IMPROVING THE KNOWLEDGE AND MANAGEMENT OF THE HISTORICAL BUILT ENVIRONMENT WITH BIM AND ONTOLOGIES: THE CASE STUDY OF THE BOOK TOWER

Danilo Di Mascio
Department of Architecture
G. d'Annunzio University, Pescara-Chieti, Italy
ddimascio@danarchitect.com, http://www.danarchitect.com

Pieter Pauwels
Institute for Logic, Language and Computation, University of Amsterdam, The Netherlands
P.Pauwels@uva.nl

Ronald De Meyer
Department of Architecture and Urban Planning
Ghent University, Ghent, Belgium
ronald.demeyer@ugent.be

ABSTRACT: *The historical built environment is acknowledged as a valuable material and cultural resource that needs to be preserved. Usually, however, there are difficulties that do not allow to effectively analyze and document it. Difficulties arising from building characteristics (e.g. irregular shape), site characteristics (e.g. particular natural or artificial context) or other exceptional events (e.g. natural disasters) make it impossible to use only traditional theories, tools and techniques. On the contrary, digital technologies give the opportunity to improve and expand the comprehension of complex artifacts. The objective of our research is to elaborate and propose a theoretical and methodological framework to improve the comprehension and management of the historical built environment with digital technologies. The recorded information can be essential to plan and manage a recovery plan and/or a maintenance program taking into consideration also aspects linked to cultural diversity and environmental sustainability. In this paper we will deal mainly with the constructive and relational characteristics of historical buildings. The constructive characteristics point out the constructive system of an artifact (number, type and material of technical elements, etc.), whilst the relational characteristics represent the relations among the internal components of the artifact and other external elements that could be of various kind (persons, places, etc.). To analyze and document these characteristics we used mainly Building Information Management (BIM) software (Revit) and an ontology editor (TopBraid Composer). Revit was used for the digital 3D reconstruction and TopBraid Composer was used to represent and organize the relational characteristics. Both were applied to a case study: the Book Tower in Ghent, Belgium. This is one of the most important historical (20th century) buildings in the city of Ghent. Through the paper we will show the methodology we used, the issues we tackled and possible future developments.*

KEYWORDS: *3D, BIM, digital reconstruction, historical built environment, information, knowledge organization, ontologies*

1. INTRODUCTION

The built environment represents a precious material and cultural resource that has to be preserved for the future generations. It is not possible to think of a development without conservation, especially in a time like the present one, where interventions on buildings are more frequent than the ones related to the realization of new buildings. The built environment is the result of an evolutionary growing and conservation process which lasts centuries; and its buildings are valuable deposits of meaning and knowledge. This meaning and knowledge includes information regarding constructive techniques, energy and materials. A proper preservation of the built environment is expressed by a sustainable use of materials and territories, but also by an awareness of the importance of the cultural roots of the elements in this built environment, which are precious expressions of identity and diversity that have to be preserved for future generations (Di Mascio, 2012). In the present paper we will draw particular attention on the historical built environment. The artifacts belonging to this heritage have specific architectural, artistic and cultural features that are valuable to be maintained for future generations. To understand and assess the qualities of the historical built environment it is important both to visit personally the buildings in order to have a direct experience of their most relevant characteristics and to collect and analyze all the available information from different sources. The analysis to be undertaken during these actions can be very diverse depending on the specific characteristics of the building that has to be studied. The value of the historical built environment always deals with cultural aspects linked to history (including economic and social aspects), architecture and arts, thus going beyond the material and functional value of the building.

2. THE CONSTRUCTIVE AND RELATIONAL CHARACTERISTICS

Each single building is characterized by a high number of material and immaterial characteristics. The latter represent all the intangible aspects such as size, lights, shadows, colors, paths, spaces, relationships, etc. (Di Mascio, 2012). They are not only the result of a culture linked to the physical features of a place, but also to aspects linked to the cultural and historical context, including artistic movements, technical-scientific discoveries, commercial exchanges, etc. In this paper we will deal with two characteristics that we retain useful to improve the comprehension and the management of any building/artifact pertaining to the historical built environment: the constructive and relational characteristics. These two types of characteristics are defined as follows:

