Chapter 9

ONTOLOGY-BASED STRUCTURING OF SPECTRAL AND SPATIAL RECORDING STRATEGIES FOR CULTURAL HERITAGE ASSETS: BACKGROUND, STATE OF AFFAIRS, AND FUTURE PERSPECTIVES

ASHISH KARMACHARYA and STEFANIE WEFERS

ABSTRACT

The activities of COSCH community and the disciplines it represents were as diverse as they could possibly be in research into cultural heritage. To achieve common goals it was of utmost importance to have a common understanding of these diverse activities and disciplines. Work on the COSCH Knowledge Representation, or COSCH^{KR}, was undertaken to develop a common semantic base representing different disciplines and to facilitate communication within the Action. The COSCH^{KR} is an ontology-based inference model, guided by inference rules that provide a semantic bridge between various interdisciplinary activities involved in non-invasive technical documentation of material cultural heritage. The model is intended to support humanities experts by recommending optimal spatial and spectral techniques. The model may also be used by technology experts to compare their own solutions with the ones recommended through COSCH^{KR}, and to understand why they may differ.

In this chapter we present the methods adopted for designing the COSCH^{KR} and the steps in the development of the inference model. The difficulties in maintaining a common level of understanding within the diverse disciplines during the knowledge acquisition process are discussed. We present mechanisms and methods of information collection, its structuring, and aligning, to formulate different axioms and theorems within the model. The design and development of COSCH^{KR} was based on an iterative procedure where the gathered knowledge was first verified with the group of experts before it was processed. This verification mechanism was important for the reliability of the model, ensuring technical consistency. This chapter highlights the importance of these iterative mechanisms in the validation of knowledge gathered and then information populated inside the knowledge base.

Keywords: COSCH ontology, knowledge representation, cultural heritage recording, Semantic Web technologies, inference system

---

Introduction

Spectral or spatial recording of material cultural heritage (CH) is an interdisciplinary task involving scientists and experts from the humanities, information technologies, and engineering. A mutual understanding and agreement about the complexities of undertaking such recoding tasks is necessary in order to deliver appropriate spectral or spatial data of physical cultural heritage objects adapted to the needs of cultural heritage experts who rely on and work with those data. The COST Action TD1201: Colour and Space in Cultural Heritage (COSCH) (Boochs 2012; Boochs et al. 2013), brought together these experts to enhance mutual understanding among the disciplines in order to better record and preserve material cultural heritage. In addition to preparing guides to good practice for cultural heritage documentation through publications, the COSCH experts have structured the relevant knowledge into a machine-readable format. This logically structured machine-readable expert knowledge has been encoded in the COSCH Knowledge Representation ontology or COSCH^{KR}.

COSCH^{KR} is intended to work as a catalyst simplifying interdisciplinary communication between technical and heritage experts in implementing the recording and processing of the data. By exploiting the encoded knowledge representation in COSCH^{KR}, cultural heritage experts will benefit from recommendations for suitable recording strategies. Apparently, as there is no all-in-one solution, these recommendations are based on the specific cultural heritage object and the required cultural heritage application. In addition, important factors that may influence the choice of the appropriate recording strategy, such as the lighting conditions, access issues, project-dependent limitations, etc., are also taken into account and are encoded inside the ontology. They will be inferred against other classes inside the ontology for recommending the optimal recording strategy. The COSCH^{KR} platform, which is currently under development, will encapsulate the ontology and the inference mechanism through interactive user interfaces for providing the recommendation based on the inference results. The intention of the COSCH^{KR} platform is to readily provide heritage experts with an overview of optimal spectral and spatial recording strategies according to their needs and not to educate them on the technicalities of spatial and spectral recording disciplines.

This chapter describes the motivation behind the development of the COSCH^{KR} platform and advocates the significance of such a tool supporting smooth communication in interdisciplinary cultural heritage research projects. It also points out the complexity of handling interdisciplinary knowledge within a single ontology (cutting across disciplines with entirely different interpretations).

Earlier Research

Increasingly ontologies are evolving as major computational artefacts that provide logical representations of a particular domain of interest. They are generally used to represent knowledge providing a computational model of a particular domain of interest (Jakus et al. 2013). Ontologies allow sharing and reuse of knowledge and have become a popular research area in the Semantic Web because the sharing and reuse of knowledge within inter-communicable domains is the primary objective of the Semantic Web (Studer et al. 1998).

