Ontology-based Thematic Framing of Tangible and Intangible Cultural Heritage

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Abstract. The digitization of cultural heritage demands advanced methods for structuring and managing knowledge. Semantic web technologies and ontologies provide a powerful framework for intelligent reasoning, interoperability, and personalized content generation. This work explores how ontology-based models and semantic reasoning can drive innovative solutions for cultural heritage engagement, enabling dynamic, context-aware, and personalized information delivery. Specifically, this paper presents an ontology-driven approach to the thematic characterization of cultural heritage knowledge. We realize an intelligent assistant, called HerMeS, that leverages semantic reasoning and contextual temporal planning to generate adaptive cultural itineraries, improving user engagement with historical and artistic assets. Unlike conventional recommendation systems, our approach integrates knowledge representation techniques for context-aware and thematic reasoning. Here, we discuss the ontology model, its integration with Artificial Intelligence planning, and its role in enabling personalized and interpretable cultural experiences, contributing to scalable and sustainable digital heritage solutions. The work is developed within a collaborative research project between the National Research Council of Italy and La Sapienza University.

Keywords: Ontology, Knowledge Representation and Reasoning, Cultural Heritage

1. Introduction

The increasing accessibility of computational resources and services for data collection, enhancement, and analysis is transforming numerous fields, including Cultural Heritage (CH) and Digital Humanities (DH). With an unprecedented volume of structured and unstructured datasets becoming available, DH brings together researchers from diverse disciplines, e.g., social sciences, arts, humanities, and computer science. This highly interdisciplinary landscape fosters new methodologies for digital knowledge representation and cultural analysis while also raising concerns about data ethics, provenance, curation, and integration. Within this context, semantic web technologies and ontologies have emerged as essential tools, enabling the formalization of knowledge, reasoning over complex datasets, and supporting scalable and interoperable solutions for cultural heritage applications. Computational semantic models are increasingly shaping the way we manage and interact with complex knowledge, including cultural heritage. The representation of structured information through ontologies allows more advanced reasoning, interoperability, and personalized information retrieval, offering significant opportunities for digital transformation [1–3]. Semantic web technologies provide a robust framework for organizing heterogeneous data, characterizing their semantics, and defining a formal and reliable basis for innovative Artificial Intelligence (AI) services that aim to improve the user experience [4–6]. Ontology-based systems have been widely explored in various domains, including cultural heritage, intelligent tourism, and urban planning. Existing research has demonstrated the potential

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of semantic reasoning and AI techniques to improve personalized recommendations, enhance search and retrieval, and support decision-making for cultural institutions and policymakers [7, 8]. While many solutions rely on standard route optimization and recommendation techniques [9, 10], our approach integrates ontological knowledge with contextual temporal planning to enable thematic reasoning and adaptive itinerary generation. This methodology extends beyond traditional recommendation systems by incorporating a structured knowledge base that can infer new relationships, handle user constraints dynamically, and support a more interpretable AI-driven decision process.

This work explores how ontology-based models and semantic reasoning can drive innovative solutions for cultural heritage engagement, enabling dynamic, context-aware, and personalized information delivery. This work presents an ontology-driven approach to cultural heritage management, developed within the *HERitage sMart social mEdia aSsistant* (HerMeS) project. This initiative stems from a collaboration between the National Research Council of Italy and La Sapienza University and it leverages knowledge representation, contextual reasoning, and AI-driven planning to generate personalized cultural itineraries [11, 12]. The designed HerMeS ontology enables a flexible, semantically enriched understanding of cultural resources, and supports thematic content recommendations based on user preferences, historical context, and spatial-temporal constraints.

This research aims to contribute to the development of intelligent frameworks that support knowledge preservation, sustainable cultural tourism, and enhanced user interaction, emphasizing the interdisciplinary intersection of AI, semantic web technologies, and cultural heritage. Our long-term vision is to investigate how ontology-based models can facilitate more scalable, explainable, and context-aware applications in digital heritage, bridging the gap between knowledge management and real-world user engagement. Specifically, the contribution of the current work concerns the definition of a novel ontological model (the HerMeS ontology) supporting a thematic description of cultural objects and the contextual correlations between tangibles and intangibles. The structure of the paper is thus as follows: (i) Section 2 provides an overview of the state of the art concerning the use of semantic technologies and ontologies in the cultural heritage domain; (ii) Section 3 motivates and describes the main features of the designed ontological model by pointing out existing models that have been integrated and extended with novel contributions; (iii) Section 4 evaluates the ontological model and the defined knowledge graph against a rich set of Competency Questions (CQs) to show the satisfaction of representation requirements. (iv) Section 5 describes the AI-based services built on top of the ontological model and explains how the resulting knowledge graph is deployed within HerMeS. In particular, this section discusses the implementation of the cultural path generation service, which relies on the integration of the semantic-based retrieval functionalities with temporal planning. (iv) Section 6 concludes the paper by summarizing and discussing the novel contribution of the work and highlighting future research directions.

2. Semantic Web Technologies in Cultural Heritage

The field of Digital Humanities has gained increasing attention in recent years, driven by the growing accessibility of data and computational resources. Within this context, semantic technologies have emerged as a key enabler for structuring, interlinking, and interpreting cultural data. They allow researchers to tag information semantically, support interoperability, and establish a shared conceptual framework through dictionaries and ontologies that formally describe cultural phenomena. Recent editorials [13, 14] exemplify the growing interest of the research community in the intersection between semantic technologies, particularly ontologies, and cultural heritage, confirming that ontological modeling plays a pivotal role in enabling richer, machine-interpretable representations of cultural knowledge. Despite this increasing attention, the integration of tangible and intangible cultural heritage (ICH) remains only partially addressed. While tangible heritage can be effectively described through established models such as CIDOC CRM, intangible heritage-defined in the UNESCO Convention (2003) as “the practices, representations, expressions, knowledge, and skills that communities recognize as part of their cultural heritage” poses additional modeling challenges. These include representing experiential, contextual, and relational aspects that link cultural expressions to people, places, and practices. This section reviews related work on semantic modeling in the cultural heritage domain, highlighting how existing approaches contribute to accessibility and interoperability, while also revealing the gaps that motivate the design of the HerMeS ontology.

Several works have focused on the use of semantic technologies in the design of innovative interfaces facilitating access to cultural heritage knowledge, thus reducing the need for technical skills. For example, [15] investigates the use of a virtual assistant to enable natural-language access to cultural heritage knowledge. The assistant relies on a Thesaurus to mediate between user queries and the knowledge graph, generating SPARQL queries that retrieve relevant information. Ontologies and semantic technologies also enhance knowledge exchange and integration among experts working in the same cultural context but from different perspectives. For instance [16] uses semantic web technologies to support data integration and communication in the modern transdisciplinary conception of archeological investigations. They propose a specialization of the CRMarcheo and CRMsci models of the CIDOC CRM family [17]. The proposed ontology acts as a meta-model providing uniform access and representation to the different types of data processed within archaeometric processes.

Another important research line leverages semantic web technologies to support the FAIR principles (Findability, Accessibility, Interoperability, and Reuse) in cultural heritage digital sources or databases [18, 19]. For example, the work in [20] enriches information retrieval techniques with ontologies to improve the finding of data from databases and help experts in the field. It organizes the semantic query layer of the proposed architecture using ArCo [21], which provides a semantic tagging layer for cultural heritage data and a modular reference structure that promotes FAIR compliance. A complementary direction involves ontology matching and semantic relatedness, aiming to enhance interoperability across cultural datasets. Works such as [22] and [23] propose, respectively, an ontology alignment framework and a metric (Rel_{Topic}), both addressing the need to connect diverse cultural vocabularies. Furthermore, studies focusing on the use of ontologies to support storytelling in the field of cultural heritage are important to define general and reusable semantics [24, 25]. For instance, the work [26] explores how semantics can enhance automated narrative plot generation through large language models. The work [27] explores linked data to capture relationships between heterogeneous cultural entities (e.g., places, events, or topic-related) and plan personalized itineraries. These contributions illustrate how semantics can support interpretive and experiential dimensions of heritage, an aspect particularly relevant to the modeling of intangible cultural heritage, where meaning often emerges from narrative and performative contexts.

In this wide landscape of contributions, several semantic models of cultural heritage have been proposed in the literature for different purposes. Standard models like CIDOC CRM [17] effectively support the structuring of cultural heritage knowledge in specific contexts (e.g., museums). However, it is challenging to fully and correctly capture the different interests and perspectives surrounding cultural heritage applications. The work [28] proposes the Cultural Heritage Abstract Reference Model (CHARM) to support the exploration and documentation of archaeological and anthropological entities. The model is intended for a diverse range of users, describing correlations and characteristics that attribute heritage value to entities. In this regard, the reference model contains 160 classes and focuses on defining suitable notions to attribute cultural heritage value to objects. The work [29] introduces the CURIOCITY ontology representing cultural heritage knowledge based on UNESCO's definitions and structured according to three ontological layers (Upper, Middle, and Lower ontologies). The work aims to design innovative tourist services by extending UNESCO's definitions and using CIDOC CRM as a basis to structure the upper ontology layer. The Upper layer defines the theoretical background characterizing concepts and properties that are common among the more specialized ontological models at the middle and lower layers. The middle layer, for example, is composed of several contextual ontological models like music or performing arts ontologies, that describe the knowledge from a particular perspective.

Although well-structured and effective within specific design contexts, existing ontological models primarily offer a static and atomic characterization of cultural entities. Such models hardly support the interpretation of cultural contents from different perspectives and interests, crucial when dealing with personalization. They usually lack the flexibility needed to "frame" the semantic description of cultural objects, struggling to support a compositional description that results from a thematic interpretation process of a cultural entity. They do not fully accommodate the semantic (topic-based) framing of cultural entities needed to characterize and integrate diverse perspectives. Furthermore, these models lack structures that can effectively correlate tangible and intangible elements, hindering the establishment of explicit, thematic connections between a territory and its cultural heritage. The presented HerMeS ontology overcomes these limitations by supporting a compositional and thematic description of cultural entities and a flexible correlation between tangible and intangible ones. Moreover, it defines key aspects of the visitor experience related to tangible cultural heritage, facilitating effective visit planning and fostering inclusive accessibility. Given the large landscape of ontological models of cultural heritage domains, the ontology has been designed by taking into account FAIR principles, especially focusing on the interoperability and reusability of the cultural knowledge. To this aim, we decided to ground the HerMeS ontology on a solid theoretical background through foundational ontologies, and sufficiently flexible models suitable to define and specialize cultural knowledge within a standard reference framework. As the next sections describe in more detail, the HerMeS ontology extends ArCo [21], which provides a modular structure supporting the desired levels of flexibility. Furthermore, unlike CIDOC CRM and other standard formalisms, ArCo relies on DOLCE [30], which represents a well-structured and validated theoretical background, crucial to support interoperability.

3. Thematic Framing of Tangible and Intangible Cultural Heritage

Cultural heritage represents the aggregation of multiple and heterogeneous facets of a certain society, territory, and historical background. A cross-thematic and multi-perspective approach is therefore necessary to provide users (e.g., tourists) with a comprehensive understanding of how habits, traditions, places, and events interconnect and evolve across time and space. While it is essential to describe the geographic and structural features of tangible cultural assets, it is equally important to characterize the intangible cultural entities (such as practices, knowledge, and social expressions) that are linked to those tangible elements. According to the UNESCO 2003 Convention, intangible cultural heritage (ICH) includes "the practices, representations, expressions, knowledge, and skills that communities, groups, and individuals recognize as part of their cultural heritage". Modeling these aspects requires explicit mechanisms to express how intangible heritage is anchored in places, objects, and communities, and how it evolves through performance and transmission. The semantic correlation between tangible and intangible items is thus key to uncovering the layered relationships among places, histories, rituals, and local traditions. These correlations also enable personalized and narrative-driven interpretations of cultural heritage, supporting both scholarly research and public engagement. In this context, the HerMeS Ontology[1] is the result of a research effort aiming at supporting the multiperspective and compositional description of cultural entities and their semantic correlations with the intangible heritage. HerMeS is a domain ontology [31] based on a solid theoretical background defined by DOLCE [30], and extending the ontological model ArCo [2] [21], the reference ontological model for Italian cultural heritage.

ArCo is the result of a research effort aiming at publishing a knowledge graph (KG) modeling the Cultural Heritage domain and a Linked Open Data (LOD) dataset about Italian cultural properties. ArCo KG is published and can be queried through its official SPARQL endpoint [3] [4]. The key advantage of ArCo ontology is its modularity, which supports ease of use and integration within HerMeS, and integration of existing thesauri e.g., PICO 4.1 [5] as well. Figure 1 shows the modular structure of the ArCo ontology. It aggregates several coherent ontological modules that describe cultural objects from specific but synergetic perspectives. The modules `arco` and `core` define top-level concepts and global relations shared among all modules. Other modules, like `catalogue`, `location`, or `cultural-event`, characterize more specific knowledge. For example, the module `catalogue` specifically characterizes the cataloging processes of records and the management of the associated data.