- Constructive characteristics: The concept of constructive characteristics indicates the constructive system of an artifact, referring to the materiality, number and type of technical elements that compose it, to which requirements it corresponds and to how they are connected/assembled. For example, for a standard brick wall with a simple door opening, these constructive features capture the dimensions of wall and door, along with their material characteristics, the way in which they are assembled or combined, and so forth.
- Relational characteristics: The concept of relational characteristics indicates the relational system both between the components within the artifact, and between these and other external elements that could be of various nature (persons, places, documents, etc.). The explanation of these relations allows to deepen and enrich the knowledge of the artifact, as if it unveils itself as a system of relations belonging to a bigger system. For the same example of the standard wall with door opening, these relational features capture not only the relation between wall and door, but also the relation between wall and surrounding spaces, between door and architect, and so forth.

Knowledge of the constructive characteristics is essential when appropriate maintenance actions or similar interventions are required for the preservation of the quality of the artifact; but all these features are also fundamental to carry out other analyses that involve evolutionary, energy, structural, perceptive characteristics. Knowledge of the relational features allow the comprehension and description of the artifact with more details and the improvement of its management. In the following section, we document the way in which we aim to capture this information and represent it in a reusable format using the appropriate technologies.

3. DISCOVERING THE INVISIBLE: METHODOLOGICAL APPROACH

The historical built environment is constituted by a variable number of artifacts and buildings that, in most cases, are not well documented. The lack of an appropriate documentation to manage maintenance operations or other (conservative) interventions can be attributed to several factors. In general, even newly built constructions often differ notably from the initial graphic works, also following a well-documented project. According to the various cases and to this situation, it is important to implement and improve the existing documentation or to create new documents. In order to describe, manage and analyze a built heritage project appropriately, it is necessary to understand it, so that information in the project can eventually be organized as correct as possible. With this aim, we suggest the procedure that is summarized in Table 1, consisting of a learning phase, a digital reconstruction phase, and a semantic enrichment phase.

Table 1: Summary of the main methodological phases.

Phase	**Main actions**
Learning phase: *Research and selection of information*	historical pictures; original drawings of the tower from the digital archive of the library of Ghent University (floor plans, elevations, sections); publications in Flemish language (old journal articles); various master thesis; an on-site survey which was documented with a series of photographs, sketches and specific measurements; a literature review of historical documents describing the construction of the tower; existing 2D CAD drawings made available by the responsible university service.
Digital reconstruction phase: *Digital reconstruction in a BIM software*	definition of which element build as parametric objects, and in which way; digital reconstruction in Revit of the bearing structures, of the closures and partitions); creation of new classes and families

Semantic Enrichment phase: *Modeling of the ontologies in an ontology editor*	IFC model was converted into an IFC/RDF graph; choice of the basic terms (taxonomy) appropriate for the ontologies; schemes on paper to understand the relations among the technical elements and the new information; definition of the ontologies in TopBraid Composer ontology editor

3.1 Understanding the complexity of the historical built environment

In an initial learning phase, one goes through all kinds of relevant information sources to construct a personal understanding or a mental model of the building. In order to understand a complex system like an existing building/artifact, it helps to break it down into simpler elements and organize this information. We will therefore use a classification scheme.

There are several criteria to classify the technical elements of a building when aiming to support the comprehension and organization of the constructive features. Which criteria are chosen and used depends on the final objective and how the information will be reused. Taking into account purposes like preservation, maintenance, renovation, etc., a functional classification was chosen based on the functions performed by the individual elements. For this reason we chose to take, as general reference, a scheme that meets these requirements, namely the UNI Norms, from the Italian Normative, that define a building as a constructive system. These Norms identify eight (8) different fundamental technological units as follows: structure, closure, internal partition, external partition, plant delivery services, safety system, internal equipment and external equipment (UNI Norm 8289/2, 1981). The UNI Norms have been used by one of the authors in several researches (Di Mascio, 2009 and 2012).

It is necessary to highlight that the UNI Norms are generally used for modern/contemporary residential buildings. Hence, when applying them to historical artifacts and buildings, they need to be adapted or usefully interpreted. For instance, in most modern buildings there is a clear division between bearing structure and closures, in contrast to many historical buildings, in which both functions are performed by the same technical element, e.g. stone wall. Furthermore, many historical buildings present unique technical elements and details. Hence, it is often necessary to customize the classification scheme for each single construction. Despite the amount of structure and objectivity one puts in working with the documents resulting from this survey, it has to be clear that the way in which these documents are interpreted by us shapes how we understand the building and subsequently document it.

