An Ontology to Support Decision-Making in Conservation and Restoration Interventions of Cultural Heritage

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Abstract

The Conservation and Restoration (CnR) of Cultural Heritage (CH) community has exploited *Semantic Web* (SW) technologies to facilitate the representation and share of knowledge and data that the experts of the domain collect and produce. The different developed models represent aspects of knowledge of the domain, while they have been employed for implementing semantic services that support CnR practice. Furthermore, to some extent, the models represent and support the decision-making process of the CnR, facilitating the organization and management of information that could lead to concrete CnR intervention decisions. However, the decision-making regarding the intervention selection (CnR-DM-I) per se, has not been modelled yet. Furthermore, the support of the experts in a more assistive way, regarding the selection of the most suitable intervention option for different cases at hand, constitutes a field of interest that can be further explored. This work proposes a formal ontology which represents the expert's knowledge related to CnR-DM-I. The ontology includes the necessary classes, properties, and individuals. The individuals represent specialized knowledge regarding the intervention problem, options, requirements, and criteria of two specific categories of CnR interventions: i) the cleaning of superficial deposits and ii) the consolidation of flaking gouache. Additionally, the ontology incorporates a set of rules, which generate necessary inferences which supplementally support the representation of the domain of interest. The ontology has been deployed in collaboration with and evaluated by conservators. Evaluation results show that the developed ontology successfully represents the domain of interest, while it provides useful inferences and queries answering which assist conservators in CnR-DM-I processes. Thus, the incorporation of the ontology in a framework could lead to the detection and selection of the most suitable intervention options, as well as the full documentation of the context of the CnR-DM-I process.

Keywords

ontology, conservation and restoration, decision-making, SWRL

1. Introduction

The CnR of tangible CH aims to maintain the physical, aesthetic, and historical integrity of *conservation objects*[2], in order to ensure the preservation and access for present and future generations [2-3]. In doing so, CnR experts seek to understand the original and present preservation state of conservation objects and –if needs be- to select the most appropriate CnR intervention to manage the change and sustain the values[3] of the conservation objects [4]. To reach conclusions and decide, the conservators follow a decision-making process which generally comprises up to six stages [4, 5]: i) *initiation* of the CnR project, ii) *risk evaluation*, iii)

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[2] *Conservation object* refers to "the object which is worthy of conservation, and not only repair, maintenance, cleaning, or care" [1].
[3] Values can be artistic, aesthetic, symbolic, historical, social, economic etc. [4].

consideration of options and selection of suitable CnR actions, iv) *design* of the CnR action plan, v) *implementation* of the agreed plan, iv) *completion* of the CnR project.

In the context of the decision-making process CnR experts collect, create, and maintain diverse information, which constitutes the CnR documentation [4, 6]. The information may be relevant to material and immaterial aspects of the conservation object, and of similar conservation objects, as well as general knowledge and specific cases about diagnosis and CnR interventions methods and results [7]. Although data interoperability and exchange is vital for the CnR domain and the decision-making process, in many cases it is difficult to achieve. The difficulty originates mainly from i) the *fragmentation of the data*, since CnR laboratories record their data in databases isolated from each other, each one developed according to different requirements [8, 9, 10] and ii) the *heterogeneity of the data*, since CnR data can be found in various forms[4] and often present terminology inconsistency [10, 11, 12].

The SW provides very promising means to tackle the aforementioned issues [10, 11], facilitating the representation and sharing of knowledge and data. Particularly, the CnR community has developed semantic models for representing aspects of CnR knowledge [13]. Additionally, it has deployed those models in various data modelling and management tasks, including information integration from different sources, efficient retrieval, and visualisation of information, as well as identification of conservation issues and recommendation of solutions [11, 14, 15].

The different developed models represent knowledge relevant to decision-making, while the models have been employed for implementing semantic services that support decision-making [13]. However, the parameters, issues, requirements, criteria, and intervention options involved in the decision-making process, and more importantly the complex *interdependence* of the aforementioned factors has *not* been modelled yet. Furthermore, the support of the process in a more assistive way, regarding the selection of the most suitable intervention option for different cases at hand (from now on the decision-making process of choosing the appropriate intervention will be referred to as CnR-DM-I), constitutes a field of interest that can be further explored [13].

