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 aim at realizing an intelligent assistant, called HerMeS, that leverages semantic reasoning and contextual temporal planning to generate adaptive cultural itineraries, enhancing 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 research collaborative 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, interoperable solutions for cultural heritage applications. Semantic web technologies, also enriched with ontologies, are increasingly shaping the way we model, manage, and interact with complex domains, including cultural heritage. The representation of structured knowledge through ontologies enables 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 enhance 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 demon-

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strated the potential 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 in detail the designed ontological model by pointing out existing models that have been extended and novel contributions; (iii) Section 4 describes the AI-based services built on top of the ontology and explains how the resulting knowledge graph is deployed within the architecture. The section also shows an evaluation of the ontology-based knowledge graph through competency questions; (iv) Section 5 concludes the paper by summarizing and discussing the contribution.

2. Semantic Web Technologies in Cultural Heritage

The field of Digital Humanities has gained an increasing attention in recent years, gathering a growing interest from the research community thanks to the increasing accessibility of data and computational resources. In this context, the use of semantic technologies seems particularly promising for semantically tagging data, supporting interoperability, and defining a common/shared language through dictionaries and properties that characterize the available data. The editorials [13, 14] recently published in two special issues exemplify the growing interest of the research community in the intersection of semantic technologies, particularly ontologies, and cultural heritage. Many works are showing that semantic technologies and ontologies can play a crucial role in increasing the accessibility, interoperability, reuse, and standardization of cultural heritage knowledge. This section discusses relevant works that propose the use of ontologies to characterize the semantics of cultural heritage datasets and/or make data access easier and more intuitive for both expert and non-expert users.

Several works have focused on the use of semantic technologies in the design of innovative interfaces facilitating the access to cultural heritage knowledge avoiding (or limiting) the need for technical competencies. In [15] the use of a virtual assistant to facilitate access to cultural heritage knowledge through natural language is investigated. Specifically, they use taxonomical knowledge like a Thesaurus to abstract the interaction between the natural language interface of the assistant and the knowledge graph exposing cultural heritage knowledge through SPARQL endpoints. The taxonomical knowledge guides the linking process of the virtual assistant necessary to compile natural language queries formulated by the user into the correct and valid SPARQL queries to retrieve the desired information from the knowledge graph. Ontologies and semantic technologies also shape knowledge exchange and integration among experts working in the same cultural context but from different perspectives. An example is the work [16] using semantic web technologies to facilitate 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 is a meta-model providing uniform access and representation to the different types of data processed within archaeometric processes.

Another important issue addressed through semantic web technologies concerns the support of FAIR principles (Findability, Accessibility, Interoperability, and Reuse) for 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] to semantically tag data. It is equally important to compare and analyze the qualities of different ontological models as well as to identify similarities and divergencies. In this regard the works [22] and [23] propose respectively an ontology matching approach and a novel semantic relatedness measure called Rel_{Topic}. 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.

In this wide landscape of contributions, several semantic models of cultural heritage have been proposed in the literature for different purposes. Standard models like the well-known 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 [27] proposes the Cultural Heritage Abstract Reference Model (CHARM) is a reference model to support the exploration and documentation of archaeological and anthropological entities. The model is intended to be used by a wide and diverse range of users to describe 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 characterize the process of ascribing cultural heritage values to objects. The work [28] 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 touristic 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. They usually lack the representational flexibility needed to "frame" the semantic description of cultural objects. Existing models struggle 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. Additionally, 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. This work introduces the HerMeS ontology designed to support a compositional and thematic description of cultural entities and the flexible correlation between tangible and intangible ones. 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 [29] 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 approach to cultural heritage is necessary to provide users (e.g., tourists) with a detailed description of habits, traditions, places, events, and connections with other cultures. It is necessary to characterize the geographic and structural features, as well as the cultural qualities, of tangible entities that are part of a specific territory and are relevant from a heritage perspective. However, it is equally important to characterize intangible cultural entities that correlate with the tangible ones of a territory and may identify "semantic connections" with other cultures and traditions. The ability to semantically correlate intangible with tangible items is key to unlocking hidden relationships between places, history, religion, food, and local traditions. In this context, the HerMeS Ontology[1] is the result of a research effort aiming at supporting the multiperspective description of cultural entities and their semantic correlations with the intangible heritage. HerMeS is a domain ontology [30] based on a solid theoretical background defined by DOLCE [29], and extending the ontological model ArCo [2] [21].

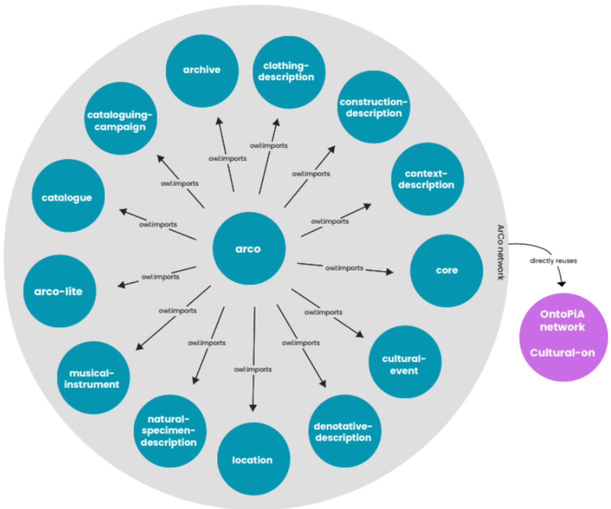


Figure 1. Overview of the ArCo network of ontology modules.

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` is dedicated to catalog records, especially useful to preserve the provenance and dynamics of the data.

