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The Brancacci Chapel from the Quattrocento to the semantic web: An ontology-assisted case study of cultural data management and site reconstruction

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ABSTRACT

This study proposes an ontological model for cultural heterogeneous data and cultural site reconstructions. It is based on the concept of *interpretative unit*, which extends the semantics of stratigraphic units also to non-archaeological contexts. The ontology is named after the case study of this research, the Brancacci Chapel in Florence. Indeed, after a state of the art overview of the development methodology and the description of the most relevant entities, a first test case is proposed. An entry of the catalogue of a recent exhibition on Masolino, a 15th century painter who worked at the decoration of the chapel, has been serialised as Turtle file and the semantics of knowledge graph has been assessed via competency questions. The positive results encourage the deepening of this line of research in the direction of connecting linked data with nodes in 3D models, as well as their visualisation and communication to non-specialist audiences.

1. Introduction

Eliciting visitors' interest towards Cultural Heritage (CH) is a priority for curators and heritage scientists. In the past, numerous studies have demonstrated how storytelling plays a pivotal role in shaping audience perception and appreciation of cultural objects (see e.g. Palombini, 2017). Well-designed narratives can make visitors feel "immersed in the artwork", allowing them to discover its history from the moment of its creation to the present day. In every artefact of historical-artistic or archaeological interest, indeed, it is possible to unveil pieces of information about its production, use and state of preservation, through which its history can be reconstructed.

Professionals engaged in the study, conservation and valorisation of CH must ensure that the full history of an artefact can be understandable beyond their specialised community. This involves answering key questions: where, when, by whom, with what materials, and using what techniques an artefact was produced. Therefore, it is necessary to "dig" beneath and/or into its surface, bringing to light everything that is not visible to the naked eye, such as the composition of the materials, preparation technologies, the artist's revisions, and other significant details. These elements may also include bibliographic sources, archival materials, and diagnostic analyses. If correctly put into relations, they enable the reconstruction of the different phases of the history of the studied artefact. These can be seen as *chapters* of a *book*: in their dissemination, the research community shall adopt communication and participation strategies to be understandable to wide and heterogeneous audiences, while - at the same time - allowing specialists to access all the collected data.

To satisfy this double need, archaeology traditionally relies on the *stratigraphic diagram*, also known as Harris' Matrix (Harris, 1979). As described more in detail in Sect. 2.1, this makes it possible to create a chronological relationship between the various *stratigraphic units* (SU), a cognitive base on which the history of the investigated archaeological contexts can be constructed. SUs can be integrated with the chronological information of absolute nature resulting, for example, from the study of finds or from dendrochronological and radiometric dating (Costa, 2019). This tool encountered a vast application also in the field of *virtual* archaeology: in this context, it is necessary to deal with a wide variety of information and data, both historical and archaeological, that are difficult to interpret even by researchers but above all to communicate outside the scientific community. In many cases, these data remain hidden to

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users who thus have a vague perception of the entire workflow and are left with no idea of the metadata used to construct and ensure the accuracy of the models (Ferdani et al., 2014). The objective of virtual archaeology is not only the digitisation or the production of a replica or a fixed "model", but also the re-use of these tools as an additional resource to verify reconstructive hypotheses and the communication of what is no longer preserved and visible to the general public (Pietroni and Ferdani, 2021).

Starting from the concept of Harris' Matrix, over the last few decades different tools have been developed. An example is the Extended Matrix (EM), a framework that extends the stratigraphic approach to the recording and managing of the re-constructive record, to communicate to a vast audience the results of archaeological research (Demetrescu, 2018). It consists of a graph visualisation, formalised as a palette for the diagramming program yEd and fully integrated into Blender, where it is possible to include and define not only archaeological stratifications (the superimposition of single units of stratigraphy) but also their hypothetical reconstructions (the *virtual stratigraphic unit*, USV). Furthermore, the sources and the whole interpretation processes (*paradata*) that have led from archaeological evidence to the reconstructive hypothesis (Ferdani et al., 2020) can be described. In addition, all these data are directly accessible from the 3D model. In this way, the reconstruction is not merely visualisation, but becomes part of an interpretative and cognitive process. Nonetheless, examples of the implementation of this conceptual model beyond archaeological sites are scarce: the EM[1] may fail in capturing specific processes which are rare in archaeology but characterise the art-historical research of other historical periods.

To this end, a meaningful example is offered by the Brancacci Chapel, located in the left transept of the church of Santa Maria del Carmine, in the Oltrarno district of Florence. In 1422 Felice Brancacci, a prominent Florentine merchant and patron of the chapel, commissioned Masolino da Panicale and the young Masaccio a complex fresco cycle on humanity's salvation and the life of St. Peter (*historia salutis*). However, these were left incomplete due to Masolino's departure to Hungary and Masaccio's untimely death in Rome in 1427. Soon after, the Brancacci family was exiled by the Florentine Republic, and any reference to them was erased from the cycle (*damnatio memoriae*). It was not until the early 1480s that the finalisation of the fresco was commissioned to Filippino Lippi, who completed the missing scenes and repainted the erased faces.

For the exceptional quality of these paintings the Chapel became a source of inspiration for artists of all times. Nonetheless, the chapel and its original decorations faced multiple threats, including Baroque alterations in 1680, loss of original frescoes during the intervention by Vincenzo Meucci (1746–1748), and even a devastating fire in 1771. In recent years, new elements of this complex history have been unveiled by numerous restoration and diagnostic campaigns.[2] In a nine years (1981–1990) restoration campaign, heritage scientists studied the original appearance of the site and even detached the sinopias of two lost semi-lunettes by Masolino and Masaccio (discussed in Sect. 4.2) (Zorzi, 1992). Later, in 2021, a new diagnostic campaign was launched to assess the conservation state of the frescoes: it involved regional and national research centres and universities[3] and implemented novel non-invasive and non-destructive methods (Leucci et al., 2023; Riminesi et al., 2024). These analyses retrieved additional data about the conservation state of the painting and the methods used in their creation, offering a deeper understanding of the artwork and its historical context.

This brief outline on the material history of the Chapel and the new data yielded by the last diagnostic campaign show how this site offers a unique case study to verify whether stratigraphic units may be adapted to describe the reconstruction and the scholarly interpretation process also beyond archaeological excavations. Answering this research question can lay the basis for the design of new tools to rigorously guide virtual reconstruction and communicate CH and its material history also to non-specialist audiences. To address this research question, we introduce here the concept of *interpretative units* and we hypothesise its possible use developing an OWL2 ontology. After the analysis of existing contributions in the domain of stratigraphy and its semantic web translations (Sect. 2), we describe the model - *BranCO*, the Brancacci Chapel Ontology. In particular, we concentrate on the adopted methodology for its development, its most relevant entities, and the alignment with international standard CIDOC-CRM and other compatible models (Sect. 4.1). In addition, in Sect. 4.2, we provide a first testing of the semantic expressivity of the ontology, populating its classes and properties with real data retrieved from a catalogue entry describing one of the sinopias retrieved during past restoration campaigns on the Brancacci Chapel.

2. State of the art

2.1. Stratigraphic matrix. From Harris to virtual archaeology

In archaeology, a Stratigraphic Unit (SU) represents a distinct physical layer or interface identified during excavation. Each SU reflects a specific event or activity, whether natural or human-made, that contributed to the site's formation. These units are the fundamental building blocks for reconstructing an archaeological site's history. SUs can be classified into two main types.

- Positive Stratigraphic Units (+SU): These are deposits, such as layers of soil, debris, or other materials that have accumulated over time due to natural processes (e.g., sedimentation) or human activities (e.g., construction or refuse disposal).
- Negative Stratigraphic Units (-SU): These are surfaces or voids resulting from the removal of materials, such as cuts, pits, or trenches caused by actions like digging or erosion.

Stratigraphic analysis is essential for archaeological interpretation. During excavation, SUs are meticulously recorded and removed in reverse order of their deposition, ensuring that findings are kept separate and linked to their original layers (Demetrescu, 2015). This process enables archaeologists to document the site's depositional sequence, reconstructing the chronological narrative of human activity and environmental changes. Harris Matrix is an indispensable tool in this process, since it graphically represents the stratigraphic relationships between SUs, organizing them into a clear sequence of layers and events. This visualisation aids in understanding the temporal and spatial dynamics of the site's formation, providing a systematic framework for interpreting its history. By combining the physical evidence of SUs with the interpretative structure of Harris' Matrix, archaeologists can piece together the intricate story of a site's past, shedding light on the processes and events that shaped it.

Harris' model laid the basis for the Extended Matrix (EM), which is a comprehensive methodology designed to ensure transparency, objectivity and scientific validity in the virtual reconstruction of archaeological contexts. It addresses the shortcomings of traditional approaches, which are often criticised for their lack of accessibility and transparency, earning them the label of "black boxes" (Demetrescu, 2018). Stemming from traditional archaeological stratigraphy, EM provides a formal

[1] At the time of the development and publication of the ontology (June 2024) the available version of the Extended Matrix is v.1.3.

