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DEVELOPMENT OF A PLATFORM RECOMMENDING 3D AND SPECTRAL DIGITISATION STRATEGIES

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Abstract:

Spatial and spectral recording of cultural heritage objects is a complex task including data acquisition, processing and analysis involving different technical disciplines. Additionally, the development of a suitable digitisation strategy satisfying the expectations of the humanities experts needs an interdisciplinary dialogue often suffering from misunderstanding and knowledge gaps on both the technical and humanities sides.

Through a concerted discussion, experts from the cultural heritage and technical domains currently develop a so-called COSCH^{KR} (Colour and Space in Cultural Heritage Knowledge Representation) platform that will give recommendations for spatial and spectral recording strategies adapted to the needs of the cultural heritage application. The platform will make use of an ontology through which the relevant parameters of the different domains involved in the recording, processing, analysis, and dissemination of cultural heritage objects are hierarchically structured and related through rule-based dependencies. Background and basis for this ontology is the fact that a deterministic relation exists between (1) the requirements of a cultural heritage application on spatial, spectral, as well as visual digital information of a cultural heritage object which itself has concrete physical characteristics and (2) the technical possibilities of the spectral and spatial recording devices. Through a case study which deals with the deformation analysis of wooden samples of cultural heritage artefacts, this deterministic relationship is illustrated explaining the overall structure and development of the ontology.

The aim of the COSCH^{KR} platform is to support cultural heritage experts finding the best suitable recording strategy for their often unique physical cultural heritage object and research question. The platform will support them and will make them aware of the relevant parameters and limitations of the recording strategy with respect to the characteristics of the cultural heritage object, external influences, application, recording devices, and data.

Key words: digital archaeology, cultural heritage, documentation, 3D recording, spectral recording, data processing

1. Introduction

In the last decade, digital 3D and spectral recording of cultural heritage (CH) objects such as archaeological finds and features (e.g. MacDonald, Guerra, Pillay, Hess, Quirke, Robson, & Ahmadabadian, 2014; Wefers & Cramer, 2015; Wefers, Reich, Tietz, & Boochs, 2016), buildings (e.g. De Luca, 2013; Kersten, Hinrichsen, Lindstaedt, Weber, Schreyer, & Tschirschwitz, 2015), paintings (e.g. Cucci, Casini, Picollo, & Stefani, 2014; Cucci, Picollo, Chiarantini, & Sereni, 2015), and archival documents (e.g. National Archives, 2016) is getting more and more common. CH stakeholders recognised digital representations not only as support for CH expert's tasks (ranging from research studies to monitoring and documentation for other humanities and conservation tasks), but as useful items especially in the dissemination field. They allow to address a wide audience through e.g. websites as well as mobile and interactive applications. In order to generate appropriate data which support the researcher and/or user in an optimal way, the 3D or spectral data recording, its subsequent data processing, analysis and visualisation has to involve experts from multiple disciplines: (a) CH experts who mainly give the stimulus to digitise a CH object and who are responsible for the knowledge about the constraints given by the CH object itself and the stakeholder (e.g. research question, conservation condition, light sensitivity, transportation possibilities); (b) recording experts who have to prepare and execute a digitisation strategy meeting the constraints given by the CH object and stakeholder (e.g. recording device needs a stable platform and space, sensors have limitations with respect to surface reflectivity and texture, accuracy and resolution needed to properly support the CH expert); (c) IT experts who understand the impact of algorithms on data during the incremental data processing (e.g. point cloud adjustment through e.g. outlier removal, point cloud registration, data comparison) and data analysis; and (d) museologist, 3D

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modellers, and communication experts who know the various possibilities how to visualise the generated data in a way that different audiences are addressed in a suitable way. Within each of the four domains more than the above mentioned parameters exist which have to be taken into account and which have influence at least on one other domain. All in all, which digitisation strategy is best suitable for a CH object actually depends on: (1) the various CH object parameters (appearance, stakeholder constraints, etc.); (2) the targeted application of the digital data (needed spectral or spatial accuracy and resolution, etc.); (3) the digitisation device and method (technical parameters relevant for recording, output data etc.); as well as (4) the data processing after the actual recording making it available for the CH expert and end-user. Altogether, for each physical CH object various applications might exist which require different data qualities and data content why the elaboration of a digitisation strategy is a complex collaborative and interdisciplinary task.