The modular architecture of ArCo provides a solid foundation for the development of HerMeS. However, ArCo's design primarily follows a descriptive and object-centered approach, optimized for cataloguing movable and tangible cultural objects. As such, it offers limited expressivity for representing the dynamic and relational nature of intangible cultural heritage. ArCo primarily focuses on `movable` cultural objects and does not offer sufficiently detailed structures to capture the characteristics of `intangible` cultural assets, defined in ArCo as: "*that part of cultural heritage represented by ephemeral performances of traditional manifestations, techniques, knowledge (festivals, musical and dance performances, theatrical performances, craft techniques, oral literature, etc.), when*

[1] https://github.com/pstlab/HERMES_ONTOLOGY.git
[2] http://wit.istc.cnr.it/arco
[3] http://dati.beniculturali.it/sparql
[4] The endpoint is based on the Open Source version of Virtuoso - https://github.com/openlink/virtuoso-opensource
[5] https://www.vocabularyserver.com/pico/it/index.php

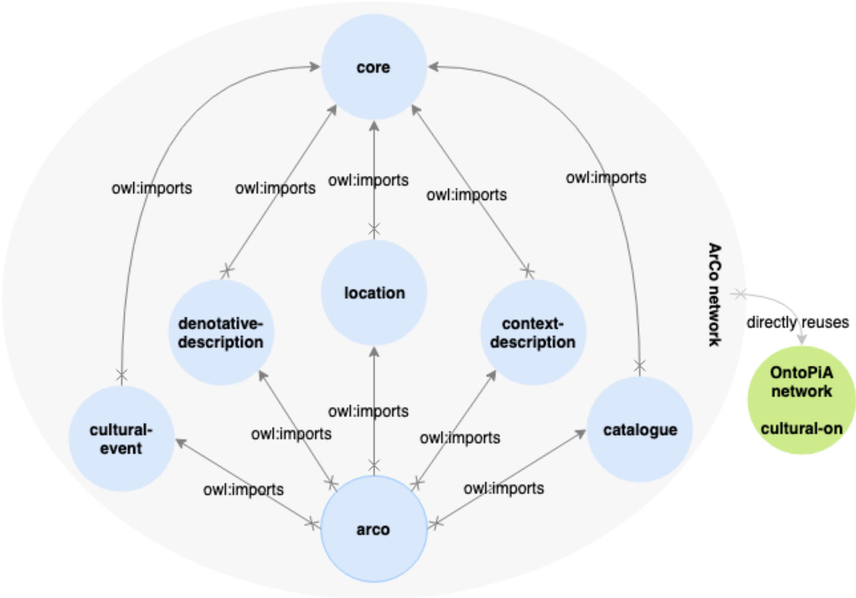

Figure 1. Overview of the ArCo network of ontology modules.

they occur and of which it is possible to keep memory only through the audio-visual recording that fixes them permanently, crystallizing them.". Intangible cultural properties are central to HerMeSand enable cross-narrative links among heterogeneous cultural aspects (for example, archaeological, social, religious, and ritual). While this definition is useful for documentation purposes, it remains too narrow to capture the living and performative essence of intangible heritage as defined by UNESCO, or to support the semantic integration of tangible and intangible entities within narrative or thematic contexts. To overcome these limitations, HerMeS extends ArCo by introducing new and refined concepts that enable the compositional and thematic representation of cultural entities. The ontology supports the linking of tangible and intangible heritage within a unified semantic framework, fostering the creation of cross-narrative interpretations that connect archaeological, social, ritual, and experiential dimensions of culture.

HerMeS extends the concept `ImmovableCulturalProperty` by introducing `TerritorialUnit` and `TopographicalComplex`. These concepts support a structured (and layered) description of a territory, identifying parts and sub-parts (areas) that are relevant from a heritage perspective. In addition, HerMeS specializes the ArCo concept `Location`, namely by introducing `LocationInfrastructure` to describe the topological structure of a territory. This concept characterizes mobility infrastructures that can be associated with a given `TopographicalComplex`. Namely, it includes infrastructural entities such as streets or squares, enabling connectivity within a territorial unit or topographical complex. HerMeS defines a detailed structure of transversal cultural and social properties that are correlated to the `TangibleCulturalProperty` (either `movable` or `immovable`). In this regard, HerMeS refines the structuring of `IntangibleCulturalProperty`, which was not specialized by ArCo. Figure 2 shows a subset of the introduced concepts under the subtree with the ArCo class `IntangibleCulturalProperty` as root. We have introduced the concepts necessary to explicitly describe non-material entities about traditions, events, and historical heritage of a territory, e.g., historical events, festivities, or traditions. Furthermore, we have refined the axiomatization of the ArCo concept `IntangibleCulturalProperty` to correlate it with the ArCo concept `TangibleCulturalProperty` through the existentially quantified object property `isCorrelatedWith`. This is the central point correlating tangible with intangible entities that capture the culture, tradition, and costumes of a territory. Another central aspect of HerMeS is the indexing of cultural entities according to different topics or interests. Concerning the construction of contextualized narratives [24], the definition of a taxonomy of topics and themes supports contextual filtering and retrieval of context-relevant entities. Each `CulturalProperty` is thus associated with a set of `Topic` used to tag their descriptive content.

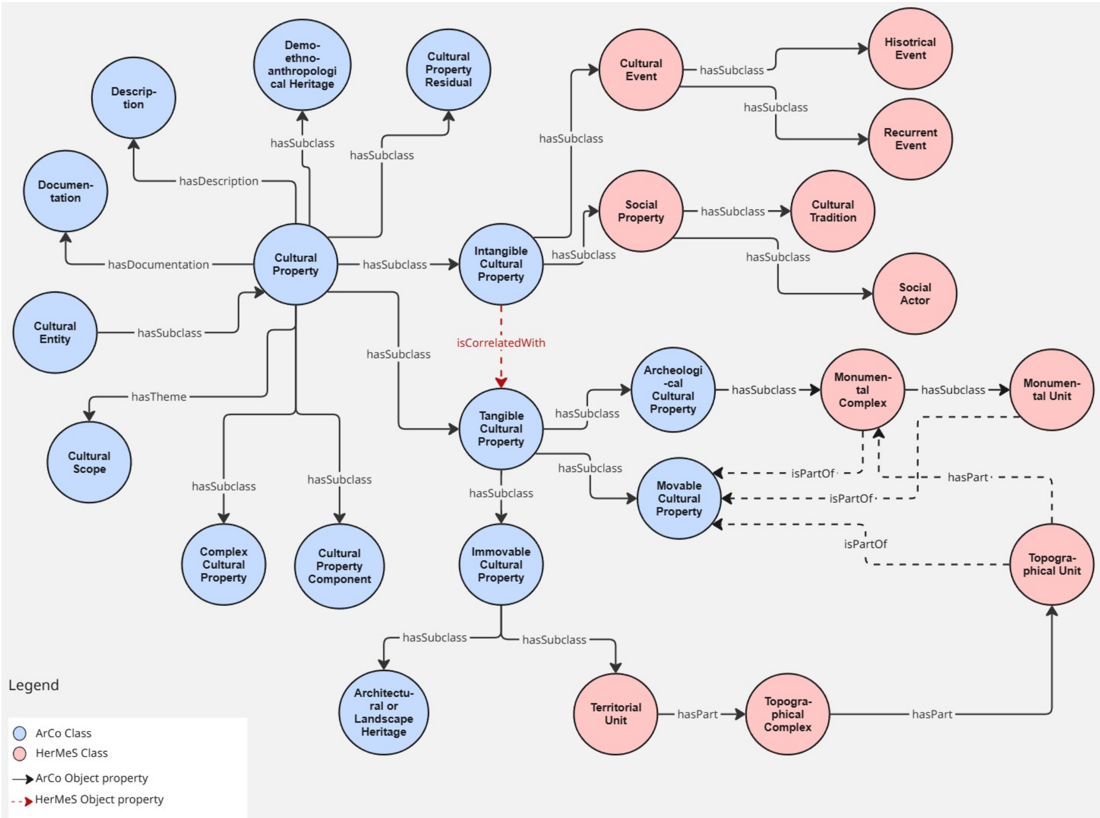

Figure 2. Excerpt of the HerMeS ontology extending the notions of `CulturalProperty`.

Taking inspiration from the concept of *Frame* [32], it is therefore necessary to build views of a region capable of identifying the subset of objects and relationships that are coherent to a certain perspective or interest of a user [33, 34]. Each "frame" constitutes a representation layer characterizing the subset of cultural entities taking into account a specific interest/theme. To support the framing within the cultural heritage domain, we refined the concept `Topic` that ArCo defined without further specializations. HerMeS refines the root `Topic` concept of ArCo to enrich the contextual characterization of the information content. Figure 3 shows the extension of this concept proposed within HerMeS. These topics are taxonomical structures defining perspectives (e.g., `religion`, `social`, `art`) that classify the type of content associated with a cultural entity.

3.1. Ontology Engineering and ArCo Extensions

The design of HerMeS ontology and the resulting knowledge graph [6] was guided by the requirements collected within the project and by following structured knowledge engineering methodologies [35]. According to standard practices, we designed several *competency questions* (CQ) to point out the kind of information the knowledge graph should encapsulate and the type of retrieval and framing to be supported. The CQs were used as a "common language" to interact with domain experts and define the level of knowledge parametrization and the level of granularity necessary to characterize cultural entities. The defined CQs could be organized into four groups.

The G1 group concerns CQs retrieving tangibles based on their location and the structural organization of the related territory. Examples of such queries are: "What are the tangibles I can find within a range of 5 km from my

[6] A publicly accessible version of the HerMeS ontology and the knowledge graph is available at the GitHub repository https://github.com/pstlab/HERMES_ONTOLOGY.git.

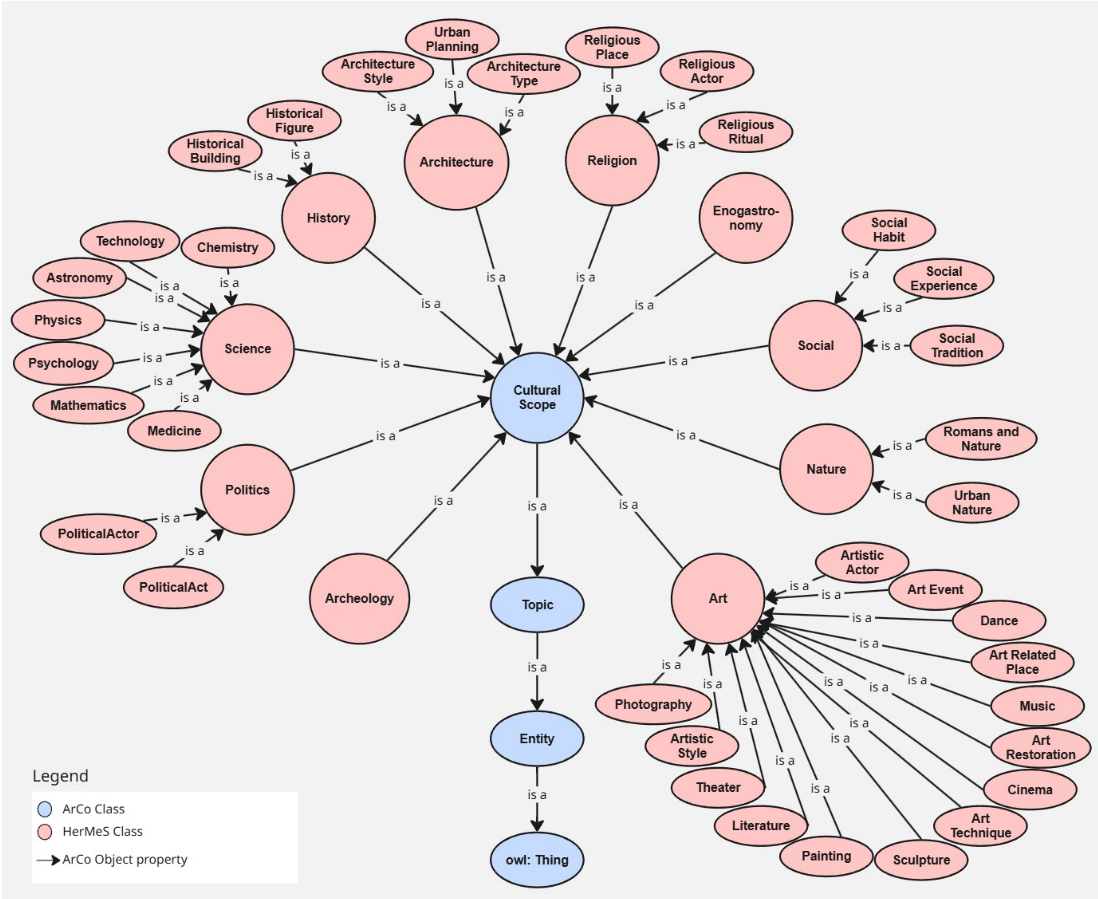

Figure 3. Extended taxonomy of `Topic` characterizing semantic links between `CulturalProperty`.

current position?"; "What are the tangibles within the urban territory of Rome?", or; "What are the tangibles located in the archaeological area of Rome?". These examples show the need for representing the geographical location (that is, as data properties specifying longitude and latitude) of tangibles. In addition, they show the need to characterize the structural organization of the territory to distinguish among areas of interest. For example, a user might be interested in the cultural entities that belong to a certain archaeological area of a city or, similarly, to the suburban area of a city. That is, it is not sufficient to represent the geographical location of entities. It is necessary to combine these data with the hierarchical and "logical" structuring of the territory. Considering the required organization of ta territory, within HerMeS we have specifically focused on the representation of the archaeological area of Rome and the distribution among historical districts like 'Rione Monti' or 'Rione Esquilino'. The resulting knowledge graph should therefore answer questions like "What are the tangibles within the district 'Rione Monti' of Rome?".

