Cultural Heritage Survey: an Ontology Design Pattern

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Abstract

This paper introduces the Cultural Heritage Survey Ontology Design Pattern (CHS-ODP), a content pattern that abstracts from specific implementations and provides a reference core for modelling survey processes within cultural heritage knowledge graphs. The pattern is grounded in a set of generalised competency questions derived from two independent real-world use cases: a Reflectance Transformation Imaging (RTI)-based documentation campaign on rock art and a diagnostic investigation on illuminated manuscripts. Designed in alignment with CIDOC-CRM, ArCo, DOLCE UltraLight, the proposed pattern supports interoperable and reusable survey-centric modelling across heterogeneous cultural-heritage domains.

Keywords

Ontology Design Pattern, Cultural Heritage, Knowledge Graph, Survey Modelling, Archaeology Survey, Illuminated Manuscript Survey

1. Introduction

Cultural heritage institutions increasingly rely on knowledge graphs to document and integrate the heterogeneous data produced during research, conservation, and documentation activities. Established ontologies such as CIDOC-CRM [1], ArCo[2] provide robust conceptual foundations for representing cultural heritage entities and the processes through which they are studied. However, when applied to concrete investigation campaigns, these models are often combined in ad hoc ways, especially when documenting structured survey activities, posing a challenge in the integration and interoperability of cultural heritage knowledge graphs. There is a lack of a shared reference schema for approaching the extension or reuse of these ontologies for modelling cultural heritage surveys.

To address this challenge we propose the Cultural Heritage Survey Ontology Design Pattern (CHS-ODP)[1], which focuses on the modelling of surveys conducted on cultural properties, understood as structured investigation activities performed within broader research or conservation projects. In the remainder of the paper, we refer to this pattern as CHS-ODP. Surveys may include non-invasive digital documentation (e.g., imaging campaigns), diagnostic analysis on artworks, manuscripts or any extracted samples, or combined procedures involving instrumentation, configuration settings, and post-processing

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[1] http://ontologydesignpatterns.org/cp/owl/culturalheritagesurvey.owl

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steps. Despite their diversity, such activities share common structural requirements: identification of the object of study (or feature of interest), specification of the adopted method, documentation of instrumentation and configuration, production of observations and outputs, interpretation of the results, and possible samples taking.

Our work originates from, and is validated through two independent real-world use cases developed by different research groups in distinct cultural heritage sub-domains. The first concerns a Reflectance Transformation Imaging (RTI)-based digital documentation campaign on rock art, where multiple photographs, acquired under a controlled configuration, are post-processed into a single interactive image. The second concerns non-invasive, point-based analytical investigations on illuminated manuscripts performed in the context of a multi-technique study aimed at characterising the materials used in the production of the illuminations. These two scenarios rely on different methodologies and extend different reference ontologies: the Italian ArCo network of ontologies for cultural properties in the first case and the international standard CIDOC-CRM for cultural heritage in the second case. Nevertheless, both cases require addressing similar competency questions (CQs), i.e., natural language questions that a knowledge base or ontology should answer. These include, for instance, identifying which survey activities were performed on a given cultural property or feature of interest, which methods and instrumentation configurations were used in a specific survey, and which observations were produced as a result of these activities. We observed that these questions are not systematically nor comprehensively covered by existing models when used independently.

Our proposal, the CHS-ODP, is a content ontology design pattern [3] that abstracts from specific implementations and provides a reference schema with clear boundaries for modelling survey processes in cultural heritage knowledge graphs. The pattern identifies a minimal, yet expressive, core that is centered on: (i) the survey activity as a coherent investigation unit; (ii) its inclusion within a broader project; (iii) the cultural property, sample, or feature of interest under study; (iv) the adopted method and related instrumentation/configuration; (v) the produced observations and related results; (vi) possible sampling activities, and (vii) the associated interpretation and claims. The pattern is grounded on relevant existing ontologies, both foundational and core for the cultural heritage domain, ensuring compatibility with event-based modelling from CIDOC-CRM, situation-based modelling from DOLCE Ultra Light [4] and ArCo.

The pattern has been developed following the guidelines of the Workshop on Ontology Design Patterns (WOP)[2] and is published on the Ontology Design Patterns portal[3], with explicit axiomatization and documented alignments. Its robustness derives from a systematic reuse of established ontology design patterns, explicit boundary definition of the survey concept, and validation against two heterogeneous real-world use cases.

The key contribution of this paper are:

1. A rigorous modelling problem statement for survey processes in cultural heritage.
2. A set of generalised competency questions derived from interactions with domain experts involved in two independent real cases.
3. The Cultural Heritage Survey ODP, including its core classes, relations, axioms, and documentation.
4. Explicit alignments with CIDOC-CRM and some of its extensions, ArCo and DOLCE Ultra Light.
5. Two empirical instantiations demonstrating the generalisation of the pattern across digital documentation and diagnostic analysis domains.

The remainder of this paper is structured as follows. Section 2 reviews related ontologies and reused patterns. Section 3 presents the modelling requirements and competency questions. Section 4 describes the proposed pattern in detail, including its axiomatisation and alignments. Section 5 illustrates its instantiation in the two use cases. Section 6 concludes the paper discussing strengths and limitations, and future work.

[2]https://github.com/odpa/workshop-on-ontology-design-and-patterns/
[3]http://ontologydesignpatterns.org/ and https://github.com/odpa/patterns-repository/

2. Related work

Among the most prominent reference ontologies in the cultural heritage domain, and of interest for our purposes, are the CIDOC Conceptual Reference Model (CIDOC-CRM) [1] and the ArCo network of ontologies [2].

CIDOC-CRM, an ISO standard (ISO 21127:2014), provides a comprehensive framework for describing the implicit and explicit concepts and relationships in cultural heritage documentation. It models complex interactions between actors, events, and objects, enabling integration of heterogeneous data. However, while CIDOC-CRM excels in representing the outcomes of cultural heritage activities such as artifacts, events, and their contextual information, it does not explicitly address the detailed processes of surveys or the granular steps involved in data collection and analysis.

The ArCo network of ontologies, developed in the Italian cultural heritage context, aligns with CIDOC-CRM and introduces specialised modules for cataloguing, places, and different types of cultural properties, such as archaeological, landscape, and artistic heritage. While ArCo introduces a survey class with methods and spatio-temporal aspects, it lacks constructs for modelling procedural and observational aspects, the equipment to be used, and possible interpretations.

Beyond the cultural heritage domain, there are additional ontologies and ODPs that are relevant for our proposed work. One of these is represented by a CIDOC-CRM extension named CRMsci[4] that has been developed with the aim to model scientific observations, measurements and processed data in descriptive and empirical sciences. In this context, the W3C's Semantic Sensor Network (SOSA/SSN) ontology [5] is designed to model the act of observation, the entities involved (e.g., sensors, platforms, feature of interest), and the resulting data, making it highly relevant for scenarios where surveys involve observing single properties of features of interest belonging to cultural properties. However, while SOSA/SSN provides a solid foundation for modelling observations and their context, it does not inherently address the domain-specific requirements of cultural heritage surveys, such as the interpretation of survey results within a historical or archaeological context. The IoT ontology [6] developed by the Italian public sector introduces ontology design patterns for modelling IoT devices, their interactions, the data they generate and the quality of the measurements. This ontology aligns with SOSA/SSN by focusing on the technical and operational aspects of IoT ecosystems, but it similarly does not provide domain-specific constructs for cultural heritage surveys.