The most prominent ontology for cultural heritage disciplines is CIDOC-CRM (Boeuf et al. 2013), which was designed as a standard for stakeholders such as museums archiving cultural heritage objects. Though the terminologies used within CIDOC-CRM are of interest for the research in COSCH, and CIDOC-CRM is actually referenced inside COSCH^{KR}, the intention and application of COSCH^{KR} differs considerably from CIDOC-CRM. Moreover, CIDOC-CRM does not provide a class structure for detailed information about the recording of cultural heritage objects. Therefore, it is not possible to make use of CIDOC-CRM. The CARARE 2.0 metadata schema (D'Andrea and Fernie 2013) prepared within the framework of the 3D ICONS project[1] provides compatibility with the structure of CIDOC-CRM. CARARE 2.0 is the second version of the CARARE schema[2] that was developed within the CARARE project, defined to support the harvesting and aggregating of metadata for Europeana. CARARE 2.0 is based on cultural heritage standards such as MIDAS (Lee et al. 2012), an XML-based harvesting schema LIDO (Coburn et al. 2010), and the EDM-Europeana Data Model (Charles 2013). It harvests meta-, para-, and provenance data of 2D and 3D data of cultural heritage objects into Europeana.[3] The schema extends the class including technical para- and metadata of recording strategies. However, it is meant to harvest the content into open knowledge hubs for linking data. It does not offer provision for making the choice of optimal para- and metadata from the existing content, when new cases arise. The development of the CARARE 2.0 metadata schema thus follows a pattern that is necessary for ontologies which manage and harvest content.

We concluded that to provide a tool which supports cultural heritage experts in finding the best suitable spatial or spectral recording strategy adapted to their application, it is necessary to develop a new common ontology. It is not possible to integrate existing domain ontologies since first, not all involved disciplines

---

[1] http://3dicons-project.eu/index.php/eng.

[2] http://pro.carare.eu/doku.php?id=support:metadata-schema.

[3] http://pro.europeana.eu/.

have their own well accepted ontology (cultural heritage has CIDOC-CRM, but for spatial and spectral technology there is no widely accepted one) and second, ontologies are designed for different purposes and scopes (e.g., CIDOC-CRM is designed for providing standards for museums archiving physical cultural heritage objects (Boeuf et al. 2013) or OPPRA.owl is designed for twentieth-century paint conservation (Odat 2014)); thus harmonizing them via inference rules is a long and tedious task.

COSCH^{KR} is able to facilitate recommendation through rules that are encoded within the ontology. Therefore, one may argue that it is possible to build a Recommender System (RS) upon this ontology. A RS is a software tool and technique providing suggestions for items to be of use to a user (Ricci et al. 2011). However, RSs traditionally rely on stochastic methods, as in the case of machine learning, to infer the recommendation. This requires significant data for their interpretations. Although recently ontologies have started to be used in combination with the traditional methods (Middleton et al. 2009; Rodríguez-García et al. 2015), they are limited for the profile matching of the users in focus and do not partake actively in inferring recommendations.

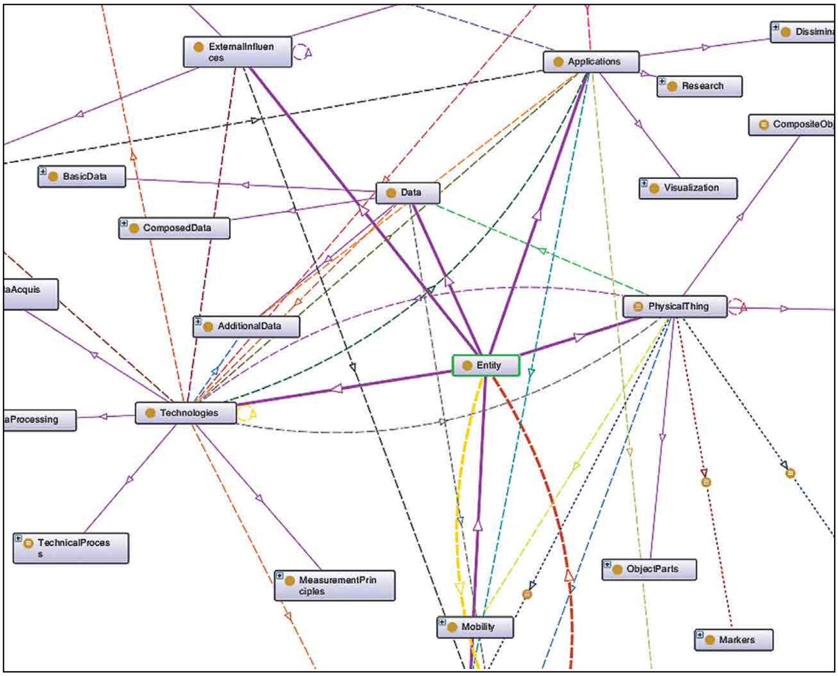

**Figure 9.1. A section of the complex graph of the COSCH^{KR}.
A larger version is available at https://coschbook.wordpress.com/9-2/.**

