An ontology-based platform for BIM semantic enrichment

Stefano Cursi[1], Davide Simeone[2], Ugo Maria Coraglia[3]
[1,2,3]Department of Civil, Construction and Environmental Engineering, Sapienza University of Rome, Via Eudossiana, 18, 00184 Rome, Italy
[1,2,3]{stefano.cursi|davide.simeone|ugomaria.coraglia}@uniroma1.it

In its application to design phases, BIM has progressively shown limits in terms of semantic representation and efficiency of supporting collaboration. This paper investigates the possibilities related to BIM representation enrichment through semantic web approaches, in order to represent knowledge rather than information and presents a prototypal application oriented to the integration of the informative model of the building with a knowledge base developed by means of ontologies, providing a more structured system of interconnected information.

Keywords: *BIM, Semantic enrichment, Knowledge Management, Ontologies*

INTRODUCTION

Since its introduction into the AEC field, building information modeling (BIM) has been appointed as a shifting point in the representation, exchange, sharing and management of information during design, construction and maintenance activities. In particular, some of the main causes of BIM spreading in the construction industry can be found in its ability to integrate geometry and semantics in a single modeling environment, providing each object with a set of non-geometrical information able to represent all its determined attributes. Although extremely powerful in theory, this approach is currently suffering from the increasing number of knowledge domains involved in AEC processes, the introduction of new representation dimensions (progressively including variables such as Time, Costs, Lifecycle and, more recently, performances simulation) and, as regards the tools, from the growing amount of proprietary data formats and standards. In this context, the introduction of Industry Foundation Classes has just made things worse. In fact, despite the progressively increasing of dimensions to the BIM paradigm and the improvement in terms of interoperability, the excessive use of IFC standards is resulting in a dangerous "representation bottle-neck", that cuts off all the knowledge that is not structured or considered in them, while the quality of the information included in the model, its accessibility, its interpretation and finally its use, or rather the theme of the semantic enrichment, is still only partially unexplored (Simeone et al., 2013). While the knowledge about architectural artifacts progressively increases during the complex design process, information models remain poor in terms of semantics, and a large area of knowledge is not integrated into representative reference models.The BIM effect, understood as the widespread diffusion of the BIM paradigm in the construction world, has only highlighted this problem: on the one hand the models are increasingly enriched with information, on the other hand it lacks a conceptual and methodological approach that allows this knowledge to be exchanged efficiently between the various specialists involved in the design process of a building. The efficiency and accuracy of the representation of knowledge are hampered and therefore designers, customers, users and all the specialists involved in the process can access and base their decisions only on partial knowledge, increasing the risk of incurring in a low-quality design and therefore generate potential irreparable errors during the construction phase. Consequently, current approaches hinder this integration of information - provided by different sources of knowledge - which allows a single figure to gain significant added value. In the AEC field, the most advanced solution to have a formal, shared and explicit description of the building's information, is related to the use of particular models called ontologies (Gruber, 1993). These formal representations allow a coherent definition of objects, not only by describing their characteristics but also by the relationships that exist between them; so that we can express and share the meanings, structure, and nature of the material and immaterial concepts that belong to the various domains of knowledge involved. Concepts are represented by entities - concrete or abstract objects - grouped into classes whose identification requires a very careful evaluation of the meaning to be expressed and the semantics and properties that represent all of its aspects.At present, the formalism of ontologies is the most appropriate approach for the defined theoretical model and the purposes considered. To this end, the core of this model is a semantic structure in which all entities considered during the construction design process are represented in terms of characteristics and interrelated relationships, in accordance with the domains concerned. In this way, it's possible to provide a modeling environment where all building-related knowledge can be homogenously formalized, managed, processed and shared between the various specialists involved in the process.From an analysis of applications to AEC design process, the potential of semantic web technologies is evident and ontologies, which are progressively introduced in the AEC sector to support collaboration and sharing of knowledge among the various actors involved in the design process (Beetz et al., 2005), enable them to represent entities not only by describing their own characteristics, but also by the relationships between them, paying attention to the meaning of the concepts and the structure and nature of the domain of study.On this basis, this article describes a semantic bridge platform - called S-Enr BIM - which allows the integration of BIM with a knowledge-based modelling approach, such as the Building Knowledge Modeling (BKM) developed by Sapienza research group (Carrara et al., 2014) and conceived to provide an effective representation of all the necessary knowledge, managed and shared during a building design process; thus obtaining, in a single modeling environment, three-dimensional informational representation and all non-geometric knowledge provided and used by the various actors involved.