Foundational ontologies, such as DOLCE+DnS Ultralite (DUL) [4], play a crucial role in ensuring semantic interoperability across domains. DUL offers a lightweight, upper-level ontology that provides a set of basic categories and relations for modelling entities, events, and their participation in processes. By aligning domain-specific ontologies with DUL, it becomes possible to establish a common semantic ground that facilitates integration and reasoning across heterogeneous data sources. In the context of cultural heritage surveys, DUL can serve as a foundational layer for modelling the high-level concepts of observations, processes, and their participants.

The ontologies discussed above each contribute valuable perspectives and modelling capabilities, yet they also exhibit gaps when applied to the specific requirements of cultural heritage surveys. For instance, the sole CIDOC-CRM, while providing a robust framework for describing activities and cultural objects, lacks dedicated classes for defining survey campaigns, acquisition instruments, or technical methodologies, as well as the relationships between raw data and processed outputs. ArCo, though focused on cultural properties and survey campaigns for them, does not structurally model observations, or interpretation and claims of the results of those campaigns. Finally, SSN/SOSA, IoT and CRMsci, while excelling in representing observations, measurements, do not contextualize this data within a cultural or historical framework, nor does it handle the complexity of survey campaigns.

In this paper, we address these gaps by introducing a pattern-based approach that leverages semantic alignments with the aforementioned ontologies. Our approach integrates the strengths of CIDOC-CRM and its extensions, ArCo, SOSA/SSN, IoT and DUL to provide a comprehensive framework for modelling cultural heritage surveys. By aligning our pattern with some of these reference ontologies, we ensure

[4]https://cidoc-crm.org/sites/default/files/CRMsci-v3.0.pdf

stronger semantic interoperability and facilitate the adoption of our model within existing cultural heritage infrastructures.

3. Requirements for Cultural Heritage surveys

A set of modelling requirements was elicited from a given scenario (reported below) with the support of domain experts and formalised as *competency questions* [7] (cf. Table 1) that guided the definition and refinement of the proposed pattern.

Prototypical Scenario. A prototypical scenario involves an investigation project dedicated to the study of one or more cultural properties. Within the project, specific surveys are conducted according to defined methods. Each survey targets a cultural property or a more specific feature of interest, possibly including samples derived from the property. The surveys and the activities of the investigation process are characterised by explicit spacial and temporal indexing, and involves experts participating with different roles. Surveys are carried out using specific hardware and software resources, configured under explicit technical conditions. Multiple observations may be performed, often under stable configurations, producing results such as images, datasets, or measurement values. In some cases, sampling activities precede observation, generating material entities that become the focus of subsequent analyses. Interpretative activities may follow data acquisition but remain conceptually distinct from observation.

Table 1
Competency questions elicited from the scenario.

ID	CQ
CQ1	Which survey or investigation activities were performed on a given cultural property or on a specific feature of interest?
CQ2	Which method or investigation technique was adopted in a specific survey or investigation activity?
CQ3	Which observations were produced during a given survey or investigation activity?
CQ4	Which experts participated in the survey or investigation activity, and with which roles?
CQ5	Which hardware, software, and technical configurations were used to conduct a specific survey or investigation activity?
CQ6	What interpretations or claims are supported by the observations produced during a survey?
CQ7	How are post-processed outputs (e.g., interactive images, spectra, datasets) related to the underlying acquisition or observation activities?
CQ8	Which acquisition parameters (e.g., exposure time, ISO, aperture) characterised a specific photographic acquisition cycle within a survey?

4. An ODP for Cultural Heritage Surveys

The Cultural Heritage Survey Ontology Design Pattern (CHS-ODP) provides a reusable conceptual schema for modelling survey activities conducted on cultural properties, with particular attention to methodological coherence, observation processes, instrumentation, and produced results. The pattern abstracts from specific institutional workflows and can be instantiated in heterogeneous contexts.

4.1. Overview of the Pattern

Figure 1 depicts the core of the CHS-ODP using the Graffoo notation, which we have extended to include entities representing ontology design patterns (yellow boxes with dashed border). These entities refer to aspects that should be addressed with a modelling pattern that fits the purpose, for example modelling temporal entities. The CHS-ODP leaves the specific modelling commitment on these entities to the case at hand.

The CHS-ODP is centered on the class `chs:CulturalHeritageSurvey`, representing a structured investigative process (a Description in DOLCE terms) performed within a broader research context and according to a defined methodological setup. A survey represents more than a simple aggregation of observations: it constitutes a coherent study unit characterised by explicit instrumentation and traceable outputs, being temporally and (possibly) geographically indexed, and involving people with specific roles.

The pattern organises the modelling of cultural heritage surveys into several interconnected conceptual components:

1. the research context (`chs:CulturalHeritageProject`),
2. the survey process (`chs:CulturalHeritageSurvey`),
3. the object under investigation (`chs:CulturalProperty`, `chs:Sample`, `chs:FeatureOfInterest`),
4. the observation layer (`chs:Observation`, `chs:ObservationCollection`, `chs:Result`),
5. the technical layer (`chs:Method`, `chs:Equipment`, `chs:EquipmentConfiguration`),
6. the interpretation layer (`chs:Interpretation`, `chs:Claim`).

Together, these components enable the representation of how cultural heritage surveys are performed, what entities are observed, which technical configurations are used, and how scientific interpretations and claims derive from the produced observations.

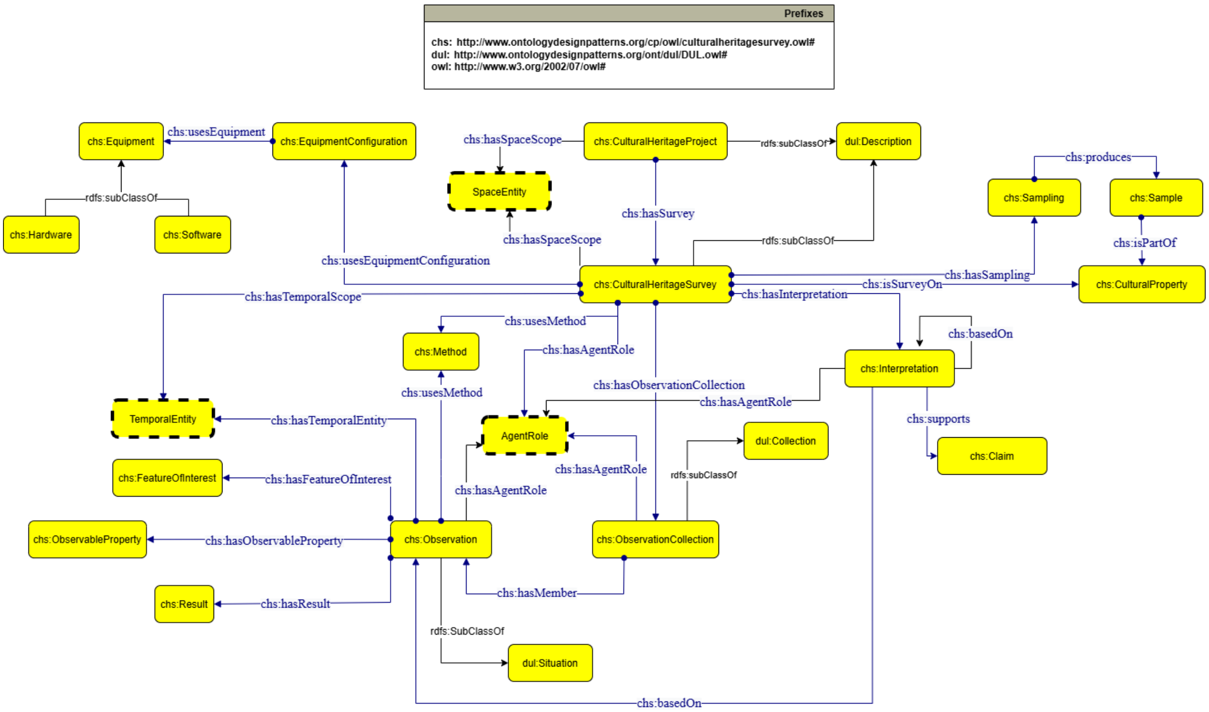

Figure 1: Graffoo diagram of the CHS-ODP. Yellow boxes represent classes. Arcs represent object properties. Yellow boxes with dashed border represent ontology design patterns.