The modules of the ArCo network represent a well-structured basis for the HerMeS ontology. However, the structure proposed by ArCO follows a traditional descriptive approach that is not well suited to support cross-correlation and linking among heterogeneous cultural entities. The main objective of HerMeS is the representation of complex cultural objects resulting from the stratification of tangible and intangible entities. ArCo primarily focuses on `movable` cultural objects and does not offer sufficiently detailed structures to capture the characteristics of `immovable` cultural properties, particularly `intangible` cultural assets. Intangible cultural properties are central to HerMeS and enable cross-narrative links among heterogeneous cultural aspects (e.g., archaeological, social, religious, and rituals). HerMeS thus extends ArCo by defining (and refining) concepts that support the needed level of expressivity. Figure 2 shows an excerpt of the HerMeS ontology pointing out new concepts and their correlation with ArCo underlying elements (`tangible` and `intangible` cultural properties).

[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

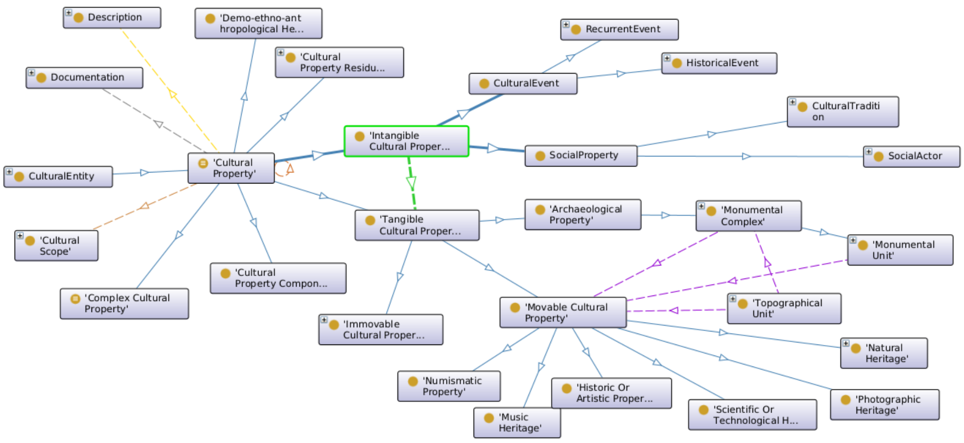


Figure 2. Excerpt of the HerMeS ontology extending the notions of `CulturalProperty`.

HerMeS extends the concept `ImmovableCulturalProperty` by introducing the concepts `Territorial Unit` and `Territorial Complex`. 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 introduces a new type of `ImmovableCulturalProperty` called `InfrastructuralProperty` supporting the description of the topological structure of a territory. These concepts characterize infrastructural entities that connect instances of `TerritorialComplex`. In addition to their infrastructural role, streets or squares, for example, could be relevant from a heritage perspective and thus be considered as tangible properties too.

HerMeS defines a detailed structure of transversal cultural and social properties that are correlated to the `Tangible` Cultural Property (either `movable` or `immovable`) defined into the knowledge. In this regard, HerMeS refines the structuring of `Intangible` Cultural Property which was not specialized by ArCo. Figure 2 shows a subset of the introduced concepts under the subtree with the ArCo class `Intangible` Cultural Property as root. We have specifically introduced the concepts necessary to explicitly describe non-material entities characterizing 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 `Intangible` Cultural Property to correlate it with the ArCO concept `Tangible` Cultural Property 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 certain territory. Another central aspect of HerMeS is the capability of indexing modeled cultural properties according to different topics and points of view. Concerning the construction of contextualized narratives [24], the definition of a well-structured taxonomy of topics and themes supports contextual filtering and retrieval of (sub-sets of). Each `Cultural Property` is thus associated with a non-empty set of `Topic` used to tag their descriptive content.

Taking inspiration from the concept of *Frame* [31] 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 [32, 33]. 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 used the concept `Topic` that ArCo defined without a taxonomical structure specializing it. 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.

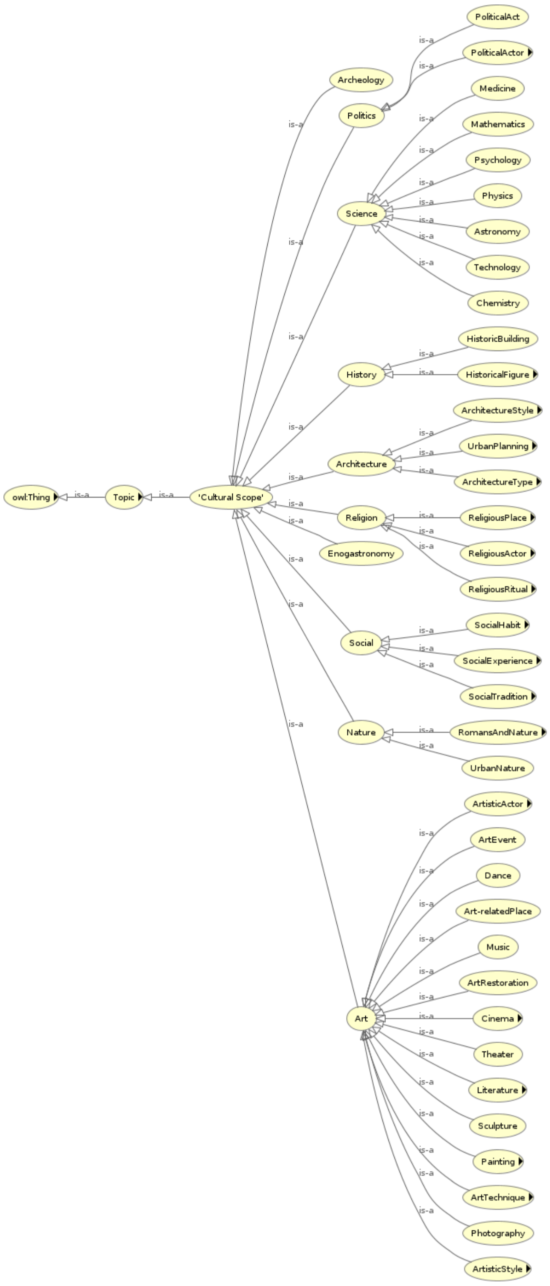


Figure 3. Extended taxonomy of `Topic` characterizing semantic links between `CulturalProperty`.