STATE OF THE ART

As illustrated, in this context, the information required for a complete understanding of the product is diversified, interconnected and, therefore, extremely difficult to represent and manage in a single information model. In addition, research has shown that sharing information alone is not enough for a true understanding and collaboration and that, in order to achieve this, it is necessary to provide the information together with their interpretive context.Recently, some research has investigated this topic - named as BIM semantic enrichment - proposing the integration of BIM representation schema with approaches and methodologies derived from the Semantic Web in order to enhance quality and level of non-geometrical information associated to tri-dimensional representations. In this field of research, as can be seen from some works by Eastman (2014), considerable efforts have been directed to improving interoperability through the development of new models and representation methodologies, usually through the implementations and possible evolutions of the IFC schemes.The development of an OWL version of the IFC schema, named ifcOWL (Beetz, op. cit.; Belsky et al., 2016) has partially fostered such approach but the choice of relying on IFC standards, although if in an ontology-based systems,

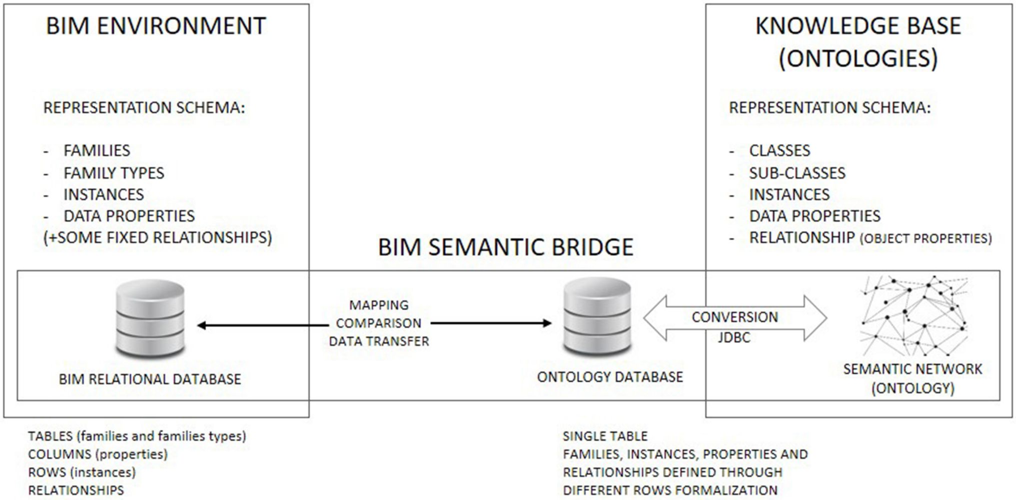

Figure 1
The conceptual schema of the BIM Semantic Bridge application.

still limits flexibility and specificity in AEC knowledge representation and management.In particular, in the last 20 years, the introduction of the Linked Data Approach and Semantic Web technologies has opened up new possibilities for the semantic enrichment of BIM. As described by Pauwels et al. (2013), the analogy between building representation schemes (e.g. IFC) and the descriptive logic of semantic networks (RDF and OWL) favored the creation of information ontologies in the AEC sector, usually in conjunction with IFC schemes and Express rules.

In 2008, Jeong investigated the use of ontologies for semantic sharing in multidisciplinary design. In the same period, Carrara et al. (2009) interprets the ontology as a way to move towards knowledge-based models to improve collaboration in the AEC processes, but to date, the collaboration support is precisely one of the aspects that are not solved in BIM and that, consequently, limit the real use in the field of building design.Similarly to the field of designing new buildings, some research has focused on the integration of semantic web technologies with Building Information Modeling to enrich the representation of historic architectural artifacts. Pauwels and Di Mascio (Di Mascio et al., 2013) rely on integrating the ifcOWL (linked to other heritage-specific ontologies) with game engines to provide a three-dimensional representation of architectural heritage. The mentioned researchers underline the potential offered by the integration of BIM environment with Semantic Web approaches; experiences that are gradually showing all the potential in enhancing the level of semantic representation in the AEC field, providing a bridge to overcome the actual gap and misalignment among the information represented in a BIM environment and those required to perform collaborative design activities.On this basis, the proposed model is conceived as an integration of the BIM modeling environment with a system of representation and management of the knowledge shared among the actors involved in the building design process.