4.2. Core Classes and Properties

Research Context and Survey Activity. Survey activities are situated within a broader research framework represented by the class `chs:CulturalHeritageProject`. Projects correspond to research initiatives, conservation campaigns, or documentation programmes that organise and contextualise multiple surveys. The class `chs:CulturalHeritageSurvey` models the individual investigative activity carried out on one or more cultural heritage entities. A survey may generate multiple observations and associated datasets, forming the empirical basis for subsequent analysis and interpretation.

Supported competency questions. By modelling surveys as structured investigative activities situated within a broader research context, the pattern enables queries about which survey or investigation activities were performed on a given cultural property or feature of interest (CQ1). In addition, surveys may involve multiple experts participating with specific roles, enabling the representation of which agents contributed to the survey and in which capacity (CQ4).

Object of Investigation. The pattern distinguishes several levels of entities that may be investigated during a survey. The class `chs:CulturalProperty` represents the cultural heritage asset under study (e.g., an artefact or a manuscript). In some cases, the investigation may focus on a physical sample extracted from the property, represented through the class `chs:Sample`. Alternatively, observations may target specific parts or aspects of the cultural property, represented through the class `chs:FeatureOfInterest`.

In addition to the entity being observed, the pattern explicitly models the property of that entity that is investigated through the class `chs:ObservableProperty`. While `chs:FeatureOfInterest` identifies the entity or portion of reality under investigation, `chs:ObservableProperty` specifies which attribute of that entity is observed. For example, in the analysis of an illuminated manuscript, the feature of interest may correspond to a specific miniature, while the observable property may correspond to its colour or pigment composition. This modelling distinction allows observations to precisely specify both the target entity and the attribute being measured or described.

Relevant axioms and supported competency questions. Each `chs:Observation` can target at most one `chs:FeatureOfInterest` and investigates at most one `chs:ObservableProperty`. This modelling supports queries about which cultural property or feature of interest is investigated and which observations are produced in relation to specific investigated entities (CQ1, CQ3).

Observation Layer. The observation layer represents the empirical data produced during the survey. Individual observations are modelled through the class `chs:Observation`, which represents the act of observing a specific feature of interest using a given method and technical configuration. Observations may produce one or more results, represented as instances of the class `chs:Result`. When multiple related observations are produced within the same survey context, they may be grouped into an `chs:ObservationCollection`. Each observation therefore links together the investigated feature of interest, the observable property being examined, the adopted method, and the produced results.

Relevant axioms and supported competency questions. Each `chs:Observation` produces one or more `chs:Result` instances and is performed using a specific method. This structure supports queries about which observations were produced during a survey and how they relate to the adopted methodological setup (CQ2, CQ3).

Method and Technical Layer. The technical dimension of the survey is captured through the classes `chs:Method`, `chs:Equipment`, and `chs:EquipmentConfiguration`. The class `chs:Method` represents the investigative or analytical technique adopted during the survey (e.g., RTI or spectroscopy). Observations refer to the adopted method through the property `chs:usesMethod`.

The class `chs:Equipment` represents the instruments used during the survey. Since several instruments may be combined during a single observation, their joint configuration is represented through the class `chs:EquipmentConfiguration`. This class allows describing the specific technical setup used to produce observations, including both hardware and software components.

Supported competency questions. By explicitly modelling methods, equipment, and equipment configurations, the pattern enables queries about which investigation techniques were adopted and which hardware, software, and technical configurations were used during a survey (CQ2, CQ5). In photographic acquisition scenarios, this modelling also allows representing acquisition parameters such as exposure time, ISO, or aperture (CQ8).

Interpretation and Claims. The pattern explicitly separates empirical observation from analytical reasoning. While observations generate raw results, their scientific interpretation is represented through the class `chs:Interpretation`. An interpretation is based on one or more observations through the property `chs:basedOn`. Interpretations may support explicit knowledge statements represented as instances of `chs:Claim`. This modelling choice allows distinguishing the analytical reasoning process from the final statements derived from it, while preserving the traceability of claims to the underlying observational evidence.

Relevant axioms and supported competency questions. Each `chs:Interpretation` is based on one or more `chs:Observation` instances and may support one or more `chs:Claim`. This modelling enables queries about which interpretations or claims are supported by the observations produced during a survey and how derived knowledge artefacts relate to the underlying observational evidence (CQ6, CQ7).

4.3. Alignment Strategy

The CHS-ODP is designed to be interoperable with existing ontologies commonly adopted in the cultural heritage domain. The alignments target those classes whose semantics can be directly mapped to external ontologies. This strategy allows maintaining the conceptual coherence of the pattern while ensuring interoperability with domain ontologies used in the analysed use cases.

Tables 2 summarises the main class alignments adopted in the pattern.

Table 2
Alignments with Dolce Ultralite, ArCo and CIDOC-CRM/CRMsci. $\sqsubseteq$ denotes subclass alignment (`rdfs:subClassOf`)

CHS-ODP class	Alignment	External class	External Ontology
chs:CulturalHeritageSurvey	$\sqsubseteq$	dul:Description	DOLCE Ultra Light
chs:Observation	$\sqsubseteq$	dul:Situation	DOLCE Ultra Light
chs:ObservationCollection	$\sqsubseteq$	dul:Collection	DOLCE Ultra Light
chs:CulturalProperty	$\sqsubseteq$	arco:CulturalProperty	ArCo-main module
chs:CulturalHeritageSurvey	$\sqsubseteq$	a-cd:Survey	ArCo-context description
chs:Method	$\sqsubseteq$	core:Method	ArCo-core
chs:EquipmentConfiguration	$\sqsubseteq$	a-cd:MeasurementCollection	ArCo-denotative description
chs:CulturalProperty	$\sqsubseteq$	crm:E22_Human-Made_Object	CIDOC-CRM
chs:CulturalHeritageSurvey	$\sqsubseteq$	crm:E29_Design_or_Procedure	CIDOC-CRM
chs:Method	$\sqsubseteq$	crm:E29_Design_or_Procedure	CIDOC-CRM
chs:Observation	$\sqsubseteq$	crm:E16_Measurement	CIDOC-CRM
chs:Equipment	$\sqsubseteq$	crm:E22_Human-Made_Object	CIDOC-CRM
chs:Observation	$\sqsubseteq$	crmsci:S4_Observation	CIDOC-CRM-CRMsci
chs:Interpretation	$\sqsubseteq$	crmsci:S6_DataEvaluation	CIDOC-CRM-CRMsci

The CHS-ODP adopts a compatible modelling structure with SOSA/SSN [5] for observation-related concepts (e.g., feature of interest, observable property, and result). This makes the pattern conceptually interoperable with SOSA-based models. However, the alignments are not explicit since the primary objective of this work is to provide alignment with foundational and core domain ontologies used in cultural heritage domain.