[2] Although several years have passed since its publication, one of the most relevant analyses of the Brancacci Chapel is the study by Procacci (1932). For the outcome of the restoration campaign in the Eighties, see Casazza and Giovannoni (1987); Zorzi (1992). A reconstruction of the original appearance by the chapel is provided by Watkins (1973). Recently, a detailed overview on the history of the site has been published in Ferdani et al., (2023).

[3] This intervention involved major Italian institutions such as the Servizio Belle Arti del Comune di Firenze, the Soprintendenza SABAP, the CNR - Institute of Heritage Science (CNR ISPC), and the Opificio delle Pietre Dure, along with universities and private professionals (Pescarin et al., 2023). The restoration is made possible through contributions from the Friends of Florence and the Jay Pritzker Foundation (Riminesi et al., 2024).

language for documenting the stratigraphic and chronological relationships that underpin reconstructions (Berto et al., 2021).

A notable innovation of the EM is the introduction of Virtual Stratigraphic Units (VSUs), which represent hypotheses about units that no longer exist. These VSUs are categorised according to their evidence base: those confirmed by direct stratigraphic relationships (VSU/S) and those inferred from external sources such as historical or photographs (VSU/N). In addition, the EM includes Special Finds (SF), which allow artefacts found out of context to be virtually repositioned. All elements - whether stratigraphic units, virtual reconstructions or finds - are meticulously linked to their properties and the sources used for validation, ensuring a robust and transparent foundation (Demetrescu and Ferdani, 2021).

As a result, the EM workflow reflects the iterative nature of archaeological investigation, beginning with the creation of a digital replica and evolving through the definition of stratigraphic relationships and the modelling of reconstructed elements. This process has been applied to projects ranging from the Late Antique walls of Aquileia (Delbarba, 2023) to the Forum of Sarmizegetusa and the Temple of Juno Moneta in Segni. By making every step traceable and linking every element to its sources, EM ensures that reconstructions are not only scientifically rigorous, but also accessible for review and collaboration.

2.2. Stratigraphic approach to CH reconstruction in the semantic web

The domain of semantic approaches to cultural heritage reconstruction is not unexplored. In 2018 a research by Messaoudi and colleagues (Messaoudi et al., 2018) resulted in the definition of a model which is fully integrated with the standard for metadata description in Cultural Heritage, CIDOC-CRM (Bekiari et al., 2024). The project is exclusively focused on the annotation on 3D models concerning pieces of information on the conservation state. Furthermore, it adopts the integrations to this ISO standard, in particular CRMinf (Stead and Doerr, 2015), a conceptual model concerning argumentation and inference making, and CRMdig (Doerr et al., 2016), to describe the provenance of metadata, especially for digitisation purposes, as described by Fig. 1.

Similarly, in 2021, an alternative solution was proposed (Hiebel et al., 2021) for the reconstruction of ancient Egyptian sites, relying also on the following integrations: CRMgeo (Hiebel et al., 2015), a global schema for integrating spatiotemporal properties of temporal entities and persistent items; CRMsci (Doerr et al., 2023), focussed on the description of metadata about scientific observation, measurements and processed data in descriptive and empirical science; CRMarchaeo (Christaki et al., 2024), tailored for the archaeological excavation process.

These examples clearly indicate how CIDOC CRM and its compatible models should be adopted as reference points for the construction of this new ontology. A full reuse of this ISO standard indeed allows to express multiple relationships of CH objects. Similarly, CRMdig is a valuable resource for the annotations of digital cultural reconstructions, translating also in the semantic web the EM intimate relationship between knowledge base and digital visualisation (Demetrescu et al., 2023). In this perspective, a recent example is the *Cultural Heritage Acquisition and Digitisation Application Profile* (Barzaghi et al., 2025), an application profile designed on a full reuse of CIDOC-CRM and CRMdig, without the introduction of new classes.

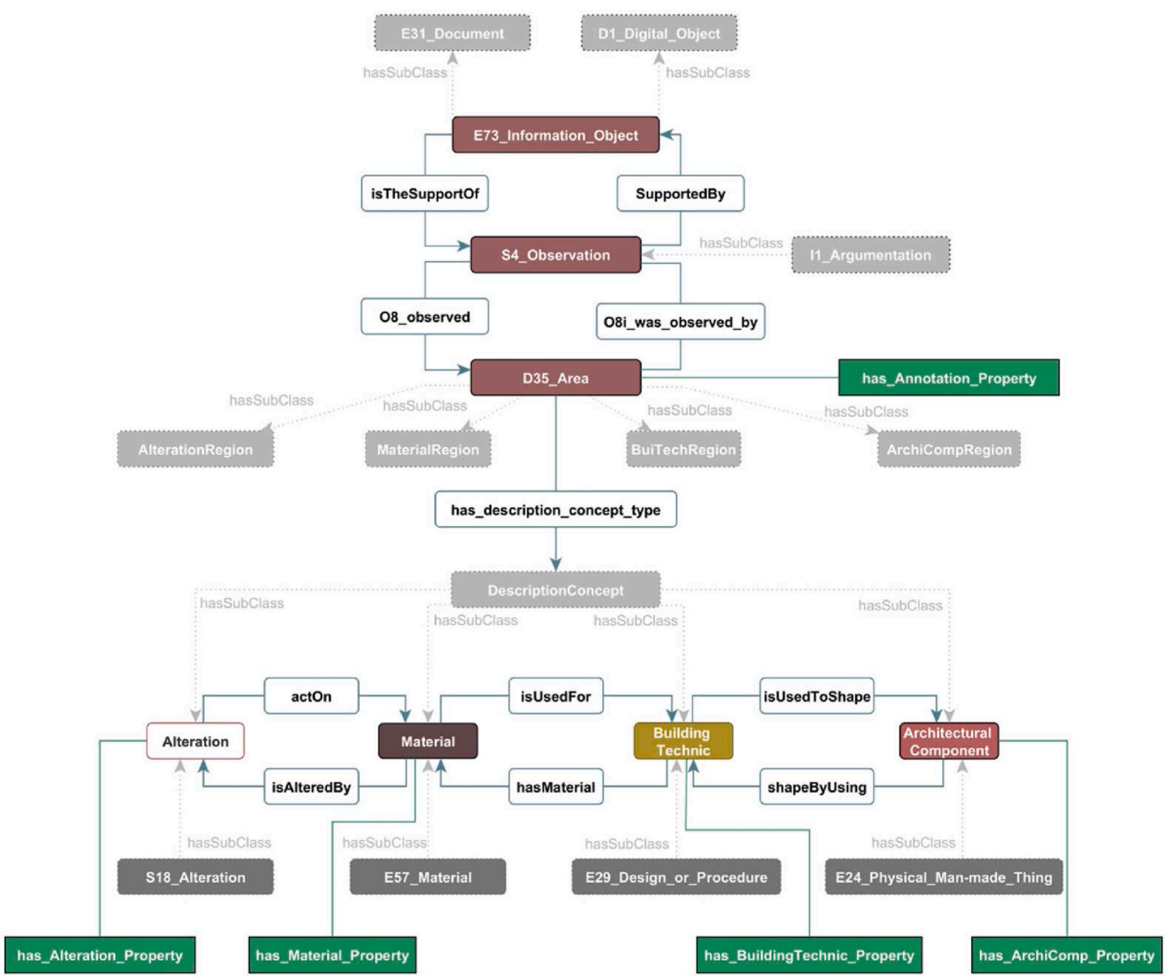

Fig. 1. Visualisation of the conceptual model used by Messaoudi and colleagues (after Messaoudi et al., 2018).

A similar approach, aimed at defining an "application profile", is not fully replicable in the current research: the serialisation of the stratigraphic unit in semantic web is indeed at odds with the conceptual model of the Extended Matrix, which is the principal reference of this project, although it is not serialised as an ontology. As a matter of fact, CRMarchaeo declares a specific class for the stratigraphic unit: A8 Stratigraphic Unit (Christaki et al., 2024). It is generated by an event (A4 Stratigraphic Genesis) and is defined as a subclass of S20 Rigid Physical Feature, asserted in CRMsci (Doerr et al., 2023) as the intersection of both E26 Physical Feature (thus a tangible physical thing) and E53 Place.

A similar solution 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 standard for the Cultural Heritage domain (Carriero et al., 2019). Here, the Stratigraphic Unit is defined by the "ARCO - Context Description Ontology" as a subclass of the location class. Conversely - as seen in Sect. 2.2 - the EM, distinguishes between Stratigraphic Units, the "archaeological remains", and Virtual Stratigraphic Units (VSU), referring to an "hypothetical presence" and to "the likelihood of a specific SU having existed in the past" (Demetrescu, 2015). Alignment with a location (as in CRMarchaeo or ARCO) or physical thing class might fail to fully describe this *uncertain* nature of VSU in EM.

