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Transdisciplinary Multispectral Modeling and Cooperation for the Preservation of Cultural Heritage

First International Conference, TMM_CH 2018
Athens, Greece, October 10–13, 2018
Revised Selected Papers, Part II

Part 2

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Cultural Heritage Sites Holistic Documentation Through Semantic Web Technologies

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Abstract. One of the goals of the INCEPTION project, funded by the EC within the Programme H2020, is to explore and enhance H-BIM knowledge management in the sector of Cultural Heritage (CH), taking into account the richness of the interdisciplinary documentation associated with the different significances of the assets.

Architectural and historical documents, structural analysis, building material characterisation and other sourced documentation for a H-BIM virtual model of a built space can be of different formats, scopes and significances but their organisation, sharing and findability are crucial for the holistic e-documentation that can be enriched from interdisciplinary users and reused for different purposes.

Conceptual frameworks of a document management system interoperable with H-BIM should guarantee an easy way to organise digital documents from variable sources and associate them to specific parts of the buildings. This to avoid overwhelming information and to allow the user to explore the virtual model with the best granularity.

Within the INCEPTION project, a layered and interoperable H-BIM ontology has been developed to gather and store new information from the original BIM model and CH information, as well as to associate the correct architectural element to each structural or decorative part of the building.

Then the H-BIM ontology has been extended implementing a specific addition to create an association between external documentation and the whole 3D model or individual elements specified in the H-BIM graph.

This paper explains how the Semantic Web technologies allow retrieving and filtering the holistic documentation by the user needs and using it in the 3D model exploration and analysis, improving the user experience and the findability of different knowledge sources.

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1 Introduction

INCEPTION is a research and innovation project funded by the European Commission under the Programme Horizon 2020, call Reflective-7-2014, *Advanced 3D modelling for accessing and understanding European cultural assets*.

Its goal is to understand European cultural identity and diversity in Cultural Heritage sites by facilitating collaborations across disciplines, technologies and sectors.

To realise this scope, one of the main achievements is the INCEPTION platform, which explores, implements and enhances 3D models in BIM (Building Information Model) environment, exchanging data format according to existing state-of-the-art standards and using Semantic Web technology.

IFC is an open BIM standard format for 3D digital reconstructions increasingly used in the architectural field. Its application to Cultural Heritage, the so-called H-BIM (Heritage Building Information Model), is still quite challenging [1] and it is still in a definition phase due to the complexity of the domain and the different scopes and usages of the 3D model of a CH asset [2].

The INCEPTION Platform will allow such models to be easily accessible and reusable by researchers, scientists, experts and creative practitioners working in the cultural and heritage industries. Having such a broad audience is mandatory to promote collaboration across sectors and facilitate cross-disciplinary researches, dissemination, education and business opportunities.

The broad application of the INCEPTION objectives shall result in three major statements that approach the context of cultural heritage stakeholders from a complex, multifaceted set of formats, sources that together offer more, and better information than the sum of individual data (thus the definition of "holistic" documentation).

Therefore, interoperability is one of the primary targets to allow a platform to be available and usable by users with different scopes but the same need to get and share information.

The Semantic Web technologies, led by the W3C consortium and broadly accepted as the international standard to share machine-readable knowledge content, is undoubtedly the best solution to save and reuse the CH documentation related to a building but significant for different domains of interest [3].

To achieve all those different objectives, an H-BIM ontology has been developed to remap the architectural features from ifcOWL (an open standard for BIM modelling in a semantic web language) and integrate them with the architectural elements specific to the CH domain issued from the INCEPTION set of demonstration cases.

The knowledge related to the 3D model can then be enriched over time by different users, approaches and skills and from various sources and formats.

The difference between several use cases related to CH immovable assets (buildings, monuments, museums and archaeological sites) strongly suggests a functional and layered architecture for the INCEPTION platform and the related ontology.

Analysing a set of use cases related to the INCEPTION demonstration cases, one of the primary concerns was the possibility to relate the complementary documentation to specific parts of the model.

This documentation has different sources, scopes and interests for the user: it is often available as a set of files of different format and content, with changing relevance and interest depending on the scope of the model exploration.