METHODOLOGY

The conceptual structure of the model

During a building design process, a large amount of information is produced, used and shared by the many specialists involved, each using its own methods and timing. Therefore, it is evident the need for a tool able to support information management through a collaborative working environment capable of structuring and formalizing the knowledge acquired by operators.Unlike the existing knowledge management models, the integration of a semantic web-based structure with a BIM environment allows to include in a single model, in addition to the geometric representation of the building and the elements that compose it, also the whole semantics to which they can be traced and which affects the various actors involved in the design process.In the transposition from the semantic web to building information modeling, some of these concepts overlap the elements of families and instances, integrating and enriching the semantic representation of the building.As mentioned before, the proposed model consists mainly of two elements: 1) a BIM environment where the artefact representation is mainly limited to the geometric characteristics of its components; 2) a knowledge base, developed by means of ontologies, able to formalize and integrate the semantic belonging to different knowledge domains necessary to provide a representation of all the knowledge exchanged during the design process of a building.Although there are differences between ontologies and relational databases (Martinez-Cruz et al., 2012), as in BIM databases, this research exploits the two main analogies of BIM and Semantic Web modeling methodologies: 1) Object-oriented representation - 2) abstract/concrete specification (often known as class/instance relationship). In the BIM environment, buildings are decomposed into an organized set of entities and relationships that correspond to the technological components of the product and their relationships (such as assembling standards or those relating to constructive and behavioral relationships). Likewise, semantic networks are structured as node-oriented nets and strings where nodes are the concepts and strings represent the relationships between two concepts. This correspondence translates the BIM modeling structure into the framework of ontologies, integrating entities and relationships into a broader knowledge base that is able to uniformly formalize the representation of different domains of knowledge.The second analogy refers to the abstraction/instantiation process that can be traced both in ontologies and in the BIM environment: Building Information Modeling is based on a family type-instance scheme that can be considered as a simplification of the common class- Subclass-instance, typical of ontology-based systems. These similarities can also be found at the property level, since in both approaches the entities are represented in terms of properties that describe their main features, with associated values to define specific instances.By comparing BIM and semantic web representation structures, we are able to recognize how BIM semantics can be incorporated into a broader homogeneous formal representation where entities, relationships, and rules of the BIM are integrated with other concepts and relationships, extending its domain(s) and increasing the semantic level of representation. In the AEC field, this semantic enrichment process is particularly effective as it provides a homogeneous modeling environment where all knowledge of different domains (with concepts, definitions, patterns and formalization methodologies), necessary for a complete understanding of the design process, can be exhaustively represented and made computable.To validate the proposed research, an ad hoc tool has been developed in order to link the semantic networks formalized in the OWL language with a BIM environment (Figure 1).

S-Enr BIM: BIM and Ontologies for architectural design processes

Rather than passing through the IFC schema, the proposed platform directly connect concepts, properties, and relationships represented in the knowledge base with the objects modeled in the BIM environment. This approach results in the following improvements in terms of knowledge management: 1) major flexibility of the knowledge base that can be effectively adapted to the specificities of the AEC pro-

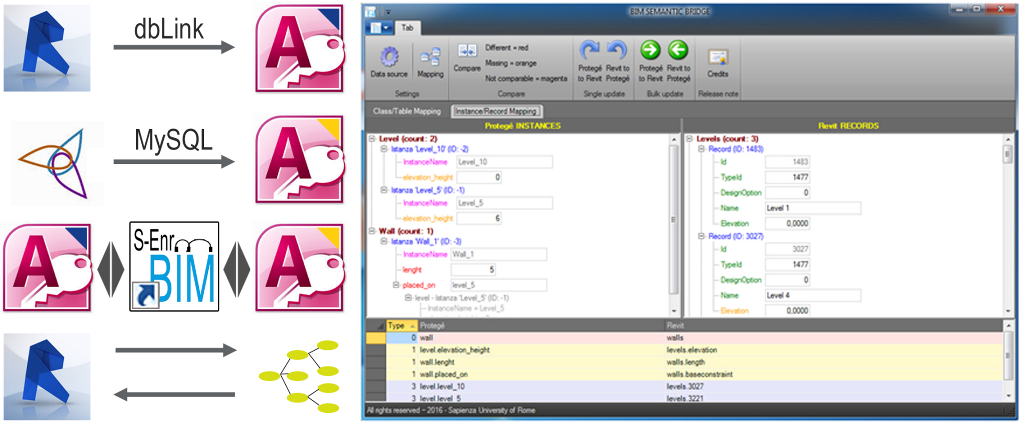

Figure 2
The developed software (S-Enr BIM) allows you to "map" the formalized instances of formal artwork into the ontology editor with their respective objects modeled in a BIM environment. The software imports the DBs of the two tools and allows comparison, verification and overwriting from one environment to the other and vice versa.

