B(H)IM - Built Heritage Information Modelling

Extending BIM approach to historical and archaeological heritage representation

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This paper describes the context and the proposal for the extension of Building Information Modelling to built heritage in order to enhance information management during the investigation and restoration activities. The core of the presented model is the integration of a BIM-based modelling environment and a knowledge base developed by means of ontologies, in order to represent all the semantics needed for a comprehensive representation of the historical artefact.To test its features, the model has been applied to the real archaeological investigation process of the Castor and Pollux temple at Cori, Italy.

Keywords: *BIM, Built Heritage, Ontology-based systems, Knowledge management, Archaeological investigation*

INTRODUCTION: INFORMATION MANAGEMENT AND BUILT HERITAGE INVESTIGATION

In Built Heritage investigation, the accuracy and the completeness of the artefact knowledge representation is a key factor that deeply influences the following activities of investigation, intervention and maintenance: in fact, any decision made by the different actors involved is based on "what is known" of the object, and any lack of knowledge or inconsistence can lead to errors and even irreparable damages.

Differently from the construction industry, where the building and all its elements are very clearly modelled in all their components and features, in this field the heritage artefact is usually a blurred-outlined knowledge domain and any lack of documentation is considered to be equivalent to the destruction of discovered remains. In addition, understanding an heritage artefact is more than understanding just its history, physical configuration and condition; It involves a large amount of knowledge about a high number of social, political, economic, and cultural issues relating to the external environment (Letellier et al, 2007).

Every heritage object can also be seen as a unique historical archive, a precious source of primary information from which any research, investigation or conservation activity will retrieve new data (Bedford, 2009). This information is collected, documented and made virtually available by the different professionals. Nevertheless, this knowledge is usually inaccessible since it is spread among different disciplines and restricted to several not-integrated "knowledge islands"; useful data about the artefact and its context - potentially able to support the process of interpretation and intervention- are buried in tons of different data repositories. Even when part of this knowledge is introduced in the investigation and intervention phases, this is not effectively represented in the Built Heritage Model and, therefore, is not fully accessible or usable by the specialists involved in the different process phases. As a result, useful data about the artefact, its context and the possible methodologies of interpretation and intervention are buried in tons of documents, databases or data repositories.

Even the introduction of digital technologies to the built heritage field has left this problem unsolved: while several efforts have been made to develop virtual reality techniques oriented to building original appearance simulation or knowledge acquisition technologies, very little research has been focused on heritage knowledge modelling and representation (Kalay et al., 2007). Some approaches (i.e. the Virtual Reality GIS -VRGIS) have started to integrate Virtual Reality models with GIS systems (Dore et al., 2012) but, at present, they are only partially able to include not-geometrical data in the artefact representation.

To solve these shortcomings, the research presented in this paper aims at extending the Building Information Modelling approach to built heritage field, providing a modelling environment able to effectively support knowledge representation and management for historical/archaeological artefacts.

In fact, while information about historical/archaeological artefacts is currently disseminated in different data repositories with a relevant issue in terms of partiality and data duplication, BIM can concentrate and organize such data in a single knowledge base that acts as an electronic reference dossier of the object during the entire process of investigation and conservation. Since a large amount of knowledge related to the object is independent from the artefact but still necessary to be introduced in its representation (i.e. historical context, social information, environmental resources, other heritage artefacts information, etc.), we have decided to integrate Building Information Modelling with a knowledge management system based on ontologies. In this way, it is possible to enclose several crucial information that would be difficult to represent in the component-based BIM approach, providing a more comprehensive and accessible model of the artefact.

In order to test the real effectiveness of the proposed modelling approach, we have chosen to apply the BIM+ontologies system - that we defined as Built Heritage Information Modelling- to the process of investigation and documentation of the roman temple of Castor and Pollux in Cori, Italy (Figure 1, 2).

STATE OF THE ART

Over the past decade, a wide number of researches concerned with the digital acquisition of existing buildings and the construction of 3D models integrated with different heritage documentation databases. Most recently, attention has been moved towards the development of information management instruments considered suitable to the analysis and maintenance of historical artefacts.