This short description illustrates the multidisciplinarity behind 3D and spectral recording of CH objects and manifold publications prove that a lack of understanding exists (e.g. Niven & Pierce-McManamon, 2011; Stylianidis & Remondino, 2016). This, however, is by no means deliberate but on the contrary comprehensible, as each domain in itself has to cover a broad variety of domain inherent topics with only few overlap to the other involved domains. Besides missing expert knowledge with respect to the counterpart, misunderstanding occurs due to the usage of terms which are taken as self-explanatory but have in fact different meanings in different domains (e.g. feature, texture, artefact; Murphy, Bentkowska-Kafel, & Wefers, in prep.).

To bridge the knowledge gap between the various experts involved in the digitisation of CH objects, a platform is under development which will give recommendations for recording strategies based on information about the CH object and intended data usage. The COST Action TD1201: Colour and Space in Cultural Heritage (COSCH) provides the opportunity to develop such kind of platform through interdisciplinary discussions as the Action is a multidisciplinary European network of humanists, conservators, and engineers who were and are involved in the spatial and spectral recording of various cultural heritage objects. Through this concerted expertise, a structured view on recording strategies is possible (Boochs et al., 2013). The so-called COSCH^{KR} platform[1] will make use of an ontology intended to be a flexible, open access, and durable tool. The platform envelops its underlying ontology COSCH Knowledge Representation or simply COSCH^{KR}. Ontologies are used to express complex real world entities and to reason the logics of existence and relations (Wolfio, 1730). COSCH^{KR} is expressed with Web Ontology Language (OWL) – an ontology language for the Semantic Web[2]. Through the ontology the relevant parameters of the four different domains involved in the recording, analysis and dissemination of CH objects are hierarchically structured and are related through rule-based dependencies. The ontology describes digital recording and data processing and henceforth the class structure and rules are triggered by the technical parameters such as the physical appearance of the CH object (see below). The aim is to support CH experts finding the best suitable recording strategy for their often unique physical CH object and research question. The platform will support them and will make them aware of the relevant parameters and limitations of the recording strategy with respect to the characteristics of the CH object, external influences, CH application, recording devices, and data. Therefore, the COSCH^{KR} platform will be first and foremost an impartial educational tool for those without much experience in 3D or spectral digitisation.

2. State of the art

CH experts including 3D or spectral data in their research normally collaborate with technical experts who generate, process, and analyse the data (e.g. Wefers & Cramer, 2015; Del Hoyo-Meléndez, Lerma, López-Montalvo, & Villaverde, 2015). In many cases this collaborative work first has to tackle communication difficulties which mainly evolve from domain inherent terminologies (Murphy, Bentkowska-Kafel, & Wefers, in prep.). Up to now various guides to good practice try to support CH experts to better understand the preconditions and limits of spatial and spectral recording devices (Archaeology Data Service, 2009; Bryan, Blake, & Bedford, 2009; Niven & Pierce-McManamon, 2011; Stylianidis & Remondino, 2016). However, no interactive platform exists helping CH experts to understand which parameters of the physical CH object, the intended application of the data, and of the generated digital data are important to choose the best suitable recording and data processing strategy.

To create such a platform relevant parameters need to be understood, structured and linked. Knowledge management and its underlying technologies are extensively used to display a structured view on interconnecting parameters. This on the one hand helps harmonising interdisciplinary knowledge while on the other hand it includes machines that assist humans in managing and processing huge and complex data and tasks. Ontologies are traditionally used to represent knowledge (Brewster & O'Hara, 2007; Jakus, Milutinovic, Omerović, & Tomažič, 2013). In general there are two kinds of ontologies: i) formal ontologies – introduced by Edmund Husserl and colleagues as "eidetic science of object as such" (Husserl, Biemel, & Biemel, 1952) where eidetic derives from the Greek word εἶδος which means "form", defining unbiased views on reality from any domain specific influences; and ii) domain ontologies – ontologies developed for and applicable to a domain with a domain specific view (Roussey, Pinet, Kang, & Corcho, 2011).

The evolvement of the Semantic Web at the beginning of this century (Berners-Lee, Hendler, & Lassila, 2001) has contributed to a wider implication of the knowledge technologies. Semantic Web is "a web of data" primarily built to allow data to be shared by wider communities (Horrocks, 2008). Therefore, the majority of applications

[1] The trigger for the development of the ontology is the COST Action TD1201: Colour and Space in Cultural Heritage (COSCH). COSCH^{KR} stands for Colour and Space in Cultural Heritage Knowledge Representation.