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 applying structured knowledge engineering methodologies [34]. The process identified

[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.

the following criteria as crucial for the proper characterization of cultural entities (generally referred to as Points of Interest - POIs):

- *Geographical location*: In which area/territorial unit is the POI located? And which transport infrastructures are available in that area? (Eg. Bus, Train/Metro stations, parking, etc.). 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, this 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, elderly, or people with motor, visual, or hearing disability?

Interestingly, the design process considered also the integration of structured meta-information to support the authoring of cultural information. HerMeS specifically integrates the PROV-O ontology [7] [35, 36] to represent meta-information about editing activities of cultural entities in a knowledge graph. In addition, several refinements of the ArCO ontological model have been considered to better support the layered and thematic correlation of tangible and intangible cultural entities. Such extensions concern: (i) the introduction of new classes (`TerritorialUnit`, `TopographicContext`, `MonumentalUnit`, `CulturalPropertyDescription`, etc.); (ii) the refinement of existing classes (`CulturalPropertyResidual`, `IntangibleCulturalProperty`, `Topic`), and; (iii) the introduction of new data and object properties (`visiting_time`, `inclusive_accessibility`, etc.). Tables 1, 2 and 3 show with further detail, respectively, the class, data property, and object property extensions made to the ArCO ontological model.

3.2. Knowledge Authoring through Provenance

PROV-O [8] [35] is a representation formalism defined to propose a standard schema characterizing meta-data 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 (`prov:Entity`) is a physical, digital, conceptual, or other kind of thing with some fixed aspects (entities may be real or imaginary). An activity (`prov: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 (`prov: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 the question: "Who entered the data within the knowledge base?" Each cultural property was tagged with the object property "was attributed to: Agent", for example, the cultural property "Anfiteatro Castrense" was attributed to "Hermes Admin". Table 4 shows in detail the concepts introduced to integrate PROV-O into the HerMeS ontology.

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

Table 1
Class extensions to ArCO ontology

Class name	Description	Relations
Territorial Unit	The set of topographic 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 are 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 Context.	Subclass of **Location**.
Cultural Property Description	Thematic description associated with a cultural property.	Subclass of **Description**.

3.3. Ontological Patterns for Cultural Framing

This section describes with more detail the main elements and relationships of the designed HerMeS Ontology, using the UML notation. Specifically, we point out some ontological patterns [37, 38] defined to structure the axioms of the resulting ontology and the relationships between the modeled cultural entities. Figure 5 shows the contextual description pattern used to support the thematic framing of the cultural heritage. As can be seen, the set of cultural

Table 2

Data property extensions to ArCO ontology

Data property	Description	Relations
accessibility_elderly	This property always has a boolean value (true/false), it defines whether a given POI is accessible to the elderly.	Subproperty of **accessibility**
accessibility_group	This property always has a boolean value (true/false), it defines whether a given POI is accessible to groups.	Subproperty of **accessibility**
accessibility_hearing_disability	This property always has a boolean value (true/false), it defines whether a particular POI is accessible to people with hearing disabilities.	Subproperty of **accessibility**
accessibility_motor_disability	This property always has a boolean value (true/false), it defines whether a particular POI is accessible to people with motor disabilities.	Subproperty of **accessibility**
accessibility_visual_disability	This property always has a boolean value (true/false), it defines whether a given POI is accessible to people with visual impairments.	Subproperty of **accessibility**
visitability	This property describes the visitability of a cultural property. E.g. visitable only by reservation, visitable only externally, free access, etc.	Subproperty of **visiting_information**
opening_hours	This property describes the opening hours of a cultural property.	Subproperty of **visitability**
visiting_price	This property gives information about the price of the entrance fee of a cultural property.	Subproperty of **visiting_information**
visiting_time	This property describes the minimum visiting time of a cultural property. The time is expressed in minutes, in the form of a decimal number.	Subproperty of **visiting_information**

Table 3

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

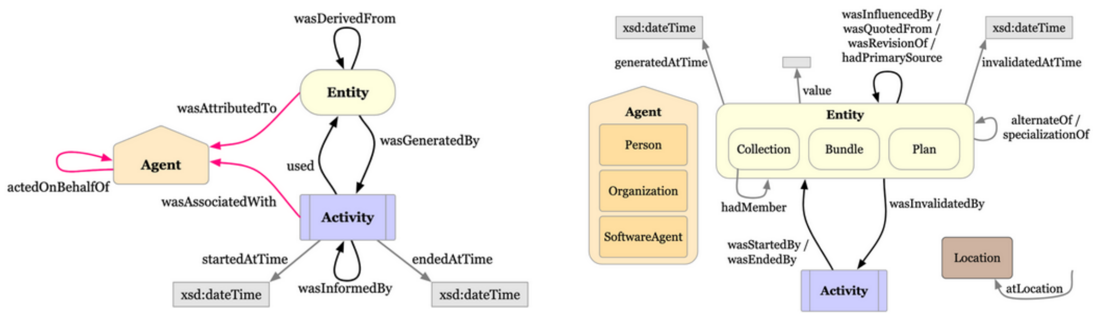


Figure 4. General structure of the PROV-O Ontology.