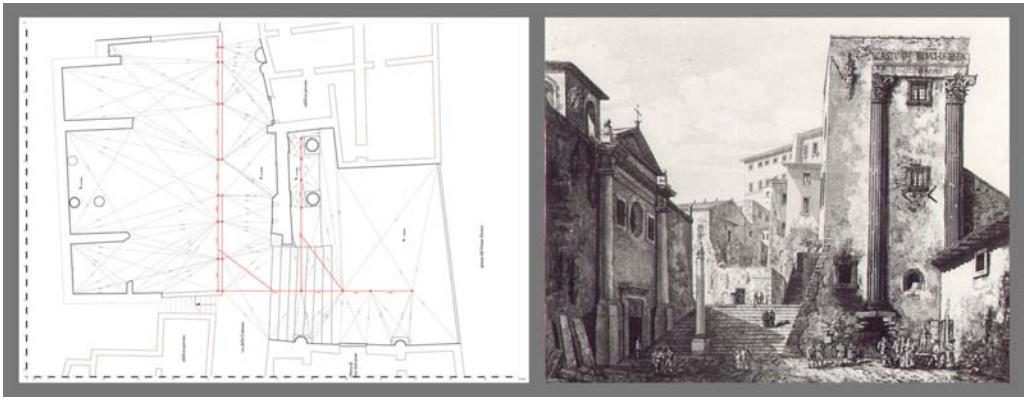
This interest can be due to the recognition of Building Information Modeling as a technology that can improve the representation of the relationships between tangible and intangible heritage knowledge.

Despite its widespread adoption for the design and management of new buildings, few projects have looked at Building Information Modeling as a technology that can improve the representation of the relationships between tangible and intangible heritage knowledge.

In fact, while the purpose of a 3D model is limited to a geometrical visualization, a BIM representation contains all the data associated to the elements that make up the artefact, with the result of an instrument which can allow different kinds of reasoning.

Figure 1
Case study: Corinthian Temple of Castor and Pollux, 1st century B.C., Cori, Italy. Remains of the original structure: two Corinthian columns, 10 meters high, decorated by 20 grooves which support an architrave (left); central cella and side wings (right).

Figure 2
Heterogeneity of knowledge related to the data acquisition, modelling and representation process: metric survey (left); Luigi Rossini, sketching of the temple of Castor and Pollux's ruins, 19th century (right).



In spite of the apparent disinterest, BIM in heritage conservation field is not without past instances. Recent researches have focused on modelling historical buildings in order to create components libraries from the laser scanning to the BIM environment (Arayici, 2008). Penttila et al. (2007) provided a case study that evaluates utilization of BIM for the retrofit of historical buildings by means of an "inventory model" as database about both past and present of an existing building condition. Nevertheless, these experiments have been focusing more on database creation and extension rather than considering BIM as a documentation hub to support and enhance specialists' activities and collaboration. Some authors (Attar et al., 2010; Fai et al., 2011) explored the potential of BIM in lifecycle management and simulation such as energy saving and fire evacuation. Besides explicit semantic description, BIM also facilitates the theoretical and historical study via historical documents enrichment (Pauwels et al., 2008).

In built heritage field, the process of cataloging is often done with the creation of large databases mainly characterized by a vast heterogeneity related to the typology of media and formats used, to their level of accessibility, and to the related logical models of representation (Volk et al., 2014).

This clashes with the limited amount and the low level of semantics that can be attributed to the objects by means of current BIM platforms: the mere description of their features through the use of a list of properties generates information which is often redundant or overly simplified in many separate slots, highlighting the inability of such data models to represent logical associations among entities with other sections of data related to different disciplines. This aspect clashes with the requirement that, as stated before, the information related to the cultural heritage have, by nature, a strong need for correlation in order to fully express their true worth.

For this reason, integration of BIM with information management techniques like semantic reasoning is essential to enhance representation of archaeological sites knowledge, requiring a modelling environment in which data and entities are linked in a relational system, revealing some information that would otherwise remain "hidden".