3.2 Digital reconstruction

With the term ‘digital reconstruction’ in Table 1 we refer to a process that foresees the action of building in a virtual environment an existing artifact that belongs to the historical and contemporary heritage of a particular region. Our built heritage is increasingly described, managed and analyzed using information and communication technology (ICT), thereby creating a considerable amount of virtual heritage. As demonstrated in earlier studies (Pauwels et al., 2008, 2009; Di Mascio, 2009, 2012), the usage of ICT instruments and methods in the reconstruction and critical analysis of our built heritage opens up new possibilities in information communication. “*Models not only illustrate what we knew when we started creating them, they also have the potential of revealing new knowledge that was always lurking below the surface of the facts but which, to emerge and be grasped, needed to be visualized in 3D*.” (Frischer 2008).

Therefore, the realization of a digital model is not the only purpose. The reconstruction process also contributes to deepen and broaden the knowledge of the artifact. The information gathered and analyzed during the learning phase (section 3.1), together with the knowledge developed during the digital reconstruction phase allow the analysis and disassembly of a historical building, by following a reverse engineering approach, in a 3D modeling environment. The digital reconstruction phase is an interactive process, because, after the analysis and interpretation of the available documentation related to an artifact and during the digital reconstruction itself, the designer can verify the correctness of his interpretations: hence he receives feedback from the model and acts accordingly.

There are various aspects that have to be considered when undertaking a three-dimensional digital reconstruction process of an artifact or building. Some of the most important aspects concern the level of abstraction, the geometry and the organization of the 3D objects belonging to the 3D digital model (Di Mascio, 2012). Different software packages can be used for the 3D digital reconstructions, including, for instance, software for 2D-3D drafting, 3D modeling and building information modeling (BIM). BIM software is mainly used in the design and management of new construction artifacts, but there are some outstanding characteristics of this technology that could be very useful in the documentation, management and analysis of the existing built environment. One of these characteristics is the focus on modeling (parametric) information, rather than mere geometry.

When modeling an (built heritage) artifact in a BIM environment, it is necessary to first determine the class (or family) of the technical elements of the artifact, instead of creating an element such as a window or a pillar only with geometric objects. The affiliation to a specific class defines both the geometric features, which can be fixed or parametric (variable according to the values of some parameters), and a set of relations and norms to control the single parameters. As a result, the model built within a BIM environment will be different from a model realized with any other 3D modeling program. In the latter case, the purpose is often limited to representation or visualization and the objects are only surfaces or geometric solids. In the former case, on the other hand, the virtual model is built including the information that is related to the diverse technical elements (walls, pillars, slabs, doors, windows, etc.). This means that information is associated to each element in order to describe its dimensional, constructive, material and economic features. This results in an information model of the artifact, which can be used for analyses, tests and calculations of various kind. By considering the parametric 3D model, it is possible to automatically generate the traditional 2D graphic works (plans, elevations and sections), in addition to schedules and other output.

3.3 Beyond the static classification: the ontologies

So far, we have considered the building system as something isolated from any other context and unchangeable in time. In reality, each architectural artifact/building is accompanied by a story that starts with its creation and finishes with the end of its use. To be precise, this story could continue also after the end of its use, with the dismissal and recycle or reuse of technical materials or elements ("cradle to cradle"). This story is about the building in all its material and immaterial parts, and about the relationship between the artifact and the environment, built or natural, close or distant. For example, in terms of sustainability it helps to immediate analyze how the artifact is linked with the use of environmental resources. Therefore, in order to represent the memory of a building as such, also useful information from domains outside its initial static classification scheme needs to be represented.

It is evident that a building can be described by a big quantity of heterogeneous data belonging to various knowledge domains. However, linking such data sets together is less evident. Not only different words refer to different meanings or to different information within two disciplines, also identical words often assume very different meanings. These differences also exist between various classification schemes. Hence, this raises the need to communicate and organize data and information among the various domains using a common language. An answer to this practical need has been identified in the knowledge management domain, and in particular in the description and usage of ontologies in this domain. The term ontology, used in the singular form, refers to a field of philosophy (among other things, these are its roots), but there are many other definitions in relation to different contexts. We will refer here to the definition of ontology used in the ICT sector, and in particular in the study of artificial intelligence and knowledge representation, hereby relying on the double definition given by Gruber (1993):

"A specification of a representational vocabulary for a shared domain of discourse — definitions of classes, relations, functions, and other objects — is called an ontology. [...]"