[2] https://www.w3.org/2001/sw/wiki/OWL

built around the Semantic Web Framework use ontologies providing a platform to share their data. In short, ontologies are used as a tool to standardise data sharing and integration (Cruz & Xiao, 2003).

For the CH domain the CIDOC Conceptual Reference Model (CRM) plays an important role. It is a formal ontology that structures all biographical condition and provenance information related to a physical CH object (artefact biography, e.g. Gosden & Marshall, 1999) and gives museums and archives the possibility to publish and link their existing databases to initiatives such as (Europeana). Europeana is a Linked Open Data (LOD) or simply Linked Data initiative that refers to a set of best practices for publishing and connecting structured data on the Web (Bizer, Heath, & Berners-Lee, 2011). The CRM "aims at providing the semantic definitions and clarifications needed to transform disparate, localised information sources into a coherent global resource, be it within a larger institution, in intranets or on the Internet. Its perspective is supra-institutional and abstracted from any specific local context" (Le Boeuf, Doerr, Ore, & Stead, 2015).

On the contrary, the technical domains within spectral and spatial technologies have limited efforts to develop a common ontology for sharing or re-using unified knowledge. One of them was presented by Odat who developed the Ontology of Paintings and PReservation of Art (OPPRA, 2016). It contains components of the spectral recording domain and is a domain ontology which aims to link databases from multiple disciplines to support conservation experts dealing with 20th century paintings. Conservation experts can use the ontology to document their work and upload their data to allow data sharing; to query and infer knowledge inside the ontology; and to extract related knowledge from various databases (Odat, 2014).

Up to now, there has been no effort in the 3D recording and the data processing domain to develop ontologies. COSCH^{KR} intends to reuse components from existing ontologies such as CIDOC-CRM and OPPRA when and where required. However, it is important to maintain the underlying semantical view of these concepts with respect to the purpose of COSCH^{KR}. One of the major limitations of the existing ontologies is that they focus on documenting CH objects and do not focus on processes and methodologies, and why they are recorded with which recording device. The ontologies are used as a tool to standardise repositories. There has been no or very less effort to use the reasoning capabilities of ontologies. The CARARE 2.0 metadata schema (Fernie, Gaverilis, & Angeli, 2013) prepared within the frame of the 3D ICONS project (compatibility to the structure of CIDOC-CRM) provides a framework to develop a knowledge base on meta-, para- and provenance data of generated 2D and 3D data to harvest into Europeana Data Model (EDM) (Charles, 2013). The schema is not intended to recommend the technologies through reasoning the knowledge base. Nevertheless, the CARARE 2.0 metadata schema extends the class including technical para- and meta-data of recording strategies, which could be reused for our purpose in the future.

3. COSCH^{KR} ontology

COSCH^{KR} which is the core of the intended platform is under development. Background and basis for this ontology is the fact that a deterministic relation exists between (1) the requirements of a CH application on spatial, spectral, as well as visual digital information of a CH object which itself has concrete physical characteristics and (2) the technical possibilities of the spectral and spatial recording devices. It is a domain ontology with structured classes which are interlinked through rules defining dependencies of the technical parameters (such as object size, measurement accuracy etc.) required to set-up a reliable 3D or spectral digitisation strategy. It is a schematic model that will be used to infer recommendations at the schema level. It will not be used to link existing CH databases because: i) our aim is to provide answers regarding the recording strategy and not to facilitate LOD; and ii) existing databases would not provide the required information needed for our purpose (such as reflectivity, appearance, shape, complexity, etc.; e.g. British Museum Collection online, 2016; Europeana, 2016; Louvre Collection, 2016). When the ontology is robust enough, the knowledge within the ontology can be inferred through an interactive Graphical User Interface (GUI) where the user enters information about his/her intended application of the data of the physical CH object. The user input could be understood as instances which are, however, not stored inside the ontology but are temporarily used for the decision making through rules inside the ontology. In fact, the ontology will be the engine of a query application, where the user has to enter the relevant information to receive recommendations. Due to the scope and implementation of COSCH^{KR}, it is not possible to integrate other ontologies such as CIDOC CRM or OPPRA. OPPRA's hierarchical structure of e.g. the classes Characterization Technique and Physical Attribute (OPPRA, 2016) as well as selected class definitions from OPPRA and CIDOC-CRM, however, could be considered for COSCH^{KR}.