Such considerations lead to a possible solution in a modelling approach that meets the different needs listed above and plays the role of representing the semantics of objects. At present, ontology-based systems allow the representation of entities not only through the description of their properties but also by formalizing the relations that exist between them (Di Mascio et al., 2013; Carrara et al., 2009; Beetz, 2005).

On these bases, we propose a BIM model integrated with a knowledge base developed by means of ontologies, in order to enclose a sufficiently accurate and computable formalization of the knowledge related to the artefact and its components, and to expand current BIM abilities of inference and rules-based reasoning on this knowledge structure.

BIM AND ONTOLOGIES FOR A COMPREHENSIVE REPRESENTATION AND DOCUMENTATION OF THE BUILT HERITAGE

A correct representation of an historical artefact requires a large amount of information that are progressively created during the different phases of the investigation process and stored in dedicated data repositories. The investigation operations are usually not synchronized in time and often several years are needed to reach a sufficient comprehension and documentation of the artefact. For this reason, the information management platform and protocols play a key role in the whole investigation process, allowing the different operators to provide, access, edit, manage, use and update such information in accordance to their role, task and expertise.

In AEC (Architecture Engineering and Construction) field, BIM has taken on this task, providing a modelling environment where geometrical information and some not-tangible data are structured in a coherent database. At the same time, its component-based perspective still leaves out of the model a large amount of knowledge, not directly relatable to arte-

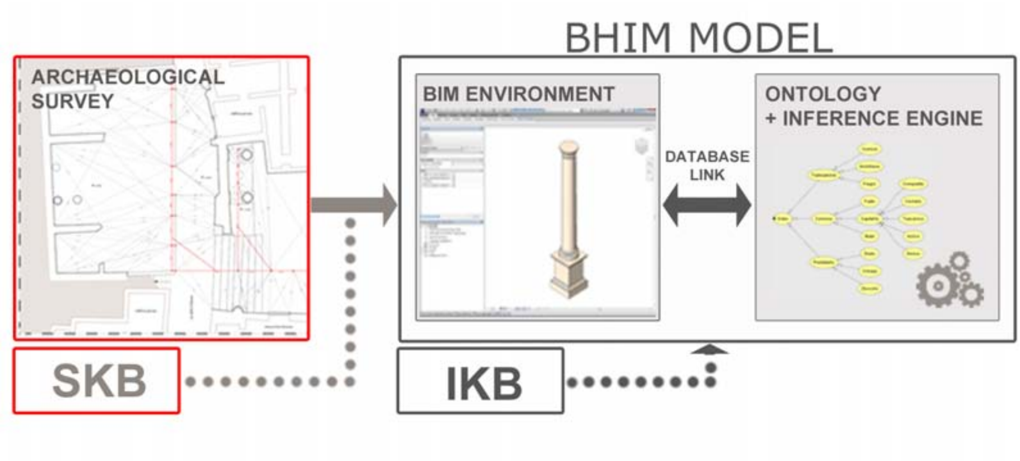


Figure 3
The conceptualization of Built Heritage Information Model: the BIM environment and the knowledge base are integrated to represent the data collected during the investigation (SKB-Survey Knowledge Base) phase and derived from the actors interpretation (ISB - Interpretation Knowledge Base).

fact's components but still needed to fully represent the object. For this reason, the BIM environment has been integrated with an ad hoc knowledge base developed by means of ontologies. This database, integrate with an inference engine, allows to include and make computable all the knowledge needed in the investigation process and provided by the different actors (Figure 3).

In the investigation process supported by the Built heritage Information Model, the first logical step is the discretization and identification of the different components of the artefact to be progressively enriched with the data collected and provided by the operators. This phase can be mainly supported by the BIM environment, creating classes and instances of the different components, making explicit their properties and creating hierarchical relationships among them (part-of, is-a).

Differently from the AEC industry where each element is defined and modeled in all its parts and properties, in built heritage often several components are not clearly identifiable (especially at the beginning of the investigation process). To overcome this problem, some classes have been developed in order to represent "unknown objects" in terms of their geometric and material features, waiting for a later interpretation that should associate them to the actual classes. In this way, each actor can see which entities are still unidentified and, on the bases of their knowledge and experience, provide suggestions for their interpretation gradually improving the completeness of the model of the artefact.