As a result, in this first version of the ontology, a new approach is tested to capture this nuance. This alternative relies on CIDOC-CRM E89 Propositional Object class: this choice emphasises how this epistemological unit is indeed a "set of propositions" (Bekiari et al., 2024) about cultural heritage connected to interpretation acts, a scholarly process which has been considerably examined in the past years in ontology engineering. A specific CIDOC-CRM integration in this regard is CRMinf (Stead and Doerr, 2015), a conceptual model concerning argumentation and inference making. It translates in RDF (Resource Description Framework) the core model for assertions making (see Fig. 2) (Doerr et al., 2011). This model allows ontology engineers to express complex inferences and set of propositions in a huge variety of descriptive and empirical sciences such as biodiversity, geology, geography, archaeology, cultural heritage, conservation, research IT environments and research data libraries.

Nonetheless, an alternative and more streamlined model is increasingly gaining popularity in the cultural heritage domain: HICO - the Historical Context Ontology (Daquino and Tomasi, 2015), illustrated in Fig. 3:

Although - to the best of our knowledge - a full alignment with CIDOC-CRM is yet to be defined, the model has been successfully implemented in different projects in the domain of art-history (see e.g. Daquino et al., 2017) as it allows to easily describe the provenance of assertions on cultural heritage, for example debated authorship of an artwork. As a result, on the basis of this brief state of the art overview, the *Brancacci Chapel Ontology* will exclusively rely on the following models, minimising the definition of new entities (mainly related to the new concept of *interpretative units*, henceforth shortened as "IntUnits").

- CIDOC-CRM, through which it is possible to define the majority of data concerning cultural heritage;
- CRMdig, for the integration of semantic annotations on digital model;
- HICO and imported models, like CITO (Peroni and Shotton, 2012), for the description of the interpretative actions on cultural heritage objects and sites.

3. Methodology

The core assumption of this study is the possibility to extend the stratigraphic approach beyond its original scope to describe the specificity of an Early-Modern site. At least in this first analysis, given the specificity of *stratigraphic units* in the archaeological domain, we proposed a different denomination for this context of application: *interpretative units*. Each of them refers to the interpretative process by domain experts and heritage scientists about a single event of the material history of a CH object/site (or one of its parts). In this broad connotation, we believe that this epistemological unit may successfully describe also non-archaeological contexts, such as the Brancacci Chapel.

Given the increasing attention paid to semantic web in CH understanding, we verify the soundness of this hypothesis via the definition of a new ontology. In this initial version, this data model is addressed at satisfying the peculiarities of our case study. To this end, our

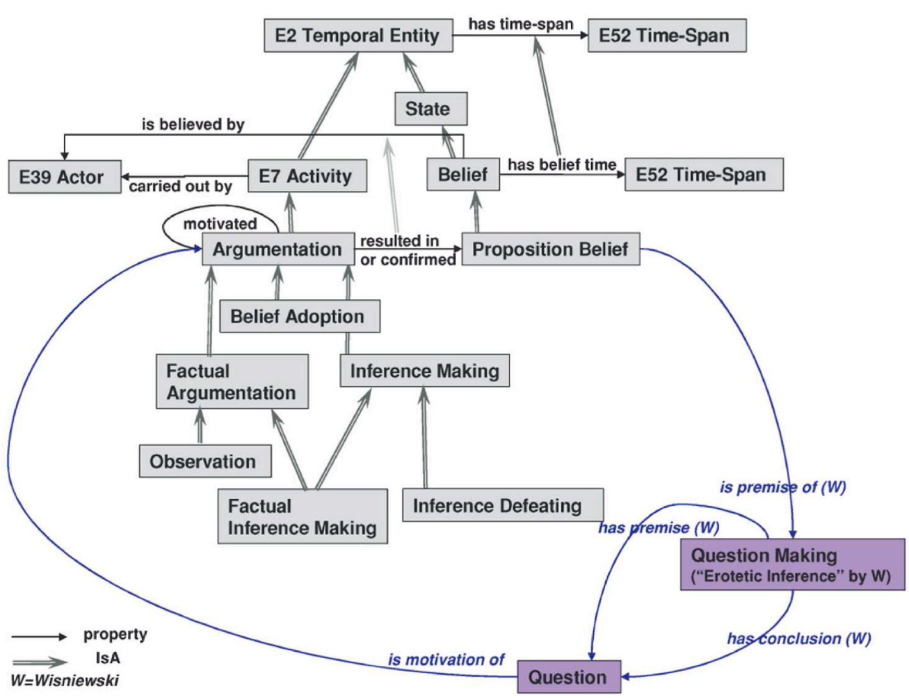

Fig. 2. Types of argumentation: factual argumentation, Inference making, and belief adoption (Doerr et al., 2011).

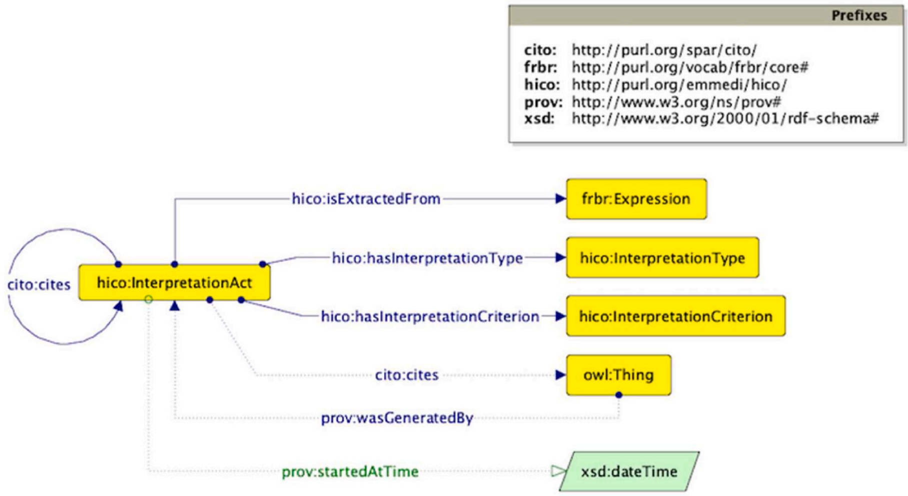

Fig. 3. Conceptual model of the Historical Context Ontology - HICO (Daquino and Tomasi, 2015).

methodological approach lays its basis on a systematic definition of needs and requirements by domain experts (specifically, art historians and heritage scientists). This preliminary phase involved professionals of the Superintendence Archeologia Belle Arti e Paesaggio and the CNR - Institute of Heritage Science (CNR ISPC) of Florence, who were among the protagonists of the last diagnostic campaign on the chapel.

Among the core needs of this new model it emerged how i) interpretative units should be able describe physical modifications to the CH objects/sites, either in its structure or its decoration; ii) asserting *data provenance* (Gupta, 2009) is of paramount importance for this context of use, as it allows to associate each interpretation to its source; iii) the model should enable future visualisation of each unit in a virtual reconstruction, e.g. via 3D semantic annotation. The systematisation of these requirements and the subsequent development of the ontology was carried out relying on SAMOD, the Simplified Agile Methodology for Ontology Development (Peroni, 2016), which is gaining increasing popularity in the domain of ontology engineering (with the reference article with 127 citations as per June 2024).

As shown in Fig. 4, this protocol is based on an iterative process in which a “domain expert” (DE) and “ontology engineer” (OE) define together motivating scenarios, i.e. small problems defined in natural language. For each of them, a set of examples is defined and competency questions are formulated: they consist of relevant questions interrogating the model on the basis of the provided examples. Subsequently, the OE serialises a standalone OWL modelet and tests it by verifying both “formal” and “rhetorical” requirements - primarily ensuring the absence of inconsistencies and comparing the solutions to SPARQL competency questions with the expected results. If these requirements are met, the OE releases a milestone: at the end of every iteration, it is merged with the previous ones and the outcome is later refactored (see later): after each of these stages, both formal and rhetorical requirements are checked anew (see Peroni, 2016 for a more detailed description of this protocol).

For the construction of *BranCO* Ontology, these modelets have been drawn with the software yEd using the graphical framework Graffoo (Falco et al., 2014). The model have been later converted into *.owl file and populated in Protégé, v. 5.0.0 (Jain and Singh, 2013). Fulfilment of formal requirements has been checked both in this software, with the reasoner HermiT, v. 1.4.3.456. (Glimm et al., 2014), and with OntOlogyPitfall Scanner - OOPS! (Poveda-Villalón et al., 2014). After populating the ontology with the example dataset, the correctness of the answers to SPARQL-format competency questions has been verified via the plug-in SPARQL Query installed in Protégé (Jain and Singh, 2013).