As it is the aim to make the possibilities and limitations of the technical domains including the recording devices involved in 3D and spectral recording apparent, only the technically relevant parameters of CH objects and applications are hierarchically structured, and linked through rules and dependencies to the parameters of recording devices, data, and recording methodologies. This means that only those parameters of physical CH objects are included which are relevant for an e.g. 3D recording device. Therefore, classes related to the physical CH objects are structured with respect to the general appearance and not through how they are called in the real world (such as church, fibula, sculpture, etc.). Finally, the ontology will express through logical rules of dependencies and constraints the decision making of a technical expert choosing the best suitable spatial or spectral recording strategy. It therefore will display a theoretical concept of this decision-making process.

COSCH^{KR} is primarily developed through a top-down approach where the top-level classes are defined first in a conceptual phase, followed by a phase where they are extended to class-subclass hierarchies. All in all, five top-level classes are defined: Technologies, Data, CH Applications, Physical Thing, and External Influences (Fig. 1).

The scope of the class “Physical Thing” is defined through the CIDOC-CRM class E18 “Physical Thing”: “This class comprises all persistent physical items with a relatively stable form, man-made or natural. […]” (Le Boeuf et al., 2015, 11). The characteristics which define the “Physical Thing” are all technology oriented, which means they describe the appearance and shape of a physical thing. For example, the death mask of Tutankhamun would be shortly characterised as a small to medium sized object with a complex shape and a partly highly reflective (gold) and partly translucent (glass and precious stone inlays) surface. The “Physical Thing”, which is meant to be digitized, is connected to a “CH Application“ which will make use of the generated “Data” and which therefore requires specific data quality and content (Fig. 1). Therefore, the “CH Application“ provides a statement of requirements on the one hand with respect to the “Physical Thing” and on the other hand with respect to the “Data” which are needed for the “CH Application”.

The scope of the class “Technologies” (Fig. 1) is defined as “a manner of accomplishing a task especially using technical processes, methods, or knowledge” (Merriam-Webster, 2016). It contains the subclasses “Tools”, “DataAcquisition”, and “DataProcessing”. Within “Tools” hardware devices (such as scanners and cameras), supporting accessories (such as reflectors and calibration tools), and software packages (such as rendering software) are listed. The class “DataAcquisition” contains a structured view on device functionalities and measurement set-ups. Within the class “DataProcessing” individual algorithms and processing tasks are listed. Altogether the class “Technologies” describes the acquisition and processing of data. And since the ontology focuses on spectral and spatial recording and data usage, the classes so far only contain information about spectral and spatial devices, measurement strategies, and data processing. All “Data” (Fig. 1) which are generated by the hardware devices (within the class “Technologies”) represent the “Physical Thing” which is recorded by a spatial or spectral instrument. And as the appearance and shape of a “Physical Thing” influences the choice of the recording tools, they play a major role in determining the data quality. Besides the “Physical Thing” and the “CH Application”, the acquisition and processing of data is affected directly or indirectly through “External Influences” (Fig. 1) such as site illumination, visibility or staff competence.