Drawing on the above, we propose an ontology for the explicit representation and integration of the expert's knowledge related to CnR-DM-I. The ontology aims to conceptualize CnR-DM-I at a granularity that will allow a more thorough representation. Apart from the necessary classes and properties, the ontology includes individuals which represent specialized knowledge regarding the intervention problem, options, requirements, and criteria of two specific categories of CnR interventions: i) the *cleaning of superficial deposits* and ii) the *consolidation of flaking gouache*. Furthermore, it incorporates a set of rules, which generate necessary inferences which supplementally support the representation of the domain of interest (e.g., inferences regarding the satisfaction of requirements that could influence the selection or rejection of an option). This thorough representation of asserted and inferred knowledge aims furthermore to the implementation of a framework which could assist conservators to i) organize their thoughts and determine requirements[5] (extrinsic and intrinsic) and criteria[6] over a case at hand, ii) validate and enrich the documentation of the input data, which are taken into account for the final decision, iii) automatically receive a set of specific suitable intervention options based on the specific parameters, requirements and criteria of the case at hand.

The rest of the paper is structured as follows: Section 2 reviews semantic models of the CnR domain, as well as ontologies related to decision-making process. Section 3 presents the ontology engineering methodology that has been followed. Section 4 describes the developed ontology. Section 5 presents the evaluation of the ontology. Finally, Section 6 concludes the paper with a brief discussion on obtained results and future research plans.

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[4] Unstructured, semi-structured, unstructured [10,11].

[5] *Requirements* include i) *intrinsic requirements* which arise from the different intervention options, and must be satisfied by the conservation object, its environment, or any planned interventions, and ii) *extrinsic requirements* which arise from external factors (e.g., budget, location restrictions), and must be satisfied by the considered plan or its supplies.

[6] The term *criteria* refer to ranking criteria of suitable options (e.g., based on the performance speed of a plan).

2. Related work

CnR lies within the wider CH domain, and therefore formal ontologies of the CH domain have been used for CnR data modelling. For instance, the *International Committee of Documentation Conceptual Reference Model* (CIDOC CRM) is a widely used top-level ontology for the representation of CH data which includes classes and relations that represent at some extent some CnR aspects [16, 17] and it has been use for CnR data modelling [18, 19, 20]. In the same context, the CIDOC CRM official extensions [21] have been used for CnR data modelling as well. Another, analogous example is the more recent *Architecture of Knowledge (ArCo) ontology network* [22]. ArCo ontology network reuses other ontologies, such as OntoPiA [23] and Cultural-ON [24] and it is aligned to existing upper-level ontologies of the CH domain, such as *Europeana Data Model* (EDM) [25] and CIDOC CRM [16]. *ArCo* includes - at some level- the aspects of the CnR domain [22].

In addition to the use of CH related ontologies for the representation of the various aspects of CnR information, the CnR community has developed specialized models exploiting SW technologies, which in some cases integrate and/or extend existing ontologies of the CH domain. Some examples are the 20th century paintings [26], the MONDIS [27], PARCOURS [11], HERACLES [28], and Polygnosis [29]. The developed models have also been deployed in platforms and services which provide unified access to the CnR information, reduce information retrieval time and improve quality of search results (e.g., information completeness).

In the same context, other works such as Acierno et al 2017 [30] and Messaoudi et al 2017 [31], have developed ontologies that are deployed in ontology-based visualization services which provide a meaningful documentation as well as correlation of the requested information (e.g., the visualization of extent and severity of an alteration phenomenon gives a thorough view of the conservation object's condition). Moreover, Zreik and Kedad 2021 [32] have proposed an ontology-based system for identifying problems and prioritizing CnR interventions in archival collections. Additionally, Wang and Chen 2020 [33] exploit ontologies for determining repair methods of Chinese buildings, by retrieving cases of damages and corresponding repair methods that present similarities with a given case. Finally, Boochs et al 2014 [34] have developed a platform for supporting choosing digitization and analysis methods of tangible CH cases.