The final refactoring stage consisted in the annotation of the entities and in the direct import of the chosen models (see Sect. 2). Lastly, a conclusive pruning stage was also performed to avoid the redundancy of the model: we omitted those entities which have been mentioned in the SAMOD scenarios but which are not essential for the definition of the IntUnits and are already defined in CIDOC-CRM. Since that pruning was performed at the end of the SAMOD iterations, a final assessment of formal and rhetorical requirements was deemed necessary. At the end of this process, a documentation of the model has been automatically created with LODE, with minor interventions on the resulting *.html file (Peroni et al., 2013).

If the formal correctness is ensured by the scrupulous implementation of the SAMOD Methodology, in this study the full expressivity of the ontology semantics for the chosen case study is verified with real data on a possible reconstruction of the Brancacci Chapel (see Section 4.2). The data are extracted on a catalogue entry of the exhibition *Empoli 1424. Masolino e gli albori del Rinascimento*, where also a sinopia of a lost decoration of the chapel attributed to Masolino was exhibited. On this occasion, the curator proposed a possible reconstruction (De Marchi, 2024). This case study aims exclusively at testing the semantics of *BranCO*: the choice of this source does not imply an implicit judgement of the validity of this art-historical reconstruction compared to alternative solutions which were proposed in the past decades. De Marchi’s interpretation has been selected since it is one of the most recent proposals in the debate on the Brancacci Chapel and provides multiple sources in support: it is therefore a complex example for the assessment of this new ontology.

4. Results

4.1. Brancacci Chapel ontology (BranCO)

The ontology was developed in three main iterations: the following section describes the scenario description, examples and competency questions of each SAMOD iteration and the most relevant entities (either declared *ex novo* or imported from other models). Supplementary materials are available at the end of this manuscript and document the development and the test of the ontology (accessible also in the GitHub Repository) and also include a full web documentation. The final configuration of the ontology can be visualised in Fig. 5:

The first iteration generally mentions the reconstruction of cultural heritage objects or sites, introduces the concept of interpretative units and describes how data objects may be annotated with scholarly data on possible reconstructive hypotheses, as described in Table 1.

The scenario can be almost fully aligned with the standard CIDOC-CRM (crm) and its compatible model CRMdig (crmdig). In particular, it introduces a core differentiation in CH analysis.

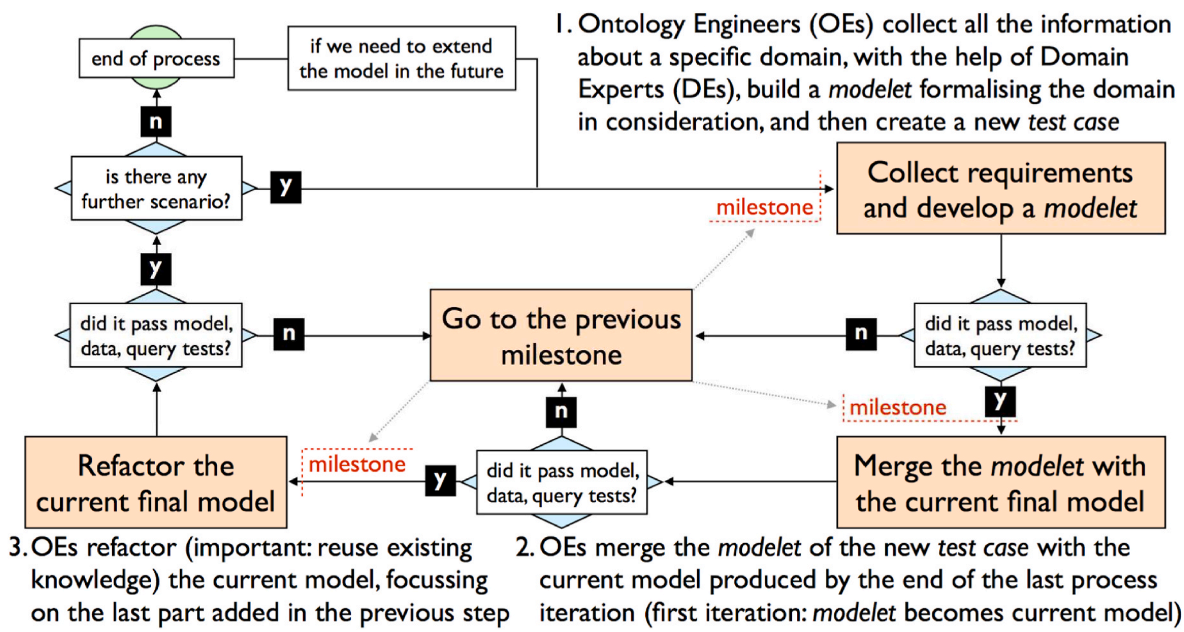

Fig. 4. Visualisation of the SAMOD methodology (Peroni, 2016).

- The tangible artefact/site, which is already defined by CIDOC-CRM with the class E18 Physical Thing and its subclasses;
- The digital object, which is the product of an acquisition or modelling campaign (both defined as D2 Digitisation Process in CRMdig), is defined as a crmdig:D9_Data_Object. In addition, semantic nodes may be added and can be described as a specific instance of the class crmdig:D29_Annotation_Object. As it will be anticipated in Sect. 5 of this study, this element is useful to associate, via the property crmdig:43i_is_annotated_by, the data connected to an interpretative unit with a specific area of the 3D model. The Open Source 3D WebXR Visualisation platform ATON already provides a useful tool for the visualisation of pieces of information (Fanini et al., 2021);
- The reconstruction of the cultural artefact or site: single IntUnits are contextualised in a full coherent system to put forward a reconstructive hypothesis. Due to the fact that the *interpretative unit* has been introduced in this study for the first time, a direct reuse of previous classes is not possible. Nonetheless, both IntUnit and Reconstruction classes may be considered subclasses of crm:E89_Propositional_Object, since they both “are, or represent in some sense, sets of propositions about real or imaginary things and that are documented as single units or serve as topic of discourse” (Bekiari et al., 2024).

The second iteration instead better describe the concept of interpretative unit, as illustrated in Table 2:

As seen, the interpretative unit models an event on the physical object, for which the class hierarchy of CIDOC-CRM may be directly reimported.

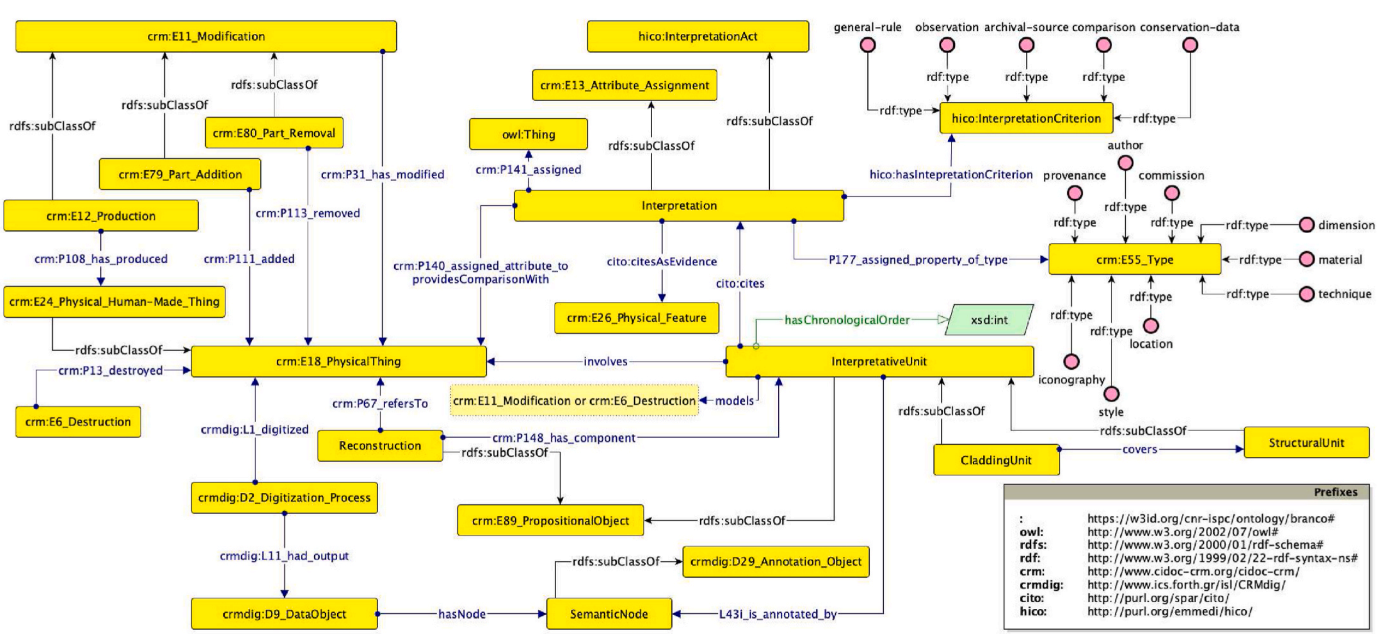

Fig. 5. Visualisation of *BranCO* conceptual model.