"An ontology is an explicit specification of a conceptualization, [in which a conceptualization is defined as] the objects, concepts, and other entities that are presumed to exist in some area of interest and the relationships that hold them (Genesereth & Nilsson, 1987)."

Therefore, an ontology includes within the same descriptive system both the concepts of a knowledge domain and the relations between these concepts. This way of describing an artifact highlights the relations hidden between various types of information. In this way, many architectural constructions belonging to the historical built environment can be documented and analyzed in innovative ways. It is important to clearly define the usage of an ontology, in addition to the comprehension of its definition (Gruber, 2001). For the creation and the manipulation of ontologies one can rely, for instance, on semantic web technologies (Berners-Lee et al. 2001), which include several standard ontology editors. The ontology editors provide tools to develop ontologies, to visually represent them through graphs, and to test their functionality. The graphic representation of the ontologies is very useful for the understanding of the relations. In a graph, the nodes represent the concepts, while the arches represent their relations. Instances, which are specific examples of information, can represent textual documents, images, bibliographic references, etc. As such, these editors provide the possibility not only to describe and visualize a knowledge domain constituted by classes, properties, instances and relations, but also to link these knowledge domains together explicitly.

4. THE CASE STUDY: THE BOOK TOWER

In our case study, we focused on the tower of the University Library of Ghent, which is also called the Book Tower. The Book Tower (Figure 1) is a famous 20th century building designed by the Belgian architect Henry Van de Velde in 1933, and it is located in the city of Ghent, in Flanders. The tower is 64 meters high, and it is composed of four floors in the basement and twenty floors above ground level. At the top of the tower, there is a panoramic 'belvedere' that overlooks the city at 360°. The floor plan of a standard floor has a squared shape, with three narrow windows on each side. For each floor there are 108 well-pillars. Such a number is justified by the amount and weight of the books on the shelves. For the construction of the tower Van de Velde decided to use reinforced concrete, which was a sign of modernity. The building's value is linked to different aspects: the name of the architect, the materials and the constructive techniques used (innovative at that time), the symbolic value of the building in the skyline of Ghent, where it represents the fourth tower of the city, a tower representing wisdom after the medieval towers of the Belfry, of the Saint Bavo Cathedral and Saint Nicholas' Church, and so forth.

Fig. 1: (left) the tower in its urban fabric pictured from the top of the Belfry; (right) two views of the Book Tower from the street. (Source: personal archive of the authors).

4.1 Constructive characteristics: issues and methodology

To digitally reconstruct the model of the tower in the BIM environment, in this case Revit Architecture, useful information had to be selected among the available information. The original drawings of the Book Tower were collected in the digital library of Ghent. This includes plans, elevations and sections, with varying level of detail. Various dissertations and publications, often in Flemish only, are accompanied by pictures and digital reconstructions, which have helped to understand aspects of the building. These documents also include information about Van de Velde and architectural references useful to comprehend his design choices. After a first vision of these documents, a first inspection of the building was made, with the aim of making a photographic survey.

4.1.1 Digital reconstruction of the Book Tower

During the digital reconstruction phase, it has been essential to document inspections of technical elements and diverse unclear details with pictures, sketches and metrical surveys (Figure 2).

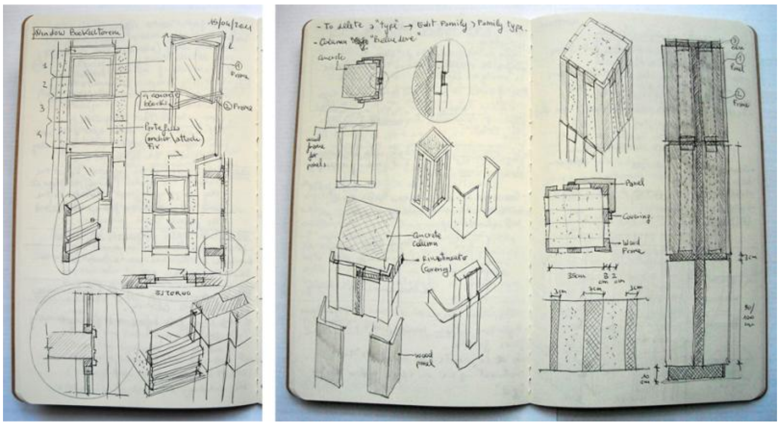

Fig. 2: Preliminary sketches to interpret the technological-constructive system of the windows of the central body of the tower and pillars of the panoramic belvedere.

