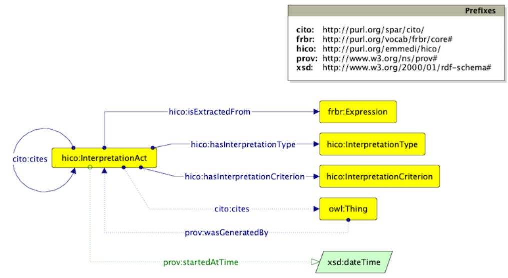

Figure 1: *Conceptual model of the Historical Context Ontology [DT15]*

This WebXR framework, developed by Italian CNR – Institute of Heritage Science, allows user to add semantic nodes and already offers an integration for Extended Matrix, EMviq [DFC23].

The future conceptual model shall maintain these milestones, integrating the new concept of the interpretative unit.

3. Methodology

For the construction of the ontology, the Simplified Agile Methodology for Ontology Development (SAMOD) has been applied [Per16]. The protocol, which is being increasingly applied in ontology design (127 citations as per June 2024), consists of an iterative procedure relying on the collaboration of an ontology engineer (OE) and domain expert (DE), as described in Fig. 2:

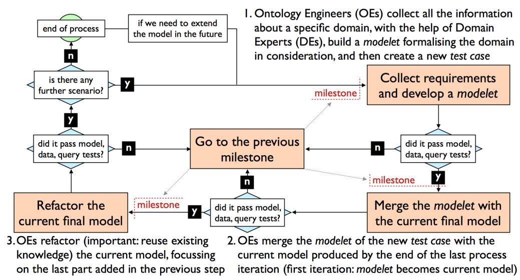

Figure 2: *Visualisation of SAMOD Protocol [Per16].*

The methodology is based on scenarios, described by both the OE and DE: the domain the final ontology aims at describing is subdivided in multiple scenarios which focus on a specific aspect. They consist of a brief natural language description, accompanied with a set of relevant examples and with corresponding questions (in natural language) the final model should be able to answer to (i.e. competency questions).

On these materials, the OE can build a modelet, i.e. a stand-alone model in OWL 2 language describing the scenario, which is tested to detect possible inconsistencies (formal requirements). Later, a minimal knowledge graph is generated starting from the given examples and is queried in SPARQL language following the original competency questions (rhetorical requirements). If both classes of requirements are met, a milestone is released. At the end of every iteration, milestones are merged and refactored, and for each of these two stages both formal and rhetorical requirements are checked anew. During refactoring, annotations for entities are added and classes or properties of other existing models are directly imported. In the current study, the direct import has been limited to CIDOC-CRM (and its compatible models) and HICO (which in turns reuses properties of CITO, the Citation Typing Ontology [PS12]).

For the construction of the model, the different steps of SAMOD have been completed with the following tools:

- modelets have been first drafted with the Graffoo palette (`https://essepuntato.it/graffoo/`) [FGP*14] for yEd (`https://www.yworks.com/products/yed`). The conversion into *.owl files has been instead performed in Protégé (`https://protege.stanford.edu/`).
- formal requirements have been checked with both HermiT 1.4.3.456 reasoner, embedded in Protégé (`http://www.hermit-reasoner.co`), and the web service OOPS! (`https://oops.linkeddata.es/`) [PVGPSF14]
- satisfaction of rhetorical requirements has been verified manually and through the execution of SPARQL queries with the ad hoc Protégé plug-in (`https://protegewiki.stanford.edu/wiki/SPARQL_Query`).

4. Definition of the Conceptual Model

The final ontology, named Brancacci Chapel Ontology (BranCO), since it has been designed choosing the Brancacci Chapel in Florence as first case study, consisted of three different SAMOD iterations; the step-by-step implementation of this protocol is fully documented in the online GitHub repository of the project (`https://github.com/dhilab-fi/branco`). Fig. 3 provides a Graffoo visualisation of the relationships among the different entities of the ontology. Refer to the full online documentation, created with LODE [PSV13], at the following link (`w3id.org/cnr-ispc/ontology/branco`) for a more thorough description of the entities of the ontology.