Although the existing models may provide useful representations that cover aspects of the CnR-DM-I process, they do not fully cover all the parameters, issues, requirements, criteria, intervention options involved, and their correlations (for further analysis see [13]). Furthermore, the exploitation of this representation to provide services that will support the selection of valid intervention options can be further explored.

3. Ontology engineering methodology

For the development of the ontology the *Human-Centered Collaborative Ontology Engineering Methodology* (HCOME) was followed [35] due to its collaborative, iterative, and human-centered features. The engineering process was organized based on the three main phases of HCOME: specification, conceptualization, and evaluation. Each phase of the methodology was accompanied by structured meetings with two conservators of the National Museum of Contemporary Art Athens (EMST) and the National Gallery Alexandros Soutsos Museum (EPMAS), as well as by asynchronous communication in the form of notes and comments on the shared documents of the team's stakeholders i.e., domain experts, and knowledge/ontology engineer. Particularly, specification and conceptualization phase included two structured meetings each, while evaluation phase included four structured meetings, in order to integrate any corrections and additions that had been highlighted by the experts. Every structured meeting has been followed by asynchronous communications until the task or issues that has been discussed was completed.

3.1. Requirements and Competency Questions

In the context of the specification phase, we analyzed and discussed with the experts the requirements that the ontology must satisfy. Based on that analysis we concluded that the information that conservators need to take into account and combine in order to eventually conduct the appropriate intervention may be relevant to three main categories: i) the characteristics of the conservation object (e.g., materials, damages, structure), its environment, and any planned CnR intervention[7], ii) the CnR intervention options, including any techniques, supplies and suitability requirements involved, iii) external factors, such as budget and location requirements/restrictions (e.g., power supply limitations), as well as preferences such as the less costly option, which must be taken into account so as to reach a final decision [8-9]. It is worth mentioning that while all these pieces of information are crucial for assessment and action decisions (i.e., the recording of how the expert reached a certain decision based on them), not every single piece of the relevant information is always documented, or at least in a sufficient, consistent, and systematic way [36]. The ontology must cover the aforementioned categories of information.

Additionally, a part of the information constitutes inferences, formed based on findings and logical rules. For instance, if an option requires the absence of a physical feature and the conservation object has this physical feature, then the requirement of the option is not satisfied and therefore the option is not suitable for this particular conservation object. At the specification stage, we highlighted those parts of information that may be inferred based on asserted information, exploiting the ontology.

Furthermore, at the same stage, a number of CQs were shaped with the participation of the experts. The CQs proved useful for the definition of the aim and use of the ontology (i.e., in the context of a framework), as well as for the evaluation of the ontology. While some of the CQs are more general (e.g., regarding the description of the conservation object or the supplies and requirements of an intervention option), some others are more specific focusing in the CnR-DM-I process (e.g., regarding the identification of suitable/rejected options or the identification of characteristics of parameters that have not been described). A few indicative CQs are presented in the form of a list below:

- What are the characteristics of the conservation object?
- What are the dimensions of the conservation object?
- What are the adjacent layers (if any) of the conservation object?
- What are the characteristics of the conservation object about which an intrinsic requirement requires their absence/presence and there is no relation of their presence/absence?
- What is the dimension type of the environment of the conservation object about which an intrinsic requirement requires a minimum/maximum value and there is no value defined?
- Which of the considered options i) have not even one intrinsic requirement which is not satisfied and ii) there is not even one extrinsic requirement which is not satisfied by them?
- What are the intrinsic requirements which are not satisfied, along with the options that have them and the entities that do not satisfy them?
- What are the extrinsic requirements about supply which are not satisfied, along with the supply that do not satisfy them and the correspondent option?
- What's the order of the suitable options according to the criterion defined by the decision-making, along with the qualitative values of the criterion?