The G2 group concerns CQs retrieving tangibles that satisfy the time and accessibility constraints of users. Examples of such queries are: "What are the tangibles that can be reached by metro or public transportation?"; "What are the tangibles that can be visited in two hours?"; "What are the tangibles that can be visited under hearing or motor impairments?"; or "What are the tangibles that can be visited for free?". These examples show the necessity of representing information about the transportation infrastructure of a territory (e.g., metro stations, bus lines available in an area of interest), and the visiting time of tangibles (i.e., average duration of a visit). Furthermore, the knowledge graph should characterize information about accessibility (i.e., support to motor, hearing, or visual impaired users) and access modalities (i.e., free or paid access, reservation).

The G3 group concerns CQs retrieving tangibles based on the associated topics. Examples of such queries are: "What tangibles are associated with the topic *Art* or *Architecture*?"; "What tangibles are associated with the topic

Barocco style?"; "What is the description of a tangible according to the topics *Art* and *Literature*?", or; "What are the topics and the thematic descriptions of a tangible?". These examples show the need to represent topics and their relationships with cultural entities. Topics should be classified at different levels of abstraction (e.g., *Architecture* and *Barocco style*) leading to a taxonomical structure. In addition, multiple topics could be associated with the same cultural entity, and each association should be made through suitable thematic descriptions. This is necessary to support *framing* and dynamically extract topic-based descriptions of tangibles, according to users' interests.

Finally, the G4 group concerns CQs retrieving tangibles based on the associated intangibles. Examples of such queries are: "What are the intangibles associated with a particular tangible entity *x*?"; "What are the tangibles associated with the intangible *Byzantine ritual*?". These examples illustrate the need to describe the relationships between tangible and intangible assets. These associations are especially crucial for supporting cross-cultural and flexible aggregations of heterogeneous cultural entities.

The requirements collected through these competency questions highlight the level of granularity needed to support a fine-grained, compositional description of cultural entities. The ontology should define a suitable representational space for tangible elements, territorial structuring, thematic topics, intangible heritage, and their associations with tangible entities. Additionally, it should capture tangible information related to visitability and inclusive accessibility. This comprehensive representation is essential for enabling cross-cultural, thematic navigation of heritage entities, and for generating contextualized and personalized itineraries. Taking into account the requirements elicited through CQs, the concepts and relationships identified for the refinement of ArCo are summarized below. .

- *Geographical location*: In which area/territorial unit is the POI located? And which transport infrastructures are available in that area? Geographic location is key to grouping POIs within Territorial Units (characterized by a range of infrastructure) that will define the area within which the planner can choose POIs in the route generation phase.
- *Type*: POIs are distinguished into two macro-types: tangibles and intangibles. This distinction is crucial for generating tourist itineraries that include not only physical monumental units but also experiences, and ephemeral performances of traditional manifestations that are part of the cultural heritage of a given place.
- *Topic*: POIs are linked to thematic/topic-based descriptions characterizing the entity from a certain perspective. HerMeS interprets the description of a cultural entity as the aggregation of multiple topic-based descriptive contents. The same POI/entity is thus described according to multiple thematic axes. For example, a church might be described from (synergetic) historical, artistic, architectural, and religious perspectives.
- *Visiting time*: each POI has an estimated visiting time, which is needed to generate itineraries based on a given time range. Eg. The user has only four hours to be able to carry out the itinerary.
- *Inclusive accessibility*: each POI, wherever possible, is enriched with information related to inclusive accessibility, to address questions such as: Is the POI accessible to groups, the elderly, or people with motor, visual, or hearing disability?
- *Visiting information*: Each Point of Interest (POI) is enriched with information regarding its visitability status. A POI may be classified as either visitable or non-visitable. Visitable POIs are further characterized based on whether a reservation is required or if access involves a fee. This classification is designed to address questions such as: "Does the POI require a reservation?" and "Is the POI accessible for free?"

More specifically, several refinements of ArCo have been considered to realize a layered and thematic correlation of tangible and intangible cultural entities. Such extensions concern: (i) the introduction of classes like `TerritorialUnit`, `TopographicalComplex`, `MonumentalUnit`, `CulturalPropertyDescription`; (ii) the refinement of existing classes (`CulturalPropertyResidual`, `IntangibleCulturalProperty`, `Topic`), and; (iii) the extensions of ArCo structures about accessibility and visitability for a finer-grained description of the visitability of tangible entities. Tables 1 and 2 provide further details on the extensions of the concepts and object properties made to the ArCo ontological model.

Table 3 instead details the reification of accessibility knowledge and visiting data. This knowledge has been introduced by specializing the ArCo concept `CulturalEntityCharacteristic`. The accessibility requirements are modeled as particular types `CulturalPropertyAccessibility`, which is the ArCo class devoted to the modeling of general accessibility, intended as "the possibility to reach or enter a particular cultural entity". Within this concept, we introduce the types of accessibility `ElderlyAccessibility`, `GroupAccessibility`,

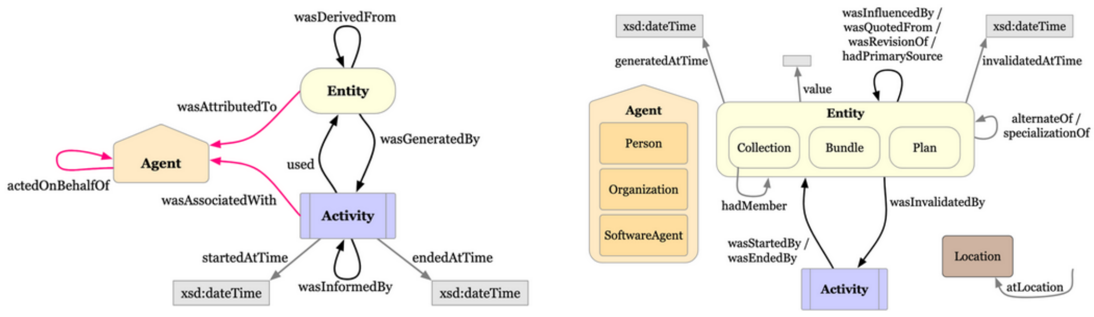

Figure 4. General structure of the PROV-O Ontology taken from the official W3C documentation.

`HearingImpairedAccessibility`, `MotorImpairedAccessibility`, `VisualImpairedAccessibility`. Each concept is associated with a domain constant representing the reference individual used to assert the accessibility property (e.g., `cost_elderly_accessibility`). Constants globally identify entities that support specific types of accessibility. They are associated with cultural entities through the relation `hasCulturalPropertyAccessibility`. Visiting data has been represented by introducing concepts and data properties. The concept `CulturalPropertyVisiting` has been introduced as a particular type of `CulturalEntityCharacteristic`. It is further distinguished between `NonVisitableEntity` and `VisitableEntity`. The latter is specialized into `FreeVisiting`, `OnPaidVisiting` (disjoint with free visiting type), and `OnReservationVisiting`. These classes are characterized according to the type of associated data properties. For example, any visitable entity is generally associated with data properties specifying the average duration of a visit (data property `visiting_time`) and the opening hours of the entity (data property `opening_hours`). The subclasses are associated with more specific data like the concept `OnPaidVisiting`, which is associated with the data property `visiting_price`.

3.2. Knowledge Authoring through Provenance

Interestingly, the design process also considered the integration of structured meta-information to support the authoring of cultural information. HerMeS specifically integrates the PROV-O ontology [7] [36, 37] to represent meta-information about editing activities of cultural entities in a knowledge graph. PROV-O [36] is a representation formalism defined to propose a standard schema characterizing metadata about the origin and editing of statements (e.g., assertions, axioms) contained in a knowledge graph (i.e., RDF structures in general). Figure 4 below provides a synthetic representation of the main concepts and relationships defined by the PROV-O ontology. The elements described in Figure 4 are the three starting point classes of PROV-O. The figure also shows the properties related to these three elements. According to the official reference of PROV-O, an entity (`Entity`) is a physical, digital, conceptual, or other kind of thing with some fixed aspects (entities may be real or imaginary). An activity (`Activity`) is something that occurs over a period of time and acts on or with entities; it may include consuming, processing, transforming, modifying, relocating, using, or generating entities. An agent (`Agent`) is something that bears some form of responsibility for an activity taking place, for the existence of an entity, or for another agent's activity.

The integration of the PROV-O ontology in HerMeS was key to tracing the provenance of the data within the cultural knowledge base. We wanted to use this framework specifically to answer questions like "Who entered the thematic description *x* about the tangible *y* into the knowledge graph?", "Who asserted the association between the tangible *x* and the intangible *y*?". The availability of such metadata was considered crucial to assess the quality and reliability of cultural knowledge. In principle, the content and structure of the knowledge graph could be edited by different actors (`Agent`), ranging from simple users, reporting their own experience, to organizations and professional entities. Provenance information introduces the possibility to transparently check and filter cultural informa-

[7] https://www.w3.org/TR/prov-o

Table 1
Class extensions to ArCo ontology

Class name	Description	Relations
Territorial Unit	The set of topographical complexes corresponds to a system of congruent and narratively assimilable spatial relations. It can be identified as a complex, e.g., the Sabina in Latium, which at the same time suggests a set of material, intangible, and natural heritage.	Subclass of **Immovable Cultural Property**
Topographical Complex	Several coherent and identifiable topographical units constitute on a larger spatial scale a topographical complex. From its mapping, it is possible to survey the arteries connecting the various areas, wheeled and rail/underground transportation lines, bus stops, and parking lots to allow for visitor flow, faster and more articulated travel, and/or scalar routes.	Subclass of **Territorial Unit**
Monumental Complex	It is given by a series of monumental units, the contextual connection of which constitutes an articulated system, allowing their fruition in compositional-architectural arrangement and development according to a precise functionality, linked to intangible heritage. Monumental complexes can also have a vertical tendency: e.g., a church composed of overlapping layers, referable to different eras, but all equally usable in their complex division into large immersive environments, and identifiable by stylistic features, frescoes, architectural modules; therefore, not only by additional or innovative interventions that have occurred over the centuries in the same space (e.g., a "baroque" Gothic church).	Subclass of **Archeological Property**
Monumental Unit	In the HerMeS project, the "monumental unit" constitutes the minimum descriptive unit, where information about the POI or specific and spatially relevant aspects of the POI is collected. The following are to be considered monumental units: a)Architectures: Palaces, churches, cemeteries b)Urban Elements: Fountains, gardens, park, arch, tower (e.g. Roman tower, medieval tower, etc. (but the square is already to be considered a monumental complex!) c)Testimonies: archaeological (e.g., an obelisk); or commemorative (statue of Cavour).	Subclass of **Monumental Complex**
Non-publicly Accessible Cultural Property	Cultural heritage that is not accessible to the public because it is stored in museum deposits and archives, and rarely exhibited or, in the case of architectural and archaeological heritage, is only extraordinarily open to the public. E.g. Hypogeum of Via Lanza in the Monti district.	Subclass of **Cultural Property Residual**
Non-visible Cultural Property	Cultural heritage whose location is known but not accessible: e.g., the area of ancient Herculaneum destroyed by the eruption that lies under the new Herculaneum and cannot be dug up. E.g., the temple of Isis that occupied the Roman College and the Pantheon, of which only the foot of her statue can be seen at "Via Pie di marmo" in Rome.	Subclass of **Cultural Property Residual**.
Vanished Cultural Property	It concerns tangible heritage and signals the presence at one time of a monument or institution that has been dismantled, disappeared, or changed its use: e.g., the historic Apollo Theater of the late 18th century in Rome, demolished a century later to build the Tiber embankments. Concerning intangible heritage, we can count as "disappeared" a craft no longer practiced that tells of the needs of a community in a certain era (e.g., the water-maker), or lost proverbial expressions, folk songs, and musical instruments in disuse, popular shows or festivals that no longer take place, but in ancient times were very much felt.	Subclass of **Non-visible Cultural Property**.
Location Infrastructure	Mobility infrastructure that can be associated with a given Territorial Unit/Topographical Complex.	Subclass of **Location**.
Cultural Property Description	Thematic description associated with a cultural property.	Subclass of **Description**.

Table 2
Object property extensions to ArCo ontology

Object property	Description	Characteristics
isCorrelatedWith	A relationship that symmetrically binds two closely related Cultural Properties together.	Transitive, Symmetric, Domains: Cultural Property, Ranges: Cultural Property

Table 3
Reification of accessibility knowledge and visiting data as extension and refinement of ArCo.