During the site survey phase, a wide amount of data is associated to each of these entities in terms of properties, values and relationships. This knowledge (defined as Survey Knowledge Base - SKB) represents all the information that can be directly gained through the different investigation activities depending on the different disciplines considered (for instance dimensions, morphology, topology, materials information, temperature, deterioration rate, carbon dating, etc.). When an element is associated to a class, it inherits all the properties that it is necessary to provide in order to reach an adequate level of representation, helping the operators in understanding which information they have to collect from the site and which ones are missing.

In addition, Building Information Modelling provides a single database where the actors can add and edit data collected along the entire investigation process. As a result, the information modelled is always up-to-date and the model itself can be considered as a track record of the results of investigation and interpretation activities.

In the presented case study, the Dioscuri's temple and its elements have been modelled in the Autodesk Revit environment; geometrical data were mainly derived through a survey campaign carried out in a traditional way (hand measuring and photogrammetry) but supported by an information manager (Figure 4). This shows how the Built Heritage Information Model is useful to support also traditional investigation processes, without forcing changes in specialists' work methods but only integrating in the platform the data resulting from their operations.

The following survey activities have focused on other physical aspects of the artefact such as materials diagnostics and environmental data collection in order to provide information for the later restoring interventions. All this data were modelled in the BIM environment quite easily, developing classes for each element type (columns, walls, stairs, etc.) and adding as properties and rules as needed. Since this was a first case study, the entire elements inventory was created from the beginning but when a standard template has been created, the same inventory can be reused in other survey campaigns, deeply reducing the related amount of work.

After modelling the current state of artefact, a historical investigation has been carried out in order to gain useful data from different archives, modelling different configurations of the area in accordance to the different historical periods.

In fact, built heritage usually bears with its history a lot of morphology mutations, use changes and even destructions or relocation of its parts. For instance, in this case study some columns where moved from their original position during time and reused in the medieval age as part of new walls. This aspect increases the complexity of the artefact and of its representation, since its different states need to be represented and visualized. For this purpose, a specific set of properties has been implemented in order to represent if the element is in place or not, the age, the period of realization, and the different phases of the heritage object life it was in.

Although sometimes the data can be collected on site with a high degree of accuracy, the Survey Knowledge Base is not sufficient to provide a comprehensive representation of a built heritage object.

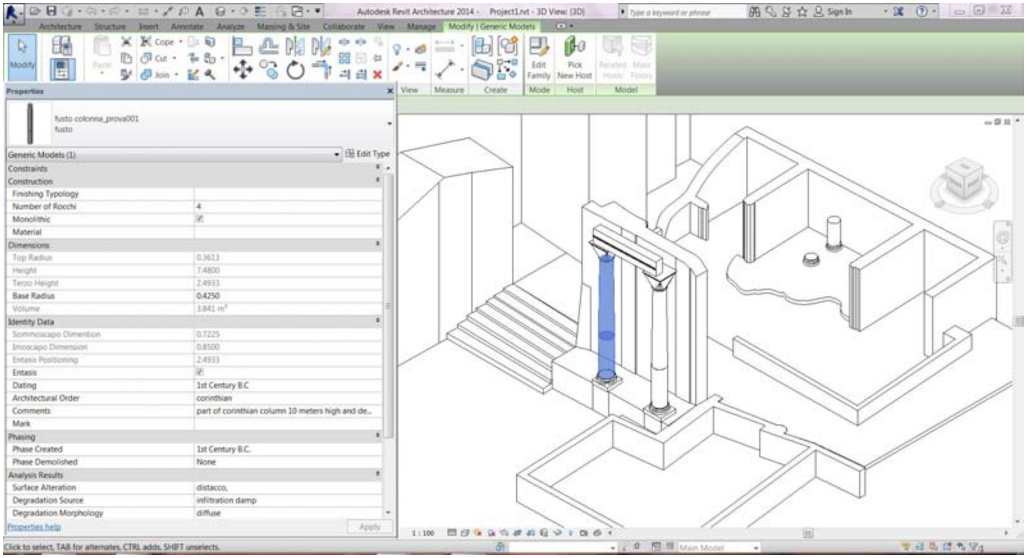


Figure 4
The Dioscuri's temple modelled in the BIM environment of Autodesk Revit. For each component identified on site, a set of properties and values has been implemented in order to enrich the artefact representation with not-geometrical data (i.e. material, historical period, degradation level, etc.).