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 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 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

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 `provo:Person`	`hermes_admin`
Editor	The editor is an agent with an advanced editorial role: checks and creates content.	Subclass of `provo:Person`	`hermes_editor`
Partner	A partner can add content, or report inconsistencies, e.g., Touring Club[9].	Subclass of `provo:Person`	`touring_club_it`
User	A user can make reports on content, which must then be reviewed by an Admin or Editor.	Subclass of `provo:Person`	`tourist`

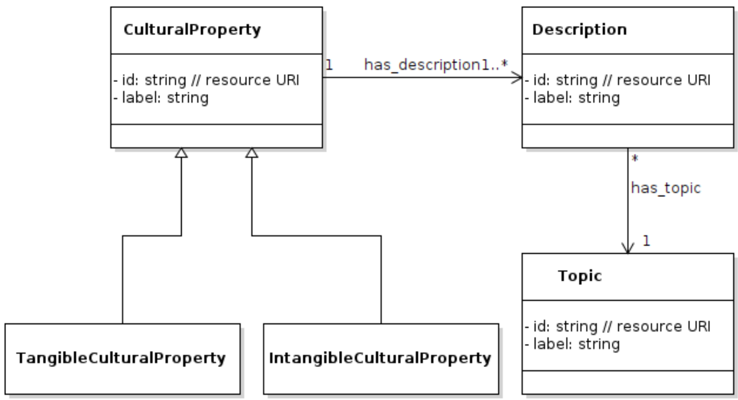


Figure 5. Contextual description pattern of cultural entities. Each individual of `CulturalProperty` is associated with one or more individuals of `Description`. Each Description characterizes a `CulturalProperty` with respect to a certain `Topic` (thematic description). The thematic contexts of each cultural property is thus inferred from the set of topics associated through its descriptions

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.). With the collaboration of DigiLab Sapienza and ISPC teams, we managed to create a dataset of the tangible and intangible cultural heritage of two districts in the historical center of Rome (the "Rioni Monti" and "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 8 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 to other cultural entities. For example, consider the sub-graph defined for the POI "Basilica Papale di Santa Maria Maggiore", as shown in Figure 9(a). The figure in particular shows:

– the POI geographical location (latitude/longitude);
– the POI accessibility, for example, this POI is accessible to groups (accessibility_groups= true), elderly (accessibility_elderly=true), people with motor or hearing disabilities (accessibility_motor_disability=true, accessibility_hearing_disability=true);

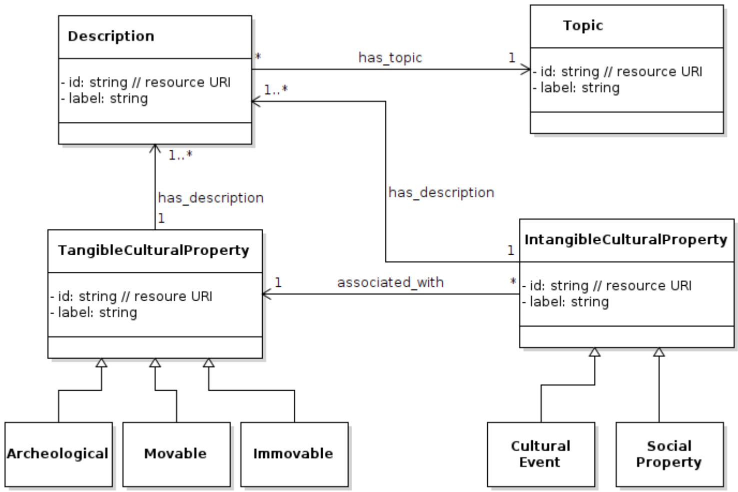


Figure 6. Contextual correlation between tangibles and intangibles through `Topic`. The set of `CulturalProperty` consists of two disjoint subsets. The subset of `Tangible` cultural property and the subset of `Intangible` cultural property. As subclasses of `CulturalProperty` they inherit the structure of contextual descriptions obtained through the relationships with the classes `Description` and `Topic`. In addition, each `Tangible` Cultural Property could be associated with some `Intangible` cultural property that support cross-perspectives cultural links encapsulated with the designed HerMeS ontology.

– the POI visiting time (visiting_time = 30 minutes)
– the POI visitability, price, address, etc.

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]. The following object properties assertions characterize 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 3 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".

The ontological structure of HerMeS facilitates the correlation of tangibles and intangibles cultural entities and aggregates POIs not only from a physical or geographical point of view but also, and most 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 3, 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.

4. 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 specifically shows the flow implementing the synthesis of personalized visits [12]. The ontology has been

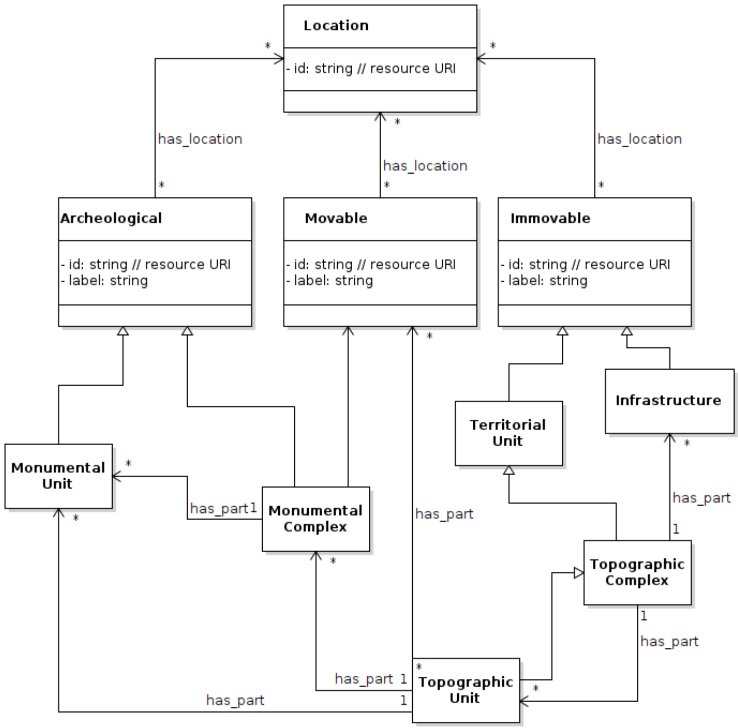


Figure 7. Layered structuring of locations and infrastructural knowledge. Given a `Location` described in terms of geographic coordinates, the knowledge graph supports the retrieval of all the cultural properties (tangible, movable, and immovable) that are included in the specified area. Such elements could be further filtered according to a set of topic. In this way, the knowledge graph supports a thematic and contextual retrieval of cultural entities within a give geographic area or general `Location`.