Class name	Description	Relations
ElderlyAccessibility	This concept characterizes the condition of supporting elderly accessibility. Whether a given POI supports this type of accessibility is asserted by associating the entity with the constant const_elderly_accessibility through the ArCo property hasCulturalPropertyAccessibility.	Subclass of the general ArCo concept **CulturalPropertyAccessibility**
GroupAccessibility	This concept characterizes the condition of supporting group accessibility. Whether a given POI supports this type of accessibility is asserted by associating the entity with the constant const_group_accessibility through the ArCo property hasCulturalPropertyAccessibility.	Subclass of the general ArCo concept **CulturalPropertyAccessibility**
HearingImpairedAccessibility	This concept characterizes the condition of supporting accessibility for hearing-impaired people. Whether a given POI supports this type of accessibility is asserted by associating the entity with the constant const_hearing_imp_acc through the ArCo property hasCulturalPropertyAccessibility.	Subclass of the general ArCo concept **CulturalPropertyAccessibility**
MotorImpairedAccessibility	This concept characterizes the condition of supporting accessibility for motor-impaired people. Whether a given POI supports this type of accessibility is asserted by associating the entity with the constant const_motor_imp_acc through the ArCo property hasCulturalPropertyAccessibility.	Subclass of the general ArCo concept **CulturalPropertyAccessibility**
VisualImpairedAccessibility	This concept characterizes the condition of supporting accessibility for visually impaired people. Whether a given POI supports this type of accessibility is asserted by associating the entity with the constant const_visual_imp_acc through the ArCo property hasCulturalPropertyAccessibility.	Subclass of the general ArCo concept **CulturalPropertyAccessibility**
CulturalPropertyVisiting	This concept characterizes the general visiting information condition of a given POI. The class is further specialized into additional subclasses to distinguish different types of visiting.	Subclass of the general ArCo concept **CulturalPropertyAccessibility**
NonVisitableEntity	This concept characterizes POIs that cannot be visited but with historical/cultural value that could be included in the cultural path.	Subclass of the concept **CulturalPropertyVisiting**
VisitableEntity	This concept characterizes POIs that can be visited and is generally associated with data properties specifying the average duration of the visit (visiting_time) and the opening hours (opening_hours).	Subclass of the concept **CulturalPropertyVisiting**
FreeVisiting	This class is a particular type of VisitableEntity and characterizes POIs that can be visited for free and do not have any additional visiting restrictions.	Subclass of the concept **VisitableEntity**
OnPaidVisiting	This class is a particular type of VisitableEntity and characterizes POIs whose access is restricted and requires a payment fee. It is associated with data property visiting_price specifying information about the fees.	Subclass of the concept **VisitableEntity**
OnReservationVisiting	This class is a particular type of VisitableEntity and characterizes POIs whose access is allowed upon reservation.	Subclass of the concept **VisitableEntity**

tion according to trusted sources (e.g., specific tourist organizations). Cultural properties could be enriched with the object property wasAttributedTo to keep track of the Agent that edited the associated piece of knowledge.

Table 4 shows in detail the concepts introduced to integrate PROV-O into the HerMeS ontology. PROV-O provides for three types of Agent that can edit the information content of a knowledge graph: Person; Organization, and; SoftwareAgent. We specialize the class Person by distinguishing three types of agents allowed to edit

Table 4

Integration of PROV-O Ontology into HerMeS.

Class	Description	Relations	Individuals
Admin	An Admin is an agent/person who can perform any kind of action on the HerMeS knowledge base.	Subclass of `Person`	`hermes_admin`
Editor	The editor is an agent with an advanced editorial role: checks and creates content.	Subclass of `Person`	`hermes_editor`
Partner	A partner can add content, or report inconsistencies, e.g., Touring Club[8].	Subclass of `Person`	`touring_club_it`
User	A user can make reports on content, which must then be reviewed by an Admin or Editor.	Subclass of `Person`	`tourist`

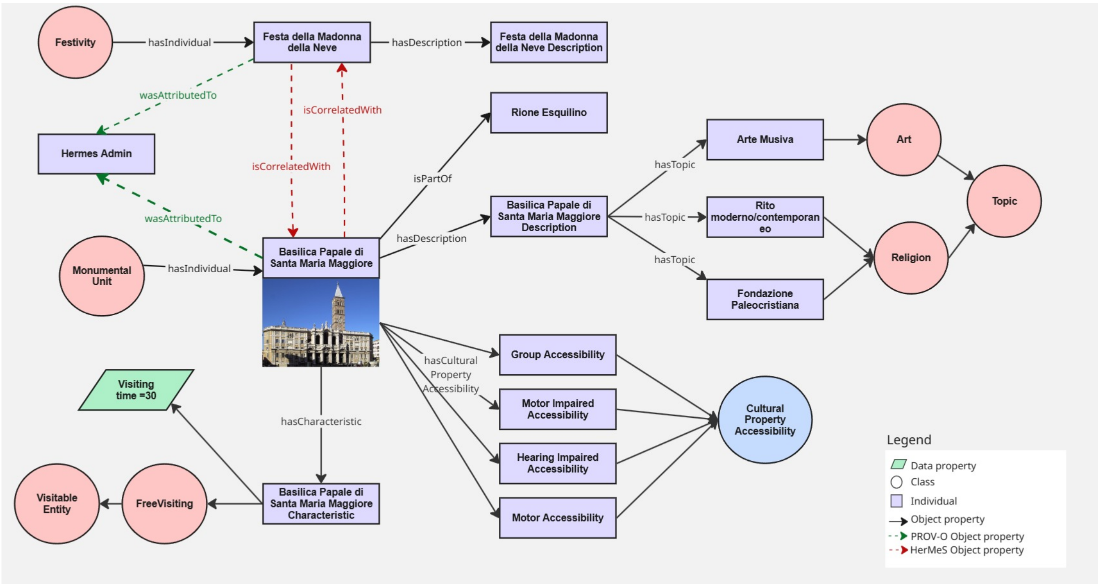

Figure 5. POI 'Basilica Papale di Santa Maria Maggiore' in the HerMeS knowledge graph.

the knowledge graph. Edit operations generally concern the creation of new entities, descriptions, and associations with topics and intangibles. The agent `User` is an end-user of the application who queries the system to receive personalized and thematic cultural paths. Such users are also allowed to introduce their personal content in terms of descriptions and comments of their cultural experience. Although socially engaging, this kind of source could not be fully trusted with respect to the quality and reliability of the cultural content and must be distinguished from other more accredited sources of knowledge. The agent `Editor` is an accredited user of the system with an editorial role and can therefore add/edit cultural descriptions and also introduce new entities and relationships. The agent `Partner` is typically associated with users referring external organizations (e.g., the Italian Touring Club) representing additional reliable sources enriching the cultural content of the system. They can add content or report inconsistencies and corrections that would be processed at higher levels. The administration level is handled by the the agent `Admin` for technical management of the knowledge graph and its editing processes.

3.3. Ontological Patterns for Cultural Framing

This section describes in more detail the main elements and relationships of the designed HerMeS Ontology, using the UML notation. Specifically, we point out some ontological patterns [38, 39] defined to structure the axioms of the resulting ontology and the relationships between the modeled cultural entities. Figure 6 shows the contextual description pattern used to support the thematic framing of the cultural heritage. As can be seen, the set of cultural properties (inherited from ArCo) can be divided into two sub-groups. The group of tangible cultural properties and the group of intangible cultural properties. Both classes of objects are associated with a set of descriptions, each of which characterizes the related object concerning a certain theme (Topic).

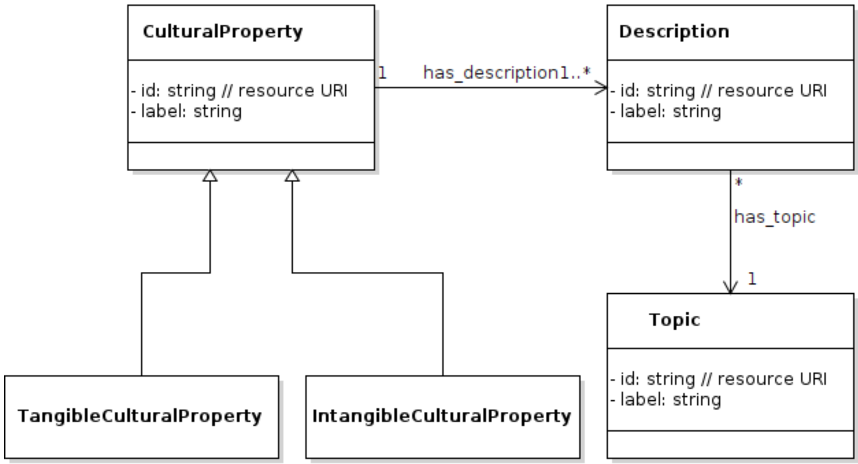

Figure 6. Contextual description pattern of cultural entities. Each individual of `CulturalProperty` is associated with one or more individuals of `Description`. Each description characterizes a `CulturalProperty` with respect to a certain `Topic` (thematic description). The thematic contexts of each cultural property are thus inferred from the set of topics associated with its descriptions.

Figure 7 shows how tangible and intangible cultural properties are further specified in the HerMeS Ontology. Unlike ArCo, HerMeS refines the classification of intangible cultural properties and explicitly represents their correlations with tangible ones. As shown, each tangible cultural property can be associated with one or more intangible cultural properties. HerMeS thus provides the constructs necessary to reify cross-cultural links by enabling the explicit representation of intangible cultural heritage and its grounding with the physical environment.

The next UML diagram, Figure 8, further describes the structure of tangible cultural properties by highlighting their relationships. In particular, HerMeS supports a layered representation of cultural sites pointing out relationships among immovable territorial units, infrastructures, related archaeological entities, and movable entities found in a specified area or place (even temporary). The described structure thus supports a flexible retrieval of the cultural entities that can be found in a certain Location. The knowledge can thus easily distinguish among movable, immovable (and intangible) cultural properties that can be reached according to their localization.

3.4. Dataset Collection and Annotation

A key element of the HerMeS project is to generate touristic itineraries that contain tangible cultural heritage (physical cultural places) and intangibles (festivities, traditions, proverbs, legends, etc.). In collaboration with the DigiLab of Sapienza and the CNR-ISPC teams, we created a dataset of the tangible and intangible cultural heritage of two districts in the historical center of Rome ('Rione Monti' and 'Rione Esquilino'), which we used to populate our ontological framework. We obtained a knowledge graph of 100 cultural places: 76 tangibles (including 35 from 'Rione Esquilino' and 41 from 'Rione Monti') and 24 intangibles. Figure 9 aggregates the modeled entities (POIs) by considering their geographic distribution over the territory. The intensity level characterizes the expected visit duration of the POIs (aggregated by geographic areas).

According to the ontological properties described in previous sections, each POI is characterized by several data properties and relations with other cultural entities. For example, consider the graph defined for the POI 'Basilica Papale di Santa Maria Maggiore', as shown in Figure 5. The figure, in particular, shows:

- the POI geographical location (latitude/longitude);
- the POI accessibility, for example, this POI is accessible to groups, the elderly, and people with motor and hearing disabilities;

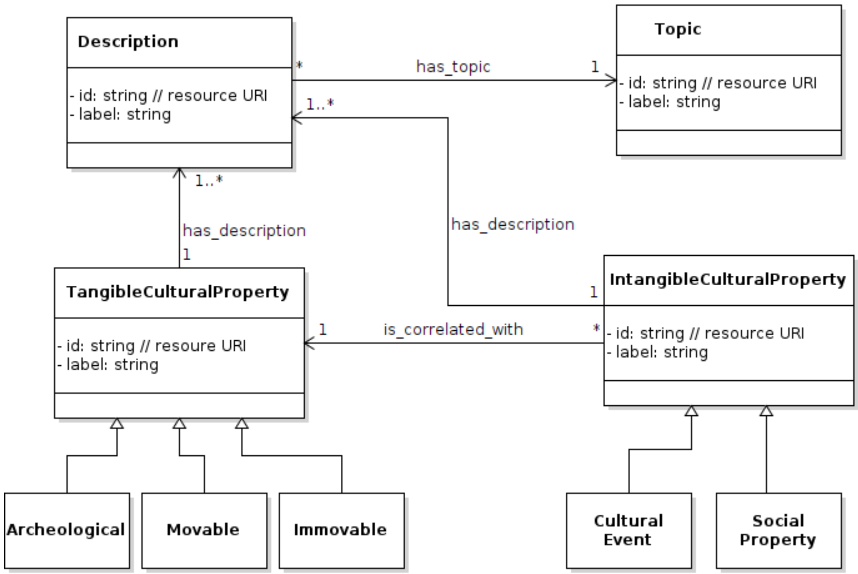

Figure 7. Contextual correlation between tangibles and intangibles through `Topic`. The set of `CulturalProperty` consists of two disjoint subsets. The subset of `Tangible` cultural property and the subset of `Intangible` cultural property. As subclasses of `CulturalProperty`, they inherit the structure of contextual descriptions obtained through the relationships with the classes `Description` and `Topic`. In addition, each `Tangible` Cultural Property could be associated with one or more `Intangible` Cultural Properties that support cross-perspective cultural links, as encapsulated in the designed HerMeS ontology.

– the POI visiting characteristic (FreeVisiting);
– the POI visiting time (30 minutes).