COSCH^{KR} Ontology

COSCH^{KR} draws on the developments in the semantic and knowledge technologies within the Semantic Web framework (Berners-Lee et al. 2001). The knowledge model is an OWL 2.0 (Horrocks 2005) ontology-based model. Figure 9.1 illustrates the complexity of the knowledge model by showing a small section of the entire graph. It represents only the second level of the hierarchical structure of the ontology. The taxonomical hierarchy has on average five levels. In addition, figure 9.1 displays twenty-three classes, whereas the entire ontology contains more than 750 classes. Although there are some interrelations displayed by connecting lines and arrows, the figure does not show the inference rules binding the classes together and allowing the retrieval of individual recommendations.

The following sections detail the development of the knowledge model. In the first section the methodologies in developing the ontology and the issues faced during the development are discussed. The second section presents how the knowledge contents were captured to build up the ontology-based knowledge model COSCH^{KR}, which itself is presented in the third section, which also elaborates different semantic constructs inside the ontology.

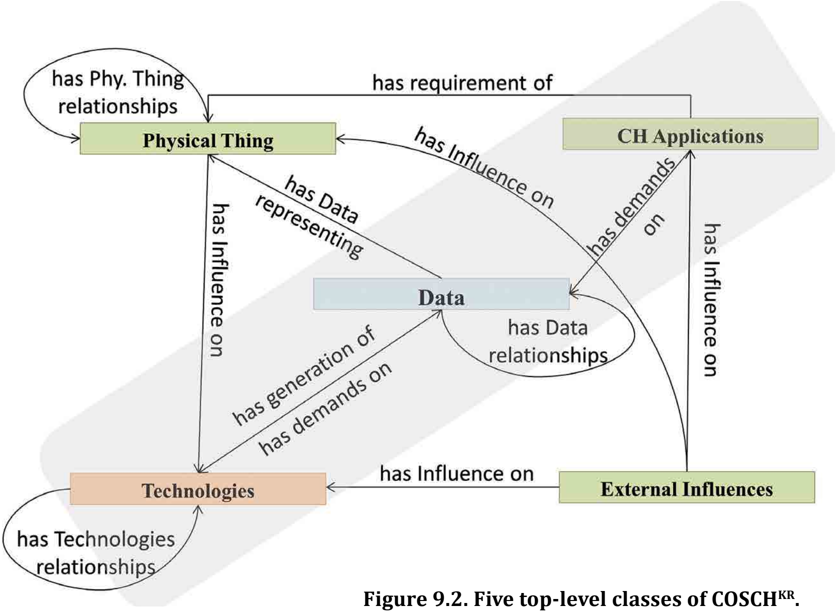

Figure 9.2. Five top-level classes of COSCH^{KR}.

Considerations for Ontology Development

The build-up of the ontology started with agreement on the necessary upper-most classes of the ontology, including natural language definitions of these classes. The top-level structure consists of five classes interrelated through five properties (see fig. 9.2): (1) Physical Thing (Boeuf et al. 2013), (2) CH Applications, (3) Data, (4) Technologies, and (5) External Influences. The first four being the obvious ones needed for generating data. The intention was to keep the ontology in line with the definitions of CIDOC-CRM in order to keep the option of cultural heritage knowledge hubs embracing the standards of CIDOC-CRM. For example, the class *Physical Thing* in COSCH^{KR} can be linked to CIDOC-CRM E18 Physical Thing with the relationship "sameAs" if required. The requirement of the fifth component "External Influences" was included as the data content and quality required for a particular cultural heritage application and Physical Thing is not only affected by the characteristics of the material cultural heritage or the characteristics of the recording technologies, but also through other external influences such as environmental conditions in which the material cultural heritage needs to be recorded or the available budget, which might affect the selection of a technology.