3.2. Data analysis

In the context of the conceptualization phase, the conservators of EMST and EPMAS museums gave us access to CnR documentation data, which were derived from condition and conservation

[7] The planned CnR intervention, is any intervention is considered to be applied to the conservation object.

reports[8] of their laboratories. The provided data were mainly focused on the two aforementioned main categories (category i and ii of information, mentioned in Section 3.1). The data regarding the conservation object, its environment and any planned CnR intervention were considered useful for the study of the representation of CnR-DM-I parameters, as well as the evaluation of the ontology. On the other hand, the data regarding the CnR intervention options constituted a base for the representation of CnR intervention plans that correspond to the options of different issues. However, the data which explain why and how conservators chose a certain CnR intervention plan (category iii of information, mentioned in Section 3.1) were either absent or documented in an inconsistent manner (for instance data were scattered, in the description of the implemented intervention for specific objects).

Considering the lack of part of the data related to CnR-DM-I, we proceeded with the systematic collection, production, and organization of such data for two CnR intervention categories i) the cleaning of superficial deposits, and ii) the consolidation of flaking gouache. This process was necessary since such data constitutes part of the knowledge that the ontology captures. It is the specialized knowledge (A-box knowledge) regarding the intervention problems, options, requirements, and criteria included in the CnR-DM-I process. The data were collected based on i) bibliographic research and ii) experts' related knowledge and experiences (the data collected in Google Sheets [37], Google Docs [38]).

The cleaning of superficial deposits refers to the reduction of superficial soil, dust, grime, insect droppings, accretions, or other surface deposits of conservation objects [39]. It is a very common intervention that all the conservators have experienced regardless of their specialty, and it is applied in a variety of different conservation objects, regarding their materials, physical features, and general structure. On the other hand, the consolidation of flaking gouache refers to the stabilization of flaked areas of gouache painting layers by introducing materials [40]. It is a more specialized intervention, applied only on the painting layers of artworks that are made with the gouache technique.

In this context, we defined i) the options which correspond to different versions of the intervention categories (e.g., cleaning with dusting brush), ii) the intrinsic requirements, which are defined by the different options and must be satisfied by the conservation object in order to consider an option suitable for it (e.g., the option of cleaning with dusting brush requires the absence of the damage of powdering[9] from the surface to be cleaned), iii) the extrinsic requirements, which are defined by the conservator (e.g., a plan that does not include the use of electric power is required) and must be satisfied by the plan and the supplies that an option involves, and iv) the criteria based on which the suitable options can be ranked (e.g., the plan with the higher performance speed is preferred). The definition of intrinsic requirements was proved significantly challenging, since the experts needed time to get familiar with the conceptualization, and start analyzing complex rules into simple components.

3.3. Analysis of existing models

Based on the conceptualization phase of the methodology followed, i.e., the HCOME, the study of data and a first identification of the main concepts of the CnR-DM-I domain, existing semantic models were studied and analyzed. The study included i) the research of the literature which was conducted using the data sources (e.g., Semantic Scholar), and searching for topics related to Conservation, Cultural Heritage, Ontology(ies), Semantic Web and CIDOC CRM, and ii) searching in ontology repositories (LOV [42] and ODP [43]). We must state that there were ontologies we considered relevant, though they were not reused in our proposed ontology due to i) limitations

[8] *Condition report* refers to the document that records the existing condition of the conservation object(s), in terms of its/their state of preservation, before any CnR intervention (e.g., treatment, moving) [6]. *Conservation report* refers to the document that records the methods, materials and equipment used to a conservation object for the treatment of different undesirable characteristics [6].

[9] *Powdering* refers to the act or process of reducing to powder, pulverization; in conservation science context refers to granular disintegration of stone and pigments [41].

of their availability, ii) specialization of their representation, iii) introduction of axioms that were considered unsuitable for this approach[10]. However, they were taken into consideration for providing useful insights in our modeling decisions. We have also based our decision to reuse existing ontologies in the criteria presented in the work of Kotis et al. 2020 [45], i.e., recent ontologies that are still 'live', are reused, and reuse others.