5. Use cases: RTI survey of rock art and point-based investigation on illuminated manuscripts

This section presents two real-world surveys involving different cultural properties and methodologies. These examples demonstrate the flexibility of CHS-ODP, showing how the pattern can be specialised for specific requirements, while maintaining its core structure. Despite being developed independently, the resulting ontologies remains conceptually and formally interoperable.

The first use case 5.1 is concerned with a RTI-based survey campaign on petroglyphs from the Rupe Magna Engraving Park (Italy). The second use case concerns the diagnostic investigations of the manuscript *De Balneis Puteolanis* (ms. 1474) preserved at the Angelica Library in Rome.

5.1. An RTI-based Rock Art Survey of *Rupe Magna*

The Rupe Magna Engraving Park (*Parco delle Incisioni Rupestri di Grosio*), located in the upper Valtellina Valley of Lombardy, northern Italy, represents one of the most extraordinary archaeological contexts of Alpine rock art, with more than 5,454 petroglyphs distributed over a surface of approximately 84 × 35 metres [8] see Figure 2. Its iconographic repertoire spans several millennia, from Copper Age geometric and schematic designs to Bronze and Iron Age anthropomorphic figures, including praying figures (*oranti*) and armed warriors [9, 10].

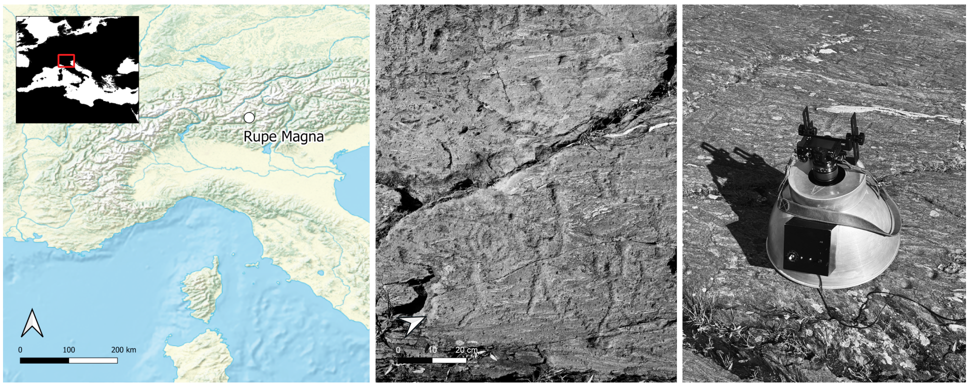

Figure 2: Left: Location of Rupe Magna within northern Italy and Europe (inset). Basemap: Natural Earth Data; map produced using QGIS. **Middle:** The Praying Figure with Spiral (*orante con spirale*), Sector AA. Early Iron Age anthropomorphic figure whose left arm overlaps an earlier spiral, establishing the anteriority of the geometric motif [11]. **Right:** The custom-built portable RTI dome deployed *in situ* at Rupe Magna. Photograph by Hüseyin Erdoğan.

Conducted in September 2025, the survey campaign used Reflectance Transformation Imaging (RTI), an open-source computational photography method for digital documentation of cultural heritage [12, 13], focused on eleven representative figures selected from six sectors of the site (*AA, B, F, L, Q, S*), pursuing two complementary objectives. The primary aim was to perform a morphological analysis of the figure surfaces using computational photography methods to enhance the legibility of weathered engravings and facilitate iconographic interpretation. Simultaneously, the project sought to achieve the structured sharing of both the acquired data and the acquisition process itself through a FAIR-compliant knowledge graph. This ensures that the entire workflow, from initial fieldwork to final digital output, remains machine-readable, reproducible, and openly accessible to the broader research community.

A total of 40 RTI datasets were acquired following a standardised protocol: surface preparation, specular sphere placement, dome positioning with ambient light exclusion, manual camera configuration ($f/8$–$f/10$, ISO 100–400, shutter speed 1/15–1/4 s), and automated sequential LED activation (48 exposures per cycle, 144 seconds total). Post-processing using the RelightLab [5] software platform included a four-tier quality assessment (Gold, Silver, Usable, Rejected) based on sphere sharpness, light leak absence, and sequence consistency, resulting in 17 selected datasets processed into final PTM/RTI files.

The RTI workflow was then modelled as an extension of the ArCo [6] ontology network [2], instantiating the CHS-ODP proposed in this paper. The acquisition was performed using a custom-built portable dome (Ø 46 cm, 48 LEDs, six azimuthal tiers), processing the data through RelightLab , and representing the entire process in RDF according to the pattern described in Section 4.

[5]https://github.com/cnr-isti-vclab/relight (visited on 29-02-2026)
[6]https://github.com/ICCD-MiBACT/ArCo/ (visited on 01-03-2026)

Figure 3 shows the Graffoo[7] diagram illustrating how the CHS-ODP is reused for our scenario. We extended ArCo with classes and properties defined in our namespace :[8]. The `chs:CulturalHeritageSurvey` class generalises over `a-cd:PhotoInterpretationRendering`, in turn a subclass of `a-cd:Survey`. This class represents the RTI documentation activity as both a photographic acquisition and an interpretative rendering process.

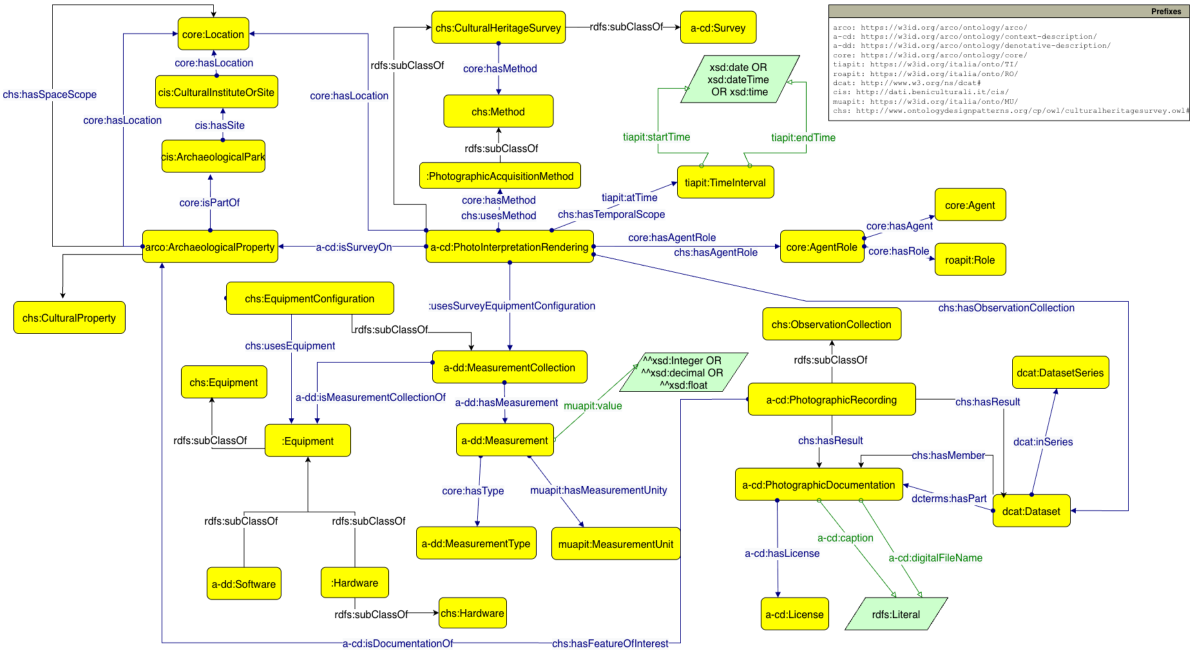

Figure 3: Graffoo diagram of the `rupemagna:` ontology module, extending the ArCo network to model RTI survey workflows. The diagram shows the instantiation of the CHS-ODP within the ArCo context: `a-cd:PhotoInterpretationRendering` (subclass of `a-cd:Survey`) serves as the `CulturalHeritageSurvey` node, connected to `arco:ArchaeologicalProperty` via `a-cd:isSurveyOn`, and to the technical layer through `:SurveyEquipmentConfiguration`, `:Hardware`, and `a-dd:Software`. New classes and properties introduced in the `rupemagna:` namespace are distinguished from reused ArCo terms.