Content Capture

Through an evaluation of the competences available within the European COSCH network three representative case studies were selected, which cover typical cultural heritage applications in the spectral (revelation of a painting's underdrawing), the spatial (deformation analysis, see below), and the visualization domain (digital 3D reconstructed models, Pfarr-Harfst and Wefers 2016). These case studies formed the basis for discussions with experienced experts to develop a class structure and dependencies, and most importantly, inference rules that link the various classes. Only through discussions with these experienced experts was it possible to develop a reliable and broadly based ontology. The experts were asked to explain the project and workflow in their case study. The workflow had to be dismantled and broken down, for example into applied instruments, instrument parts, and accessories. Workflows, which are accepted or standardized within the specific domain, especially needed accurate discussion, as the underlying decisions are linked to technical principles for example, which have to be structured and integrated in the ontology.

At the very beginning of the development of the ontology, the COSCH community established a core group responsible for collecting, managing, and structuring knowledge from the relevant expert groups. The core group was also responsible for defining a common vocabulary. It developed theoretical concepts on the basis of the collected unstructured knowledge through questionnaires and discussions.

These theoretical concepts were represented through respective axioms and theorems. The selected case studies were used to harmonize the collection process of information and to structure the information and knowledge. They also facilitated discussions with the humanities experts involved, as well as the spectral and spatial recording domains, in order to make reference to their work in our discussions.

Questionnaires were applied to ask for the technical and contextual details of spectral and spatial recording approaches in various humanities projects. For each recorded material cultural heritage object with similar physical characteristics and application purposes one questionnaire had to be completed. The original version of the questionnaire consists of twelve main questions with subordinate questions asking, primarily, for technical details,[4] including:

1. spatial and spectral technique/s chosen
2. name of the cultural heritage object or site
3. aim of documentation
4. level of resolution / uncertainty required
5. details for the data collection for either: (a) spatial data (b) spectral data
6. size of the documented cultural heritage object or site
7. shape of the cultural heritage object or site
8. appearance of the cultural heritage object surface
9. whether it is static, moving, movable, transportable
10. budget allocated
11. reasons behind the selection of the technique/s
12. fulfilment of the initial needs by the selected technique/s.

The completed questionnaires supported the analysis to structure the content, to define work areas through the determination of relevant terms and vocabularies, and to identify contact persons having a specific expertise and being available for discussions and feedback. It should be stressed that the approach of using questionnaires does not provide for the collection of knowledge which is already structured and ready for the integration into the ontology (see below). In contrast, the specific content related to one material cultural heritage object and application, which is described within the completed questionnaires, gives evidence for structuring the theoretical concepts included in the ontology.

---

[4] http://www.cosch.info/documents/10179/144419/COSCH_KR_questionnaire.doc/7645d217-4666-4394-833b-cde0a0492bdf.

The COSCH^{KR} Ontology—Classes and Rules

Figure 9.2 represents the five top-level classes of COSCH^{KR}. Each has its own role within the knowledge model that defines the existence and importance of these classes. Additionally, they share relationships with other classes establishing a base for the formulation of inference rules. Finally, these inference rules are used to deliver recommendations for optimal recording strategies for specific material CH and applications.

Classes of COSCH^{KR} Ontology

Classes within the green strip shown in figure 9.2 represent the core part of the knowledge model. The class *CH Applications* describes the most common research questions of cultural heritage domains related to spectral or spatial data through their requirements around data content and quality. The data content and quality is described within the class *Data*. Technologies within the class *Technologies* are described through their capabilities of generating data. Therefore, the axis "Applications → Data ← Technologies" forms the core of COSCH^{KR}. The other two classes *Physical Thing* and *External Influences* provide conditional semantics that restrict or support a certain acceptable technical strategy.

Each of the five top-level classes includes a knowledge description regarding the class:

- The class *Technologies* encompasses the technical process, measurement principles, tools/instruments and the way they are set up to generate or process data. They are represented through sub-classes where each sub-class contains semantic descriptions that represent and/or support their best practice and limitations through their semantic characteristics encoded by the inference rules. The class *Technologies* includes four sub-classes:
    - *BasicDataAcquisition* includes instruments and tools and their required setups to record digital data of material cultural heritage. The class is further broken down into sub-classes: (i) *Tools*—representing instruments and accessories and (ii) *MeasurementSetups*—representing the required setups of these instruments and accessories.
    - *MeasurementPrinciples* includes the principles that govern the instruments. In most cases these measurement principles decide the nature of data generated in terms of quality. They play a vital role in prescribing the proper technological solution(s). The class is further broken down into (i) *Electro-Optical*—where the principles take patterns encoded in the optical propagation and their interaction with the capturing sensors. The class includes *AngleMeasurement*, *DistanceMeasurement*, and *PointVariation* (each are presented through

    their respective classes) and (ii) *Optical*—where the principles consider the behaviour of the characteristics of surface reflectance of cultural heritage objects to the optical propagation. The sub-classes within include *CentralProjection*, different projection mechanisms as sub-classes of *ProjectionMechanism* (*Area-Based-Projection*, *Line-Based-Projection*, and *Point-Based-Projection*), *TriangulationPrinciples* (each are presented through their respective classes). Both classes share the principles *AngleMeasurement* and *PointVariation*.