Because of obvious reasons, certain assumptions had to be made regarding inaccessible areas of the building. However, a careful internal and external examination of the Book Tower has permitted to identify areas where the deteriorated condition of technical elements (i.e. lack of plaster on walls) have shown and hence permitted to document details that were generally hidden (thicknesses and materials). The digital reconstruction phase includes elements belonging to the following classes of technological units: the bearing structures (walls, pillars), the closures (walls, windows) and the internal partitions (walls, shelves). Revit has a classification of *types* and *families* which have their own semantics (parameters and structure). Because most elements of the Book Tower are not standard, it was not possible to adapt the objects in Revit by simply modifying the parameters. Thus it was necessary to create new families and types with their parameters.

4.1.2 The constructive-technological aspects and the definition of the parametric objects

Before starting the modeling phase, it was necessary to identify the elements that have to be considered in the digital reconstruction process and with which level of detail. In general, the UNI Norms have been a reference also to classify the technical elements into specific categories and so to choose in how many parts they should be divided. Questions like the following arose: "in how many parts should the window frame be divided? Should the concrete bricks be modeled, or can we make the approximation of modeling one wall with the added material property 'concrete'?". Answering these questions is essential, because the quality and the kind of information extracted from the model and inserted in schedules, depends on these initial choices. Therefore, it is important to carefully plan the modeling phase.

The first object that has been created was the window that is repeated 12 times in each of the 108 floors of the Tower. The only windows that differ from this standard or typical window are the windows of the basement, which are different in height, and the windows of the belvedere, which have completely different shapes. Before all these windows were modeled, questions like the following were answered in order to plan the modeling phase. Of how many elements is the window composed? What are the fixed and moving parts of the windows? In which direction can the window be opened? How is the frame connected on the wall? Is there a lintel or a sill? Which materials are used? Once these questions were answered, the window has been recreated in Revit as a new family (Figure 3).

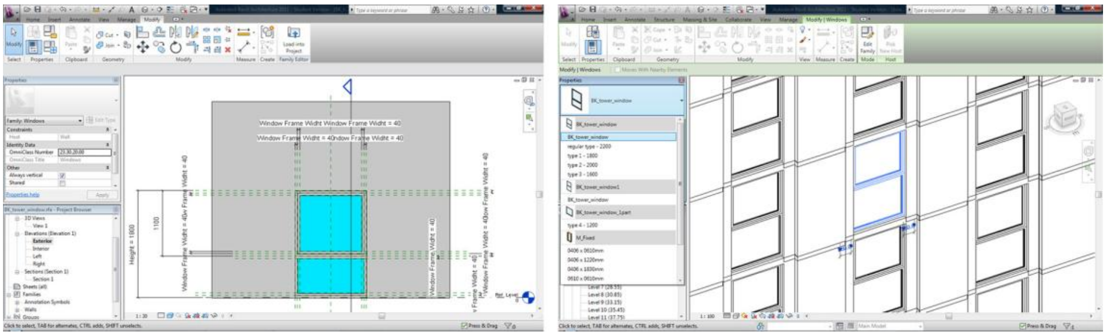

Fig. 3: Creation of a new family for the windows and definition of parameters.

The digital reconstruction of the perimeter walls, in particular the vertically oriented areas close to the windows, was not straightforward. The windows in the facades are bordered by two vertical rows of concrete blocks that continue uninterruptedly from the basement to the top floor. As analyzed and reported on some sketches (see Figure 2), every four blocks of concrete correspond approximately to a window or floor height. The two extremes of these borders coincide with the middle of the inferior and the superior floor. Considering that Revit only allows the insertion of windows inside a wall, a third wall had to be modeled just for inserting these windows. This was the most adequate option considering the available information and tools. For what concerns the representation, this has been an acceptable choice, but on the constructive level the two rows of vertical blocks will appear in the lists of the elements with the same acronym, because they indicate a single wall.