Table 1
First SAMOD iteration for the development of *BranCO*.

#1	From the physical object to the reconstruction
Scenario	Every physical object can be digitised in a data object, which may contain different semantic nodes. Moreover, physical objects are not always complete: a reconstruction is therefore necessary. It is a set of propositions about the studied physical objects and systematises different interpretative units. Each interpretative unit can be visualised in a semantic node.
Examples	1. The domus A has been digitised in 3D with a photogrammetry campaign. The site has been studied to reconstruct its original aspect. 2. At the end of this reconstruction process, different interpretative units have been identified: IntUnits1, IntUnits2, IntUnits3 and IntUnits4 3. Later, in this 3D model, four semantic nodes have been added to represent the four units of the reconstruction
Competency questions	1. When was the domus A digitised? [Event] [Photogrammetry campaign] 2. Which are the 3D models of the domus? [DataObject] [3D Model] 3. How many interpretative units (IntUnits) were identified for the domus? [list of units] [IntUnits1, IntUnits2, IntUnits3, IntUnits4] 4. Are there semantic nodes on the 3D model? If yes, to which US do they correspond? [Semantic Node (SemN) and IntUnits] [IntUnits1, SemN1; IntUnits2, SemN2; IntUnits3, SemN3; IntUnits4, SemN4]

```
[...] - - - - E5 Event
- - - - - - - - - - - - - - E7 Activity
- - - - - - - - - - - - - - - - - - - - - E11 Modification
- - - - - - - - - - - - - - - - - - - - - - - - - - - - E12 Production
- - - - - - - - - - - - - - - - - - - - - - - - - - - - E79 Part Addition
- - - - - - - - - - - - - - - - - - - - - - - - - - - - E80 Part Removal
- - - - - - - - - - - - - - E63 Beginning of Existence
- - - - - - - - - - - - - - - - - - - - - E12 Production
- - - - - - - - - - - - - - E64 End of Existence
- - - - - - - - - - - - - - - - - - - - - E6 Destruction
```

Snippet 1. CIDOC-CRM class hierarchy: E5 Event and its subclasses.

Table 2
Second SAMOD iteration for the development of *BranCO*.

#2	From the event to the interpretative units
Scenario	Physical objects may undergo and be modified by different events: for instance, they can be destroyed. Other types of modifications are production, addition and removal of parts. All these events may be registered by a document and each of them is conceptualised as a unit. Every unit can either be structural or cladding: the latter covers the first one. They can be organised chronologically.
Examples	1. The domus B was built in the 2nd century BCE, but in 62 AD the Southern wall collapsed due to an earthquake. The site was eventually destroyed in the eruption of Vesuvius in 79 AD. This event is witnessed by a letter by Pliny the Younger 2. During the earthquake of 62 AD, on the Northern wall of the domus B the previous decoration was destroyed. A new decoration was hence added.
Competency questions	1. Which are the units associated with the Southern wall of domus B? Organise them chronologically starting with the most recent [List of units and their description] [Construction, Partial collapse, Destruction] 2. Which are the units associated with the Northern wall domus B (both structural and cladding units)? Organise them chronologically starting with the most recent [List of units and their description] [Construction, First decoration, Loss of the decoration, Second decoration, Destruction] 3. Which units refer to the earthquake of 62 AD? [List of units and their description] [Partial collapse on Southern Wall, Loss of the decoration in the Northern Wall]

The newly introduced property branco:models (consider branco: as the prefix of the current ontology) connects an interpretative unit to any individual of the union of the classes E11 Modification and E6 Destruction. The scenario also introduces the differentiation between structural and cladding units (e.g. a wall and the fresco) which allows a finer granularity of examination and to provide more precise pieces of information on single elements of the decoration. Lastly, these units, similarly to traditional archaeological matrices, may be organised chronologically: a specific data property (branco:hasChronologicalOrder) has been then asserted.

As the name suggests, each interpretative unit shall be connected to specific interpretations, which indicate scholarly and scientific analysis which produces new knowledge on the studied object or event. As shown in Table 3, this is the core focus of the third SAMOD iteration:

The interpretative unit is here directly connected to the events described in the previous SAMOD iteration and it is put in relationship with scholarly interpretations via the property cito:cites defined in the ontology CITO (Peroni and Shotton, 2012). As described in the state of the art (Sect. 2), the Historical Context Ontology (HICO, prefix: hico) already models interpretative acts, with a specific focus on cultural heritage. Nonetheless, the model is not aligned with the standard CIDOC-CRM: to hence grant a full alignment with the ISO standard and preserving HICO semantics, *BranCO* defines the class branco:Interpretation as intersection of hico:InterpretationAct and crm:E13_Attribute_Assignment.

The property hico:hasInterpretationCriterion allows ontology engineers to define the criterion adopted in the interpretation. In the current version, this class is populated with the following individuals, mainly derived from the controlled vocabulary of EM.

- archival source,

Table 3
Third SAMOD iteration for the development of *BranCO*.

#3	Interpretative units and interpretative acts
Scenario	Each interpretative unit is linked to a physical object, whose qualities are analysed in an interpretative act. Traditional interpretations concern location, dimension, material, technique, authorship, provenance, commision, styles and iconography. For these last two classes, it is possible to recognize single features to assign a style or an iconographic subject (alignable with ICONCLASS) to an artwork. Lastly, any interpretation is justified by interpretative criteria, like direct observation, diagnostic data, general rule, archival sources, or comparison with other objects.
Examples	1. The Interpretative Unit IntUnitC1 is related to the decoration of the wall of *domus* C. In the reconstruction, it is based on the interpretation which claims that it should be 3 m tall and decorated in Pompeii first style, on the basis of diagnostic data 2. The addition of a - now lost - altarpiece in the Chapel X is described by IntUnitC2. Different interpretations have been made on the iconography: it can be either a story of Christ stilling the storm on the Sea of Galilee (ICONCLASS: 73C31) or story of Christ walking on the water, 'Navicella' (ICONCLASS: 73C32). 3. The former interpretation of IntUnitC2 derives from archival sources, whereas the latter one derives from a comparison with the altarpiece in the Chapel Y of the same church.
Competency questions	1. Which is the criterion for the reconstruction of IntUnitC1? [Criterion] [Diagnostic Data] 2. Which is the supposed height for IntUnitC1? [Dimension (value and unit)] [3m] 3. Which are the different interpretations for the reconstruction of the altarpiece in Chapel X? [Interpretative Criterion, Iconography, Comparison (if any)] [Christ stilling the storm on the Sea of Galilee, Archival Sources; Navicella, Comparison with Chapel Y]

- comparison (combined with the property branco: providesComparisonWith);
- diagnostic data,
- general rule,
- observation, which has been added to group the evidence which may be found via a direct inquiry of the cultural object

The same approach, following both hico:hasInterpretationType and crm:P177_assigned_property_of_type, has been adopted to describe which property is attributed during the interpretation act. In *BranCO* v.0.9.0 a first controlled vocabulary has been proposed, enriching the one put forward by EM with properties which may recur specifically in non-archaeological contexts. The asserted properties can be assigned with the property crm:P141_assigned, as summed up in the snippet of Turtle file below and Table 4 (the interpretation type individual, together with the asserted property and its class here are emphasised in bold).

```
@prefix : <https://www.example.com/> .
@prefix crm: <http://www.cidoc-crm.org/cidoc-crm/> .
@prefix branco: <https://w3id.org/cnr-ispc/ontology/branco#> .

:example-interpretation a branco:Interpretation ;
      crm:P177_assigned_property_of_type :author;
      crm:P141_assigned :Masaccio .

:author a crm:E55_Type .

:Masaccio a crm:E39_Actor .
```

Snippet 2. Classes and object properties connected to the entity branco: Interpretation.

Table 4
Individuals in the proposed controlled vocabulary for the object of property crm: P177 assigned property of type.