  - *DataProcessing* includes processing tasks and algorithms (represented by the classes *Tasks* and *Algorithms* respectively) through which the data acquired with tools and instruments are altered until they fit to the cultural heritage application.
  - *TechnicalProcess* includes classes describing the complete technical process of data acquisition and processing, preparing the data for the specific purpose of the cultural heritage application. For example, *StructurefromMotion* is a class under *TechnicalProcess* that requires *Camera* (sub-class of *Tools*) with certain setups (sub-class of *MeasurementSetups*) and data processing tasks and algorithms (sub-classes under *DataProcessing*) to generate the 3D data required by the Application (sub-classes under *CHApplications*). These requirements are encoded inside the class representing Structure from Motion through inference rules.[5]
- The class *Data* includes all possible digital/analogue data and document types that are either generated or used to process existing/generated data to achieve the results required by the cultural heritage applications. The class contains three basic sub-classes: (i) *AdditionalData* are information represented by data that may or may not be in a digital format but do not fall under a conventional data category such as oral, visual or textual information, (ii) *BasicData* includes the raw data acquired by the recording instrument and have to be processed further to make them appropriate for usage, and (iii) *ComposedData* includes data that have been processed for the actual cultural heritage application.
- The class *CH Applications* subsumes cultural heritage research questions applying to spectral or spatial data. It determines the required data quality and content. The class is further broken down based on the data requirements

---

[5] The class *StructurefromMotion* is already included in the ontology, however, it is not modelled in depth. Therefore, it will not be included in the description of section 4.

of the applications. Currently there are three sub-classes that in broad terms require different data types: (i) *Dissemination*, (ii) *Research*, and (iii) *Visualization*. The sub-classes under *Research* in general require higher data quality than that of the other two classes. The applications that encode the data requirements presented in this chapter—*DeformationAnalysis* and *RevelationOfUnderdrawing*—are specializations of the class *Research* and demand high-quality data (see below).

- The class *Physical Thing* represents the main subject/object to be measured (in our case it is material cultural heritage). COSCH^{KR} does not define these objects as their real world counterparts. On the contrary, they are defined through their physical and optical characteristics that stem from the measurements and the data that have been recorded for the objects. For example, churches do not have a pseudo-representation through a class "Church" inside the class *Physical Thing*. Therefore, they cannot be asserted as "Church." They are asserted as a composite object (under sub-class *Composite Objects*) as they are built-up of different materials having different physical and optical characteristics (e.g., low surface reflectivity, light colour).
- The class *External Influences* has similar technical implications to the class *Physical Thing*. It defines constraining semantics which effect the recommendations of the technologies. They include physical and optical characteristics (such as lighting conditions) and project limitations such as budget, human resources, or available space for measurement, access, and similar external conditions and factors.

The Rules of COSCH^{KR} Ontology for Inferring Knowledge

The classes within COSCH^{KR} are associated with inference rules, which cut across the other classes defined through the top-level classes. For example, a sub-class within the class *CH Applications* is constituted through an associated rule describing what kind of data are needed, so cutting across the sub-classes of the class *Data*. An example of such a rule is:

> **CH Application (Revelation of Underdrawing)** has Requirement on Data (2D_Data)

This rule states that the cultural heritage application of revealing an underdrawing of an artwork requires 2D data (e.g., an image). This rule is further supported by other rule(s) such as:

> **Application (Revelation of Underdrawing)** has Requirement on **Penetration (Paint Pigments)** at the **Surface of Artwork (Physical Thing)**

In combination, both rules imply that recording an artwork (which is a *Physical Thing*) for revealing the underdrawing (a *CH Application*) requires images (*2D_Data*) with certain spectral wavelengths, which could penetrate paint pigments of an artwork.