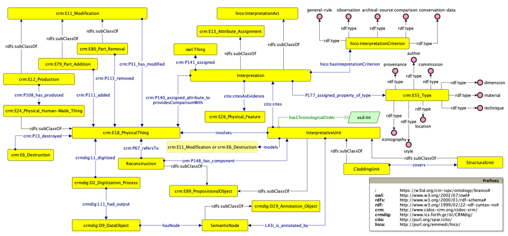

Figure 3: *Visualisation of BranCO final conceptual model.*

The first scenario pertains to the definition of the reconstructive process and puts into relation the final reconstruction, in which different interpretative units are systematised, with digital models. In particular, in the modelet the IntUnits are defined as subclass of a crm:E89_Propositional_Object, whereas the artworks (instance of crm:E18_Physical_Thing) can be digitised into a crmdig:D9_Data_Object. The property crmdig:43i_is_annotated_by enables to associate pieces information retrieved in a single interpretative unit to specific semantic nodes in the 3D model (as it can be visualised in the aforementioned frameworks ATON and EMviq).

The second scenario, instead, better describes the interpretative units, which model possible events affecting the cultural object. CIDOC-CRM class hierarchy already provides a possible taxonomy of these events, in particular the class crm:E6_Destruction and crm:E11_Modification, together with its three sub-classes E12_Production, E79_Part_Addition and E80_Part_Removal. The scenario also introduces the differentiation between structural and cladding units (e.g. a wall and the fresco) which allows a greater granularity of examination and to provide more precise pieces of information to single elements of the decoration. Furthermore, the data property branco:hasChronologicalOrder (newly introduced entities are here declared with the prefix branco:) enables to chronologically order the different IntUnits, as in traditional archaeological Matrix.

Lastly, the final SAMOD iteration pertains to the description of the scholarly interpretation processes involved in the analysis of IntUnits. To the best of our knowledge, no full alignment with CIDOC-CRM is available for HICO: as a result a new class branco:Interpretation has been declared as intersection of hico:InterpretationAct and crm:E13_Attribute_Assignment. Thanks to the property hico:hasInterpretationCriterion, it is possible to assert the criteria adopted in the interpretation act via a controlled vocabulary (the current version, v. 0.9.0, of the ontology includes the following individuals, mainly derived from EM: archival source; comparison, in combination with the property branco:providesComparisonWith; diagnostic data; general rule; direct observation, which has been added to group the evidence which may be found via a direct inquiry of the cultural object). The reuse in HICO of the ontology CITO permits to declare possible references or cited scholarly interpretations (the property cito:cites does not have domain nor range restriction).

The property asserted during the scholarly interpretation is declared via crm:P141_assigned, whereas crm:P177_assigned_property_of_type can be adopted to specify its type. Similarly to the interpretation criterion, also in this latter case a controlled vocabulary has been made available. BranCO v. 0.9.0 includes nine different individuals and suggests the use of the following classes in the range of crm:P141: material (crm:E57_Material); technique (crm:E55_Type); dimension (crm:E54_Dimension); location (crm:E53_Place); author (crm:E39_Actor); commission (crm:E39_Actor); provenance (crm:E39_Actor); iconography (crm:E36_Visual_Item, with a possible integration of the Visual Representation Ontology - VIR, `https://w3id.org/vir` [CDL19]); style (crm:E55_Type). For each of them, interpretations may be supported by the recognition of specific features in the cultural object.

5. Conclusions and Future Works

In this study we describe a first conceptual model aimed at implementing the concept of stratigraphic unit beyond its traditional application in archaeological sites. The model, in particular, is named *Brancacci Chapel Ontology* (BranCO) since it has been designed starting with Brancacci Chapel as a first case study. The description

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of the data gathered in recent diagnostic and restoration campaign on the Florentine site showed the necessity to adapt existing tools also to non-archaeological contexts.

More specifically, the project considered as a major starting point the Extended Matrix by Demetrescu, a conceptual model (yet not defined as an OWL ontology) which relies on Stratigraphic and Virtual Stratigraphic Units for the description of archaeological excavations and reconstructions of these contexts. Additionally, it provides integration for Blender and for subsequent visualisations in the WebXR framework ATON.

Relying on the major results of this initiative and on the most relevant model for CH semantic description (in particular CIDOC-CRM and its compatible models), we developed an ontology following the SAMOD protocol: based on an iterative process of scenarios definition, modelet design and testing, this approach ensures the logical consistency of the final ontology. Conversely, the testing of the semantic expressivity of this model is still in a preliminary stage.

Since BranCO integrates CRMdig entities for the description of digitisation practices, digital reproductions and annotation of cultural heritage, the final goal of this ongoing project is the design and development of a new ATON-based visualisation system, in which scholars will be supported in the storage of CH data to semantically annotate 3D object. This future tool hopes to enhance visitors' engagement and participation to CH, enabling non-specialist audiences to understand and touch with hand the full scholarly interpretative and reconstructive process concerning cultural artefacts and sites.

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