Property type	Description	Type of the object of crm:P141
Material	The material of which the studied object is made	crm:E57_Material
Technique	The technique used for the production of the studied object	crm:E55_Type
Dimension	The dimension of the object	crm:E54_Dimension, whose numerical value may be xsd:float (Doerr et al., 2020)
Location	The location in which the object of an interpretative unit might be found	crm:E53_Place, with specifications asserted via crm: P157_is_at_rest_relative_to
Author	The artist (or group of artist) who created the cultural object or its	crm:E39_Actor or its subclasses
Commision	The person or group who commissioned the creation of the cultural object	crm:E39_Actor or its subclasses
Provenance	The person or group who used to have in custody or own the cultural object	crm:E39_Actor or its subclasses
Style	The style in which the object is made. "By style, it is meant the constant form - and sometimes the constant elements, qualities, and expression - in the art of an individual or a group" (Shapiro, 1953)	crm:E55_Type Style recognition usually relies on the identification of specific features: they can be serialised as follows, reusing an object property declared in CITO ontology: branco:Interpretation cito: citesAsEvidence crm: E26_Physical_Feature
Iconography	Usually referred to cladding unit, the iconography pertains to "the identification of images, stories and allegories" (Panofsky, 1955)	crm:E36_Visual_Item. With this axiom, this conceptual model is interoperable with the Visual Representation Ontology (VIR) and the class IC9 Representation, in turn subclass of crm:E36_Visual_Item (Carboni and De Luca, 2019). Association of an iconography to an Iconclass concept can be asserted as crm:E36_Visual_Item crm: P48_has_preferred_identifier crm: E42_Identifier

4.2. Testing BranCO semantic expressivity

At the time writing, an exhibition is currently taking place in Empoli (province of Florence, 6th April - July 7, 2024): *Empoli 1424. Masolino e gli albori del Rinascimento*. It is focused on the figure of Masolino, a protagonist of the first decorative campaign of the Brancacci chapel. On the occasion of the sixth centenary of the decoration of the Church of Santo Stefano degli Agostiniani in Empoli with the frescoes inspired by *The Legend of the True Cross*, the exhibition is aimed at reconstructing the cultural context in which Masolino worked.

Among the different artworks exhibited in Empoli 1424, the sinopia of one of the lunettes of the back wall - detached during 1981 restoration campaign (see Sect. 1) - witnesses the importance of the Brancacci Chapel for the understanding of Masolino's art (Fig. 6). As anticipated in Sect. 3, in the catalogue the sinopia is analysed in the more complex system of the Brancacci Chapel and the entry also provides a partial reconstruction of this cultural site (De Marchi, 2024). In the context of the developed ontology, this document is a precious resource as it cites heterogeneous data on different artefacts connected to the chapel.

In this section, a serialisation of this text is being proposed relying on *BranCO* and its interoperable models. If the creation of this knowledge graph and the answer to relevant competency questions is possible, the ontology can be considered already in this version as a possible support tool for the description of this cultural heritage site and its reconstruction. Owing to copyright, the source text cannot be reproduced in this study; its analysis however delves on the following topics: the decoration of the vault by Masolino; two lunettes of the back wall, with special attention to the authorship attribution, the iconography and iconological meaning; the provenance, iconography and iconology of a bas-relief

Fig. 6. Sinopia of the *Pasce oves meas* (right lunette of the back wall of the Brancacci Chapel), attributed to Masolino. Source: Wikimedia Commons.

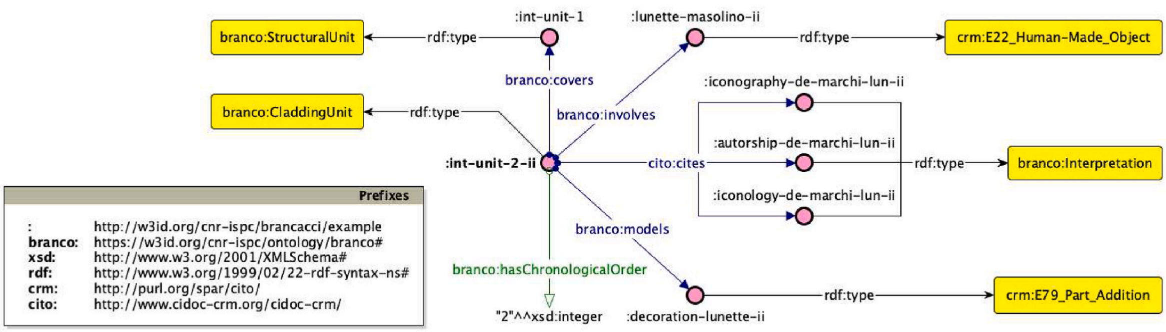

Fig. 7. Visualisation of the Turtle knowledge graph of the Interpretative Unit 2.2, related to the decoration of the right lunette (*Pasce oves meas*).

by Donatello, now exhibited at the Victoria & Museum in London.

The serialisation in Turtle syntax is available in the Supplementary Material (filename: 'test/de-marchi.ttl').[4] The knowledge graph has been validated, and logical inconsistencies and the following SPARQL competency questions (CQs) have been checked in Protégé. The visualisation, created with Graffoo palette for yEd, graphically shows how the *interpretative unit* is a valid tool to group together the event and the physical thing, as well as the connected interpretations, as shown by Fig. 7. The CQs have been formulated by the domain expert of the SAMOD protocol to reduce possible bias connected to previous knowledge of the final configuration of the ontology and reflect the most relevant observations of the catalogue entry.

Firstly, the entry mentions the famous restoration campaign which took place in the 1980s in the chapel (documented in Zorzi, 1992). As mentioned, in this occasion two sinopias of the original Quattrocento decoration could be identified and removed under the later vault frescoes by Meucci. Snippet 3 shows how these data can be serialised with the class Matter Removal of CRMsci model, fully integrated in the class hierarchy of CIDOC-CRM and therefore fully interoperable with the *BranCO* conceptual model (in the following serialisations, ellipses are indicated in […]: refer to the aforementioned Turtle file for the complete knowledge graph).

The first competency question therefore focuses on the result of this campaign.

- What could be studied thanks to the 1984 restorations? The sinopias of the two lunettes
- In SPARQL: SELECT ?obj WHERE {:restoration-1984 crmsci: O2_removed ?obj}
- Results (in brackets the string value of the property rdfs:label):
  - :lunette-masolino-sinopite-i ("Sinopite of the right lunette by Masolino")
  - :lunette-masolino-sinopite-ii ("Sinopite of the left lunette by Masolino")

The discussion of the possible authorship attribution for these two sinopias has as necessary premise the quotation of one of the most relevant sources for Early-Modern Art: *Lives of the Most Excellent Painters, Sculptors, and Architects* by Giorgio Vasari. As a matter of fact, in the *Life of Masolino* the historiographer provides an accurate description of the scene of the fresco decoration, included the ones replaced by Meucci's intervention in the 18th century (Vasari, 1912):

> He was commissioned to adorn the Chapel of the Brancacci, in the said church [Carmine], with the stories of S. Peter; of which chapel, with great diligence, he brought a part to completion, as on the vaulting, where there are the four Evangelists, with Christ taking Andrew and Peter from the nets and then **Peter weeping for the sin committed in denying Him**, and next to that his preaching in order

```
:restoration-1984 a crmsci:S1_Matter_Removal ;
     crmsci:O1_diminished :vault-lunette-meucci ;
     crmsci:O2_removed :lunette-masolino-sinopite-i ;
     crmsci:O2_removed :lunette-masolino-sinopite-ii .

# The vault by V. Meucci
:vault-lunette-meucci a crm:E22_Human-Made_Object ; [...] .

:lunette-masolino-sinopite-i a crm:E22_Human-Made_Object ;
     rdfs:label    "Sinopite    of    the    right    lunette    by
     Masolino"^^xsd:string ;
     a crmsci:S11_Amount_of_Matter ; [...] .

:lunette-masolino-sinopite-ii a crm:E22_Human-Made_Object ;
     rdfs:label    "Sinopite    of    the    left    lunette    by
     Masolino"^^xsd:string ;
     a crmsci:S11_Amount_of_Matter ; [...] .
```

Snippet 3. Section of the serialisation of the knowledge graph mentioning the entities of the first test case.

[4] The prefixes declared in the Turtle file should be repeated in the following SPARQL queries.

to convert the Gentiles. He painted there the shipwreck of the Apostles in the tempest.

The section in bold refers to the iconography of one of the two lunettes (on the left), which could therefore be attributed to Masolino. These data can be serialised in *BranCO* relying on the reuse of CITO and HICO, as shown in Snippet 4.

They can then be retrieved through the following competency question.

On the contrary, the subject of the second lunette (identified by the IntUnit 2.2) is not mentioned in the *Lives* of Vasari. As cited also by De Marchi, the presence of a sheeps in the lower corner of the sinopia and of two human figures in the upper part suggests as possible iconography the “Pasce oves meas” (in Latin: “feed my sheep”), associated with the role of St. Peter as head of the Christian Church (Gv 21, 15).