Some of these properties, such as geographical coordinates, accessibility information, and visiting time, are crucial to support specific reasoning processes, like planning for the synthesis of personalized visits [12]. Below is a list of shown object properties characterizing the considered individual (POI):

– `isPartOf` 'Rione Esquilino', a topographical complex;
– `wasAttributedTo` 'HerMeS Admin', an individual of the PROV-O class `Agent`;
– `hasDescription` 'Basilica Papale di Santa Maria Maggiore Description', a cultural property description, which in turn is linked to three topics through the relation `hasTopic`:
  * `ArteMusiva` (subclass of `Art`),
  * `FondazionePaleocristiana` (subclass of `Religion`),
  * `RitoModerno` (subclass of `Religion`);
– `isCorrelatedWith` the intangible cultural property 'Festa della Madonna della Neve';
– `hasCulturalPropertyAccessibility` 'const_group_acc', 'const_elderly_acc', 'const_motor_acc', 'const_hearing_acc';
– `hasCharacteristic` 'BasilicaPapaleSantaMariaMaggioreChar', which is an instance of the concept `CulturalPropertyVisiting`, and is classified as `FreeVisiting`, with a visiting time of 30 minutes.

The ontological structure of HerMeS facilitates the correlation of tangible and intangible cultural entities and aggregates POIs not only from a physical or geographical perspective, but also, and more importantly, from a (multi-) thematic one. Reasoning processes can then identify a subset of cultural places that align with a specific set of topics reflecting a user's interests (e.g., a tourist). Furthermore, the taxonomical structure of topics described in Figure 5 supports reasoning at different levels of abstraction by following users' interests that could be more or less specific according to their profiles (e.g.`RenaissanceArt` vs a more generic `Art`). Knowledge reasoning supports the automatic inference of relevant sub-topics and related cultural entities depending on the subsumption relationships specified in the ontology.

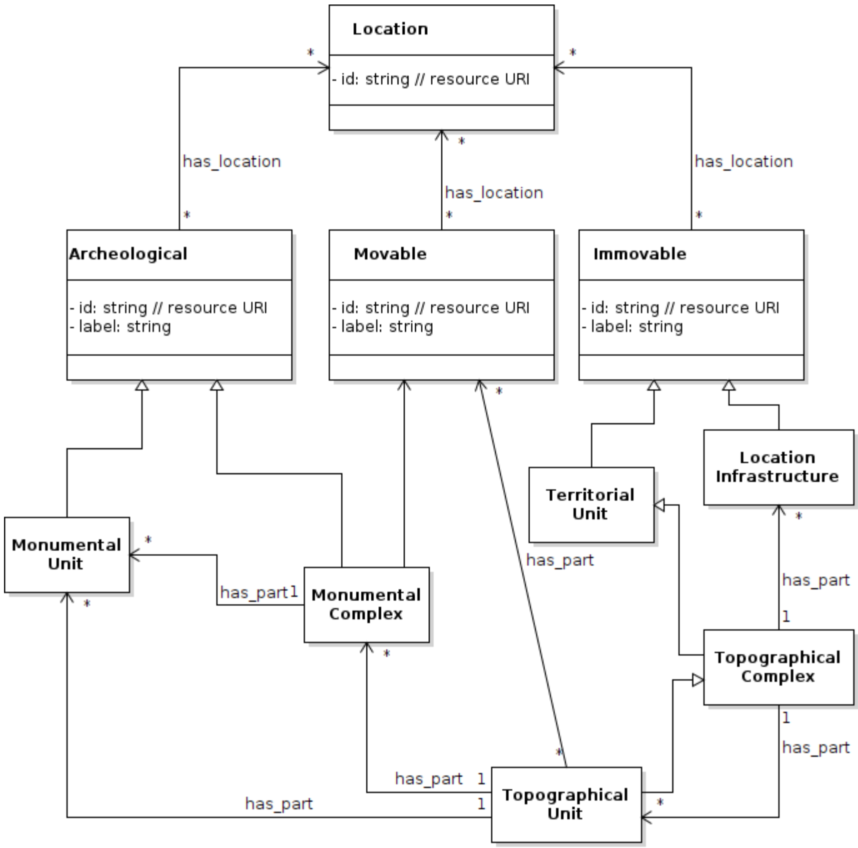

Figure 8. Layered structuring of locations and infrastructural knowledge. Given a `Location` described in terms of geographic coordinates, the knowledge graph supports the retrieval of all the cultural properties (tangible, movable, and immovable) that are included in the specified area. Such elements could be further filtered according to a set of topics. In this way, the knowledge graph supports a thematic and contextual retrieval of cultural entities within a given geographic area or general `Location`.

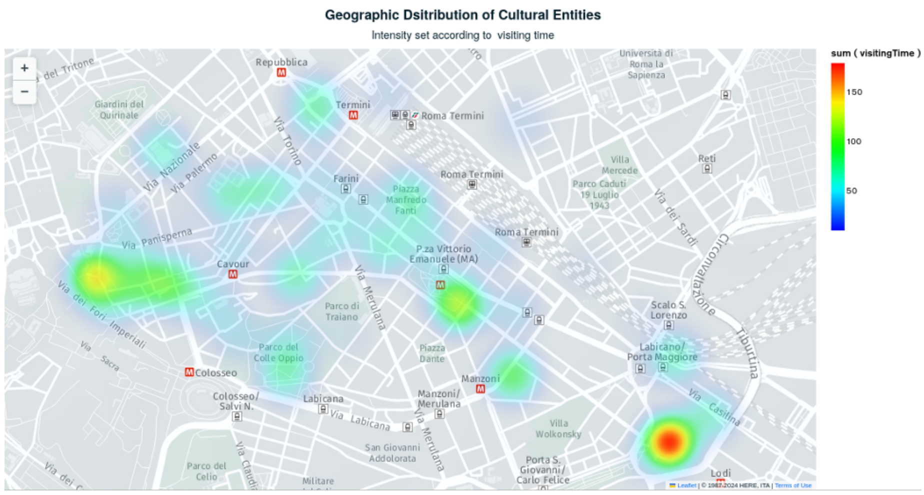

Figure 9. Distribution of POIs considered for the 'Rione Monti' and 'Esquilino' in Rome.

4. Evaluation through Competency Questions

To evaluate the expressivity of the designed ontological model and related knowledge graph(s), we rely on the Competency Questions (CQs) defined to support the requirement analysis of the ontology. Although CQs are generally used in the design phase, their implementation and evaluation as SPARQL queries is effective to verify the accuracy and precision of the developed ontological model. Namely, here CQs are used to validate the defined semantic model and verify whether it supports the retrieval and *framing* necessary to realize more complex services (e.g., visit planning). To this end, we have instantiated the knowledge graph to run SPARQL queries over it [9]. The selected CQs represent carefully defined queries that the knowledge graph should be able to answer to effectively support planning services and expressive access to the cultural knowledge. For each group of CQs defined during the design process (from G1 to G4), we show a possible implementation as SPARQL queries and discuss the results. It is worth noticing that the assessed retrieval capabilities constitute the semantic primitives that can be combined to realize increasingly complex reasoning and interacting services. Section 5 shows the functional structure of the HerMeS architecture and specifically shows the implementation of REST-based planning services for the synthesis of personalized cultural visits. The retrieval capabilities evaluated in this section are the building blocks supporting the planning process for generating (alternative) cultural paths.

4.1. Running CQs of group G1

Evaluate the semantic model against a selection of CQs taken from the G1 group. The group concerns the retrieval of tangible entities based on geographic and territorial information. In particular, we consider CQs the retrieval of entities: located within a certain distance from a reference position (e.g., the current position of a tourist); or, that belong to a specific structural area of the territory.

CQ 1.1 The question is “What are the POIs that can be found within *X* meters of the current position of a user?”. The knowledge graph must retrieve tangible cultural entities whose latitude and longitude fall within the geometric bounds computed from the given position of a user (expressed in geographical coordinates) and distance (*X* meters). To show the implementation of this query, we assume the computation of the geographical bounds of the area of requested area of interest determines that POIs should have a latitude within 41.85 and 41.89 and a longitude within 12.50 and 12.52 [10].

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX arco-loc: <https://w3id.org/arco/ontology/location/>
PREFIX hermes: <http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#>

SELECT DISTINCT ?poi ?label ?lat ?lon
WHERE {
    ?poi rdf:type ?pType .
    ?pType rdfs:subClassOf* hermes:ComplessoMonumentale .
    ?poi rdfs:label ?label .
    ?poi arco-loc:lat ?lat .
    ?poi arco-loc:long ?lon .
    FILTER (?lat > 41.85 && ?lat < 41.89 && ?lon > 12.50 && ?lon < 12.52)
}
```

Listing 1: SPARQL code implementing the Competency Question CQ 1.1.

The listing 1 contains the SPARQL code implementing the competency question. It is worth noticing the FILTER clause constraining the retrieval of tangibles to those that meet the location requirements (without the clause, the query would return 66 individuals instead of the 5 shown below). Running the query on the knowledge graph, it retrieves all 4 individuals who meet the requirements of the competency question [11]. Table 5 shows the list of individuals found.

[9]The evaluation concerns the version v1.1 of the knowledge graph on the GitHub repository - https://github.com/pstlab/HERMES_ONTOLOGY. It has been imported into GraphDB and tested using the embedded SPARQL endpoint.

[10]These bounds are used for demonstration purposes, and are not supposed to be realistic.

[11]The query took 0.1s for its execution on GraphDB

Table 5

Results of the competency question CQ 1.1 on the knowledge graph.

Individual	Cultural Entity Name	Latitude	Longitude
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#AnfiteatroCastrense	Anfiteatro Castrense	418.877.850.555.315	125.150.501.558.221
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#CancelloKounellis	Cancello di Kounellis	418.882.366.061.217	125.151.718.711.644
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#BasilicaSantaCroceGerusalemme	Basilica di Santa Croce in Gerusalemme	418.883.976.575.792	125.154.428.981.509
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#MuseoNazionaleStrumentiMusicali	Museo Nazionale degli Strumenti Musicali	418.886.062.665.411	125.164.036.846.577

CQ 1.2 The question is "What are the POIs that can be found within the urban area of 'Rione Monti' in Rome?". The knowledge graph must retrieve tangible cultural entities that are located in the requested urban area. To successfully answer the question, the knowledge graph should characterize the structural logic of the territory and the associations with the available cultural entities.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX arco: <https://w3id.org/arco/ontology/arco/>
PREFIX arco-core: <https://w3id.org/arco/ontology/core/>
PREFIX hermes: <http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#>

SELECT DISTINCT ?poi ?label
WHERE {
    ?poi arco-core:isPartOf hermes:RioneMonti .
    ?poi rdf:type ?pType .
    ?poi rdfs:label ?label .
    {?pType rdfs:subClassOf* hermes:ComplessoMonumentale .}
    UNION
    {?pType rdfs:subClassOf* arco:ArchitecturalOrLandscapeHeritage .}
    UNION
    {?pType rdfs:subClassOf* arco:CulturalPropertyResidual .}
}
```

Listing 2: SPARQL code implementing the Competency Question CQ 1.2.

The listing 2 contains the SPARQL code implementing the competency question. It is worth noticing the use of the relation `arco-core:isPartOf`, which is used to represent the structural correlations between the tangibles and the territorial units. Running the query on the knowledge graph, it retrieves 34 individuals who meet the requirements of the competency question [12]. Table 6 shows the list of individuals found.

4.2. Running CQs of group G2

Evaluate the semantic model against a selection of CQs of the G2 group. The group concerns the retrieval of tangibles according to the visiting preferences and constraints of a user. The tests thus demonstrate the capability of characterizing tangibles according to different combinations of user constraints and preferences.

CQ 2.1 The question is "What are the POIs that can be visited by a person with motor impairments?". The knowledge graph should find tangibles that are associated with accessibility type `MotorImpairedAccessibility`. The tangibles must be associated with accessibility data related to motor disabilities.

```
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX hermes: <http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#>

SELECT DISTINCT ?poi ?label
WHERE {
    ?poi ?p hermes:const_motor_imp_acc .
    ?poi rdfs:label ?label .
}
```

Listing 3: SPARQL code implementing the Competency Question CQ 2.1.

The listing 3 contains the SPARQL code implementing the competency question. It is worth noticing the use of the domain constant `const_motor_imp_acc` to easily identify the individuals (i.e., tangibles) that support

[12] The query took 0.1s for its execution on GraphDB

Table 6

Results of the competency question CQ 1.2 on the knowledge graph.