From a technical point of view within the sub-classes of *Technologies*, *Multi-Band-Imaging,* or *MultiSpectral-Imaging* are sub-classes of the *TechnicalProcesses* (*Technologies* ⟶ *TechnicalProcess* ⟶ *MultiBand-Imaging/MultiSpectral-Imaging*) that generate images (*2D_Data*) but would require technical components (e.g., filters, sensors) that can capture wavelengths penetrating paint pigments on the surface of an artwork. Therefore, such a technical process should consist of instruments or instrument components that have the capabilities to record spectral ranges penetrating the paint pigment. Furthermore, the physical characteristics of a paint pigment imply whether specific spectral ranges could penetrate it. Near infrared radiation of 700 nm to 2500 nm is expected to be able to penetrate paint pigments that do not contain inorganic elements such as metals. In such a case, user input is required to provide information about the nature of paint pigments of the artwork. The assertion of paint pigments is then inferred using the inference rules of relevant technologies (*Multiband* and *Multispectral Imaging*) defined inside the ontology. For example:

> **Multiband Infrared Imaging** uses **Instruments** that generate **Images** with Spectral Range of **Near Infrared**

and

> **Near Infrared Radiation** is Technical Characteristics of **Instruments** that **penetrates CH Object Surface** with **Organic Paint Pigments**

If the user asserts the paint pigments as organic then COSCH^{KR} will infer that the

> **Multiband Infrared Imaging (Technical Process)** is suitable for the **Revelation of Underdrawing (CH Application).**

A Case of CH Application: Deformation Analysis

Case studies are not only used to enrich the knowledge model but also to verify the inference mechanism and the results generated by the mechanism. First, a case study was selected that dealt with waterlogged wood samples that were recorded in 3D before and after conservation treatment to define the influences of various conservation treatments on the shape of the waterlogged wood samples. Technically speaking, a geometric deformation analysis was performed.

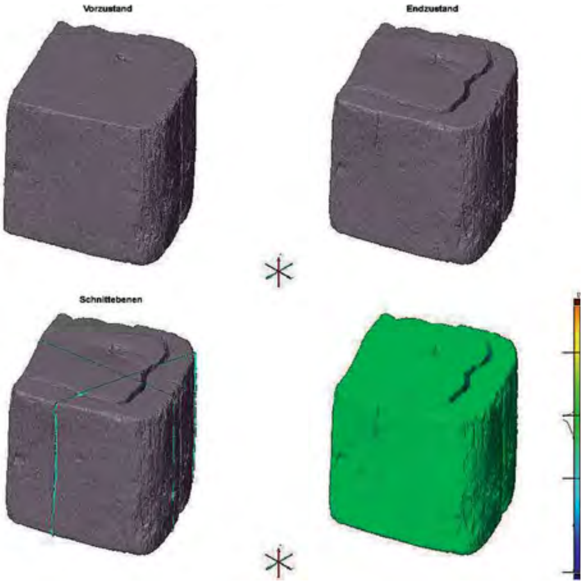

Figure 9.3. **3D models of one waterlogged wood object. The shape before and after conservation treatment and the spatial differences as well as section planes are shown. The model is available for viewing at https://coschbook.wordpress.com/9-2/ and www.rgzm.de/kur.**

The analysis was carried out within the research project "Massenfunde in archäologischen Sammlungen"[6] (Mass Finds in Archaeological Collections) of the Römisch-Germanisches Zentralmuseum (RGZM).[7]

The physical CH objects of interest are samples from different time periods having a minimum size of 100 mm × 60 mm × 60 mm (fig. 9.3). The material condition of the samples before conservation treatment was an important issue as the archaeological waterlogged wood samples had a dark brown to black appearance and were partly shiny. The translucent and reflective surface of the untreated samples had an impact on the data quality. However, this impact was reduced to a minimum through careful towelling of the samples before recording. Another crucial factor was the high number of samples: all in all 777 objects were recorded before and after treatment. As regards data requirements for such analysis, the nature of data first depends on the surface characteristics of the objects and then the nature of application. Deformation analysis will always require high-quality spatial data, so precision and resolution are necessary requirements for data accuracy. Since the deformation analysis needs to be analysed in every direction and on every side of the object, this CH application will only be served with 3D data of the objects of at least two eras.

---

[6] http://www.rgzm.de/kur/.

[7] http://web.rgzm.de/.

These conditions are defined within the relevant classes inside COSCH^{KR}. The class *CH Applications* triggers the entire inference process. Therefore, the definitions of applications inside this class set the tone for the rest of the process. The class *DeformationAnalysis* (*CH Applications* ⟶ *Research* ⟶ *ChangeDetection* ⟶ *DeformationAnalysis*) is defined through the following rules:

requirement on data **3D Data**

requirement on data **High Accuracy, Resolution, and Precision**

The first rule demands that data must be 3D data. The second rule demands that the application requires highly accurate, precise and high-resolution 3D data (= high-quality data). These two rules are then inferred against the rules defined under classes and sub-classes of *Technologies* to find out which technologies are able to generate the necessary 3D data.