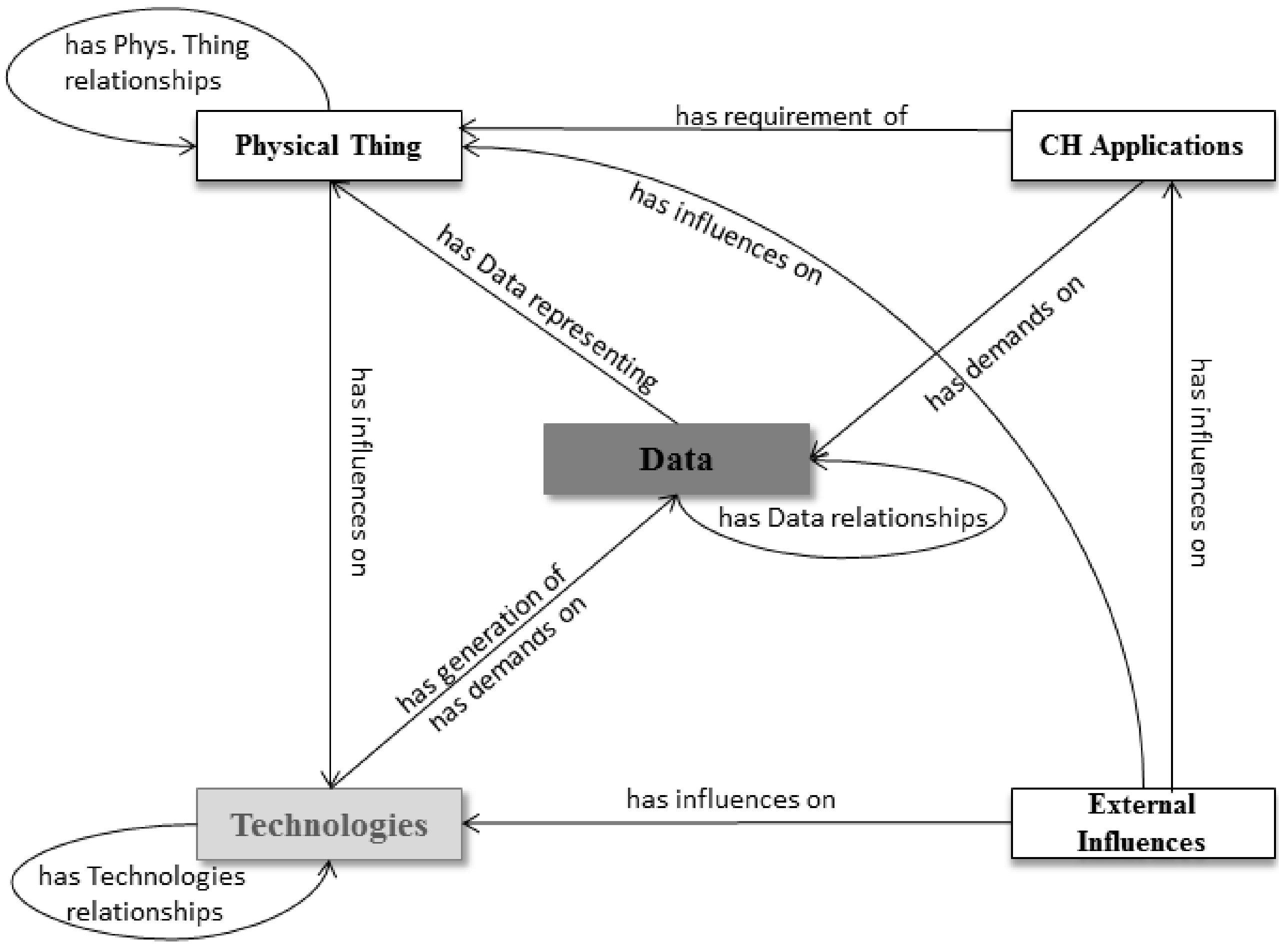

Figure 1: Top-level classes of the COSCH[KR] ontology. The white boxes are classes related to CH domains, the light grey box is a class related to spectral and spatial recording domains, and the dark grey box is a class related to data processing domains. The five classes are linked through different properties displayed as arrows.

The scope of the class "Data" (Fig. 1) is defined through "facts or information used usually to calculate, analyse, or plan something" (Merriam-Webster, 2016). Besides describing all kind of generated or processed digital data, the class "Data" also represents additional data about the "Physical Thing", e.g. facts published in a book. Therefore, the class "Technologies" might have also demands on the class "Data" as e.g. for digital reconstruction and visualisation purposes all kind of resources might play a role and have to be included in the data processing tasks. It is a two-way relationship (see Fig. 1).

Through these five top-level classes all aspects relevant within a digitisation and visualisation process, from the data acquisition to the data processing and data usage, are covered and can be integrated. The classes especially of the technical branches are already created through a global view on expert knowledge (Wiemann, Wefers, Karmacharya, & Boochs, 2014). Through logical rules and dependencies, a link between the CH application and the data requirements is established which allows users to exploit the ontology and retrieving recommendations.

4. Case Studies

So far the rules which connect the classes have been created using three CH case studies as a framework for discussions: the first deals with the comparison of spatial data-sets allowing the evaluation of geometric alteration (Mazzola, 2009; KUR project, 2016; see below); the second deals with spectral data and the revealing of an underdrawing of a painting (Cucci et al., 2014); and the third deals with the digital reconstruction of a CH building (Pfarr-Harfst, 2016). Through these case studies, all subjects which should be part of the ontology (spatial and spectral recording, data processing, and visualisation) are covered, providing concrete facts for the discussion with experts from multiple disciplines. These facts on the one hand are the basis for a common understanding and on the other hand are helpful to stay focused during the development of the rules inside the ontology.

Through the three case studies, we seek to create a first frame displaying the dependencies and logical rules needed to connect the data requirements of the CH application with the influences of the physical characteristics of the CH object on the recording devices. This frame will support further class extensions and will help to add more rules. The case studies will be used to further develop the ontology: as soon as the theoretical concept of one case study is displayed in the ontology through classes, dependencies, and rules further rules, and dependencies will be added by parameter modifications of the case study. E.g. if the original case study was related to small physical CH objects a parameter modification could be to imagine the physical CH object being very large. Depending on the facts under discussion, this approach helps to enlarge the ontology at different branches of the ontology.