Individual	Cultural Entity Name
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#BasilicaSPietroVincoli	Basilica di S. Pietro in Vincoli
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#BasilicaSantaPrassede	Basilica di Santa Prassede
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#CasaCavalieriRodi	Casa dei Cavalieri di Rodi
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ViaPanisperna	Via Panisperna
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSPudenziana	Chiesa di S. Pudenziana
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#TermeTraiano	Terme di Traiano
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PalazzoGrillo	Palazzo del Grillo
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PiazzaMartinoMonti	Piazza S. Martino ai Monti
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ViaMadonnaMonti	Via della Madonna dei Monti
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#VillaAldobrandini	Villa Aldobrandini
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#AraMercurio	Ara di Mercurio
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#BasilicaSMartinoSSilvestroMonti	Basilica di San Martino e San Silvestro ai Monti
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaAgataGoti	Chiesa di S. Agata dei Goti
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaAnnaGioaccMonti	Chiesa di S. Anna e Gioacchino ai Monti
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaGesuBambino	Chiesa di Gesù Bambino
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaMariaMonti	Chiesa di S. Maria ai Monti
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaQuiricoGiulitta	Chiesa dei Ss. Quirico e Giulitta
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSFrancescoPaola	Chiesa di S. Francesco di Paola
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSLorenzoFonte	Chiesa di S. Lorenzo in Fonte
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSLuciaSelci	Chiesa di S. Lucia in Selci
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSalvatoreMonti	Chiesa di S. Salvatore ai Monti
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PalazzoCollegiNeofitiCatecumeni	Palazzo del Collegio dei Neofiti e Catecumeni
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSantiSergioBaccoUcraini	Chiesa dei Santi Sergio e Bacco degli Ucraini
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSsDomenicoSisto	Chiesa dei Ss. Domenico e Sisto
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#CisternaSetteSale	Cisterna delle Sette Sale
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ExVillaSforza	Ex Villa Sforza
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#FontanaCatecumeni	Fontana dei Catecumeni
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#MercatoRionaleMonti	Mercato Rionale Monti
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#MuraglioneForoAugusto	Muraglione del Foro di Augusto verso la Suburra
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PalazzoEsposizioniRoma	Palazzo Esposizioni Roma
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#TermeTito	Terme di Tito
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#TorreDeiConti	Torre dei Conti
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ColleOppio	Colle Oppio
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#IpogeoLanza	Ipogeo / Mitreo di Via Lanza

motor impairment accessibility. Running the query on the knowledge graph, it retrieves all 27 individuals who meet the requirements of the competency question [13]. Table 7 shows the list of individuals found.

CQ 2.2 The question is "What are the POIs that can be visited for free?". The knowledge graph must retrieve all the tangible entities that are associated with a `FreeVisiting` type of characteristics.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX arco-core: <https://w3id.org/arco/ontology/core/>
PREFIX hermes: <http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#>

SELECT DISTINCT ?poi ?label ?time
WHERE {
 ?poi arco-core:hasCharacteristic ?c .
    ?c rdf:type hermes:FreeVisiting .
    ?poi rdfs:label ?label .
    OPTIONAL {
        ?c hermes:visiting_time ?time .
    }
}
```

Listing 4: SPARQL code implementing the Competency Question CQ 2.2.

The listing 4 shows the SPARQL code of the query. It is worth noticing the use of the relation (object property) `arco-core:hasCharacteristic` in conjunction with the type `hermes:FreeVisiting` to filter individuals that represent tangibles that can be visited for free. In addition, the query retrieves information about the average visiting time when available (through the OPTIONAL clause). The association with the requested topic is found

[13]The query took 0.1s for its execution on GraphDB

Table 7

Results of the competency question CQ 2.1 on the knowledge graph.

Individual	Cultural Entity Name
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#MuraServiane	Mura Serviane
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ArcoGallieno	Arco di Gallieno / Porta Esquilina
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#BasilicaPapaleSantaMariaMaggiore	Basilica Papale di Santa Maria Maggiore
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#BasilicaSMartinoSSilvestroMonti	Basilica di San Martino e San Silvestro ai Monti
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#CancelloKounellis	Cancello di Kounellis
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#BasilicaSantaPrassede	Basilica di Santa Prassede
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#DomusAurea	Domus Aurea
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#GiardinodiPiazzaVittorio	Giardino di Piazza Vittorio
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaMariaMonti	Chiesa di S. Maria ai Monti
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSAntonioAbate	Chiesa di S. Antonio Abate
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ViaPanisperna	Via Panisperna
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSLorenzoFonte	Chiesa di S. Lorenzo in Fonte
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSPudenziana	Chiesa di S. Pudenziana
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSVitoSModesto	Chiesa di San Vito e San Modesto
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSalvatoreMonti	Chiesa di S. Salvatore ai Monti
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PalazzoCollegiNeofitiCatecumeni	Palazzo del Collegio dei Neofiti e Catecumeni
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSantaBibiana	Chiesa di Santa Bibiana
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSantiSergioBaccoUcraini	Chiesa dei Santi Sergio e Bacco degli Ucraini
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ColleOppio	Colle Oppio
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#FontanaCatecumeni	Fontana dei Catecumeni
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#HortiDiAlessandro	Horti di Alessandro/Trofei di Mario
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#MuseoNazionaleRomano	Museo Nazionale Romano
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#NuovoMercatoEsquilino	Nuovo Mercato Esquilino
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PalazzoEsposizioniRoma	Palazzo Esposizioni Roma
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PalazzoFreddoFassi	Palazzo del Freddo Fassi
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PiazzaSuburra	Piazza della Suburra
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#VillaAldobrandini	Villa Aldobrandini

through the associated descriptions. Running the query on the knowledge graph, it retrieves all 49 individuals who meet the requirements of the competency question [14]. Table 8 shows the list of individuals found.

CQ 2.3 The question is "What are the POIs that people affected by hearing and visual impairments, whose visit duration is less than 1 hour on average?". To answer correctly, the knowledge graph should find tangibles that are associated with accessibility types `HearingImpairedAccessibility` and `VisualImpairedAccessibility`. The resulting entities should also be associated with the topic `Art` and its subtopics.

```
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX arco-core: <https://w3id.org/arco/ontology/core/>
PREFIX hermes: <http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#>

SELECT DISTINCT ?poi ?label ?time
WHERE {
    ?poi ?p hermes:const_hearing_imp_acc .
    ?poi ?p hermes:const_visual_imp_acc .
    ?poi rdfs:label ?label .
    ?poi arco-core:hasCharacteristic ?c .
    ?c hermes:visiting_time ?time .
    FILTER (?time < 60)
}
```

Listing 5: SPARQL code implementing the Competency Question CQ 2.3.

The listing 5 contains the SPARQL code implementing the competency question. It is worth noticing the use of the domain constant `const_hearing_imp_acc` and `const_visual_imp_acc` to identify the cultural entities that support both hearing and visual impairment accessibility. This is the most restricting condition of the query and is here used as the first pattern of the SPARQL WHERE clause. The FILTER clause checks the average duration of the single visit. Running the query on the knowledge graph, it retrieves 10 individuals who meet the requirements of the competency question [15]. Table 9 shows the list of individuals found.

[14]The query took 0.1s for its execution on GraphDB
[15]The query took 0.1s for its execution on GraphDB

Table 8

Results of the competency question CQ 2.2 on the knowledge graph (the visiting time is expressed in minutes).

Individual	Cultural Entity Name	Time
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#AcquarioRomano	Acquario romano	60
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#MuraServiane	Mura Serviane	20
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#BasilicaSantaCroceGerusalemme	Basilica di Santa Croce in Gerusalemme	60
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#AraMercurio	Ara di Mercurio	15
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ArcoGallieno	Arco di Gallieno / Porta Esquilina	20
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#BasilicaPapaleSantaMariaMaggiore	Basilica Papale di Santa Maria Maggiore	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#BasilicaSMartinoSSilvestroMonti	Basilica di San Martino e San Silvestro ai Monti	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#BasilicaSPietroVincoli	Basilica di S. Pietro in Vincoli	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#CancelloKounellis	Cancello di Kounellis	10
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#BasilicaSantaPrassede	Basilica di Santa Prassede	20
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PortaMaggiore	Porta Maggiore	10
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#GiardinodiPiazzaVittorio	Giardino di Piazza Vittorio	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaAgataGoti	Chiesa di S. Agata dei Goti	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaAnnaGioaccMonti	Chiesa di S. Anna e Gioacchino ai Monti	20
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaGesuBambino	Chiesa di Gesù Bambino	10
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaMariaMonti	Chiesa di S. Maria ai Monti	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaQuiricoGiulitta	Chiesa dei Ss. Quirico e Giulitta	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSAntonioAbate	Chiesa di S. Antonio Abate	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSBernardinoSienaPanisperna	Chiesa di S. Bernardino da Siena in Panisperna	10
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ViaPanisperna	Via Panisperna	10
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSEusebio	Chiesa di S. Eusebio	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSFrancescoPaola	Chiesa di S. Francesco di Paola	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSLorenzoFonte	Chiesa di S. Lorenzo in Fonte	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSLorenzoPanisperna	Chiesa di S. Lorenzo in Panisperna	10
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSLuciaSelci	Chiesa di S. Lucia in Selci	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSPudenziana	Chiesa di S. Pudenziana	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSVitoSModesto	Chiesa di San Vito e San Modesto	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSalvatoreMonti	Chiesa di S. Salvatore ai Monti	10
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PalazzoCollegiNeofitiCatecumeni	Palazzo del Collegio dei Neofiti e Catecumeni	15
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSantaBibiana	Chiesa di Santa Bibiana	20
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSantiSergioBaccoUcraini	Chiesa dei Santi Sergio e Bacco degli Ucraini	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSsDomenicoSisto	Chiesa dei Ss. Domenico e Sisto	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#TermeTraiano	Terme di Traiano	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ColleOppio	Colle Oppio	20
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#FontanaCatecumeni	Fontana dei Catecumeni	10
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ScalinataBorgia	Scalinata dei Borgia/Vicus sceleratus	10
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#MercatoRionaleMonti	Mercato Rionale Monti	60
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#MuraglioneForoAugusto	Muraglione del Foro di Augusto verso la Suburra	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#MuseoNazionaleRomano	Museo Nazionale Romano	60
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#NuovoMercatoEsquilino	Nuovo Mercato Esquilino	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PalazzoFreddoFassi	Palazzo del Freddo Fassi	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PiazzaMartinoMonti	Piazza S. Martino ai Monti	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PiazzaSuburra	Piazza della Suburra	10
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ViaMadonnaMonti	Via della Madonna dei Monti	10
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#SepolcroMVEurisace	Sepolcro di Marco Virgilio Eurisace/ Tomba del Fornaio	10
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#SacelloSZenone	Sacello di S. Zenone	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#TermeTito	Terme di Tito	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#TorreGrillo	Torre del Grillo	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#VillaAldobrandini	Villa Aldobrandini	10

Table 9

Results of the competency question CQ 2.3 on the knowledge graph (the visiting time is expressed in minutes).

Individual	Cultural Entity Name	Time
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#MuraServiane	Mura Serviane	20
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ArcoGallieno	Arco di Gallieno / Porta Esquilina	20
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#GiardinodiPiazzaVittorio	Giardino di Piazza Vittorio	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ViaPanisperna	Via Panisperna	10
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PalazzoCollegiNeofitiCatecumeni	Palazzo del Collegio dei Neofiti e Catecumeni	15
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ColleOppio	Colle Oppio	20
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#FontanaCatecumeni	Fontana dei Catecumeni	10
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#NuovoMercatoEsquilino	Nuovo Mercato Esquilino	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PalazzoFreddoFassi	Palazzo del Freddo Fassi	30
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PiazzaSuburra	Piazza della Suburra	10

4.3. Running CQs of group G3

Evaluate the semantic model against a selection of CQs of the G3 group. The group concerns the identification of entities that are relevant to a set of topics, and the retrieval of their thematic descriptions. Specifically, it shows the capability of *framing* the description of cultural entities according to the interests of a user.

CQ 3.1 The question considered is "What are the POIs that are characterized by the architectural style 'Barocco'?". To correctly answer the question, the knowledge graph must retrieve all the tangible entities that are correlated with the specific topic `StileArchitettonicoBarocco`.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX w3id: <https://w3id.org/italia/onto/l0/>
PREFIX hermes: <http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#>

SELECT DISTINCT ?poi ?label ?dt
WHERE {
    ?t rdf:type hermes:StileArchitettonicoBarocco .
    ?d w3id:hasTopic ?t .
    ?poi w3id:hasDescription ?d .
    ?d rdfs:comment ?dt .
    ?poi rdfs:label ?label .
}
```

Listing 6: SPARQL code implementing the Competency Question CQ 3.1.

The listing 6 contains the SPARQL code implementing the competency question. It is worth noticing that the association between the cultural entity and the requested topic depends on the contextual description *?d*. Running the query on the knowledge graph, it retrieves all 13 individuals who meet the requirements of the competency question [16]. Table 10 shows the list of individuals found.

Table 10

Results of the competency question CQ 3.1 on the knowledge graph.