For this reason, in fact, it is crucial to include, in the model, immaterial information that can document others of its aspects such as its evolution during time, its historical, social and technological context, its intended use, materials caves and sources, etc.

This knowledge base is derived by other knowledge domains and, when introduced and made accessible in the proposed model, it can be used to support the following actions of interpretation, investigation and intervention. For instance, information about the historical period and the pits available at that time can help in understanding materials typology and construction techniques, while social context data can provide useful information for identifying possible uses of spaces. In order to include external knowledge in the artefact model, we have chosen to integrate the BIM representation environment with a knowledge management system based on ontologies.

An ontology, as defined in the ICT field, is an explicit specification of concepts that includes within the same descriptive system the concepts of a knowledge domain and the relations between them (Gruber, 1993); and only recently those tools have been proposed as a method to formalize immaterial knowledge about cultural heritage (Pauwels, 2008).

In the proposed model, ontologies allow structuring and managing concepts related to the different domains that are needed to fully comprehend the historical artefact, and any kind of data and documentation that can be useful for its interpretation such as external links, textual documents, images, modeled objects, bibliographic references, etc. (Figure 5).

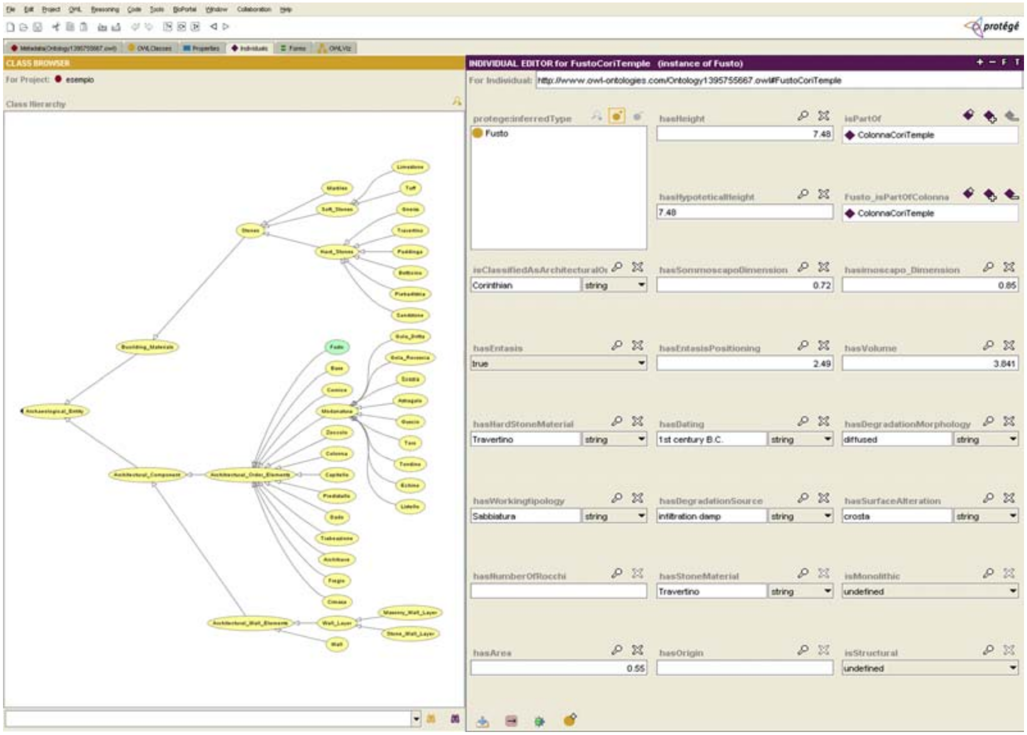


Figure 5
A building component modeled by means of the ontology-editor “protégé”. The entity ‘Fusto’(Part_Of _Column) has been formalized with a set of properties related to the historical documentation of the Dioscuri’s temple and provided by the different specialists during the investigation process.