Another interesting technical element is a typical column of the belvedere. The columns are in concrete as the entire bearing structure and they have a wooden panel covering up to a certain height (about 4.30 m). Also in this case a slightly detached panel has allowed the discovery of a supporting wood structure, which would have been impossible to find out in other cases). The wood frame is constituted by vertical and horizontal square sectioned elements, finished by wedged panels with an "L" shape. A new parametric object was created in Revit using different separate solids (Figure 4). A distinct material was assigned to each single solid.

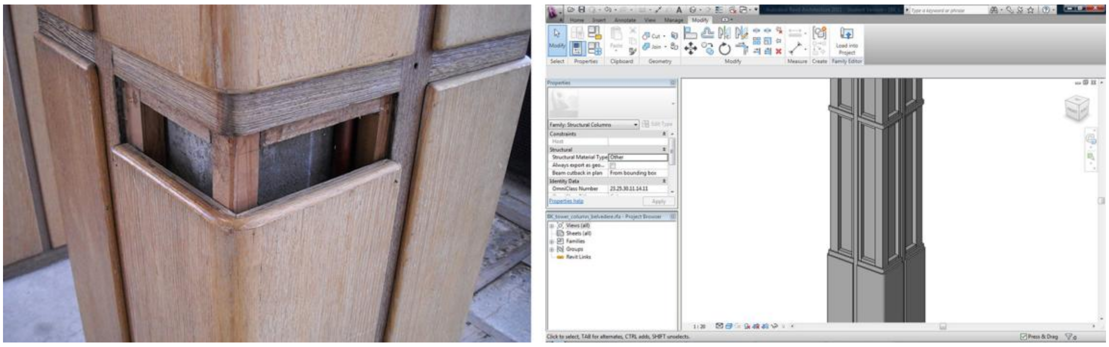

Fig. 4: (left) Picture of a column of the belvedere; (right) a 3D view of the new parametric object of the column.

4.1.3 Generation of schedules

Every technical element in the virtual reconstruction is highlighted by a number and an acronym that identifies a particular category and a particular floor of the tower. The indicative information is assigned even through a grill of invisible vertical floors that defines the position of those objects that belong to the model. In the end this has allowed to automatically obtain several custom schedules, each one with the aim of highlighting and documenting particular characteristics of the artifact.

4.2 Relational characteristics: issues and methodology

4.2.1 Acquisition of the basic documentation and semantic enrichment

The objective of this phase is to enrich the already obtained documentation with additional information of various kinds, organized within an ontology. The BIM model in Revit constitutes the basic information that has to be broadened and enriched with further information. To semantically enrich this BIM model, it is necessary to define one or more knowledge domains and the relations between the classes belonging to each domain. All the ontologies are here considered as part of a central ontology of the tower.

We chose to define six domains, each represented by a distinct ontology with a variable level of detail. For the definition of each ontology, and of the terms to use, we have consulted both online and paper resources. The experimental nature of this research has allowed us to define terms with some degree of freedom, but we tried to build the ontologies so that they can be considered representative at least for a broader audience and for broader common knowledge. The basis of the ontologies has been discussed and defined using paper and pencil, and only in a second step the modeling of ontologies moved towards an ontology editor.

Table 2: The six ontologies that have been defined with the purposes to representing the Book Tower from different points of view.

UNIOntology	the ontology constituted by the classification suggested by the UNI Norm 8290 (September 1981) for the breakdown of the technological system; they provide another classification scheme of the technical elements of the tower, in relation to the scheme used in Revit;
BuildingDesign:	this ontology contains the information about the design of a building (architect, planning references, constructor, etc.);
DocumentationOntology	this ontology describes the available documents (books, images, texts, drawings, video, web sites, etc.);
BuildingDegradation	this ontology describes degradation information (origin of degradation, pathologies of degradation, evolution of the pathologies, change of performances, intervention procedures, guidelines, etc.);
MaterialOntology	this ontology describes material information (constructive materials, raw materials, renewable materials, properties of the materials, etc.);
LocationOntology	this ontology describes geographical locations (countries, regions, cities, villages, etc.).