Individual	**Cultural Entity Name**
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaAgataGoti	Chiesa di S. Agata dei Goti
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaGesuBambino	Chiesa di Gesù Bambino
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaMariaMonti	Chiesa di S. Maria ai Monti
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSBernardinoSienaPanisperna	Chiesa di S. Bernardino da Siena in Panisperna
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSFrancescoPaola	Chiesa di S. Francesco di Paola
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSLorenzoFonte	Chiesa di S. Lorenzo in Fonte
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSLorenzoPanisperna	Chiesa di S. Lorenzo in Panisperna
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSalvatoreMonti	Chiesa di S. Salvatore ai Monti
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSantaBibiana	Chiesa di Santa Bibiana
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSantiSergioBaccoUcraini	Chiesa dei Santi Sergio e Bacco degli Ucraini
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSsDomenicoSisto	Chiesa dei Ss. Domenico e Sisto
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PalazzoCollegiNeofitiCatecumeni	Palazzo del Collegio dei Neofiti e Catecumeni
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#VillaAldobrandini	Villa Aldobrandini

CQ 3.2 The question is "What are the POIs that are associated with any type of Art?". To correctly answer this question, the knowledge graph must retrieve all the tangible entities that are correlated with the sub-tree of the taxonomical structure under the topic `Art`. The query is not interested in a specific topic in this case, but in any topic that falls under `Art`, within the taxonomical structure of the ontology.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX w3id: <https://w3id.org/italia/onto/l0/>
PREFIX hermes: <http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#>

SELECT DISTINCT ?poi ?label ?time
WHERE {
    ?tType rdfs:subClassOf* hermes:Art .
    ?t rdf:type ?tType .
```

[16] The query took 0.1s for its execution on GraphDB

```
    ?d w3id:hasTopic ?t .
    ?poi w3id:hasDescription ?d .
    ?poi rdfs:label ?label .
}
```

Listing 7: SPARQL code implementing the Competency Question CQ 3.2.

The listing 7 contains the SPARQL code implementing the competency question. It is worth noticing the use of `rdfs:subClassOf*` to navigate the taxonomical structure of the ontology and retrieve all the sub-topics of `Art`. Running the query on the knowledge graph, it retrieves all 20 individuals who meet the requirements of the competency question [17]. Table 11 shows the list of individuals found.

Table 11

Results of the competency question CQ 3.2 on the knowledge graph.

Individual	Cultural Entity Name
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#BasilicaPapaleSantaMariaMaggiore	Basilica Papale di Santa Maria Maggiore
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#BasilicaSPietroVincoli	Basilica di S. Pietro in Vincoli
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#CancelloKounellis	Cancello di Kounellis
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#BasilicaSotterraneaPortaMaggiore	Basilica Sotterranea di Porta Maggiore
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaQuiricoGiulitta	Chiesa dei Ss. Quirico e Giulitta
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSLuciaSelci	Chiesa di S. Lucia in Selci
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSPudenziana	Chiesa di S. Pudenziana
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSantaBibiana	Chiesa di Santa Bibiana
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSsDomenicoSisto	Chiesa dei Ss. Domenico e Sisto
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#CircoloMecenate	Circolo di Mecenate
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#TermeTraiano	Terme di Traiano
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#CoroPiazzaVittorio	Coro di piazza Vittorio
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ExVillaSforza	Ex Villa Sforza
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#FontanaCatecumeni	Fontana dei Catecumeni
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#MuseoNazionaleRomano	Museo Nazionale Romano
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#MuseoNazionaleStrumentiMusicali	Museo Nazionale degli Strumenti Musicali
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PalazzoEsposizioniRoma	Palazzo Esposizioni Roma
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#PalazzoGrillo	Palazzo del Grillo
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ViaMadonnaMonti	Via della Madonna dei Monti
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#SacelloSZenone	Sacello di S. Zenone

4.4. Running CQs of group G4

Evaluate the semantic model against a selection of CQs of the G4 group. The group concerns the correlations between tangibles and intangibles. Specifically, it shows the capability of retrieving cultural connections between tangibles and intangibles and, more interestingly, the capability of semantically correlating tangibles through common intangibles.

CQ 4.1 The question is "What are the intangibles associated with at least one cultural entity?". To correctly answer the question, the knowledge graph must analyze the associations between tangibles and intangibles through the relation `hermes:isCorrelatedWith`.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX arco: <https://w3id.org/arco/ontology/arco/>
PREFIX hermes: <http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#>

SELECT DISTINCT ?i ?iLabel ?iType(COUNT(DISTINCT ?poi) as ?count)
WHERE {
    ?i hermes:isCorrelatedWith ?poi .
    ?i rdf:type ?iType .
    ?iType rdfs:subClassOf* arco:IntangibleCulturalProperty .
    ?i rdfs:label ?iLabel .
}
GROUP BY ?i ?iLabel ?iType
```

Listing 8: SPARQL code implementing the Competency Question CQ 4.1.

[17] The query took 0.1s for its execution on GraphDB

The listing 8 contains the SPARQL code implementing the competency question. It is worth noticing the use of `hermes:isCorrelatedWith*` in conjunction with the pattern on the subject of the retrieved triples, `rdfs:subClassOf*`. This combination of patterns allows the knowledge graph to retrieve only the intangibles effectively associated with tangibles. Running the query on the knowledge graph, it retrieves all 14 individuals who meet the requirements of the competency question [18]. Table 12 shows the list of individuals found. Furthermore, the result shows, for each intangible, the number of associated tangibles.

Table 12
Results of the competency question CQ 4.1 on the knowledge graph.

Individual	Intangible Name	Intangible Type	# of Tangibles
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#FestaQuinquatriMinori	Festa dei Quinquatri minori	hermes:Festivity	1
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#FestaMadonnaNeve	Festa della Madonna della Neve	hermes:Festivity	1
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#FestaSAntonioAbate	Festa di S. Antonio Abate	hermes:Festivity	2
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#FestaSGiovanniEsquilino	Festa di S. Giovanni all'Esquilino	hermes:eligiusEvent	2
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#NagarKirtan	Festa del Nagar Kirtan	hermes:ReligiusEvent	1
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#CapodannoCinese	Festa del Capodanno Cinese	hermes:SocialEvent	1
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#LeggendaPortaMagica	Leggenda della Porta Magica	hermes:Legend	2
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#LeggendaVicusSceleratus	Leggenda del Vicus Sceleratus	hermes:Legend	1
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ProverbioSanMartino	Proverbio su San Martino	hermes:Proverbs	2
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ProverbioSantaBibiana	Proverbio su Santa Bibiana	hermes:Proverbs	1
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Mecenatismo	Mecenatismo	hermes:Proverbs	2
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#CultoNeopitagorismo	Culto misterico del Neopitagorismo	hermes:Rituals	1
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#CircoloMecenate	Circolo di Mecenate	hermes:ArtisticMovement	2
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#CoroPiazzaVittorio	Coro di piazza Vittorio	hermes:ArtisticMovement	1

CQ 4.2 The question is "What are the tangibles that have two or more intangibles in common?". To correctly answer the question, the knowledge graph must again analyze the associations between tangibles and intangibles through the relation `hermes:isCorrelatedWith`.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX arco: <https://w3id.org/arco/ontology/arco/>
PREFIX hermes: <http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#>

SELECT DISTINCT ?poi ?pLabel (COUNT(DISTINCT ?i) as ?count)
WHERE {
    ?poi hermes:isCorrelatedWith ?i .
    ?i rdf:type ?iType .
    ?iType rdfs:subClassOf* arco:IntangibleCulturalProperty .
    ?poi rdfs:label ?pLabel .
}
GROUP BY ?poi ?pLabel
HAVING (?count > 1)
```

Listing 9: SPARQL code implementing the Competency Question CQ 4.2.

The listing 9 contains the SPARQL code implementing the competency question. As seen in the implementation of the previous CQ, the relation `hermes:isCorrelatedWith*` is used in conjunction with the pattern on the subject of the retrieved triples, `rdfs:subClassOf*`. Running the query on the knowledge graph, it retrieves 2 individuals who meet the requirements of the competency question [19]. Table 13 shows the list of individuals found. The result shows, for each tangible, the number of common intangibles.

Table 13
Results of the competency question CQ 4.2 on the knowledge graph.

Individual	Tangible Name	# of Intangibles
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ArcoGallieno	Arco di Gallieno / Porta Esquilina	2
http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#GiardinodiPiazzaVittorio	Giardino di Piazza Vittorio	3

[18]The query took 0.1s for its execution on GraphDB
[19]The query took 0.1s for its execution on GraphDB

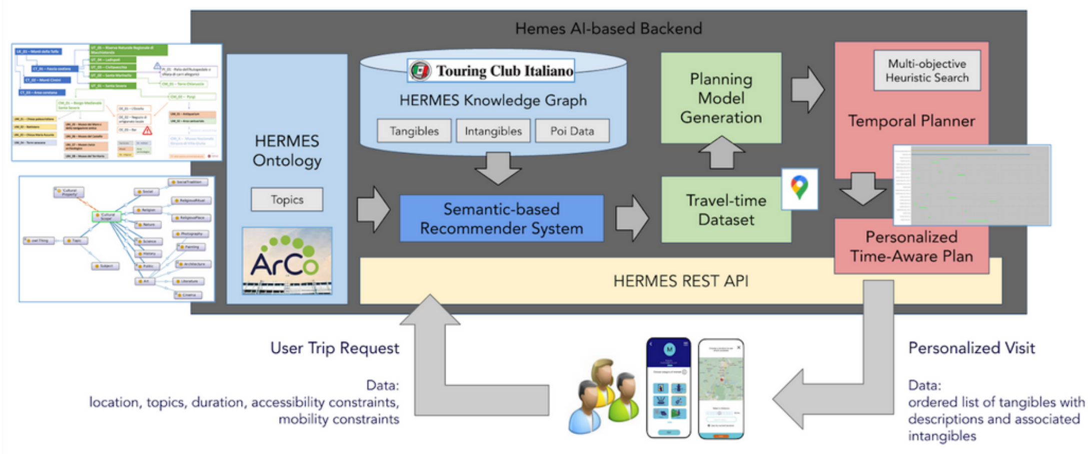

Figure 10. HerMeS AI-based pipeline based on the ontological model of cultural heritage.

5. Cultural Reasoning as-a-Service

The designed ontology constitutes the core semantics and data models of the reasoning services realized to access and compose cultural knowledge within the HerMeS project [11, 12]. It guides the integration of AI-based modules that retrieve and contextualize cultural heritage knowledge according to the requests and related preferences of users. Figure 10 shows the flow implementing the synthesis of personalized visits [12]. The ontology has been designed using the Protégé ontology editor [20]. The knowledge graph with the associated reasoning and knowledge retrieval services has been developed using the open source library Apache Jena [21]. The process is triggered by users sending a trip request through the HerMeS application [11]. The request is received by an HTTP REST interface, which encapsulates the user's interests for the visit (i.e., set of topics) and preferences (i.e., duration of the visit, accessibility, and mobility preferences). A semantics-based recommender system then retrieves the information that matches the interests and preferences of the user from the knowledge graph. The process relies on the evaluated retrieval capabilities to compose contextualized and personalized views of cultural entities. The extracted set of tangibles is used to build and refine a travel dataset containing information about the expected travel distance between any pair of tangibles according to different mobility preferences (e.g., bus, metro). Temporal planning is integrated into the pipeline to synthesize a time-aware "cultural path" [40, 41]. The planner generates *cultural timelines* representing personalized visits consistent with time requirements (i.e., the total time available for the overall visit and the visiting time of tangibles) and the estimated travel time between pairs of tangibles. The planned sequence of tangibles is sent to the user as a response to the initial request. The HerMeS app is then deals with the execution of the visit by showing the framed cultural content and interacting with the user [22].

5.1. REST API and Application-level Data Model

The HTTP REST API exposes reasoning capabilities implemented using the knowledge graph and planning components. Here, we describe the data model characterizing the communication protocol established by the REST API and the related stateless services. Concerning the data model it is worth noticing that the API abstracts from the details of the underlying knowledge graph and ontology.

---

[20]https://protege.stanford.edu/
[21]https://jena.apache.org/
[22]The code of the AI-based service is available on GitHub https://github.com/pstlab/HERMES_REST_API.git. Furthermore, a running instance of the service could be easily instantiated and run as a Docker container by downloading the image available at the link https://hub.docker.com/r/pstlab/hermes_ai_server.

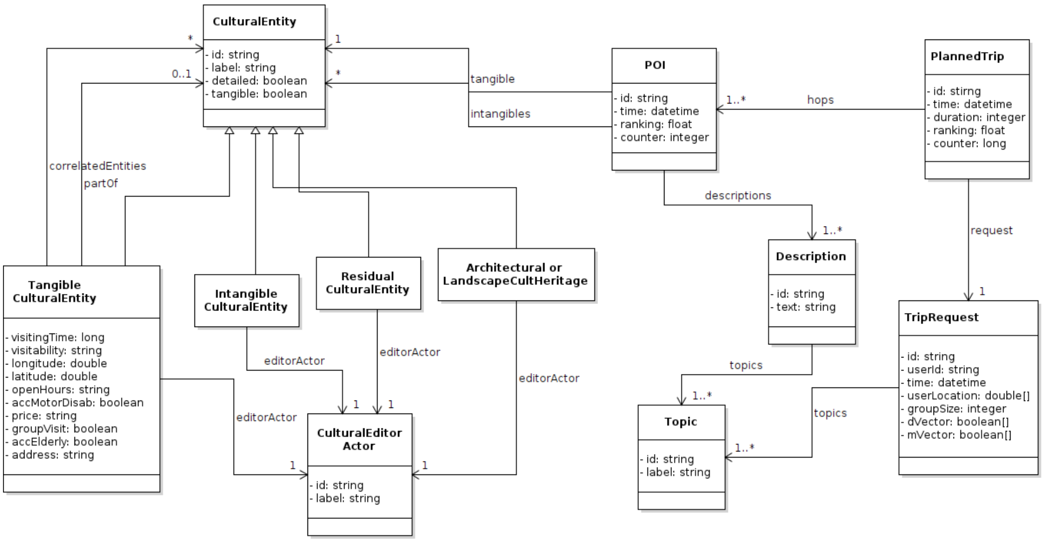

Figure 11. Data model of the REST API. The API offers dedicated endpoints where a client can retrieve all the descriptions and all the data associated with a specific `CulturalEntity` associated with a POI containing the set of textual descriptions of a cultural entity that match a given set of topics.

Figure 11 shows the structure of the data model using the UML notation. The central element of the data model is the POI, which aggregates the knowledge extracted from the knowledge graph. Each POI is associated with one specific tangible cultural entity and a list of correlated intangible cultural entities. There is no 1:1 mapping between the POIs of the data model and the cultural entities of the knowledge graph. A POI represents a topic-based view of a tangible cultural entity by aggregating (sub)sets of descriptions coherent with the selected themes. At the application level, the association between cultural entities and descriptions is made through POIs that encapsulate a contextual representation of the information contained in the knowledge graph. In principle, the KG may contain different descriptions associated with the same cultural property, each tagged with a different set of topics. A contextual description of a POI is meant as the (sub)set of textual descriptions associated with a given cultural property that matches a given set of topics. The (sub)set of the associated intangible entities and related descriptions is determined by the set of selected themes. The set of instances and knowledge aggregated by a POI thus depends on the set of topics selected by the user. Therefore, there could be multiple POIs describing the same tangible cultural entity, each associated with a different perspective (i.e., subsets of topics).

The object `CulturalEntity` encapsulates the individuals of the concept `CulturalProperty`. At the application level, we distinguish three types of cultural entities: (i) `Tangible` cultural entity; (ii) `Intangible` cultural entity, and; (iii) `Residual` cultural entity. All three entities encapsulate basic information concerning the ID (i.e., the URI of the ontological resource represented in the knowledge graph) and the label. Also, all three types of `CulturalEntity` are associated with a `CulturalEntityActor` representing the `Agent` responsible for the generation of the individual and related information into the knowledge graph. This information is retrieved using the relation `wasAttributedTo` and is crucial to maintaining editorial information and reasoning about the provenance of the knowledge (e.g., highlighting trustworthy knowledge coming from certified sources). In addition to common information, `Tangible` cultural entity has a list of attributes representing the data properties extracted from the knowledge graph. This data represents useful information about the visit and is therefore important to plan trips that are coherent with the requirements of the users (e.g., global visit time, mobility needs, etc.). Instances of `Tangible` cultural entity are also associated with other `CulturalEntity` according to the relationships `isCorrelatedWith` and `isPartOf`. Associated cultural entities could be of any type (i.e., other tangibles, intangibles, or residual). Such associations, in addition to topics, express compositional or structural relationships between entities and provide users with suitable contextual links during a visit path.

Information about cultural paths is generated upon user requests (instances of `TripRequest`) and is encapsulated by the object `PlannedTrip`. The central information object of a trip is the POI, which provides a contextual abstraction of the underlying cultural entities that are the actual elements of the trip. Each POI is associated with a specific `Tangible` cultural entity and a list of `Intangible` cultural entities that are thematically close to the tangible one because of the list of Topic selected in the `TripRequest`. Each POI is then associated with a list of `Description`, each characterizing the corresponding `Tangible` cultural entity according to one or more of the `Topic` selected in the request. Since a cultural entity could be associated with more than one `Description` (each tagged with a specific set of topics), the use of POI allows the system to provide different descriptive views of an entity according to the specific interests of the user (again, the list of topic specified in the request). A client application sends a `TripRequest` to the REST API endpoint "/planner/trip" specifying the technical requirements of the visit (e.g., duration, accessibility needs, etc.) and the list of `Topic` that is coherent with the user's interests. The API endpoint responds with the planned list of POIs in the shape of JSON objects. The application can show the path to the user by displaying the information encapsulated in the returned POIs. For each POI (i.e., each hop/stage of the path) the returned JSON object contains the description with associated topics, the detailed information about the tangible cultural entity (e.g., visiting time, editor information, accessibility flags, etc.).

According to the data model, the returned JSON objects of tangible entities contain contextual information concerning the two relationships: (i) `partOf`; (ii) `correlatedWith`. The application shows contextual information in the detailed view of a particular POI (tangible entity) included in the planned path. It is important to point out that information about these entities might not be complete. Namely, the associated second-level JSON objects would contain only ID-related information without associated description, data, and relationships with other cultural entities. This is necessary to avoid the risk of loops in the retrieval of the information and to minimize the exchange of information between the app and the REST API by following a "lazy load approach". The next paragraphs describe some services exposed by the REST API, showing examples of requests and responses.

Retrieve the data of a cultural entity. This service allows a client to retrieve information associated with the data properties of a given cultural entity (e.g., visiting time, accessibility, latitude, longitude, etc.).