The technologies are compared first through their principles under *Measurement Principles* (sub-class of *Technologies*) to check which generate 3D data. Then they are checked against instruments and the technical processes involved to determine whether they are capable of generating high-quality 3D data (including accuracy, precision, and resolution). With the first inference process, the machine suggests *Laser Scanning* and *Structured Light 3D Scanning* (both are sub-classes of *Technologies*) as they are capable of delivering high-quality 3D data based on their respective principles used: Angle/Distance Measurement Principles for Laser Scanners and Triangulation Principle for Structured Light 3D Scanners. Both principles are capable of generating high-quality 3D data. This is defined through:

Angle/Distance Measurements generate **3D Data** with **high** or
medium or **low Accuracy**

Angle/Distance Measurements generate **3D Data** with **high** or
medium or **low Resolution**

Angle/Distance Measurements generate **3D Data** with **high** or
medium or **low Precision**

Triangulation generates **3D Data** with **high** or **medium** or **low Accuracy**

Triangulation generates **3D Data** with **high** or **medium** or **low Resolution**

Triangulation generates **3D Data** with **high** or **medium** or **low Precision**

Laser Scanners use **Angle/Distance Measurements**

Structured Light 3D Scanners use **Triangulation**

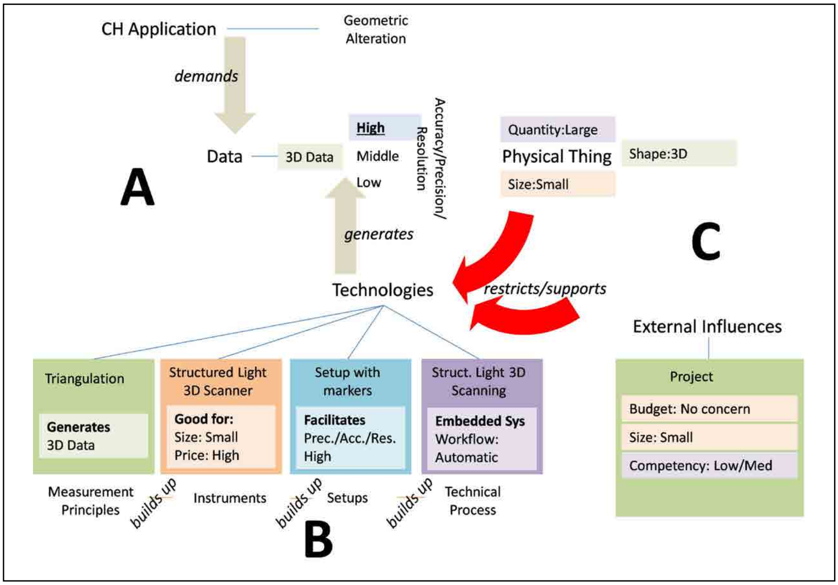

Figure 9.4. The inference mechanism (A) demands on data: deformation analysis demand high accuracy 3D data, (B) generation on data at technical level through technologies first through the principle then instruments adapting to the technical process (C) the restrictions provided by CH objects and other external influences on the technologies. A larger version of this diagram is available at https://coschbook.wordpress.com/9-2/.

The inference mechanism first considers the rules relevant to the data (see fig. 9.4). It should be noted that the technical questions relating to the requirements around data or to technical solutions are not presented to the users. They are inferred through the rules defined inside the class. However, if there are some requirements that decide the type of data, the user will be asked for input. For example, the question about the shape of the object can sometimes decide the required data type (see fig. 9.5, where the red boxes demand user inputs and grey boxes represent inferred information), and so the question will be asked. Until this point, the interface raises queries that address the quality requirement around data but hereafter it raises queries related to other issues. These issues are generally raised to check their impact on the technologies and their underlying solutions. For example the material of the CH object, the surrounding of the CH object, lighting conditions and similar factors which have an impact on the selection of any particular technical solution. Here, the platform would ask for input from the user in order to make further decisions. For example, asking questions regarding the size and number of CH objects, budgets, technical competence, have profound effects on what instruments are selected. In this case the rules defined at