The solutions must not overwhelm the user but give him the possibility to explore at the same time the model and its further deepening with a reasonable level of detail and granularity.

The INCEPTION platform is grounded on an ontology that allows to link and define metadata for those files, as well as the possibility to store, retrieve and, if the format allows it, visualise them in the 3D model analysis and exploration.

2 H-BIM Holistic Documentation

In the cultural heritage field, the management of the site documentation is a necessity enhanced by the inter-disciplinarity of the stakeholders [4].

BIM is a digital representation of physical and functional properties of a building and the answer in the Architecture, Engineering and Construction (AEC) industry to the previous lack of a management system to interlink 2D and 3D information.

The information, to which the 'I' of the BIM acronym refers, is not only related to the construction representation but even to other information necessary for building management during its lifecycle. BIM is also thought as virtual modelling of the building, in which any kind of physical element logically correlates with the other through a data storage (usually a database, but we can also think of semantic repositories).

In the field of Cultural Heritage, managing information related to 3D models is mainly focused on reverse architecture, starting from data acquisition at an intermediate point in a building's lifecycle. The chosen time-period could also be related to a specific condition of the asset in the past, retrieved by research and historical sources. This typical use case highlights the documentation complexity and layering, even more relevant according to the 3D model scope.

Thus, not only we can have different digital reconstruction related to the various historical time frames, but also the related documentation can have multiple layers in time and sources.

In addition, external documentation can be originated before the digital model is created, as a source for it (point clouds, photographs, historical pictures representing the building at a given time) or can be added as a further analysis or study research, after the model completion.

It is essential to understand that the way of retrieving and taking advantage of the model documentation is just as important as its classification. Obviously if having a valuable set of files correctly classified through acknowledgeable standards and referenced to the entire 3D model is a starting point, those data are not usable if they are not available in an exploitable format or if we are facing a huge, not manageable, amount of information. Any exploring instrument and native interlinked format have to give the

user a path and an easy way to search, explore, utilise and enjoy it. As the term holistic [5] suggests, we must think the documentation and the virtual building model, including the enrichment data interconnected with the architectural structure, as a whole.

INCEPTION lists nine main demonstration cases in six different European countries and ranging from museums, palaces, castles, churches and archaeological sites. The diverse nature of the sites requires several different approaches towards users, depending on the intrinsic value of the CH area but also on the user background and scope. Analysing the existing documentation and needs of those demonstration cases was of great importance in prioritising the platform tools and architecture to upload the related documentation and allow using it proficiently.

The typology of the external documentation can be various: in some cases, existing ontologies or structured databases were available. However, in most cases, the available sources were already existing external files or digitised objects.

Of course, there are a lot of different formats and possibilities: for example externally linked data, high definition details, textures, websites, databases or already defined ontologies. For each of these specific needs, INCEPTION provides web services to allow 3D models interoperability. However, to simplify and gather the already existing use cases issued from the demonstration cases, the focus has been put on an ontology that allows linking files created outside the platform to specific sections of the 3D model. The ontology language also targets the aim of reusing existing data, one of the issues addressed by INCEPTION.

3 Ontology for Media Resources

With the advent of new ways of exploiting CH 3D models through VR and AR, we can be sure that a typical example of data enrichment would be through media files [6]. Images, videos, audios, texts are exploitable interchangeable formats that channel information also on the intangible culture linked to the assets. Media files well-known extensions can be immediately usable through common software tools like an internet browser.

Starting from this set of files, the possibility to classify the external resources have been addressed using an integration of the ontology for Media Resources 1.0, W3C standard metadata recommendation to bridge the different descriptions of media resources and provide a core set of descriptive properties also generally valuable for any file format. This recommendation defines a core set of metadata properties for media resources, along with their mappings to elements from a set of existing metadata formats [7].

The ontology is implemented in RDF/OWL, the standard language of Semantic Web also used to define the INCEPTION H-BIM ontology. The scope of Media Resource ontology is to target most of the media resources formats commonly used on the World Wide Web.