Therefore, i) the CIDOC CRM, ii) its compatible model CRMsci [46], iii) the CIDOC CRM extension about typed properties and negative typed properties [47], as well as iv) SKOS ontology [48] were thoroughly studied and selected for reuse.

4. Knowledge representation

4.1. Technical choices

The ontology was developed in Protégé 5.5.0 [49] and it consists of three modules:

- *DCRI ont*, which directly imports CIDOC CRM, CRMsci, CIDOC CRM extension about typed properties and negative typed properties, and SKOS and extends them with classes and properties related to the CnR-DM-I domain. It includes all the necessary classes and properties for the representation of the CnR-DM-I process.
- *DCRI voc*, which directly imports SKOS and includes individuals which express types of different basic concepts of the CnR-DM-I domain (e.g., types of materials, types of CnR interventions, types of damages). While it has been developed to be used as part of the ontology, it can also be used independent of it, as a SKOS vocabulary for the CnR-DM-I domain.
- *DCRI ont special*, which directly imports DCRI ont and DCRI voc and indirectly imports CIDOC CRM, CRMsci, CIDOC CRM extension about typed properties and negative typed properties, and SKOS. This special module extends DCRI ont with classes and properties required for the case study. It also includes the individuals related to the case study which constitute the A-box knowledge of the model, i.e., the individuals of the different plans, supplies, options, intrinsic requirements.

4.2. Classes, relations, individuals

The classes and relations of the ontology, including all the different files (namely DCRI ont, DCRI voc, DCRI ont special), covers four different –though interlinked- thematic clusters:

1. *CnR-DM-I process,* which refers to the decision-making about a CnR intervention conducted by a conservator. It includes classes and properties that represent the decision-maker, the issues, the options, the requirements, and the criteria involved in the CnR-DM-I process. Additionally, it includes the necessary properties to achieve the interconnections between the CnR-DM-I process and the considered parameters.
2. *conservation object*, which refers to the material and immaterial characteristics of the tangible CH. It includes classes and properties that represent administrative information (identification, ownership, preservation, and management), materials and technology (production materials and techniques, structural layers and components, qualitative characteristics, dimensions) and alteration (deterioration) of the conservation object.
3. *conservation object's environment,* which refers to the environment that the conservation object is located in. It includes classes and properties that represent quantitative and qualitative characteristics of the conditions of the location of the conservation object.
4. *CnR intervention plans,* which refers to planned actions that can be applied to a conservation object or its environment. They can be either general plans that can be applied to any conservation object/environment, or specific plans that are designed for certain

[10] For instance, the Decision Making ontology [44] was not reused due to differences in some conceptualizations that were presented (namely regarding the requirements and criteria representation), although it was studied in terms of the design patterns proposed which were followed in many cases.

conservation objects/environments. It includes entities and relations that represent the plans, their aims, techniques, and supplies.
The following concept map (Figure 1) presents a number of core concepts of the ontology.