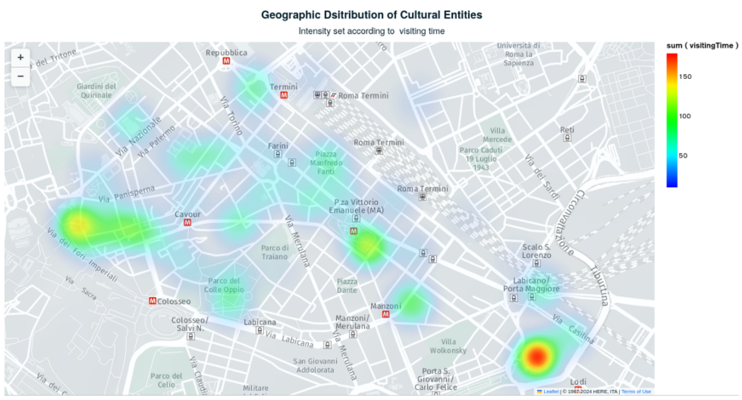
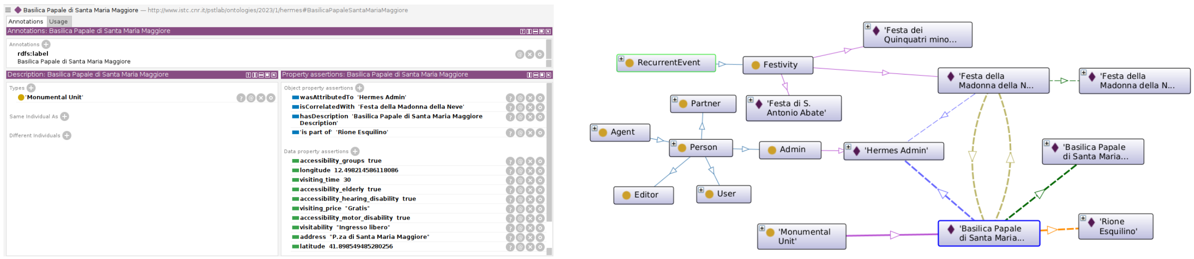


Figure 8. Distribution of POIs considered for the “Rione Monti” and “Esquilino” in Rome.

designed using the Protégé ontology editor [10]. The knowledge graph with the associated reasoning and knowledge retrieval services have been developed using the open source library Apache Jena [11]. The process is triggered by users sending a trip request through the HerMeS application [11]. The request is received by a REST API interface, which encapsulates the user’s interests for the visit (i.e., set of topics) and preferences (i.e., duration of the visit,

[10]https://protege.stanford.edu/
[11]https://jena.apache.org/



(a) (b)

Figure 9. Example of data properties and relationships associated with the tangible individual “Basilica Papale di Santa Maria Maggiore”.

accessibility, and mobility preferences). A semantic-based recommended system then retrieves the information that matches the interests and preferences of the user from the knowledge graph. The process relies on the defined ontology to extract a contextualized view of relevant cultural entities by taking into account thematic correlations with modeled intangibles and compositional relationships with other tangibles.

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, foot). The temporal planning component then synthesizes a “cultural path” by explicitly reasoning on temporal requirements (i.e., the total time available for the visit and the visiting time of tangibles) and the travel time of alternative sequences of visited tangibles. The optimized sequence of tangibles is sent to the user as a response to the original trip request. The HerMeS app is then in charge of interacting with the user and showing the planned tangibles with the correlated intangibles/tangibles.

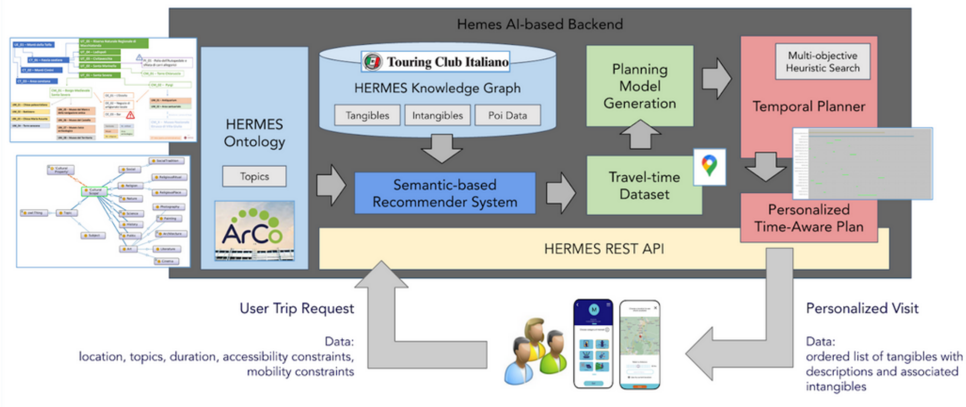


Figure 10. HerMeS AI-based pipeline based on the ontological model of cultural heritage.

4.1. REST API and Data Model

The REST API interface 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.

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 multi-thematic 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).