4.1. Spatial case study (deformation analysis)

The case study is about a completed conservation project dealing with the analysis of waterlogged wood: through unavoidable conservation treatment the shape and volume of this material changes. To be able to measure the influence of various conservation treatments on the shape and volume, a high number of samples of waterlogged wood were recorded in 3D before and after conservation treatment. Comparing two 3D models representing one sample, conservation experts were able to better evaluate the changes and influence of different conservation treatments (Mazzola, 2009). The real application used a structured light scanner for the 3D recording. All relevant aspects of this discussion (which need to be considered for modeling) could be identified through discussions.

Identified aspects relevant for the knowledge representation are: object size and shape, number of objects, surface texture and reflectivity, the object condition, technical competence of the operating staff, semi-automated workflow possibilities, instrument accuracy, required data accuracy, resolution, etc.

The appearance of the samples before conservation treatment was an important point for the development of the recording strategy as the archaeological waterlogged wood samples had a dark brown to black appearance and were partly shiny due to a wet surface. Additionally, the translucent and reflective surface of the untreated samples had impact on the data quality. However, this impact was reduced to a minimum through careful toweling of the samples before 3D recording. Furthermore, the data quality could be improved through markers which were directly attached to the samples.

After conservation, the appearance of the samples could change immensely as the water inside the wood was gone and conservation materials stabilized the object causing sometimes a colour change to light brown. However, all sample surfaces were dry after treatment which means they were not reflective anymore. These changes of the physical characteristics of the wooden samples had no negative influences on the recording devices. Therefore, the recording strategy did not need to be adapted at this point.

A crucial factor was the high number of samples: all in all 777 objects were recorded before and after treatment, that is why a highly professional industrial version of a structured light scanner was chosen since selected processing steps could be automated and controlled through scripts of associated software. The workflow control was applied for quality management of the required data and accuracy. Due to the workflow control a less experienced operating staff of the structured light scanner could be appointed without major impact on the workflow and data quality as the number of possible error sources was reduced to a minimum. Nevertheless, the less experienced operating staff still needed supervision by a 3D recording expert. The choice of the 3D recording technique was mainly determined by the workflow control possibilities. All above described parameters are represented as classes and rules in the ontology.

If parameters of the case study change, e.g. the CH application is a visualisation on a website instead of a deformation analysis, a different recording strategy might be better suitable to meet the requirements of the data with respect to the CH application. For example, photogrammetry could be a suitable recording strategy to provide a digital 3D representation with a realistic visual appearance, but less geometric accuracy for a website visualisation. To extent the entire knowledge model, further parameters (similar to the ones described above for the case study) will be simulated, e.g. instead of a high number of physical CH objects a low number is assumed to identify why and how the recording strategy would change. Later on this will allow querying the ontology through a GUI which is under development.

5. Accessing the stored knowledge

On the basis of the above described case study, the following user interface can be simulated to illustrate the usage of such an ontology, and clarify the benefits for CH experts (Fig. 2). First, information about the intended CH application would be required. The user would be able to select an application from a list. In the above-described case, it would be “Deformation Analysis”. Through the additional input of the object shape (cubic) specific classes and rules within the ontology would already be applied: Unambiguously, 3D data are required and only spatial recording devices are of interest. Second, further relevant questions would be asked which are related to the CH object. On the one hand, the object size (small) would be the determining factor that a terrestrial laser scanner is not suitable and a high accuracy is needed. On the other hand, the low surface texture would be decisive to eliminate the structure from motion technique. However, the remaining technology –a structured light scanner– would have problems with the wet surface (reflectivity high) of the wooden samples. If the user would enter “high reflectivity” s/he would be informed that the required accuracy cannot be provided by any technology. Only through lowering the reflectivity the required accuracy could be provided. However, the object condition could also be problematic with respect to the data accuracy as additional markers could improve the data quality. Last but not least, through the input that a high number of objects should be digitised the final recommendation would be that:

- A structured light 3D scanner is the best suitable **Technology**
- For these **CH Objects**
- And **CH Application**
- As a **Semi-Automated Workflow** could be implemented, which could lower the required budget
- Through employing operating staff with **Low Technical Competences**.

It is intended that further recommendations on the recording strategy such as technical set-ups, data processing and algorithm influences will be given.