The `Method` class is specialised by `rti:PhotographicAcquisitionMethod` (instantiated with the entity RTI), temporally indexed through `tiapit:TimeInterval`, recording temporal scope. Agents and roles are represented through `core:AgentRole`, linking each `core:Agent` to a `roapit:Role` (e.g., operator, photographer). The equipment used is represented through the class `rti:Equipment` (which specialises `chs:Equipment`), instantiated by differentiating `:Hardware` instances (dome, camera) and `a-dd:Software` instances (RelightLab, RTIViewer). The `chs:EquipmentConfiguration` specialises the ArCo class `a-cd:MeasurementCollection`, defining quantitative acquisition parameters, such as aperture, ISO, and shutter speed, through `a-dd:Measurement`.

The survey produces a set of observations `chs:ObservationCollection`, here specialised by the class `a-cd:PhotographicRecording`. Each observation produces a `a-cd:PhotographicDocumentation` as result (`chs:Result`), and is performed on a `chs:FeatureOfInterest`: the specific engraved figure, an `arco:ArchaeologicalProperty` (specialising `chs:CulturalPoperty`). For each figure and acquisition cycle, 48 photographs (RAW and JPG) together with the RelightLab-processed RTI files are collected and stored in a `dcat:Dataset`. Since multiple acquisition cycles may be performed per figure, all datasets for the same figure are grouped in a `dcat:DatasetSeries`. Each record carries metadata for attribution, licensing, and FAIR compliance (`a-cd:caption`, `a-cd:digitalFileName`, `a-cd:License`). Finally, both the archaeological property and the survey are connected to their spatial scope via `core:Location`, further linked to `cis:ArchaeologicalPark`.

[7]https://essepuntato.it/graffoo/ (visited on 01-03-2026)
[8]The RTI ontology is yet to be published.

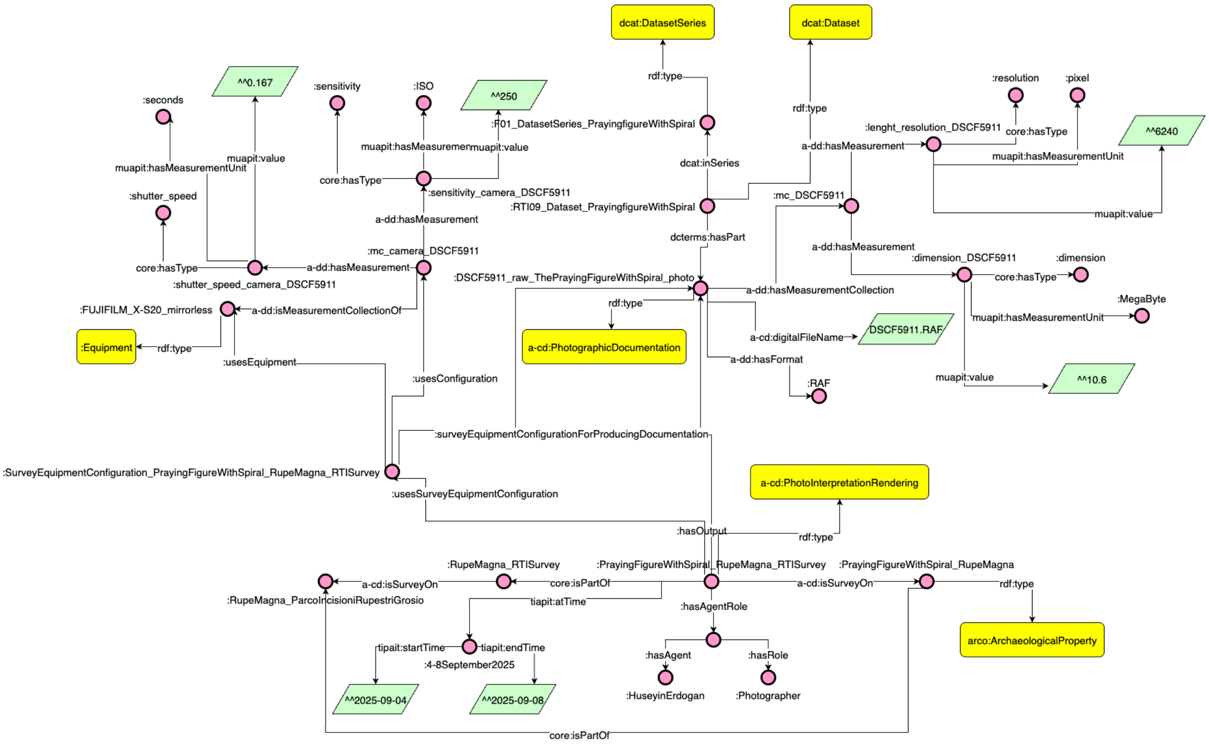

Figure 4: The excerpt instantiates the core classes of the CHS-ODP: the survey activity (a-cd:PhotoInterpretationRendering), the feature of interest, the agent, the equipment configuration, and the digital output.

Figure 4 presents an excerpt of the resulting knowledge graph, centred on the RTI survey of the *Praying Figure with Spiral* (Sector AA). The individual :PrayingFigureWithSpiral_RupeMagna_RTISurvey, typed as a-cd:PhotoInterpretationRendering, constitutes the chs:CulturalHeritageSurvey instance. It is connected via a-cd:isSurveyOn to the documented property :PrayingFigureWithSpiral_RupeMagna (arco:ArchaeologicalProperty), and its temporal extent is recorded through tiapit:startTime ("2025-09-04") and tiapit:endTime ("2025-09-08"). The agent is linked via core:hasAgentRole to an instance of core:AgentRole, associating the responsible core:Agent (Hüseyin Erdoğan) with the roapit:Role of photographer.

The equipment configuration :SurveyEquipmentConfiguration_PrayingFigureWithSpiral_RTISurvey is linked via :usesSurveyEquipmentConfiguration and connects to the camera instance :FUJIFILM_X-S20_mirrorless through :usesEquipment. Acquisition parameters are modelled in the measurement collection :mc_camera_DSCF5911: for instance, an exposure time of 0.167 s and an ISO value of 250 are each described with their type, value, and unit following the ArCo a-dd: and muapit: vocabularies. The digital output is represented by :DSCF5911_raw_ThePrayingFigureWithSpiral_photo, typed as a-cd:PhotographicDocumentation, constituting one of the 48 photographs acquired in that session and collected through a photographic recording and stored in the corresponding dcat:Dataset.