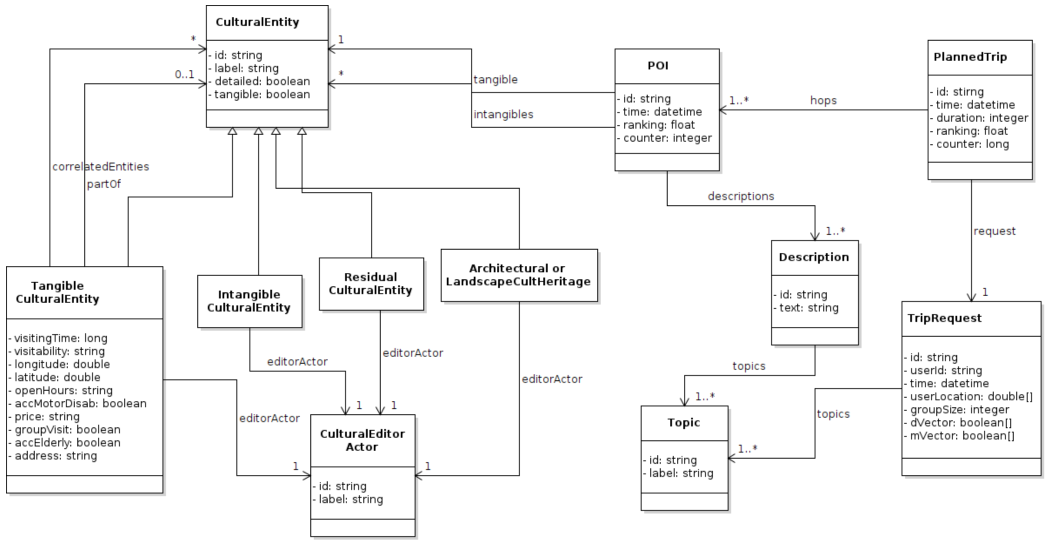


Figure 11. Data model of the REST API. The API offers dedicated endpoints where a client can retrieve all the descriptions and all the data associated with a specific `CulturalEntity` associated with a POI containing the set of textual descriptions of a cultural entity that match a given set of topics.

The object `CulturalEntity` encapsulates the individuals of the concept `arco:CulturalProperty`. At the application level, we distinguish three types of cultural entities: (i) `Tangibel` 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 `provo:Agent` responsible for the generation of the individual and related information into the knowledge graph. This information is retrieved using the relation `provo:wasAttributedTo` and is crucial to maintaining editorial information and reasoning about the provenance of the knowledge (e.g., highlighting trustable knowledge coming from certified sources).

In addition to common information, `Tangible` cultural esntity has a list of attributes representing the data properties extracted from the knowledge graph (e.g., `accessibility_groups`, `visiting_price`, `visiting_time`, etc.). 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 `arco: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 entity 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 end-point "/planner/trip" specifying the technical requirements of the visit (e.g., duration, accessibility needs, etc.) and the list of `Topic` that is coherent with 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 (i.e., 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) `arco:partOf` and; (ii) `correlatedWith`. The application may show such contextual information would be shown in the detailed view of a particular POI (tangible entity) being visited during the 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". However, there are dedicated REST end-points the app/client could use to retrieve additional information about cultural entities as needed:

- The endpoint "/knowledge/entity/data" retrieves information about the data properties of a given cultural entity and the associations with the properties `arco:isPartOf` and `isCorrelatedWith`.
- The endpoint "/knowledge/descriptions" similarly retrieves information about descriptions associated with a given cultural entity.

The combined use of these two endpoints thus is useful for the application to enrich the information provided to a user during the execution of a planned trip according to his/her interactions. 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 1: 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 2: 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 3: 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 TrinitĂă divina soltanto il Padre puĂš 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 cercĂš 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 4: Example of JSON objects returned as result .

Request a personalized visit. This service encapsulates the designed temporal planning component [12, 39], 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 to 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 5: 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
   },
   {
      "id":"POI_3",
      "time":"2023-11-26T20:03:22.871+00:00",
      "descriptions":[
         {
```

```
            "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Chiesa_di_S._Lorenzo_in_Panisperna_desc_Barocco",
            "text":"Descrizione Barocco\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#Chiesa_di_S._Lorenzo_in_Panisperna",
               "label":"Chiesa_di_S._Lorenzo_in_Panisperna"
            }
         }
      ],
      "tangible":{
         "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Chiesa_di_S._Lorenzo_in_Panisperna",
         "label":"Chiesa_di_S._Lorenzo_in_Panisperna"
      },
      "intangibles":[

      ],
      "ranking":0.0,
      "counter":0
   },
   {
      "id":"POI_4",
      "time":"2023-11-26T20:03:22.917+00:00",
      "descriptions":[
         {
            "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Chiesa_nazionale_ucraina_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_nazionale_ucraina_dei_Ss._Sergio_e_Bacco",
               "label":"Chiesa_nazionale_ucraina_dei_Ss._Sergio_e_Bacco"
            }
         }
      ],
      "tangible":{
         "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Chiesa_nazionale_ucraina_dei_Ss._Sergio_e_Bacco",
         "label":"Chiesa_nazionale_ucraina_dei_Ss._Sergio_e_Bacco"
      },
      "intangibles":[

      ],
      "ranking":0.0,
      "counter":0
   },
   {
      "id":"POI_0",
      "time":"2023-11-26T20:03:22.715+00:00",
      "descriptions":[
         {w
            "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Basilica_di_S.Martino_ai_Monti_desc_History",
            "text":"Descrizione Storica \n[text to be added]",
            "topic":{
               "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Medioevo",
               "label":"Medioevo"
            },
            "entity":{
               "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Basilica_di_S._Martino_ai_Monti",
               "label":"Basilica_di_S._Martino_ai_Monti"
            }
         }
      ],
      "tangible":{
         "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Basilica_di_S._Martino_ai_Monti",
         "label":"Basilica_di_S._Martino_ai_Monti"
      },
      "intangibles":[

      ],
      "ranking":0.0,
      "counter":0
   },
   {
      "id":"POI_5",
      "time":"2023-11-26T20:03:22.963+00:00",
      "descriptions":[
         {
            "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Torre_dei_Conti_desc._History",
            "text":"Descrizione Storica",
            "topic":{
               "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Medioevo",
               "label":"Medioevo"
```

```
            },
            "entity":{
               "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Torre_dei_Conti",
               "label":"Torre_dei_Conti"
            }
         }
      ],
      "tangible":{
         "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Torre_dei_Conti",
         "label":"Torre_dei_Conti"
      },
      "intangibles":[

      ],
      "ranking":0.0,
      "counter":0
   },
   {
      "id":"POI_6",
      "time":"2023-11-26T20:03:23.008+00:00",
      "descriptions":[
         {
            "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Chiesa_di_GesÃź_Bambino_desc_Barocco",
            "text":"Descrizione Barocco \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#Chiesa_di_GesÃź_Bambino",
               "label":"Chiesa_di_GesÃź_Bambino"
            }
         }
      ],
      "tangible":{
         "id":"http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#Chiesa_di_GesÃź_Bambino",
         "label":"Chiesa_di_GesÃź_Bambino"
      },
      "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 6: Example of JSON objects returned as result.