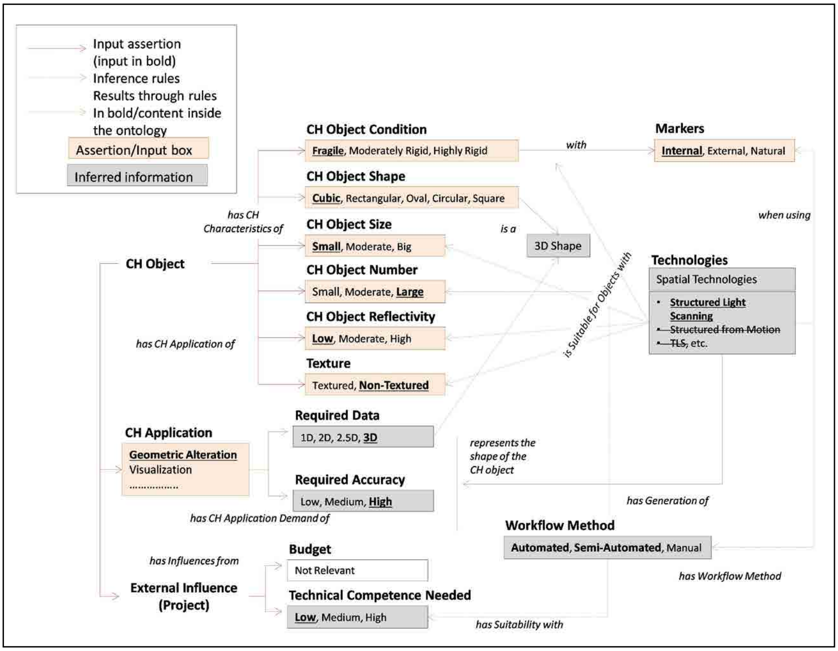

Figure 9.5. Simulation of a GUI for the case study in conservation of waterlogged wood. The red boxes represent the user input and the grey boxes represent the inferred information. A larger version of this figure is available at https://coschbook.wordpress.com/9-2/.

the end will skip Laser Scanning (and its main instrument Laser Scanners) because they are not suitable for scanning small and many objects with the required resolution to identify the expected deformation. Since the budget was irrelevant in this case study, Structured Light 3D Scanning (more specifically an Industrial System) and the instrument Structured Light 3D Scanner were recommended. The recommendation would be completely different if for example budget comes into play or one single large object needs to be scanned or the CH application is different, requiring no high-quality data. These parametric-dependent diversions of recommendation when new constraining parameters are included are indications of the flexibility that semantic techniques bring. The quality of recommendations inferred entirely depends on the quality of parameters and inference rules which are encoded inside. Likewise, when these parameters and inference rules are defined with a high degree of exclusiveness, the chances of recommending a single optimal technical solution become high. It should, however, be noted that COSCH^{KR} is under development and in the course of time more rules and parameters will be added to it, and this will certainly improve the likelihood of generating useful recommendation(s).

Conclusions and Future Work

The COSCH^{KR} ontology practically encodes inference rules and can be used as a tool to represent the knowledge of all disciplines and experts involved in the digital documentation of material CH. Other reasoning engines within the Semantic Web technologies which were developed to reason those encoded rules exhibit serious limitations due to aggregating complexities when executing the inference. In short, existing engines lack the capabilities to infer the complex aggregated semantic descriptions defined at the conceptual level. Therefore, this mechanism is under development to translate these complex aggregated inference rules into Prolog statements, to be able to infer the recommendations. Last but not least, a web service will be developed that will infer and retrieve knowledge through an interactive user interface.

To be able to publish a convincing COSCH^{KR} platform the underlying ontology has to have a considerable number of CH Applications integrated within it. Therefore, one of the major tasks is to identify, structure, and encode a large number of typical CH Applications. As more and more information about CH Applications are included through their relevant classes, relations, and rules, the regular task of structuring the ontology will ease off.

As soon as the first spectral, spatial, and visualization CH Applications are integrated and interwoven, we intend to hand over the development and maintenance of this ontology to a wider community. The ontology will thus be publicly available for use. The entities inside the ontology will be documented to make clear the reason for their existence inside the ontology and also how they are interrelated within the ontology. We also intend to develop Application Programme Interfaces (API) to access and use the ontology for any future developments based on the ontology. Cultural heritage stakeholders in particular should be interested in maintaining and developing this ontology as the preservation of material cultural heritage will be supported through digital surrogates which fit the requirements of the cultural heritage experts. This will address the issue of sustainability and use of the ontology in the long term. Cultural heritage stakeholders' archives will also contain more reliable and durable digital copies of their material cultural heritage.