5.2. Diagnostic Investigation of the *De Balneis Puteolanis* Manuscript

The copy of *De Balneis Puteolanis* (ms. 1474), preserved at Rome's Angelica Library, is a key example of southern Italian Swabian manuscript production. Likely commissioned by Manfredi, son of Frederick II, between 1258 and 1266, it is the earliest surviving copy of Pietro da Eboli's poem describing the thermal baths of Pozzuoli and Baia. The poem's composition date remains debated: traditionally linked to Frederick II (1211–1221) [14], recent studies suggest an earlier origin (1194–1197), possibly dedicated to his father, Henry VI [15, 16]. The volume belongs to a corpus of "profane" illustrated manuscripts conceived as *libri di figure* for courtly audiences [17]. It contains eighteen epigrams paired with full-page illuminations; however, the loss of several folios have disrupted the original text-image harmony.

In 2023, the artefact underwent multimodal diagnostic analysis as part of the CODEX 4D project [18]. The resulting data is accessible through the Illuminated Manuscripts Hub [19, 20], a digital platform under development within the H2IOSC[9] initiative.

For illuminated and highly decorated manuscripts, such as the present case, the pre-selection of specific folios is essential, especially when combining multiple analytical methodologies and techniques.

This case study focuses on folios cc. 12v–13r, dedicated to the *Balneum de Ferris* (Fig. 5). These folios were analysed through a specialised campaign conducted by the mobile laboratory (MOLAB) of the European Research Infrastructure for Heritage Science (E-RIHS)[10].

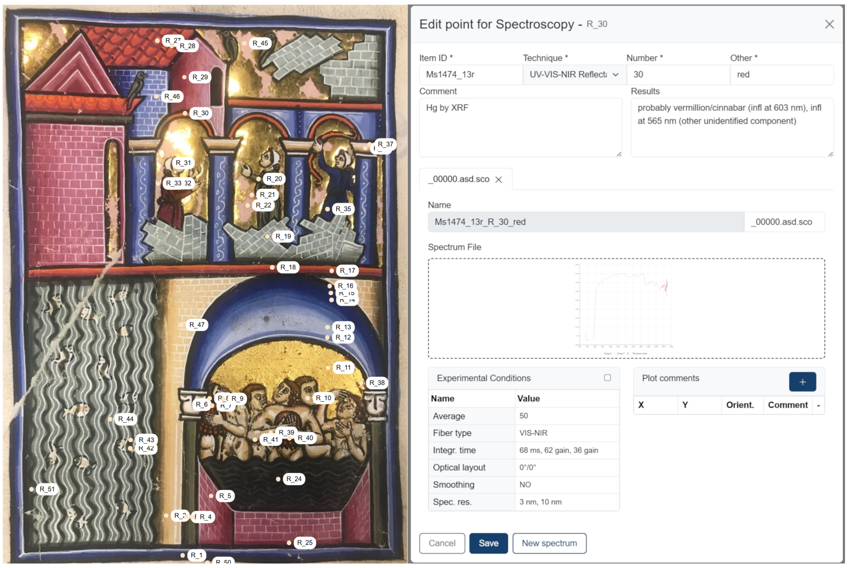

Figure 5: Rome, Angelica Library, ms. 1474, f. 13r - point measurement in UV-VIS-NIR reflectance spectroscopy.

The *Balneum de Ferris* was situated along the shores of Lake Avernus, near the Temple of Apollo. Like the other illuminated pages, this scene is composed of two registers: the upper register portrays the ruined temple, while the lower register illustrates bathers immersed in a polygonal pool.

On this folio, the following analyses have been conducted: X-ray Fluorescence, Raman Spectroscopy, Hyperspectral Imaging, Multi-Band Imaging, and UV-VIS-NIR reflectance spectroscopy. The integration of all data enabled a comprehensive understanding of the nature of the pigments and preparatory layers, the composition of the pigments, the techniques, as well as the manuscript's state of preservation. The results provided substantial new insights, enabling a reassessment and further refinement of earlier interpretations, which had relied exclusively on visual examination of the codex until now [17].

The DIGILAB-IT Ontology Network Applied to Analytical Investigation Campaigns. DIGILAB-IT, the digital laboratory of E-RIHS.it, was established within the H2IOSC project and is now nearing full operational capacity. It serves as a cutting-edge platform for integrating multi-domain data related to cultural heritage entities, leveraging a shared ontology network (currently still under implementation and consolidation) and interoperable services [21].

Figure 6 shows the Graffoo diagram of a section of one of DIGILAB-IT's ontologies of the above mentioned network related to diagnostic investigations. The ontology is also aligned with CIDOC-CRM.

A *dinv:InvestigationCampaign* (subclass of *chs:CulturalHerigateProject* of CHS-ODP) represents the overarching research initiative within which multiple, often complementary, investigation activities are planned and executed. Each *dinv:InvestigationActivity* (subclass of *chs:ObservationCollection*) is defined

[9] https://www.h2iosc.cnr.it/
[10] https://www.e-rihs.eu/

within the campaign and within a *dinv:DiagnosticInvestigation* (subclass of *chs:CulturalHeritageSurvey*) through the *dinv:definesInvestigationActivity* property, and it is linked to the investigated heritage asset (*cultherit:TangibleCulturalEntity*, in turn subclass of *crm:E18_Physical_Thing* and *chs:CulturalProperty*) via the property *dinv:isPerformedOn*.