```
curl -X GET http://$REST_API_HOST:$REST_API_PORT/knowledge/entity/data -H 'Content-Type: application/json' -d '{"uri" : "http
    ://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ColleEsquilino"}'
```

Listing 10: Example of a HTTP GET request with JSON object in the data body.


```
{
   "id": "http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ColleEsquilino",
   "label": "ColleEsquilino",
   "tangible": true,
   "detailed": true,
   "correlatedEntities": [
       {
           "id": "http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#ChiesaSEusebio",
           "label": "ChiesaSEusebio",
           "tangible": true,
           "detailed": false,
           "correlatedEntities": [],
           "partOf": null,
           "editorActor": {
               "id": "http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Hermes_Admin",
               "label": "Hermes Admin"
           },
           "visitingTime": 30,
           "visitability": "Ingresso libero",
           "longitude": 12.503479123276394,
           "latitude": 41.89700101858133,
           "openHours": "unknown",
           "accMotorDisab": false,
           "price": "Gratis",
           "groupVisit": false,
           "accElderly": false,
           "address": "P.za Vittorio Emanuele II, 12/a"
       }
   ],
   "partOf": {
       "id": "http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#RioneEsquilino",
       "label": "RioneEsquilino",
       "tangible": true,
       "detailed": false,
       "correlatedEntities": [],
       "partOf": null,
```

```
        "editorActor": null,
        "visitingTime": 1,
        "visitability": "unknown",
        "longitude": 0.0,
        "latitude": 0.0,
        "openHours": "unknown",
        "accMotorDisab": false,
        "price": "unknown",
        "groupVisit": false,
        "accElderly": false,
        "address": "unknown"
    },
    "editorActor": {
        "id": "http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Hermes_Admin",
        "label": "Hermes Admin"
    },
    "visitingTime": 1,
    "visitability": "unknown",
    "longitude": 0.0,
    "latitude": 0.0,
    "openHours": "unknown",
    "accMotorDisab": false,
    "price": "unknown",
    "groupVisit": false,
    "accElderly": false,
    "address": "unknown"
}
```


Listing 11: Example of JSON object returned as result .

Retrieve the descriptions of a cultural entity. This service retrieves the whole set of descriptions associated with a cultural entity specified in the request body. The response contains JSON objects representing the individuals of `Description` extracted from the knowledge base. Each description is associated with its topics.

```
curl -X GET http://$REST_API_HOST:$REST_API_PORT/knowledge/descriptions -H 'Content-Type: application/json' -d '{"uri" : "http
    ://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#CultoAriano"}'
```

Listing 12: Example of a HTTP GET request with JSON object in the data body.


```
[
    {
        "id": "http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#CultoArianoDescription",
        "text": "LâĂŹeresia di Ario (m. Costantinopoli 336), secondo la quale nella TrinitÃă divina soltanto il Padre puÃš
      considerarsi veramente Dio, non generato e non creato, eterno e immutabile, mentre il Figlio, intermediario tra Dio e il
      mondo e suo strumento nellâĂŹopera della creazione, fu creato dal nulla e Âńnon sarebbe esistito, se Dio non ci avesse
      voluto creareÂż. LâĂŹa. fu condannato in Occidente dal Concilio di Nicea (325), mentre in Oriente fu appoggiato
      dallâĂŹimperatore Costanzo, che cercÃš di imporlo anche allâĂŹOccidente. Dopo il Concilio di Costantinopoli (381), lâĂŹa.
      sopravvisse solo presso le popolazioni germaniche, cristianizzate dal vescovo goto Ulfila.\nFonte: https://www.treccani.it
      /enciclopedia/arianesimo_%28Dizionario-di-Storia%29/",
        "topics": [
            {
                "id": "http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Arianesimo_const",
                "label": "Culto Ariano"
            }
        ]
    }
]
```


Listing 13: Example of JSON objects returned as result .

Request a personalized visit. This service encapsulates the designed temporal planning component [12, 41], configured according to the AI pipeline described in Figure 10. A client sends the request to generate a new trip for a user. The request body should contain an instance of `TripRequest` in JSON format (see Figure 11). The request contains the information necessary for the AI pipeline of Figure 10 to filter knowledge and generate a personalized cultural path. If successful, the service returns an instance of a newly created `PlannedTrip` (see Figure 11) with the associated sequences of POIs.

```
curl -X POST http://$REST_API_HOST:$REST_API_PORT/planner/trip -H 'Content-Type: application/json' -d '{"userId":"test", "
    duration":180, "userLocation":[0.8, 1.23, 3.45, 2.11], "groupSize":5, "dVector":[false, false, false], "mVector":[true,
```

```
    false, false], "topics": [{"id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Barocco", "label":"Barocco"},{"id
    ":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Medioevo", "label":"Medioevo"}]}'
```

Listing 14: Example of a HTTP POST request with JSON object in the data body.

```
{
   "id":"PLAN_0",
   "time":"2023-11-26T20:03:23.053+00:00",
   "duration":1000,
   "hops":[
   {
      "id":"POI_1",
      "time":"2023-11-26T20:03:22.772+00:00",
      "descriptions":[
         {
            "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Fontana_dei_Catcumeni_desc_Architecture",
            "text":"Architectural Description\n\n[text to be added]",
            "topic":{
               "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Barocco",
               "label":"Barocco"
            },
            "entity":{
               "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Fontana_dei_Catecumeni",
               "label":"Fontana_dei_Catecumeni"
            }
         }
      ],
      "tangible":{
         "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Fontana_dei_Catecumeni",
         "label":"Fontana_dei_Catecumeni"
      },
      "intangibles":[

      ],
      "ranking":0.0,
      "counter":0
   },
   {
      "id":"POI_2",
      "time":"2023-11-26T20:03:22.822+00:00",
      "descriptions":[
         {
            "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Chiesa_di_S._Salvatore_ai_Monti_desc_Barocco",
            "text":"Descrizione Barocco",
            "topic":{
               "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Barocco",
               "label":"Barocco"
            },
            "entity":{
               "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Chiesa_di_S._Salvatore_ai_Monti",
               "label":"Chiesa_di_S._Salvatore_ai_Monti"
            }
         }
      ],
      "tangible":{
         "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Chiesa_di_S._Salvatore_ai_Monti",
         "label":"Chiesa_di_S._Salvatore_ai_Monti"
      },
      "intangibles":[

      ],
      "ranking":0.0,
      "counter":0
   },
    ...,
   ],
   "request":{
   "id":"REQ_0",
   "userId":"test",
   "time":"2023-11-26T20:03:22.151+00:00",
   "duration":180,
   "userLocation":[
      0.8,
      1.23,
      3.45,
      2.11
   ],
   "groupSize":5,
   "dVector":[
      false,
      false,
      false
   ],
```

```
   "mVector":[
      true,
      false,
      false
   ],
   "topics":[
      {
         "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Barocco",
         "label":"Barocco"
      },
      {
         "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Medioevo",
         "label":"Medioevo"
      }
   ]
   },
   "ranking":0.0,
   "counter":0
}
```


Listing 15: Example of JSON objects returned as result.

6. Conclusions

This paper has presented the design and assessment of the HerMeS ontology, demonstrating its capability to support thematic cross-correlation and filtering of both tangible and intangible cultural entities. Our evaluation confirms that knowledge graphs built upon the HerMeS ontology successfully characterize topic-based semantic networks, allowing for meaningful connections between cultural artifacts, historical contexts, and thematic narratives. By leveraging ontology-driven reasoning, these structured knowledge representations facilitate a more interpretable, adaptive, and context-aware understanding of cultural heritage data. The retrieval processes, enriched by semantic relationships and contextual reasoning, provide a layered and multidimensional view of cultural heritage, ensuring that information is tailored to diverse user perspectives. Beyond technical contributions, the HerMeS ontology offers a scalable and interoperable framework that can be integrated into broader semantic web applications for cultural heritage management, digital humanities, and AI-enhanced cultural tourism. Future work will focus on refining the ontology, improving automated reasoning capabilities, and expanding its integration with linked open data and AI-driven recommendation systems. Additionally, the dynamic refinement of cultural entity data will be emphasized, including updating visit times and incorporating user rankings/feedback. Efforts will also be directed toward automating data collection and tagging. Further empirical studies will explore the impact of ontology-driven knowledge graphs on user engagement, accessibility, and decision-making in cultural heritage applications. Finally, we plan to investigate the potential reuse of additional properties from existing vocabularies such as Schema.org, in order to enhance interoperability and align with widely adopted semantic web standards.

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