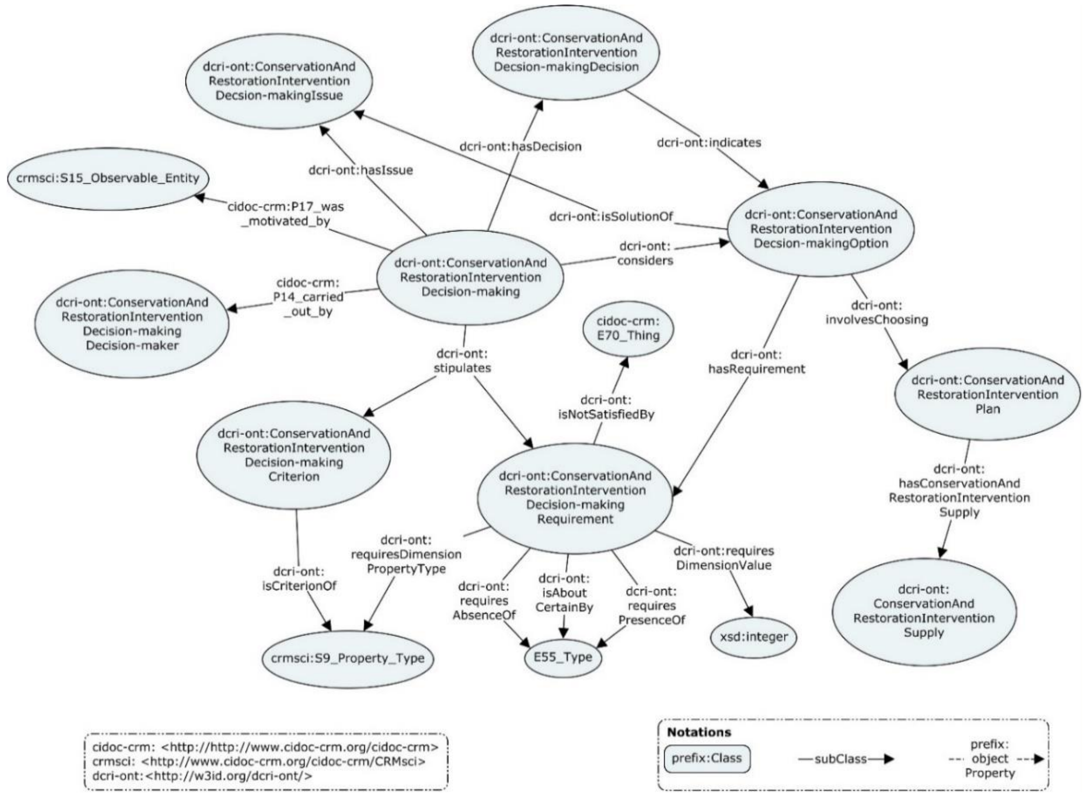

Figure 1: Concept map with core classes and properties of the developed ontology.

The reuse of CIDOC CRM and CRMsci classes was conducted in two ways, depending on whether the concept to be represented constituted a specialization of or was semantically equivalent with CIDOC CRM/CRMsci class. In the first case, a new class was defined as a subclass of some CIDOC CRM/CRMsci class (e.g., *dcriont:ConservationandRestorationInterventionDecision-makingOption* as a subclass of the *cidoc-crm:E89_Propositional_Object*). In the second case, the equivalent CIDOC CRM/CRMsci class has been identified and marked for future data modeling (e.g., cidoc-crm:*E57_Material* is equivalent to the concept *Material*). Regarding the object/data properties, similarly either new properties were added, or existing properties were identified for future data modeling. Furthermore, a number of proposed typed and negative typed properties were imported from the respective CIDOC CRM extension in order to correlate individuals of parameters with individuals of types based on their existence or absence.

As we already discussed in Section 3.2, the ontology includes several individuals which capture specialized knowledge regarding certain categories of CnR interventions. Those individuals are related to i) specific *types* of different basic concepts of the ontology, ii) qualitative values, iii) issues about which the CnR-DM-I is conducted, iv) CnR intervention plans, v) options of CnR intervention plans, vi) intrinsic requirements of CnR intervention options. The individuals related to the specific types of concepts were individuals of i) the SKOS class *Concept* and ii) some sub-class of the CIDOC CRM class *E55_Type*. In cases where a term is narrower or broader compared to other terms, then the respective individuals are interrelated through the SKOS object properties *has_narrower/has_broader*. On the other hand, the individuals related to the qualitative values and the issue, plans, options, and intrinsic requirements of the case study were individuals of the reused or newly added classes of the ontology.

The working version of the ontology, including all the three modules, is available in OWL and accessible online at https://github.com/ii-aegean/DCRI-ont. Regarding the documentation of the ontology, WIDOCO [50] has been used for the development of a site where the aim and components of the ontology can be browsed (DCRI ont documentation: https://ii-aegean.github.io/dcri-ont-doc/, DCRI voc documentation: https://ii-aegean.github.io/dcri-voc-doc/, DCRI ont special documentation: https://ii-aegean.github.io/dcri-ont-spe-doc/).

