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Original article

Knowledge-based data enrichment for HBIM: Exploring high-quality models using the semantic-web

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ABSTRACT

In the last decade, the paradigm Historical Building Information Modeling (HBIM) was investigated to exploit the possibilities offered by the application of BIM to historical buildings. In the Cultural Heritage domain, the BIM-oriented approach can produce 3D models that are data collector populated by both geometrical and non-geometrical information related to various themes: historical documents, monitoring data, structural information, conservation or restoration state and so on. The realization of a 3D model fully interoperable and rich in its informative content could represent a very important change towards a more efficient management of the historical real estate. The work presented in these pages outlines a novel approach to solve this interoperability issue, by developing and testing a workflow that exploits the advantages of BIM platforms and Semantic-Web technologies, enabling the user to query a repository composed of semantically structured and rich HBIM data. The presented pipeline follows four main steps: (i) the first step consists on modeling an ontology with the main information needs for the domain of interest, providing a data structure that can be leveraged to inform the data-enrichment phase and, later, to meaningfully query the data. (ii) Afterwards, the data enrichment was performed, by creating a set of shared parameters reflecting the properties in our domain ontology. (iii) To structure data in a machine-readable format, a data conversion was needed to represent the domain (ontology) and analyze data of specific buildings respectively; this step is mandatory to reuse the analysis data together with the 3D model, providing the end-user with a querying tool. (iv) As a final step in our workflow, we developed a demonstrative data exploration web application based on the faceted browsing paradigm and allowing to exploit both structured metadata and 3D visualization. This research demonstrates how is possible to represent a huge amount of specialized information models with appropriate LOD and Grade in BIM environment and then guarantee a complete interoperability with IFC/RDF format. Relying on semantically structured data (ontologies) and on the Linked Data stack appears a valid approach for addressing existing information system issues in the CH domain and constitutes a step forward in the management of repositories and web libraries devoted to historical buildings.

1. Introduction

Nowadays, Building Information Modeling (better known as BIM) has become a globally spread standard able to ease the project collaboration, the data integration and to support project activities. Even if it was initially conceived for the planning and design phases of a project, it is actually used in the construction for a wide range of applications such as 4D simulation, clash detection, and providing detailed spatial and material quantities [1]. The strength of its approach resides mostly in a shift of paradigm in the workflow of a project, focusing all the decisional process in the early stages, improving transparency and interoperability for all the actors involved in the decisional and managerial phases. However, despite BIM's efficiency on new buildings is widely proven, there's a lot of uncertainty when dealing with historical buildings.

The reason of this mainly depends on the purpose that drove the development of BIM, conceived for architectural design. Consequently, parametric objects are not suitable for the modeling of existing historical architectural elements. Moreover, another bottleneck is represented by the lack of complex components or by the inconsistency in the geometric representation of irregular shapes. As a matter of fact, often the modeling tools in the existing platforms perform very simple operations that are not always sufficient to geometrically describe the complexity of the real object, because of the high level of geometric abstraction.

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However, in the last years, research was oriented toward the "HBIM" paradigm, which is the acronym of Historical (or sometimes Heritage) Building Information Modeling and investigates the possibilities offered by the application of the BIM approach to historical buildings [2]. There are several important differences between HBIM and BIM, arising from inherent characteristics of historical buildings like the uniqueness of components and the absence of the concept of life-cycle [3]. In fact, an historical building is the product of a non-industrial process of construction and all the uses of a management tool are motivated by analysis, conservation and maintenance purposes. Due to these issues, it is worthwhile to investigate the possibilities offered by management tools to be exploited also in the Cultural Heritage (CH) domain.

The obstacles preventing HBIM towards a complete conversion in practical use are twofold: the data enrichment and the 3D interoperability, described in the following.

The data enrichment (and its related information management) represents the crucial part of the HBIM model, because it is intended more as a data collector rather than a geometrical representation. In a BIM-oriented approach we must imagine our model populated by both geometrical and non-geometrical data which, in the CH field, embodies a large set of information related to various themes: historical documents, monitoring data, structural information, conservation or restoration state and so on.