4.2. Evaluation through Competency Questions

To evaluate the expressivity of the designed ontological model and related knowledge graph(s) we defined a set of *Competency Questions*. Given the general structure summarized in the previous section, it is important to verify whether the defined schema/semantics supports the retrieval of all the knowledge necessary to correctly (and completely) implement the services exposed through the REST API. To this end, we have exposed a SPARQL endpoint [12] to implement the defined Competency Questions (CQ) and assess the quality of the underlying knowledge graph. CQs represent carefully defined queries that the knowledge graph should be able to answer in a correct, complete, and efficient way. They therefore are suitable for identifying possible knowledge/semantic gaps preventing the navigation of the information as desired. We have defined eight competency questions to assess the correct analysis and "traversal" of thematic links between tangibles and intangibles. The HerMeS knowledge graph was able to answer successfully all 8 CQs by retrieving all the expected triples and individuals. The queries were all processed efficiently by responding to the request in a highly efficient time (a few milliseconds). The following paragraphs describe the competency questions defined by showing the SPARQL queries with the expected and obtained results.

CQ1. The first competency question considered is "What are the religion-themed POIs that can be visited by a person with motor disabilities on a full-day tour?". To correctly answer CQ1 the knowledge graph must retrieve tangible cultural entities whose descriptions are tagged by religion-related topics. The tangibles must be associated with accessibility data concerning motor disability. The listing 7 shows the SPARQL query translating the query in the pattern matching identifying the set of relevant triples in the knowledge graph. In particular, the SPARQL query returns the list of individuals (*?poi*) that satisfy the pattern. The query response contains all (and only) the five tangibles that were expected:

- <hermes:chiesa_di_gesu_bambino>
- <hermes:chiesa_di_s_lorenzo_in_fonte>
- <hermes:basilica_di_s_Martino_ai_monti>
- <hermes:chiesa_di_s_lorenzo_in_panisperna>
- <hermes:chiesa_nazionale_ucraina_dei_ss_sergio_e_bacco>

```
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-catalogue: <https://w3id.org/arco/ontology/catalogue#>
PREFIX arco-context: <https://w3id.org/arco/ontology/context-description/>
PREFIX arco-core: <https://w3id.org/arco/ontology/core#>
PREFIX w3id: <https://w3id.org/italia/onto/l0/>
PREFIX hermes: <http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#>

SELECT DISTINCT ?poi
WHERE {
    ?poi w3id:hasDescription ?d .
    ?poi hermes:prices ?price .
    ?poi hermes:accessibility_motor_disability true .
    ?d w3id:hasTopic ?t .
    ?t rdf:type ?tType .
    ?tType rdfs:subClassOf* hermes:Religion .
}
```

Listing 7: SPARQL code implementing the Competency Question CQ1.

CQ2. The second competency question is "What are the Art-themed POIs that can be visited by people with hearing and visual disabilities in a 4-hour tour?". To correctly answer CQ2 the knowledge graph must retrieve tangible cultural entities whose descriptions are tagged by art-related topics. The tangibles must be associated with accessibility data concerning visual and hearing disability. Furthermore, the query filter triples concerning tangibles whose declared visiting time is shorter than 4 hours. The listing 8 shows the SPARQL query translating CQ2 in the pattern matching identifying the set of relevant triples in the knowledge graph. In particular, the SPARQL query

[12] The SPARQL endpoint has been realized using Apache Jena Fuseki - https://jena.apache.org/documentation/fuseki2/

returns the list of individuals (?*poi*) that satisfy the pattern. The query response contains all (and only) the three tangibles that were expected:

- <hermes:chiesa_di_s_Salvatore_ai_Monti>
- <hermes:palazzo_del_collegio_dei_neofiti_e_catecumeni>
- <hermes:chiesa_di_s_lorenzo_in_fonte>

```
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-catalogue: <https://w3id.org/arco/ontology/catalogue#>
PREFIX arco-context: <https://w3id.org/arco/ontology/context-description/>
PREFIX arco-core: <https://w3id.org/arco/ontology/core#>
PREFIX w3id: <https://w3id.org/italia/onto/l0/>
PREFIX hermes: <http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#>

SELECT DISTINCT ?poi
WHERE {
  ?poi w3id:hasDescription ?d .
  ?poi hermes:accessibility_hearing_disability true .
  ?poi hermes:accessibility_visual_disability true .
  ?poi hermes:visiting_time ?time .
  ?d w3id:hasTopic ?t .
  ?t rdf:type ?tType .
  ?tType rdfs:subClassOf* hermes:Art .
  FILTER (?time <= 4.0)
}
```

Listing 8: SPARQL code implementing the Competency Question CQ2.

CQ3. The third competency question considered is “What are the Religion-themed POIs and specifically `Byzantine_rite type` Religious Rituals, which can be visited free of charge?”. To correctly answer CQ3 the knowledge graph must retrieve all the tangible entities that are correlated with the specific topic `Byzantine_rite`. Among all these tangibles the query is interested in retrieving only those that have free entry. The listing 9 shows the SPARQL query translating CQ3 in the pattern matching identifying the set of relevant triples in the knowledge graph. In particular, the SPARQL query returns the list of individuals (?*poi*) that satisfy the pattern. The result of the processed query contains all and only the two expected tangibles that are identified by the following individuals:

- <hermes:chiesa_di_s_salvatore_ai_monti>
- <hermes:chiesa_nazionale_ucraina_dei_ss_sergio_e_bacco>

```
PREFIX arco: <https://w3id.org/arco/ontology/arco#>
PREFIX arco-catalogue: <https://w3id.org/arco/ontology/catalogue#>
PREFIX arco-context: <https://w3id.org/arco/ontology/context-description/>
PREFIX arco-core: <https://w3id.org/arco/ontology/core#>
PREFIX w3id: <https://w3id.org/italia/onto/l0/>
PREFIX hermes: <http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#>

SELECT DISTINCT ?poi
WHERE {
  ?poi w3id:hasDescription ?d .
  ?d w3id:hasTopic hermes:rito_bizantino .
  ?poi hermes:visiting_price "Free" .
}
```

Listing 9: SPARQL code implementing the Competency Question CQ3.