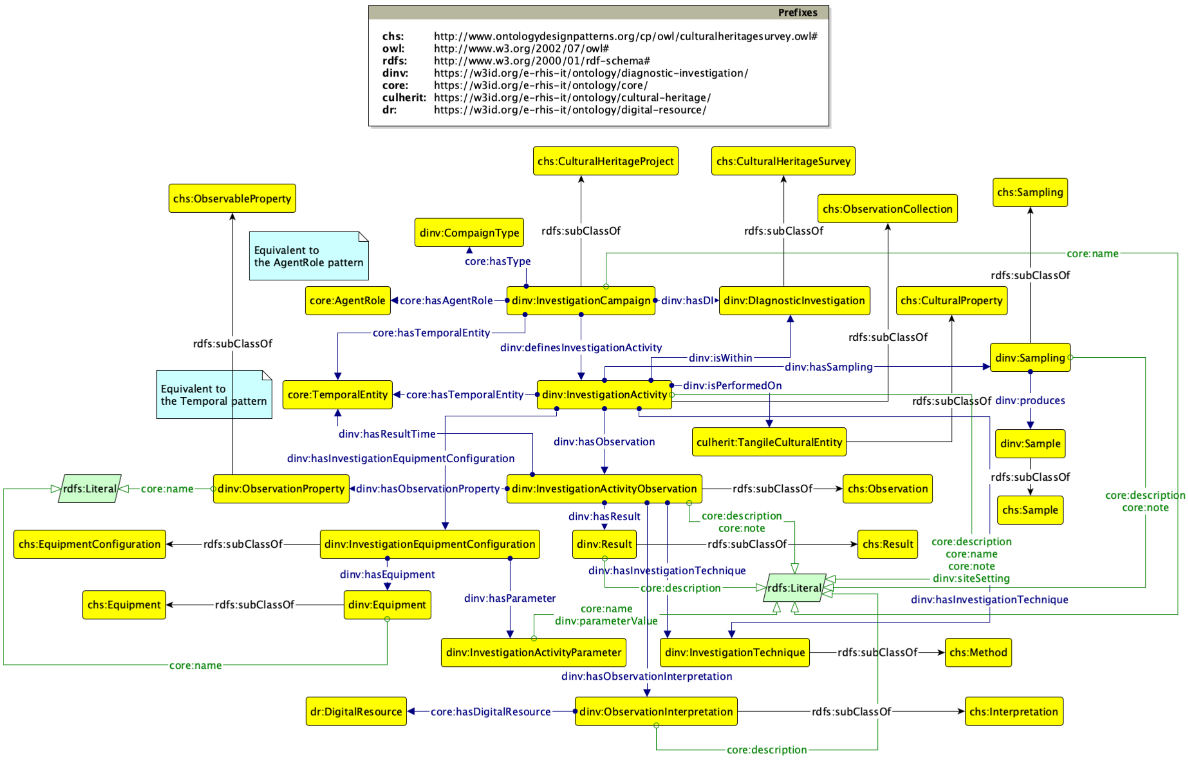

Figure 6: Graffoo diagram of an excerpt of DIGILAB-IT's diagnostic investigation ontology.

The *dinv:InvestigationActivity* is a collection of observations (the class *dinv:InvestigationActivityObservation* that is subclass of *crmsci:S4_Observation*, *crm:E16_Measurement* and of *chs:Observation*) done on specific points, areas of 3D regions.

Agents and roles are represented through the use of the ODP *core:AgentRole* (implementing the related ODP indicated by CHS-ODP) of the *core* ontology of the network. This class is then linked to a *core:Agent* and a *core:Role* (respectively subclasses of *crm:E39_Actor* and *crm:E55_Type* in CIDOC-CRM [1]). The pattern can be associated either with the overall campaign or with specific investigation activities. Temporal scope, as suggested by CHS-ODP, is implemented through the *core:TemporalEntity* class, aligned with the CIDOC CRM time-span pattern.

Each *dinv:InvestigationActivityObservation* is linked to the adopted investigation technique (*dinv:InvestigationTechnique*), the measured property (*dinv:ObservationProperty* subclass of the *chs:ObservableProperty*) and to the time to get the result (the property *dinv:hasResultTime* linking to the class *core:TemporalEntity*). The collection of investigation activities are associated with the experimental setup and parameters. This is done through the definition of an equipment configuration class (*dinv:InvestigationEquipmentConfiguration*), that is in turn linked to the Equipment (the class *dinv:Equipment*) and the parameters (the class *InvestigationActivityParameter*). This overall part of the model is fully aligned with the CHS-ODP.

The result of the observations is represented as a *dinv:Result* which is align with *chs:Result*. Additionally, interpretation of the observations are possible through their representation via the class *dinv:ObservationInterpretation*, aligned with *chs:Interpretation*.

The instantiation of the diagnostic investigation ontology Figure 7 illustrates an example instantiation of the DIGILAB-IT ontology for diagnostic investigations. The example is based on a legacy dataset originally produced in the MOVIDA 1 software [22] and subsequently ingested in MOVIDA 2, currently under development, to validate data harmonisation and interoperability across heterogeneous analytical sources.

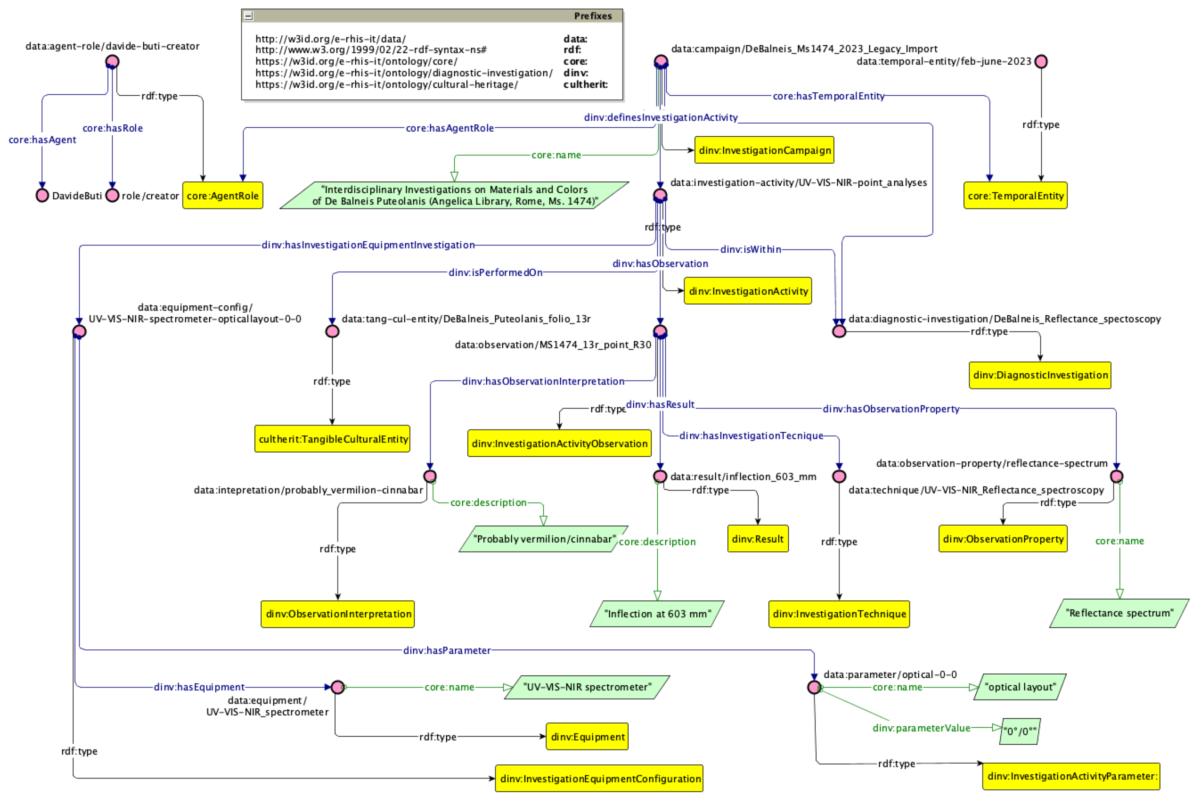

Figure 7: Example instantiation of the investigation activity knowledge graph.

In the dataset we have a *dinv:InvestigationCampaign* identified as *DeBalneis_Ms1474_2023_Legacy_Import* and labelled “Interdisciplinary Investigations of De Balneis Puteolanis (Angelica Library, Rome, ms. 1474)”. The campaign is temporally scoped by a *core:TemporalEntity* corresponding to February–June 2023.

Responsibility of the campaign is represented by associating an agent (David Buti) with the campaign through the role Creator.

The campaign has a diagnostic investigation that in turn has a collection of observations (*dinv:Investigation Activity*). The investigation activity regards the analyses of points done by UV-VIS-NIR spectometer and is performed on the *cultherit:TangibleCulturalEntity* “De Balneis Puteolanis (Angelica Library, Rome, Ms. 1474), folio 13r”. Within this activity, a specific observation (*dinv:InvestigationActivityObservation*), done using a *dinv:InvestigationTechnique* whose instance is UV–VIS–NIR Reflectance Spectroscopy, concerns point R_30, described as a red area on Ms1474_13r. The observation has a specific observation property labelled ”Reflectance spectrum”. The observation produces a result, instance of the class *dinv:Result*, that is labelled as ”inflection at 603 mm”. Based on this result of the observation, an interpretation is produced. This latter is an instance of the class *dinv:ObservationInterpretation* and is labelled as ”probably vermillion/cinnabar”.