The BIM model has been exported from Revit into the Industry Foundation Classes (IFC) scheme, which is a standard recently developed in construction industry for describing building information. Second, this IFC model was converted into an IFC/RDF graph using the IFC-to-RDF converter service (UGent Multimedia Lab, 2013). After this step all the information related to the BIM model has been made available in an RDF graph.

For modeling the six other ontologies shown in Table 2, we used the TopBraid Composer ontology editor (Maestro Edition). This ontology editor relies on the Resource Description Framework (RDF) for building graphs. The resulting RDF graphs represent information about the Book Tower and can be understood as directed labeled graphs: a logical AND operator is applied to a range of logical statements containing representations of concepts or objects in the world and their relations. These statements are RDF triples, consisting of a subject, a predicate and an object. Each ontology has a variable level of detail. For instance, the ontology referring to the UNI Norms presents a taxonomic, hierarchical structure, composed by 42 objects that represent classes and subclasses. On the contrary, the ontology location is constituted by 5 objects, among which classes and subclasses. This differentiation is given by different types of information that each ontology represents. The objectives of these ontologies can be synthesized in two main aspects: to enrich the BIM model with new information and to assign to each element a different ontology to improve the information communication between expertise pertaining to other fields. After all classes and properties are modeled, each ontology is populated by a variable number of instances. It is important to remember that instances are concrete examples of information (used documents, materials, etc.). To each instance, one or more properties is assigned, providing different information. For example, an instance of a book has two properties: the first is related to the code that identifies the location of the book in the library; the second refers to the hyperlink of the book sheet available on the website of the University of Ghent Library. Other instances present links to DBpedia which provide general information about specific instances in the building model.

The added value of the ontology not just consists of the possibility of specifying the relations between the classes and consequently also between the instances. The main added value is that all this information can be made publicly available to a wide audience, in a language (RDF) that can be understood by the systems that they use, so that this wider audience can reuse this information in other contexts (including building maintenance or restoration projects). In order to query the ontology in an efficient way, it is necessary to create a widespread network of relations between the instances. This is a procedure that allows a better description of the building. All ontologies are connected to create a single description of the Book Tower; the central ontology of the building was named *Building Ontology*. Through the option *HTML generator*, the whole ontology has been exported and it could be consulted as a web site, through hyperlinks.

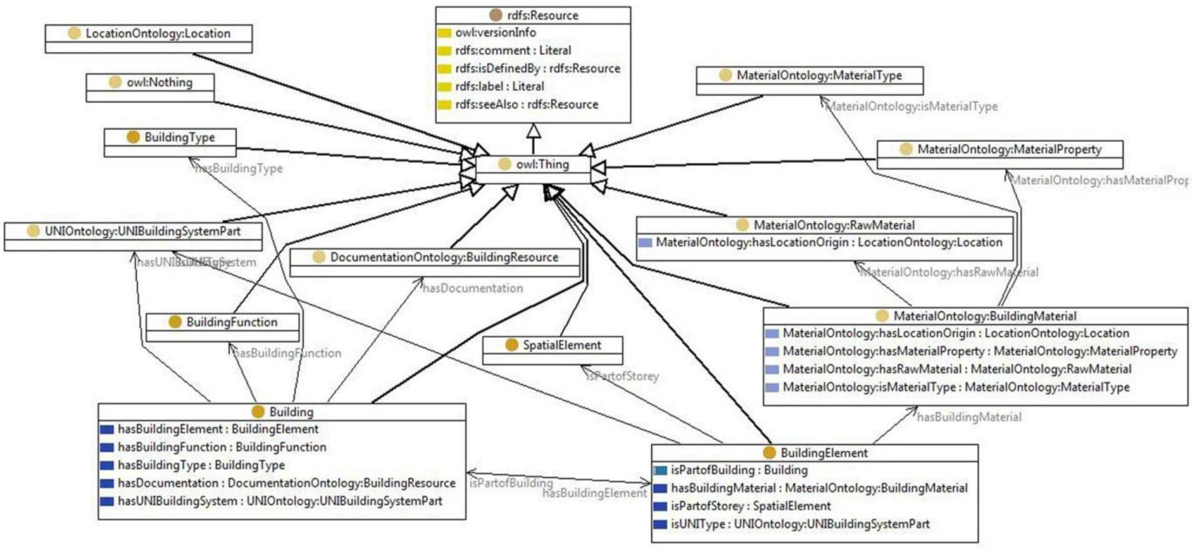

Fig. 5: Diagram of the relations, within the *Building Ontology*, among the classes belonging to the single ontologies.