The ontology describes the most important properties and maps a set of metadata in the commonly used set of elements shared and indicated from the media files. Different software and applications could share and reuse these metadata remapping them through the Media Resources table format.

4 INCEPTION H-BIM Ontology

One of the first steps in designing the INCEPTION platform was the construction of the H-BIM ontology, an extendable open standard that uses existing ontologies as part of its architecture and tries to bridge the gap between geometry and knowledge representation.

4.1 Architectural Classification

The H-BIM ontology uses Semantic Web technologies as RDF/OWL language to export the definitions of the architectural structure of the building and use it as a knowledge layer to interlink the site elements with any structured knowledge not directly mapped on the geometry layer.

The ontology starts from a subset of the IfcOWL open standard [8] but incrementally adds the correct hierarchical specification of sections and components.

The geometrical descriptions are translated from ifcOWL/IFC towards a dedicated GEOM ontology allowing the integrated use of a library being able to convert the content into 2D/3D representations for (web-based) 3D viewers and third-party applications. This project ontology is the base to link specific properties to a specific part of the building and to retrieve all the components related to these properties. In the properties set, the reference and the link to some documents, that are resources needed to assert the origin of the modelling decisions, can be added.

To correctly map this behaviour, we need to attach a unique global identifier for every component in the model and define semantic (as opposed to geometrical), relationships between parts.

The base ontology allows linking different ontologies to enrich information related to a single component and have all the hierarchically related building parts automatically updated if the relationship is transitive.

Due to the interoperable structure, the ontology will be incremented and developed over time, but being INCEPTION focused on user needs and approaches, to assess that the "base" was correctly set, we have tested it with examples from the INCEPTION demonstration cases, analysing their context and the different users' approaches.

By collecting the results of the INCEPTION use cases, it was possible to highlight two primary requirements:

1. the need to identify a specific part of the model;
2. the need to link information or other documents to a specific component and retrieve them easily.

Those requirements define the core part of the H-BIM ontology:

A set of classifications for building components compatible with the CH needs that can be enriched with definitions, synonyms, information and documentation.

This approach clearly does not accomplish the possibilities of enrichment and all the possible relationships between different parts of the model but provides a way to interlink the information related to the building history and representation to the specific part of the model to which they are connected.

A "feature to document" granularity provides many benefits also from a usability point of view, allowing the user to explore the documentation inside the model, giving a sort of "3D structure" to a flat set of files. Other filters, like timeframe, users scope and file formats, can be applied to the document retrieval, giving a very personalised experience.

4.2 Architectural Features Names

Standard BIM does not entirely answer to the complex nomenclature of heritage buildings, so the ontology classification of the building features was integrated with a glossary to bridge the gaps in current BIM definitions and have a first hierarchical classification on Heritage buildings.

The INCEPTION approach in the selection of the nomenclature also examined classical architectural sources: a "taxonomy of monuments" according to holistic e-documentation needs is the base to understand the approach on "names". It is the starting point of a classification in Semantic Web language in order to connect terms with H-BIM ontology.

Nevertheless, the glossary was set by a top-down approach, starting from the INCEPTION demonstration cases' needs and scholars analyses and assessments, and checking the mapping with the Getty AAT [9], one of the most comprehensive sources of architectural definitions.

4.3 H-BIM Core Ontology

H-BIM ontology is the RDF/OWL ontology that inherits the main classification structure from ifcOWL and maps the components of a BIM in the Cultural Heritage field.

The starting point has been the analysis of the ifcOWL classes and properties and the collection of the semantically convenient classification useful for enrichment. Secondly, the glossary structure was hierarchically organised and integrated with the definition of the architectural component of the base H-BIM first ontology. Those are new classifications not yet included in the first ontology derived from ifcOWL: any new insertion was tested to understand if the model converted from IFC were correctly classified.

One of the results of this approach was that the complex hierarchy and the new descriptions automatically enriched models without losing the backward compatibility.

Flexibility was one of the criteria to be followed, so some of the classifications belong to different hierarchies. This process was also necessary to add a new definition or classification of one component without changing the original one but adding layers of descriptions and a deeper understanding of the building structure.