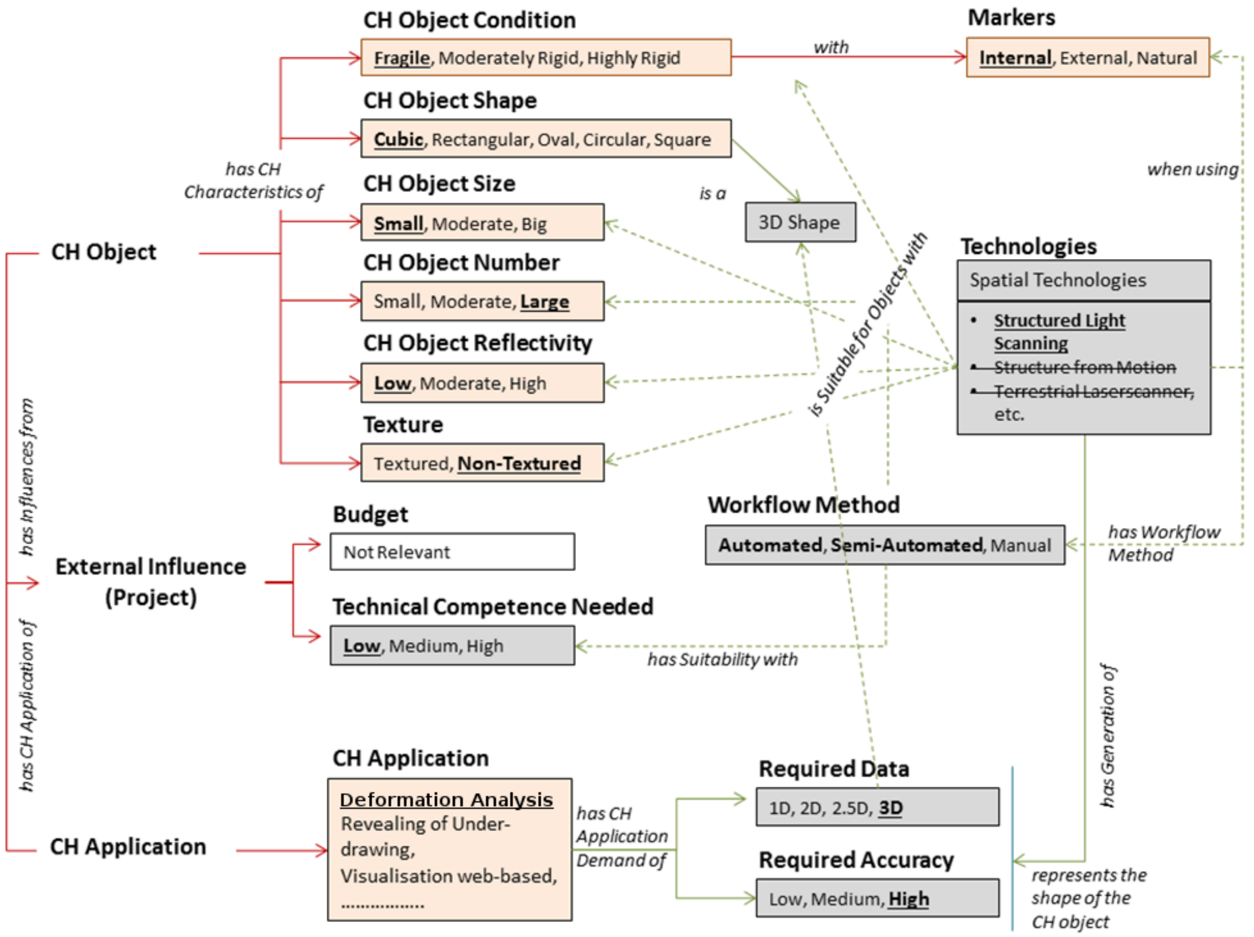

Figure 2: User Interface simulating the spatial case study. Pink boxes represent user input; grey boxes represent automatically inferred information. Green arrows represent rules and automatically drawn conclusions.

6. Discussion

The successful creation of such an ontology and platform needs to be based on mutual understanding of experts from the involved domains. It has to start in the consolidation of a common vocabulary with unambiguous terms, goes on in the formalisation of domain inherent knowledge and ends in the connection of this formalised knowledge (e.g. Gruber, 1993). A special challenge is the content capture and its formalisation. For instance, in humanities research questions are often directly linked to a specific CH object and domain that inherent research question. The same physical CH object might be connected to different research questions, which are asked for differing data requirements due to the physical characteristics of the CH object, which might have differing influences on the decision making of a recording strategy. This makes the formalisation of decisive factors in humanities research questions a sensible task which has a strong impact on the identification of the best suitable recording strategy.