CQ4. The fourth competency question considered is “What are the Baroque-themed POIs with free visits?”. To correctly answer CQ4 the knowledge graph must retrieve all the tangible entities that are correlated with the specific topic `Baroque` with free entry. The listing 10 shows the SPARQL query translating CQ4 in the pattern matching identifying the set of relevant triples in the knowledge graph. The result of the processed query contains all and only the six expected tangibles that are identified by the following individuals:

- <hermes:chiesa_di_gesu_bambino>
- <hermes:chiesa_di_s_lorenzo_in_panisperna>
- <hermes:chiesa_di_s_Maria_ai_monti>
- <hermes:chiesa_di_s_pudenziana>
- <hermes:chiesa_di_s_salvatore_ai_monti>
- <hermes:fontana_dei_catecumeni>

```
PREFIX arco: <https://w3id.org/arco/ontology/arco#>
PREFIX arco-catalogue: <https://w3id.org/arco/ontology/catalogue#>
PREFIX arco-context: <https://w3id.org/arco/ontology/context-description/>
PREFIX arco-core: <https://w3id.org/arco/ontology/core#>
PREFIX w3id: <https://w3id.org/italia/onto/l0/>
PREFIX hermes: <http://www.istc.cnr.it/pstlab/ontologies/2023/1/hermes#>

SELECT DISTINCT ?poi
WHERE {
  ?poi w3id:hasDescription ?d .
  ?poi hermes:visitability "Free" .
  ?d w3id:hasTopic hermes:Barocco .
}
```

Listing 10: SPARQL code implementing the Competency Question CQ4.

CQ5. The fifth competency question considered is “What are the History-themed POIs, and specifically the history of the twentieth century?”. To correctly answer CQ5 the knowledge graph must retrieve all the tangible entities that are correlated with the specific topic `History`. In particular, the query filters the triples that are associated with the specific sub-topic `TwentiethCentury`. The listing 11 shows the SPARQL query translating CQ5 in the pattern matching identifying the set of relevant triples in the knowledge graph. The result of the processed query contains the unique expected tangible, identified by the following individual:

- <hermes:via_panisperna>

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

SELECT DISTINCT ?poi
WHERE {
  ?poi w3id:hasDescription ?d .
  ?d w3id:hasTopic ?t .
  ?t rdf:type ?tType .
  ?tType rdfs:subClassOf* hermes:History .
  FILTER (?t = hermes:TwentiethCentury)
}
```

Listing 11: SPARQL code implementing the Competency Question CQ5.

CQ6. The sixth competency question considered is “What are the Architecture-themed POIs, and specifically Neoclassical Architecture?”. To correctly answer CQ6 the knowledge graph must retrieve all the tangible entities that are correlated with the specific topic `Architecture`. In particular, the query filters the triples that are associated with the specific sub-topic `NeoclassicalArchitecture`. The listing 12 shows the SPARQL query translating CQ6 in the pattern matching identifying the set of relevant triples in the knowledge graph. The result of the processed query contains the two expected tangible that the following individuals identify:

- <hermes:chiesa_di_s_lorenzo_in_fonte>
- <hermes:chiesa_nazionale_ucraina_dei_ss_sergio_e_bacco>

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

SELECT DISTINCT ?poi
WHERE {
  ?poi w3id:hasDescription ?d .
  ?d w3id:hasTopic ?t .
  ?t rdf:type ?tType .
  ?tType rdfs:subClassOf* hermes:Architecture .
  FILTER (?t = hermes:Architettura_Neoclassica)
}
```

Listing 12: SPARQL code implementing the Competency Question CQ6.

CQ7. The seventh competency question considered is “What are the POIs whose description refers to a pictorial movement?”. To correctly answer CQ7 the knowledge graph must retrieve all the descriptions that are correlated with the specific topic `PaintingStyle`. The listing 13 shows the SPARQL query translating CQ7 in the pattern matching identifying the set of relevant triples in the knowledge graph. The result of the processed query contains all and only the eight expected tangible that are identified by the following individuals:

- <hermes:chiesa_di_gesu_bambino>
- <hermes:chiesa_di_s_lorenzo_in_panisperna>
- <hermes:chiesa_di_s_Maria_ai_monti>
- <hermes:chiesa_di_s_pudenziana>
- <hermes:chiesa_di_s_salvatore_ai_monti>
- <hermes:chiesa_nazionale_ucraina_dei_ss_sergio_e_bacco>
- <hermes:fontana_dei_catecumeni>
- <hermes:palazzo_del_collegio_dei_neofiti_e_catecumeni>

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

SELECT DISTINCT ?poi
WHERE {
    ?poi w3id:hasDescription ?d .
    ?d w3id:hasTopic ?topic.
    ?topic  rdf:type ?tType.
    ?tType rdfs:subClassOf* hermes:PaintingStyle .
}
```

Listing 13: SPARQL code implementing the Competency Question CQ7.

CQ8. The eighth competency question considered is “What are the Art-themed POIs, specifically Renaissance?”. To correctly answer CQ8 the knowledge graph must retrieve all the descriptions that are correlated with the specific topic `Renaissence`. The listing 14 shows the SPARQL query translating CQ8 in the pattern matching identifying the set of relevant triples in the knowledge graph. The result of the processed query contains all and only the two expected tangible that are identified by the following individuals:

- <hermes:chiesa_di_s_Maria_ai_monti>
- <hermes:chiesa_di_s_pudenziana>

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

SELECT DISTINCT ?poi
WHERE {
    ?poi w3id:hasDescription ?d .
    ?d w3id:hasTopic hermes:Renaissence .
}
```

Listing 14: SPARQL code implementing the Competency Question CQ8.

5. 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.

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