It is essential to highlight that this procedure also considers all the single project ontologies based on the H-BIM ontology schema: any of them is composed by architectural elements that are correctly defined in the H-BIM ontology framework.

Starting from the H-BIM architectural elements, an H-BIM Document ontology can be integrated to link external documentation defined in CH classifications to be used for single architectural elements enrichment.

5 File Management in the INCEPTION Platform

One of the issues to manage in linking external documents to a 3D model is that the INCEPTION platform could have several different files formats to be stored and to be related to different databases, which store the 3D geometry, the semantic definition of the architectural features or other enrichments like external websites.

Metadata and external structured descriptions of the file allow uncoupling the hardware storage organisation and the proper content of the file from the H-BIM ontology relationship.

Hence the ontology can take for granted the correspondence between the metadata description of the file and its content, giving to the INCEPTION platform the task to correctly store and visualise them. Given the standard use case of media files attached to the 3D model to enhance interactive experiences, tools to visualise and explore the content could be easily accessible by the user, enriching his experience in real time.

If the file is not available in some already managed formats, the INCEPTION platform incremental flexibility allows to develop or connect external applications to explore specific data formats, for example, files regarding structure or technical analysis like infrared outputs or measurement sets.

5.1 URL and URI

In order to be linked through a semantic relationship, files have to be provided with a URI or a URL [10].

A Uniform Resource Identifier (URI) is a compact string of characters for identifying an abstract or physical resource. The syntax of URI's goes back from Tim Berners Lee, the creator of the internet. A Uniform Resource Locator (URL) is a form of URI which expresses an address to access the referenced object using network protocols. An http URI is a URL.

When embedded within a document, a URL in its absolute form may contain a lot of information already known from the context of that document's retrieval, including the scheme, network location, and parts of the URL path. For existing Internet access protocols, it is normal to assign the encoding of the access algorithm into something concise enough to be designated as an address.

The primary component of the Resource Description Framework (RDF) data model is a semantic triple, the atomic data entity in the Semantic Web. As its name indicates, a triple is a set of three entities that codifies a statement about semantic data listing three parts: subject, predicate, object. Every part of an RDF triple is individually addressable via unique URIs, which represent entities and properties.

Once saved in the INCEPTION platform storage, the documentation file has then a URL to be reached from, that can be used to share the content through the platform, giving information about the location, the format and the scheme This URL can also be considered its unique identifier but being correlated with a web location any change of it should then be remapped to the new position.

To link external files through RDF triples, a persistent URI should be associated with the individual file, leaving the access position to different properties of the H-BIM document position.

5.2 Semantic Metadata

The link between the specific 3D model part and the file properties and location is mapped in a project-specific ontology that is not bounded to the file format or metadata. Files to map are usually already existing, and the INCEPTION approach is that the platform should not ask that formats and descriptions must be constrained to a specific standard at the upload time. Otherwise, there is the risk to avoid enriching the model due to the lack of time and resources.

Some of the metadata could be implicitly set at upload time, like the file format, size and location, other could be optionally filled getting them from the user profile, like the scope of the file or its possible utilisation.

The inclusion of ontologies like Media Resources 1.0 also gives a better mapping on possible existing metadata embedded on the file, so to save them in the semantic repository and reuse them if there is they are useful from a specific use case.

In this way, without the user having to set a massive amount of other information, at upload time we would understand much information from the context of the upload operation. The INCEPTION platform is also able to set a defined set of project specific properties, allowing to retrieve them to enhance the user experience.

6 H-BIM Document Ontology

H-BIM ontology has been extended to include an easy way to link all kind of external documentation to the whole 3D model or an interesting part of it.

The H-BIM Document ontology now includes and complete W3C Media Resource 1.0 to enrich with different digital files the single architectural element. The file can also not be of a specific media format, but the raw content is saved and retrieved from the platform, using metadata and properties to assign further external usages.

In CH field we can have a lot of peculiar formats and technical archives for data acquisition, so the W3C Media Resource was a starting point to define general properties necessary for files storage not related to common file extensions but typical from the CH domain.