Furthermore, to be able to publish a convincing COSCH^{KR} platform the underlying ontology has to have a considerable number of CH Applications integrated. Therefore, one of the major tasks is to identify and structure typical CH Applications.

The already implemented “Deformation Analysis” CH Application is actually a subclass of the class “Change Detection”. This will include different cases of data comparison to detect spatial (Deformation Analysis) or spectral (Colour Alteration) changes of one CH object. It requires at least two datasets representing the same object at different periods. Another class within the class “Change Detection” could be “Monitoring” which also requires at least two datasets representing the same object at different periods. However, this application would have the precondition to avoid any alteration of the CH object, that is why a differing recording strategy is needed having strong dependencies on the CH object and external influences.

A further CH Application class will need to set the differentiation of both spatial and spectral recording strategies: “Enhancing visibility of faint or obscured features”. Besides the usage of spatial data for e.g. rock inscriptions (Schmidt, Schütze, & Boochs, 2011), spectral data can support CH experts to better understand faint or obscured features such as the artist’s signature on a painting, and also a combined usage of spectral and spatial data is sometimes needed to enhance the visibility of e.g. petroglyphs (Wefers et al., 2016). Therefore, this CH Application class will need a more elaborated view to allow a logical structuring.

Furthermore, a class might be needed which subsumes a variety of applications connected to the analysis of paintings such as “Identification of paint materials/ingredients”, “Discriminating two paint materials/ingredients having the same visual appearance”, “Revealing a retouching or previous restoration in paintings”, and “Mapping of paint materials/ingredients in paintings”. The technical approach is always connected to spectral recording techniques supporting the chemical identification of materials through e.g. hyperspectral imaging.

A CH Application class which will be only connected to spatial recording techniques is “3D print out”, which will have subclasses such as “3D print out of a CH object” or “Negative 3D print out of a CH object used as support”. Differentiating these two 3D print-outs might be needed due to the fact that a support asks for a higher geometric accuracy than a 3D print-out as the CH object has to fit in the support.

Last but not least, the class “Visualisation” needs a more elaborated view on typical case studies. It will subsume several visualisation purposes such as “3D visualisation for a website”, “3D representation for research”, “3D representation to visualise research results”, etc. However, which aspects have to be taken into account to identify and structure visualisations of CH objects is still under discussion (Pfarr-Harfst, 2016).

With respect to the above mentioned and further CH applications, more classes, rules, and dependencies have to be created which are given by the individual “Physical Thing”, “Data”, “Technology”, and “External Influences” parameters. Therefore, the elaboration and integration of each CH Application (not only within the CH Application class but also with respect to the other classes “Physical Thing”, “Data”, “Technologies”, and “External Influences”) into the ontology is a serious collaborative and interdisciplinary task. For each CH Application a theoretical concept has to be developed which can be integrated into the ontology as formal axioms and inference rules linking all top-level classes within the ontology.

As soon as the first three case studies (spatial, spectral, and visualisation case studies) are represented mainly through rules inside COSCH^{KR} the further development can be handed over to a wider community since the ontology can be used as a guiding frame. To make the COSCH^{KR} platform a sustainable solution, the most promising approach is to make the ontology publicly available (open access and connectable through APIs) allowing the involvement of an interested community. This, on the one hand, will allow an extension and further development of the ontology and, on the other hand, will help to keep it up-to-date as new technologies will evolve relevant for the digitisation of CH objects. It is extremely important to have a robust and well-documented framework able to allow users a quick understanding, including references which might help to identify the most promising starting-points for further developments and enrichments. Especially, CH stakeholders and big CH museums should be interested in having access to technical experts to elaborate further the ontology as in a long-term perspective under which they will benefit from other digitisation projects that rely on the recommendations from the COSCH^{KR} platform.

7. Conclusion

Through the COSCH^{KR} platform all CH experts, who intend to digitise CH objects for data usage, will benefit as they could check the technical possibilities and requirements, and get practical ideas which will support any project planning and will be more confident and autochthonous with respect to collaborative related projects. In a long-term perspective, the application of

CH object triggered digitisation results will be more sustainable and durable since the entire approach presented herein is well-thought-out through an interdisciplinary collaborative discussion of CH experts and engineers coming from different backgrounds.

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