4.3. Semantic rules

The classes, properties, and individuals of the ontology capture a significant part of the knowledge of the CnR-DM-I domain. Based on this, there is an additional part of knowledge which must be inferred, and therefore it is captured in the form of "IF-THEN" rules using the rules language SWRL [51] and the Protégé plugin SWRLTab [52].

Overall, twenty-five rules were developed. The developed rules provide inferences regarding:

1. the options and intrinsic requirements in the context of a CnR-DM-I process. The options are directly correlated to the issues that they solve, as well as the intrinsic requirements that they have, while the intrinsic requirements are directly correlated to the types of parameters about which they must be taken into account (A-box knowledge). On the other hand, the CnR-DM-I process is directly correlated to the issue that must be decided about and the conservation object about which the intervention decision must be made (according to any case at hand). Furthermore, the conservation object is related to its environment and any planned activity, all of which have a particular type. Based on those asserted relations, it is required to infer the relation between the CnR-DM-I process and the options that it considers, as well as the intrinsic requirements that it stipulates.
2. the satisfaction of requirements (both intrinsic and extrinsic requirements) regarding the absence/presence of characteristics. The characteristic (a physical feature such as powdering, a quantitative value such as slow performance speed), as well as the type of the parameter (e.g., structural layer) that must satisfy the requirement, it is directly correlated to the requirement. On the other hand, the characteristic or quantitative value that a parameter has, and the type of the parameter, are directly correlated to the parameter. Based on those asserted relations, it is required to infer the relation between the requirement and the parameter that does not satisfy it.
3. the satisfaction of requirements (both intrinsic and extrinsic requirements) regarding the maximum/minimum value of a dimension of a parameter. The dimension type (e.g., relative humidity), the maximum/minimum value (e.g., 50%), as well as the type of the parameter (e.g., exhibition environment) that has this dimension and must satisfy the requirement, are directly correlated to the requirement. On the other hand, the parameter is correlated to a dimension instance which in turns is correlated to a dimension type and a value. Based on those asserted relations, it is required to infer the relation between the requirement and the parameter that does not satisfy it.
4. the relations of individuals/terms which describe different CnR-DM-I parameters as well as broader/narrower terms of the CnR domain. The broader/narrower relations directly correlated different individuals/terms (e.g., the term Canvas is narrower of the term Textile). The individuals/terms are directly correlated to different parameters (e.g., the substrate layer consists of Canvas). Based on those asserted relations, it is required to infer the indirect relation between the parameters and individuals/terms of broader/narrower meaning (e.g., the substrate layer consists of Canvas and therefore we can state that it is also consists of Textile).

5. Evaluation

In the context of the evaluation of the ontology, in terms of the classes, properties as well as the rules that it incorporates, we populated it with i) individuals describing different cases of conservation objects, their environment and planned intervention and ii) decision-making processes about those conservation objects. Particularly, the experts that participated in the engineering process provided data regarding the description of the conservation objects, their environment and any planned CnR interventions. Furthermore, we collaboratively created data regarding a potential decision-making process about those conservation objects, for the two intervention categories that the ontology captures at this point, namely i) the cleaning of the superficial deposits and ii) the consolidation flaking gouache. Those data have been successfully imported in the ontology, using Protégé 5.5.0 and the tab of Individuals.

Moreover, the reasoner Pellet [53] was used for inferencing in the environment of Protégé, contributing to the evaluation of the ontology. This process was necessary for the finding of any inconsistencies of the ontology itself, and more importantly for the assessment of the inferences that the rules produce. For instance, it is inferred the fact that *"the intrinsic requirement about the absence of adhesion problem is not satisfied by the ground layer 10482"*[11] (Figure 2). The soundness of the inferences was presented to and discussed with the experts.

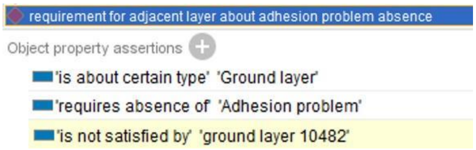

Figure 2: Asserted and inferred relations (yellow background) for the individual *"requirement for conserservation object about adhesion problem absence"*.