In particular, we chose to rely on an ontology-based model oriented to the representation of entities (concrete or abstract; part of the artefact or external) in terms of three knowledge components defined as meanings, properties and rules. This template has been previously developed and tested by the research group to provide a BIM-based modelling environment - defined Building Knowledge Modeling-, in which actors can share not only data but also all related concepts and all knowledge attached to any entity involved in new buildings design process (Carrara et al., 2009).

The first component - the meaning- provides a domain-dependent description of the entity; properties, instead, represent all the descriptive aspects related to the concerned element (e.g.: geometrical, physical, historical, technological features); at last, Rules represent the connections among entities, by expressing relationships or reasoning links.

MPR template allows a dynamic and recursive approach to the formalization of knowledge being as effective in the representation of simple entities as in those of greater complexity, focusing the description of concepts on the analysis of their structure and effective representation and, therefore, improving cooperation among the actors of the investigation process. This structure allows not only to efficiently define and manage the knowledge belonging to the built heritage modeled entities but also to perform activities of reasoning about the concepts represented.

In the ontology-based system, an inference engine checks the formalized entities and the relationships among them, assuring the consistency and the coherence of the information represented in the model. In addition, some data are automatically inferred by executing operations and algorithms on the introduced properties values, providing a complete knowledge base to support actors' decisions and operations. This is very useful in archaeological heritage investigation, since many historic layers usually overlap, many elements are re-used with different functions over time and several interpretation inconsistences can emerge.

As well known in information management practice, the availability of large amount of information is not sufficient to assure collaboration among different specialists: integrating all this semantics in a single model could even be counter-productive, since the needed information can be hidden in this complex system of entities and data. For this reason, a semantic filter has been implemented in the modeling environment, letting each actor access, edit and visualize only the information that he needs in accordance to his field of expertise and its tasks in the heritage process.

In the proposed case study the knowledge base has been created by means of the ontology editor Protégé [1], representing each entity through the Meaning-Properties-Rules structure. In this way, all the information related to the historical documentation of the Dioscuri's temple has been embedded in the model of the artefact. Paintings and pictures from the first excavation phase (1940-50), paintings and drawings representing the heritage site in different times (as the one shown in fig.2), ancient texts about the temple and the city of Cori were modelled and made accessible in the knowledge base, providing a comprehensive representation of the artefact.

In order to connect the BIM environment with the knowledge base, particular attention has to be given in creating a correspondence between the ontologies structure and the entities network in the BIM environment. For this reason, specific relationships (i.e. Is-Part-of for representing encapsulation of entities, or Is-A to formalize features inheritance between father-son classes) were implemented in the knowledge base.

In our experiment, the bridge between the BIM and the ontology-based databases has been implemented by means of the Revit DBLink plugin.

Differently from previously knowledge management models, the integration of the ontology-based model with the Building Information Modeling environment allows to have at the same time a geometrical representation of the artefact and its components, and all the semantics (material and immaterial information) provided in both the survey and interpretation phases. This database comprehensively represents "what is known" of the object and "what is needed to know" for further proceed with the process of investigation, conservation and communication.

CONCLUSIONS

In this paper, we presented a knowledge modelling approach aimed at extending the Building Information Modelling approach to represent built heritage artefacts in order to support the information management during investigation and restoration phases. Its structure, developed by integrating a BIM environment with an ontology-based system, allows accurate representation and effective integration of all the knowledge related to the artefact, either gained from the archaeological survey or derived from other knowledge areas. Similarly to its impact on the AEC sector, Building Information Modelling introduction into the Built Heritage field supports the management of the information collected, modelled, used and provided by the different actors involved in the investigation/conservation process. In fact the Built Heritage Information Model improves the availability and accessibility of all the knowledge related to a historical/archaeological artefact, making easier to interpret its nature, monitor its changes and document each investigation and intervention activity. As a result, more aware decisions can be made by relying on the knowledge formalized in the proposed model in order to effectively identify emergency situations, schedule intervention activities and plan routine management and maintenance.

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