5. DISCUSSION OF THE RESULTS

A digital model has been built in a BIM environment for analyzing the constructive characteristics of the Book Tower. This model allows to manage the high number of technical elements of the tower which are repeated in each floor, and to create tables with various information (dimensional, material, etc.), useful to manage a maintenance plan. The digital reconstruction of the Book Tower has arisen some reflections concerning the use of BIM software for the documentation of existing artifacts. In order to realize a BIM model, one needs to take care of the way in which the geometric and constructive aspects are modeled. In the BIM model, the technical elements and their constructive relations need to be clearly defined. For example, it is necessary to avoid mistakes like the penetration of solids that represent serious constructive mistakes. The quality of the modeling depends both on a correct understanding/interpretation of the constructive system of the real building/artifact, and from a correct use of the methods and tools in the BIM environment. This is not different from the way in which any other 3D modeling package should be used.

The use of ontologies has allowed to enrich the BIM model with information that documents the aspects linked both to the life cycle of an artifact and its cultural features. By linking the BIM model to the UNI Norms classifications in the TopBraid ontology editor, it has also been possible to provide an additional terminological interpretation of the constructive system of the Book Tower. As a result, the technical elements of the Book Tower can be read either according to the Revit ontology or according to the UNI Norms ontology. In this way it widens the communicability of the information.

Both the digital modeling and the semantic enrichment phase of the considered digital heritage project confirmed how essential a careful initial planning phase is. It is necessary to carefully define the objectives that one wants to reach. From this information it is possible to choose an adequate terminology and taxonomy. There are diverse interpretations through which an artifact can be represented and the creation process on such representations always is an iterative process that is characterized by continuous adjustments.

6. CONCLUSIONS

In this paper we have elaborated and proposed a methodological path (in detail: a theoretical framework, methods and tools) to improve the comprehension and documentation of buildings/artifacts pertaining to the historical built environment. The BIM modeling environment proved to be a tool fit for the digital reconstruction and management of the constructive characteristics of a building pertaining to the historical built environment. Some features of the BIM modeling environment are obviously created for new constructions, which could result in some difficulties regarding the reconstruction of constructive and formal nonstandard solutions (e.g. window sidings of the Book Tower). But in general, BIM modeling environments prove to be relevant for the digital reconstruction of buildings belonging to the historical built heritage. Through the digital three-dimensional model it is possible to make further analyses, like the ones related to energy and structural aspects; it is possible to design and manage renovation and requalification interventions, in order to save time and economic and material resources; and so forth.

The elaboration of specific ontologies and their connection and representation using ontology editors allows to understand, visualize and communicate heterogeneous information linked to the studies artifact. Through this network of relations it is possible to rebuild the links with the place of the building, with the experts that have worked for its construction, with cultural references to those elements that have influenced the design and constructive choices, with the origin of the materials and of the technical elements, with the available documentation related to the building and its technical elements, and so forth. Once this complex network of relations has been built, it is possible to use it in preservation and maintenance actions. These actions can consequently take into consideration the functional aspects as well as the cultural value of the artifact/building and of aspects linked to the sustainability.

Both the three-dimensional model and the ontologies contribute to improve the dialogue among domain experts and professionals who collaborate during the maintenance, preservation and renovation processes. The shared conceptualization represented by this model and the ontologies allows domain experts with various aims to clearly interpret and use the represented information for their purposes. Of course, in specific (maintenance or preservation) projects, the decisions still need to be coordinated by a central figure, for example an architect, in order to reach a well-defined general objective. The instruments and methods outlined in this paper can of course be used in real world built heritage projects, but, with the adequate adjustments, it can be applicable also to other projects and objectives. One such objective can be the diffusion of heritage information in real and virtual museums for cultural purposes. The Finnish CultureSampo platform (Hyvönen et al. 2009) is a recent example of such a semantic cultural heritage platform. Other objectives can also be targeted, simply because semantic web technologies allow to widely spread knowledge to interested parties, while also enabling these interested parties to understand the meaning of this information.

7. ACKNOWLEDGMENTS

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