The third competency question therefore interrogates the knowledge graph in this regard, relying on a subproperty of CITO ontology. In the Turtle file (see Snippet 5), this is expressed through the axioms, which integrates CIDCO-CRM model with HICO and VIR (see Table 4).

```
:authorship-de-marchi-lun-i a branco:Interpretation ;
     hico:isExtractedFrom :catalogue-masolino-2024-ita ;
     crm:P140_assigned_attribute_to :lunette-masolino-i ;
     crm:P177_assigned_property_of_type branco:author ; [...]
     cito:citesAsSourceDocument :vasari-vite ;
     crm:P141_assigned :masolino .

:catalogue-masolino-2024 a fabio:Catalog ;
     frbr:realization :catalogue-masolino-2024-ita .

:vasari-vite a fabio:Biography ;
     rdfs:label "Vasari, Le vite de’ più eccellenti pittori, scultori
     ed architetti"^^xsd:string .

:masolino a crm:E21_Person ;
     owl:sameAs viaf:14747968 .
```

Snippet 4. Section of the serialisation of the knowledge graph mentioning the entities of the second test case.

```
:iconography-de-marchi-lun-ii a branco:Interpretation ;   [...]
     crm:P140_assigned_attribute_to :lunette-masolino-ii ;
     crm:P177_assigned_property_of_type branco:iconography ;
     cito:extends :vasari-vite ;
     cito:citesAsEvidence :sheep-saint-peter-lun-ii ;
     crm:P141_assigned :pasce-oves-meas .

:lunette-masolino-sinopite-ii a crm:E22_Human-Made_Object ;
     crm:P56_bears_feature :sheep-saint-peter-lun-ii .

:sheep-saint-peter-lun-ii a crm:E26_Physical_Feature .

:pasce-oves-meas a vir:IC9_Representation ;
     rdfs:label "Pasce Oves Meas"^^xsd:string ; [...] .
```

Snippet 5. Section of the serialisation of the knowledge graph mentioning the entities of the third test case.

- What source can be used to attribute the frescoes in the Brancacci Chapel to the different painters? Vasari’s *Lives*
- In SPARQL: SELECT ?doc WHERE {?attribution crm:P177_assigned_property_of_type branco:iconography. ?attribution cito:citesAsSourceDocument ?doc. }
- Result:

  - :vasari-vite (“Vasari, Le vite de’ più eccellenti pittori, scultori ed architetti")

- Did the sinopias provide more information on the decoration of the Brancacci? The sinopia of “Pasce oves meas”, not described by Vasari
- In SPARQL: SELECT ?icon ?absent_in_doc WHERE {?attribution crm:P177_assigned_property_of_type branco:iconography. ?attribution cito:extends ?absent_in_doc. ?attribution crm:P141_assigned ?icon.}
- Result:

- ?icon = :pasce-oves-meas ("Pasce Oves Meas"); ?absent_in_doc = :vasari-vite ("Vasari, Le vite de' più eccellenti pittori, scultori ed architetti")

As suggested above, the choice of this specific iconography, also in relationship with the other scenes of the Chapel, has a devotional and political implication. According to De Marchi, they can be reconducted to the importance of the ecclesiastical mission of the Saint. In addition, the subject has been interpreted as a loyalty declaration to the Pope Martin V, who stayed in Florence between 1419 and 1420. Lastly, the saint is the eponym of Piero di Pulvichese, who founded the construction of the chapel and was uncle of Felice Brancacci, commissioner of the fresco decoration to Masaccio e Masolino.

The identification of iconology has not been defined in the current version of *BranCO*, yet the type of an interpretation is rendered through a controlled vocabulary, whose entries can be easily extended with the introduction of a new term. The last competency question therefore investigates the iconology of this decoration, starting from the analysis of the sinopia. Snippet 6 proposes a possible serialisation (note that a connection between iconography and iconology is possible through the object property K14_symbolize of VIR ontology).

```
:iconology-de-marchi-lun-ii a branco:Interpretation ;  [...]
     crm:P140_assigned_attribute_to :lunette-masolino-ii ;
     crm:P177_assigned_property_of_type :iconology ;
     crm:P141_assigned :mission-saint-peter ;
     crm:P141_assigned :loyalty-to-rome ;
     crm:P141_assigned :pulvichese-homage.

:pasce-oves-meas a vir:IC9_Representation ;
     rdfs:label "Pasce Oves Meas"^^xsd:string ;
     vir:K14_symbolize :mission-saint-peter .

:mission-saint-peter a crm:E90_Symbolic_Object ;
     rdfs:label    "Saint    Peter's    ecclesial    mission    on
     Earth"^^xsd:string .

:loyalty-to-rome a crm:E90_Symbolic_Object ;
     rdfs:label "Loyalty to the Church of Roma and the Pope Martino
     V"^^xsd:string .

:pulvichese-homage a crm:E90_Symbolic_Object ;
     rdfs:label "Homage to Piero del Pulvichese, ancestor of Felice
     Brancacci"^^xsd:string .
```

Snippet 6. Section of the serialisation of the knowledge graph mentioning the entities of the fourth test case.

- Why was the Brancacci Chapel decorated with the frescoes with stories of St. Peter? To pay homage to his ancestor, Piero di Piuvichese, who had founded the chapel, but also to affirm his loyalty to the Church of Rome, in the person of Pope Martin V
- In SPARQL: SELECT ?iconology WHERE {?attribution crm:P177_assigned_property_of_type:iconology. ?attribution crm:P141_assigned ?iconology.}
- Results:
  - :mission-saint-peter ("Saint Peter's ecclesial mission on Earth")
  - :pulvichese-homage ("Homage to Piero del Pulvichese, ancestor of Felice Brancacci")
  - :loyalty-to-rome ("Loyalty to the Church of Roma and the Pope Martino V″)

5. Discussion

The full application of the SAMOD protocol ensures the logical correctness of the Brancacci Chapel Ontology and the absence of inconsistencies in the alignment with existing models. Among them, the study reused in particular entities from CIDOC-CRM, the international standard for the semantic description of CH. Indeed, the ISO standard has been imported to assert the main properties and events concerning cultural objects and sites. In addition, the CRM compatible model CRMdig provided the necessary entities to assert axioms about the digitisation and virtual restoration processes. The systematic use of these ontologies also allows the integration of entities from other CRM-based models, e.g. CRMsci, for scientific observation and diagnostic data, or the Visual Representation Ontology (VIR).

Nonetheless, if in traditional archaeological contexts *stratigraphic units* enable to connect all these different aspects, new solutions should be envisioned to describe peculiarities of art-history scholarship (e.g. claims attribution). Literature already offers possible solutions to translate elements of traditional stratigraphy in the semantic web, relying on classes describing locations or physical things. In this perspective, *BranCO* proposes a new solution derived from the Extended Matrix, an existing framework frequently adopted in the virtual archaeological domain. The Brancacci Chapel Ontology proposes a first RDF serialisation of this model: in particular, in its development attention has been paid to the EM node of VSUs, which describe an "hypothetical presence" of an object or one of its parts. Therefore, extending the semantics of *stratigraphic units* beyond its traditional scope, a new concept has been introduced, *interpretative units*. As the EM is thought to be the starting point of the interpretative and reconstructive process (Demetrescu, 2018), we instantiated IntUnits as a subclass of CIDOC-CRM E89 Propositional Object class to encompass not only USs, but also VSUs.

One of the main objectives of interpretative units is asserting the *data provenance*, since it associates each single event of the material history of the CH object to an array of interpretation processes. In this manner, ontologies can capture the scientific and scholarly process through

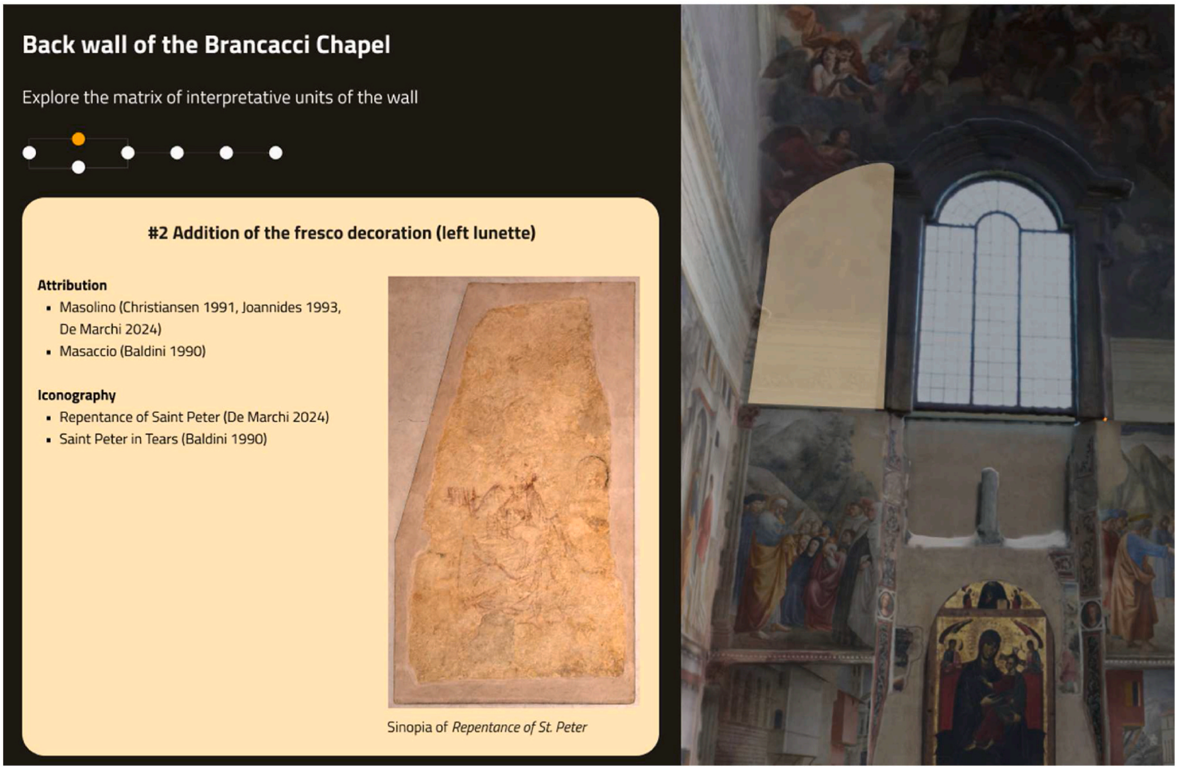

Fig. 8. Proof of concept for a visualisation in Figma of the information for the Interpretative Unit 2.1, related to the decoration of the left lunette (*Repentance of St. Peter*).