To upload the file, the user also has to identify all content' scopes and significances: this allows to filter the documentation by the user needs and avoid showing a bundle of not significant information to the final user that could be different from the one who has uploaded the file.

For example, the historian can filter the uploaded documents retrieving only the ones with the scope of "CH enrichment" and significance "historical", the technician only the ones with scope "maintenance" and the administrator the one with significance "economic".

Every document can have multiple scopes and significances. Although the "scope" property seems to be the most relevant, we have chosen to add the not mandatory property "significance" for CH standards compliance (Fig. 1).

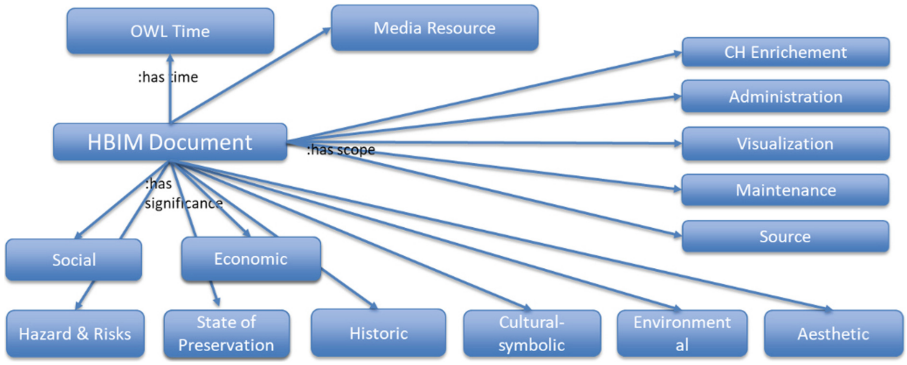

Fig. 1. Each document can set the not mandatory properties HBIM:hasScope and HBIM:hasSignificance to clarify the context of the content.

6.1 An INCEPTION Use Case: Istituto degli Innocenti

The developments achieved within INCEPTION allowed testing their validity on several real use cases, such as the documentation of the Istituto degli Innocenti in Florence.

The building was originally designed by Filippo Brunelleschi, who left after few years from the beginning of the construction. Several modifications affected the building through time, resulting in a site that partially represents the whole history of the city. The schemas below show how the workflow, made possible by the INCEPTION developments, can enhance the knowledge of the building. From the architectural research, the reconstruction of several models in different eras was possible, also giving the chance to connect the digitised source material to each building element.

Starting from a BIM model created for historical reconstructions, it is possible to attach to each element source material as well as detailed models, a specific nomenclature (i.e., the original capitals) and a time classification (see Fig. 2).

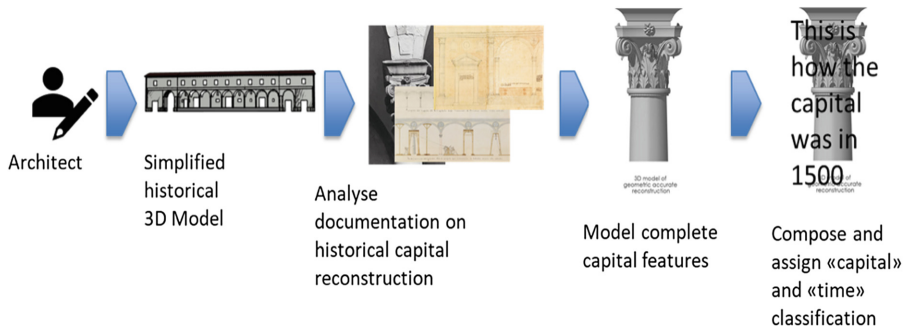

Fig. 2. How to use the H-BIM ontology to explain and manage the reconstruction of a capital at a given time of the building history.

On the other hand, the knowledge added to the H-BIM model can be accessed, explored and enjoyed by the tourist who is looking for more information on the monument that he is visiting and can be guided by exploring significant documentation attached by renowned researchers.

A user, such as a tourist or a citizen, can take advantage of the knowledge added by researchers or technical users guided by a specifically developed storytelling that, thanks to the definition of different points of interest, can highlight the documentation collected around the building (See Fig. 3).