Additionally, the CQs were transformed into SPARQL queries [54] which were formulated and executed using the Snap SPARQL, a Protégé plugin [55]. The Snap SPARQL considers not only the assertions but also the inferences which have been produced by the reasoner. In this way we were able to answer all the formulated queries and evaluate the correctness of the answers in collaboration with the experts. For instance, using the ontology, it is possible to answer the question *"Which of the considered options i) have not even one intrinsic requirement which is not satisfied and ii) there is not even one extrinsic requirement which is not satisfied by them?"*, and therefore find which are the suitable option for the coating layer (which is the case at hand) (Figure 3). During this process we also made necessary refinements, especially regarding extra intrinsic requirements that had to be added according to experts observations and comments.

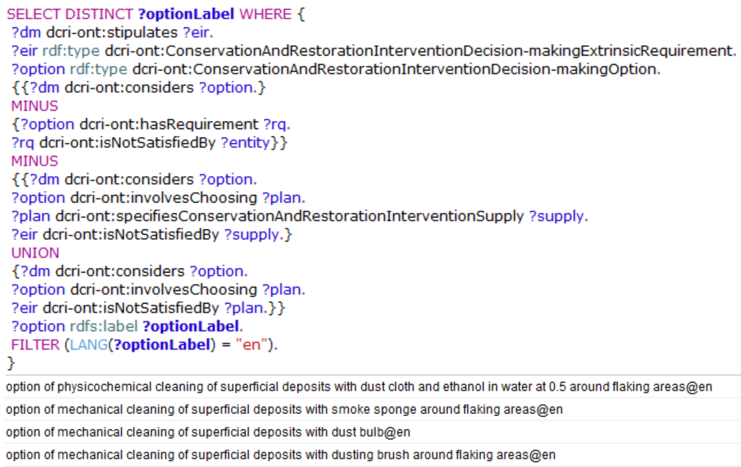

Figure 3: The SPARQL query and retrievals, for the CQ regarding the suitable options.

Finally, the ontology (including the three modules) was evaluated with the OOPS! [56], and we worked on the important errors that were detected.

[11] This is an intrinsic requirement regarding an adjacent layer of type ground. The case at hand, about which we wanted to decide how to clean the superficial deposits, had an adjacent layer of type ground which had adhesion problem, and therefore it does not satisfy the requirement.

6. Conclusions and future work

This work presents an ontology which aims to the explicit representation and integration of the expert's knowledge related to CnR-DM-I, to support decision-making in the CH domain. Apart from the necessary classes and properties, the ontology includes individuals which represent specialized knowledge of two specific categories of CnR interventions: i) the cleaning of superficial deposits and ii) the consolidation of flaking gouache. Furthermore, the ontology incorporates a set of rules, which generate necessary inferences which supplementally support the representation of the domain of interest.

The ontology has been thoroughly documented, and it has been evaluated, in collaboration with conservators from conservation laboratories of museums in Greece. The evaluation included the use of ontology for the modelling of data regarding different cases at hand, in terms of the decision-making process about the selection of a suitable option for different conservation objects. Additionally, the evaluation included the assessment of the correctness of the rules' inferences and the answers of a set of CQs. The work so far indicates that the ontology efficiently represents the domain of interest, and it constitutes a concrete proposal for its conceptualization.

Based on the study of the CnR-DM-I so far, and to further exploit the capabilities of the ontology, we have designed and currently developed a framework that will deliver intervention recommendations, as an explicit *decision-support* service. The framework will exploit the expressiveness of the developed ontology for the formal representation of the experts' knowledge and it will incorporate the inferences and the retrieval capabilities that the ontology provides, as the evaluation stage has proved, in a workflow which will contribute to the consistent and structured documentation of the context of the CnR-DM-I, and provide useful and correct CnR intervention options, supporting the day-to-day work of the professionals in the CH domain. Furthermore, more categories of CnR interventions could be added, enriching the knowledge that the ontology incorporates and improving its usefulness for the conservators.

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