which historians, heritage scientists and in general domain experts produce new knowledge and understanding on cultural artefacts and phenomena. The definition of the single interpretative acts connected to a IntUnit was carried out merging two different entities: i) the class crm: E13_Attribute_Assignment of the standard CIDOC-CRM; ii) the class hico:InterpretationAct, drawn from the Historical Context Ontology (HICO), an *ad hoc* model designed to define the context of a claim, with a particular focus for historical disciplines. At the current state of the art, a full alignment between these two entities is absent (Daquino and Tomasi, 2015). *BranCO* provides a new solution, defining a new class, branco:Interpretation, as a subclass of both these two concepts.

However, the integration and the harmonisation of these two models would require further research and refinement in the future. Indeed, in the development of the ontology priority was given to light-wight solutions to maintain the full semantic of EM while limiting the number of classes in the final model. As an example, to describe nodes such as Documentary Stratigraphic Unit, indicating no longer existing elements known only from archive documents, IntUnits may be specified via *ad hoc* object properties declaring the criterion of the interpretation act and not by introducing new subclasses. To handle this issue, CIDOC-CRM itself does not currently provide a specific pattern, but instead relies on the complex structure of the argumentation model of CRMinf. Conversely, HiCO provides an optimised solution, enabling OEs to assert axioms in the form hico:InterpretationAct hico:hasInterpetationCrtierion hico:InterpretationCriterion.In addition, the reuse of the Citation Typing Ontology (CiTO) allows a streamlined assertion of different sources for an interpretation.

The simplicity of these architectures does not impact their semantic expressivity: therefore, HiCO was favoured in the definition of this section of the ontology. Nonetheless, in the current version of *BranCO*, the potential of this model is not exploited at its fullest. The key distinction between hico:InterpretationAct and crm:E13_Attribute_Assignment lies in their function: while crm:E13_Attribute_Assignment is designed to assign a value to another entity - further detailing the assignment's context (e.g., type, responsible entity, sources) - HiCO class can represent also one or more statements extracted from a source, which are relevant to multiple entities sharing similar characteristics, via named graphs (Tomasi, 2023). In this regard, HICO offers greater expressiveness than CIDOC CRM, as it allows for the grouping of statements rather than just instances of classes, reducing redundancy. Notwithstanding, as *BranCO* is primarily aligned with CIDOC CRM, we follow the intended use of crm:E13_Attribute_Assignment, while integrating the entities related to hico:InterpretationCriterion.

The class hico:InterpretationCriterion can be populated with terms from a controlled vocabulary, similarly to crm:E55_Type - here used to specify the type of an interpretation (e.g. authorship attribution, provenance etc.). This approach enables even applications which have not been considered in the original SAMOD scenario. The first test on one of the lunettes described in the catalogue of exhibition *Empoli 1424. Masolino e gli albori del Rinascimento* (De Marchi, 2024) provides insights in this regard. The catalogue entry mentions possible iconological interpretations for the frescoes; however, iconology was not included in *BranCO* list of possible interpretation types. In the test, this limitation was overcome by specifying a new interpretation type (instance of crm: E55_Type) to express statements on iconology. With this approach, the original expressivity of the model was expanded, without modifying its entire structure.

This observation paves the way to a broader consideration on the possible limitations and specificity of this project. As the name itself suggests, the development of the ontology stems from a thorough analysis of the case study of the Brancacci Chapel. Also the domain experts who actively contributed to the definition of the ontology requirements were involved in the last research project on this site. This risk of the ontology being overly specific is partially mitigated by the consistent reuse of entities from standard models in the CH domain. The feasibility of the application of *BranCO* to different contexts is therefore likely, but it should be empirically verified in future studies.

6. Conclusion

This study proposes a first conceptual model extending the concept of *stratigraphic units*, traditionally applied in archaeological excavations, also to other cultural sites, through the definition of *interpretative units*. To verify this hypothesis, an OWL 2 ontology has been developed. The project considered as a major starting point the Extended Matrix (EM) by Demetrescu, a conceptual model for the description of stratigraphic units and visual stratigraphic units in archaeological sites. This initiative, formalised as palette for the software yEd, also offers integration for Blender and for subsequent visualisations in the WebXR framework ATON (EMviq).

Nonetheless, this model is not serialised as an OWL ontology and fails in capturing some of the most relevant interpretative processes for the analysis of non-archaeological context. As a result, in this study, we provided a first state of the art on the related project in the field of semantic web and, later, the adopted methodology has been described: the ontology has been developed following the iterative protocol of the Simplified Agile Methodology for Ontology Development (SAMOD). Sect. 4.1 documents the different SAMOD scenarios and describes the most relevant entities of the model and the systematic direct import of classes properties from the standard CIDOC-CRM, its integration CRMdig, and the Historical Context Ontology (HICO).

The ontology is the first RDF translation of EM and is named *Brancacci Chapel Ontology* (*BranCO*) since it has been designed and firstly tested on the Brancacci Chapel as a case study. Indeed, if the full implementation of SAMOD proves the absence of logical inconsistency, Sect. 4.2 describes a first case study to assess the semantic expressivity of the model. Its classes have been populated with data from a catalogue entry of the exhibition *Empoli 1424. Masolino e gli albori del Rinascimento,* which scrutinised the pictorial activity by Masolino, a 15th century painter who worked at the decoration of the chapel. This document provides a brief yet rich art-historical overview and reconstruction of one the 15th century lunette of the back wall, retrieved during a recent restoration campaign under the subsequent frescoes by Vincenzo Meucci (1746–1748). The knowledge graph has been queried in SPARQL and competency questions have been successfully answered.

These first results encourage the deepening of this line of research. For this study, the research perspectives are at least twofold. On the one hand, effort should be made to enhance the ontological model. In particular, priority should be given to overcome the limitations emerged in the Discussion (Sect. 5). These include a broader reflection on the integration of HiCO, which relies on named graphs, in a CIDOC-CRM architecture, as well as additional testing of the ontology. The semantic expressivity of *BranCO* should be tested not only on new data connected to the Brancacci Chapel, but also on new cultural contexts. This would eventually verify the applicability of the model also in other scenarios.

In addition, future revisions and integrations of the model should also focus on verifying the compatibility of the ontology with new versions of the Extended Matrix. Indeed, after the finalisation of this study and the publication of this first ontology, in September 2024 the version 1.4. of the EM was released (Scopinaro et al., 2024), which introduces Transformation Stratigraphic Units (TSUs). This concept is conceived to systematically document visible damages (e.g. cracks, discolouration) and changes detected through diagnostic analysis, such as pigment changes, repainting or dirt deposits. Whether the current version of Brancacci Chapel Ontology can also describe these changes should be therefore discussed in future studies.

On the other hand, this first assessment of *BranCO* suggests how this model may effectively contribute in creating a new tool for enabling access also for non-experts to the data heritage scientists rely on for the reconstruction of cultural sites. The Digital Heritage Innovation Lab at CNR ISPC in Florence, one of the major stakeholders of this study, is currently working on a preliminary proof of concept of a visualisation system, proposed in Fig. 8. The tool shall be able to easily add axioms to the triplestore and highlight the object(s) at the core of every interpretative units, a matrix representing the chronological evolution of a specific section of the CH site (in the figure: the back wall of the chapel), as well the most relevant sources and documents which may be consulted for the examination of the site. This future system would provide facilities for intuitive visualisations targeted also at non-specialist audiences, able to make visitors fully aware of the complex interpretative process connected to the understanding, reconstruction and communications of our shared cultural legacies.

CRediT authorship contribution statement

Manuele Veggi: Writing – original draft, Methodology, Conceptualization. **Ivana Cerato:** Writing – original draft, Validation, Supervision, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary Materials

The ontology, together with further documentation on its use, is available online w3id.org/cnr-ispc/ontology/branco. Materials and documentation hosted in the GitHub repository have been released and registered on Zenodo (Veggi and Cerato, 2025).

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