Fig. 3. Exploring the model with deep granularity through linked data and external documentation enrichment.

7 Conclusions

Cultural Heritage buildings' and sites' importance hugely depends on their significance on the broad spectrum of social and historical events that involved the asset through time.

IFC/ifcOWL, the open BIM standard for digital representation of physical and functional features, has to be enhanced to manage the complexity of CH assets, leading to the so-called H-BIM approach.

One of the main issues to be addressed within the H-BIM environment is the amount of external documentation related to different scopes connected to the 3D model: research, conservation, maintenance, restoration, administrative or historical issues. Although there are many examples of documentation included in software storages like databases, ontologies, we can assume that one of the main envisaged solutions is just allowing linking existing digitised files to the model.

The H-BIM ontology layer allows relating the 3D model to other knowledge sources, like external files, to a level of granularity that could be embedded in the virtual model navigation. Linking the different files to the specific architectural features allows managing required knowledge separated into different levels to be filtered depending on the user context and to be connected with each part of the building structure.

To upload and store the files, a set of semantic properties (metadata) can be extracted from the contextual information and set through the H-BIM Documentation

ontology, partially derived from the W3C Media Resources. Other properties, like the scope or the significance of the information, can be added directly to the semantic repository.

Those properties are essential to retrieve the significant information accurately and to manage the file visualisation. The INCEPTION end user can thus enjoy a focused user experience, navigating the model and retrieving the information on the part of the building and the topics he is interested in. The filtering through 3D position and properties avoids overwhelming the visitor with not relevant information depending on its profile: layering the knowledge without deciding a priori which documentation can be useful but allowing the access "just in time" so to allow a genuinely "holistic" experience. Other metadata, such as size and format, are useful to embed media viewers and to give the building explorer a powerful and easy experience.

INCEPTION approach allows to incrementally enrich the model with external information but also to navigate it depending on the context, receiving the correct information at any time of the user experience.

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References

1. Logothetis, S., Delinasiou, A., Stylianidis, E.: Building information modelling for cultural heritage: a review. ISPRS Ann. Photogram. Remote Sens. Spat. Inf. Sci. **2**(5), 177 (2015)
2. Arayici, Y., Counsell, J., Mahdjoubi, L., Nagy, G.A., Hawas, S., Dweidar, K. (eds.): Heritage Building Information Modelling. Routledge, Abingdon (2017)
3. Pauwels, P., Bod, R., Di Mascio, D., De Meyer, R.: Integrating building information modelling and semantic web technologies for the management of built heritage information. In: Digital Heritage International Congress, vol. 1, pp. 481–488. IEEE (2013)
4. Ioannides, M., et al. (eds.): Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-48974-2. Proceedings of the 5th International Conference, EuroMed 2014
5. Ioannides, M., et al.: Towards monuments' holistic digital documentation: the saint neophytos enkleistriotis case study. In: Ioannides, M. (ed.) EuroMed 2016. LNCS, vol. 10058, pp. 442–473. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-48496-9_36

6. Ioannides, M., Magnenat-Thalmann, N., Papagiannakis, G. (eds.): Mixed Reality and Gamification for Cultural Heritage. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-49607-8
7. Brusaporci, S.: Advanced mixed heritage: a visual turn through digitality and reality of architecture. Int. J. Comput. Methods Heritage Sci. (IJCMHS) **2**(1), 40–60 (2018)
8. Bonsma, P., et al.: IOP Conf. Series: Materials Science and Engineering, vol. 364 (2018)
9. López, F.J., Martin Lerones, P., Llamas, J., Gómez-García-Bermejo, J., Zalama, E.: Linking H-BIM graphical and semantic information through the Getty AAT: Practical application to the Castle of Torrelobatón. In: IOP Conference Series: Materials Science and Engineering, vol. 364 (2018)
10. Berners-Lee, T., Fielding, R., Masinter, L.: IETF (Internet Engineering Task Force). Uniform Resource Identifiers (URI): Generic Syntax (1998)