The realization of a 3D model fully interoperable and rich in its informative content could represent a very important change towards a more efficient management of the historical real estate. Nonetheless, storage, portability and interoperability issues among architects and cultural heritage actors dealing with 3D technologies remain a huge challenge [4]. In fact, digital repositories seem unable to guarantee affordable features in the management of 3D models and their metadata; this is mainly because of the nature of most of the available data format for 3D encoding, not suitable for the necessary portability required by 3D information across different systems.

However, many ontologies and schemas are available which produce standard sets of metadata, providing rich collections of classes and properties to capture every degree of granularity required for the description of 3D models and for their enrichment with annotations. Even if some attempts have been carried out to facilitate accessing these information to the majority of the users [5], the research community is focusing his efforts in the portability towards the web, since it is able to reach the most of the users, exploiting its advantages like accessibility, data visualization, interactive interfaces, inquiry facilities and enhanced access to remote repositories [6]. Also BIM systems designed for CH could benefit from this process.

Thus, whether the semantic structuring of the 3D model allows organizing representations over time, taking into account the variety of hypothesis, the data enrichment process is mandatory to relate attributes describing time, the hypothetical value of the reconstruction and its reliability [7].

In this perspective, several points must be discussed and analysed: how to manage that information in a hierarchical way, how to connect them to a model and how to ensure the interoperability of data enrichment with non-proprietary tools. The previous points could be summarized in the following research challenge: how one can use semantic-web techniques for a more efficient survey of multiple cases data as a tool of comparison in support of any decisional process?

From the above said, emerged the need to create a shared parametric semantic-aware repository, based on an ontology-oriented approach, allowing a full interoperability among the implemented data enrichment and the developed 3D model.

The work presented in these pages outlines a novel approach to solve this interoperability issue, by developing and testing a workflow that exploits the advantages of BIM platforms and semantic-web technologies, enabling the user to query a repository composed of semantically structured HBIM data. As stated in the research aim section, a description of interoperability between BIM generated resources and semantic technologies for web applications is provided. Will be addressed the topic of how semantic-web technology can be exploited to provide semantic interoperability, working on complex Romanic architectures and other set of BIM models. The remainder of the paper is organized as follow:

Section 3 will be dedicated to the description of the whole workflow and to the discussion of the various steps towards the realization of the prototype Web application. The latter allows to query and visualize specific and complex architectures, as explained in the Section 4. The results obtained with the workflow and the potential of semantic-web applications for the CH domain are discussed in Section 4 as well.

Concluding remarks and new scenario offered by our approach are outlined in Section 5.

2. Research aim

From the introduction section emerged the need of a real semantic interoperability solutions between the models developed into a BIM platform and their interpretation, management and querying in a more practitioner-centered environment. This is mainly because, enabling interoperability at a semantic level plays a pivotal role for bringing the benefits of BIM modeling and data enrichment. The choice of using technology is a natural and effective way to convey the meaning, which can be structured in a machine-readable format and interpretable by the insiders.

Taking advantage from the historical case study that will be shown in the paper, the aim of this work is to validate a workflow capable of grouping and organizing all the available information in a database managed in a hierarchical way by means of ontologies (including in our case taxonomies). By establishing a connection between the database and a proper HBIM model with sufficient level of development, we were capable to deliver in one solution the activities of building management. This work also provides a study of the interoperability of the data connected, analysing the possible usage of any actor of the process, even if not in possess of any BIM-authoring platform.

3. Materials and methods

3.1. State of art: HBIM, interoperability and data management

The first definition of HBIM appeared in 2009, due to Maurice Murphy [8]. According to this definition, a HBIM is composed by a library of parametric objects and a system capable of mapping those objects to survey data, like point clouds or images. Whilst other definitions appeared in the literature [9], the research community came up with a common thread defining HBIM as the process of creation of a model starting from survey data (i.e. Terrestrial Laser Scanning (TLS), digital photogrammetry, etc.), aimed at the creation of a library of parametrical objects, combined with the informative data in order to enrich the object besides the modeling phase [10].

The difference between BIM arises from the goals of defying the state of conservation and planning future operations, rather than the realization or the computing phase (which is a BIM prerogative). More in general, literature shows that the existing gaps originate from differences between processes for as-planned building and processes for as-built model [11].

The development of BIM approach in Architectural Heritage (AH) domain faces the following challenges and needs: semantic object vs. unsegmented geometries, standardization vs. irregularity

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