Experimental conditions are captured through the equipment configuration that is linked to the *dinv:Equipment* class, whose instance is named ”UV-VIS-NIR_spectrometer” and consists of a variety of parameters, including: fiber type = “VIS-NIR”, Smoothing = “NO”, Optical layout = “0°/0°”, Average = “50”, Integr. time = “68 ms, 62 gain, 36 gain”, and Spec. res. = “3 nm, 10 nm”. For the sake of conciseness, we reported in Figure 7 only the Optical layout parameter whose value is "0°/0°".

6. Concluding Remarks

This paper introduces the Cultural Heritage Survey Ontology Design Pattern (CHS-ODP), a reusable model designed to represent survey activities in the cultural heritage domain. By abstracting from specific implementations, the pattern provides a structured approach to documenting the workflows of cultural heritage investigations, from data acquisition to interpretation, while ensuring alignment with established cultural ontologies such as CIDOC-CRM and ArCo, foundational ontologies like DOLCE UltraLight, and compatibility with W3C standards such as SOSA/SSN.

The CHS-ODP addresses a gap in existing models, which often lack dedicated constructs for representing the procedural, observational, and interpretative dimensions of surveys, as coherent units. The pattern's strengths lie in its modularity, and in the alignments to foundational and cultural heritage core ontologies that ensures compatibility with existing cultural heritage infrastructures and facilitates data integration and reuse across heterogeneous knowledge graphs. Its usefulness and applicability has been validated through two real-world use cases: an RTI-based documentation campaign on rock art and a diagnostic investigation of illuminated manuscripts. These case studies demonstrate the pattern's ability to accommodate diverse methodologies, instrumentation, and analytical workflows while preserving traceability and contextual integrity.

Despite its strengths and while supporting the representation of sampling activities, interpretations, and claims, the CHS-ODP pattern would benefit from including a model to support the representation of uncertainty or conflicting interpretations, a common challenge in cultural heritage research, which we leave for future work. In order to strengthen the generality and robustness of the pattern, we also plan to further validate it to additional use cases across different cultural heritage subdomains, such as 3D digitisation campaigns, conservation treatments, and large-scale archaeological excavations campaigns, thereby testing its applicability beyond the two scenarios currently considered and supporting its consolidation as a reusable modelling solution.

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Declaration on generative AI

In the preparation of this work, the authors used GPT-5 in order to: Grammar and spelling check. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

References

[1] M. Doerr, The CIDOC CRM - an Ontological Approach to Semantic Interoperability of Metadata, Ai Magazine - AIM 24 (2003).

[2] V. A. Carriero, et al., ArCo: The Italian Cultural Heritage Knowledge Graph, in: The Semantic Web – ISWC 2019, Springer International Publishing, 2019, pp. 36–52. doi:10.1007/978-3-030-30796-7_3.

[3] A. Gangemi, V. Presutti, Ontology Design Patterns, Springer, 2009, pp. 221–243. doi:10.1007/978-3-540-92673-3_10.
[4] V. Presutti, A. Gangemi, Dolce+D&S Ultralite and its main ontology design patterns, Ontology Engineering with Ontology Design Patterns (2016). doi:10.3233/978-1-61499-676-7-81.
[5] A. Haller, et al., The modular SSN ontology: A joint W3C and OGC standard specifying the semantics of sensors, observations, sampling, and actuation, Semant. Web 10 (2019) 9–32. doi:10.3233/SW-180320.
[6] A. Gangemi, et al., A pattern-based ontology for the internet of things, in: WOP@ISWC, 2017.
[7] M. Grüninger, M. S. Fox, The role of competency questions in enterprise engineering, in: Benchmarking—Theory and practice, Springer, 1995, pp. 22–31.
[8] A. Arcà, I numeri, in: Rupe Magna: La Roccia Incisa Più Grande Delle Alpi, Quaderni Del Parco Delle Incisioni Rupestri Di Grosio, Consorzio per il Parco delle Incisioni Rupestri di Grosio, 1995, pp. 119–124.
[9] A. Fossati, Cronologia e interpretazione, in: Rupe Magna: La Roccia Incisa Più Grande Delle Alpi, Quaderni Del Parco Delle Incisioni Rupestri Di Grosio, Consorzio per il Parco delle Incisioni Rupestri di Grosio, 1995, pp. 99–110.
[10] E. Marchi, Figure antropomorfe: Armati e lottatori, in: Rupe Magna: La Roccia Incisa Più Grande Delle Alpi, Quaderni Del Parco Delle Incisioni Rupestri Di Grosio, Consorzio per il Parco delle Incisioni Rupestri di Grosio, 1995, pp. 51–60.
[11] A. Arcà, Figure geometriche, in: Rupe Magna: La Roccia Incisa Più Grande Delle Alpi, Quaderni Del Parco Delle Incisioni Rupestri Di Grosio, Consorzio per il Parco delle Incisioni Rupestri di Grosio, 1995, pp. 73–86.
[12] T. Malzbender, et al., Polynomial texture maps, in: Proceedings of the 28th Annual Conference on Computer Graphics and Interactive Techniques, ACM, 2001, pp. 519–528. doi:10.1145/383259.383320.
[13] Ø. Hammer, et al., Imaging fossils using reflectance transformation and interactive manipulation of virtual light sources, Palaeontologia Electronica 5 (2002) 1–9.
[14] S. Maddalo, Il De balneis Puteolanis di Pietro da Eboli: realtà e simbolo nella tradizione figurata, number 414 in Studi e Testi, Biblioteca Apostolica Vaticana, Città del Vaticano, 2003.
[15] P. da Eboli, De Euboicis aquis, Edizioni del Galluzzo, Firenze, 2018.
[16] A. Bisanti, Recensione di pietro da eboli, De Euboicis aquis, ediz. critica, trad. e commento a cura di t. de angelis, Bollettino di Studi Latini 49 (2019) 867–876.
[17] G. Orofino, Incognitae officinae: il problema degli scriptoria di età sveva in italia meridionale, in: Medioevo: le officine. Atti del Convegno Internazionale di Studi, Electa, Milano, 2010, pp. 468–480.
[18] E. Pietroni, et al., "codex 4d" project: Interdisciplinary investigations on materials and colors of de balneis puteolanis (angelica library, rome, ms. 1474), Heritage 7 (2024) 2755–2791. doi:10.3390/heritage7060131.
[19] A. Chirivì, et al., An evolving scenario in the study of illuminated manuscripts: innovative approaches to research questions, Digital Applications in Archaeology and Cultural Heritage 40 (2026) e00496. doi:10.1016/j.daach.2026.e00496.
[20] E. Pietroni, et al., The Illuminated Manuscripts pilot project: a hub dedicated to the interdisciplinary study of ancient codices, integrated into the DigiLab-IT platform, in: Digital Heritage, The Eurographics Association, 2025. doi:10.2312/dh.20253210.
[21] A. Bucciero, et al., D3.1 guidelines for data, services, software platform policy implementation, 2026. doi:10.5281/zenodo.18759206, final deliverable.
[22] A. Amat, et al., Non-invasive multi-technique investigation of artworks: A new tool for on-the-spot data documentation and analysis, Journal of Cultural Heritage 14 (2013) 23–30. doi:10.1016/j.culher.2012.02.015.