cess and of its final result, the building; 2) extensibility and reusability of the domains modelled through ontologies and of the related concepts, properties, and relationships; 3) user-oriented customization, not only of the knowledge base but also of the correspondences between concepts and objects in the two environments; 4) representation of knowledge not directly associable to building objects. Since these two representation approaches are based on different modeling principles and protocols, it was necessary to conceive a specific platform - that we defined as BIM Semantic Bridge - able to translate the two modeling environments in a homogenous format and to create correspondences between the different entities represented in them. The BIM semantic enrichment platform embeds a mapping engine that creates a direct correspondence between classes, instances, properties, and relationships. Such a connection (based on a list of couples) relies on a mapping schema that can be fully editable by users (even by using ifcOWL correspondences). Once the connection has been established, data and information can be exchanged between the two environments through simple overwriting protocols. The mapping flexibility is the additional value of the proposed platform: it allows different specialists to link their own concepts to the building information modeling entities, in accordance with their own domains and activities. Inferences and checking rules operate in the two parts of the platform depending on where the related information is located. In addition, the platform makes the knowledge management system leaner, since only the information related to mapped entities is exchanged between the knowledge base and the BIM environment. All the domain-specific knowledge, that the different specialists involved in the process don't share (or do not want to share), is part of the specialist ontology and, therefore, not transferred to the BIM environment. The implementation of the connection involves the following steps: 1) exports in Access format, through the plug-in DBLink, of the database containing the objects (and their properties) that make up the historical building modeled in Revit; 2) Conversion into a MySQL open-source database of the ontology formalized in Protégé OWL. This conversion produces an unstructured database but rather made up of strings in single-table format; 3) so is required a reading phase of the ontology database through a tool specifically developed by the research team, able to identify the strings regarding the instances related to the components of the building, the properties and the values assigned to them in addition to the Classes they belong to. 4) Manual mapping of the instances - with their properties -, corresponding in the two databases (Protégé-Revit) through the software developed by the research group (Figure 2).

The developed BIM Semantic Bridge operates to remodel the taxonomies of classes, properties, and related instances, of both databases sides, that of BIM and that of ontology, so as to allow the mapping and to perform comparison and data transfer. Currently conceived with a family-instances structure, BIM databases are organized as a set of connected tables, each one representing an element family with instances formalized in rows and properties in columns. Ontologies databases, instead, are usually made of a single table and the differences between classes, properties, relationships and instances are controlled through "type" values and identified with a unique string made of different substrings referring to the "mother class", the type, etc. By means of this structure, the taxonomy of ontologies results to be extremely flexible and adaptable to the specific knowledge domain to be represented. Classes and properties mapping are stored in a file and can be re-used in similar design processes that involve the same typologies of entities, reducing the time necessary to formalize all the relationships between the BIM representation structure and the ontology taxonomy. The more relevant contribution of the proposed platform is the possibility to customize such mapping organization, in order to integrate the BIModel with project-specific knowledge databases. To date, the instances mapping has to be re-performed for each project as it is still project-dependent. The software interface developed to connect the two databases can override in both directions, from the Database Protégé to the Revit one and vice versa, the values assigned to the properties "mapped" by the user. It is also possible to check for any inconsistencies between the values assigned to the properties of the mapped objects, in addition, to identify which existing information in a database result missing in the other. Through this system, it is possible to fill the knowledge related to the building and formalized in the ontology with the data retrieved from the objects modeled in Revit and vice versa updating the BIM model database with new values and definitions derived through the rules modeled in the SWRL language in the ontology. The prototype has been implemented using the most suitable resources made available by the development of computer technology regardless of the tools currently use in order to connect A BIM database underlying an Autodesk Revit model and formalised through the Autodesk DBLink application and an OWL database generated through the ontology editor Protegé 3.5 and an ODBC connection (Figure 3).

CONCLUSIONS

This research proposed a knowledge-based system integrated with parametric object-oriented modeling platforms to improve building process and to enhance collaboration among the involved actors. A model defined in this way can potentially both represent enough knowledge to set up and run a collaborative design process involving a number of specialists from very different specialized fields and represent the knowledge 'contained' in the final solution as the result of the design process.This approach has made a new definition of the workflow typical of the design process; the use of the plug-ins and computer programs implemented has shown how this approach can aid the verification of design rules and constraints, demonstrating the system's overall potential. The system we implemented attests good potential for proposing a new generation of assisted design tools, a field that permits the development of further research and analysis.In terms of the software application, has been presented a custom system that acts as a bridge between a knowledge base developed through the ontology editor Protégé and the BIM environment provided by Autodesk Revit. Our current work is focusing on improving the "semantic

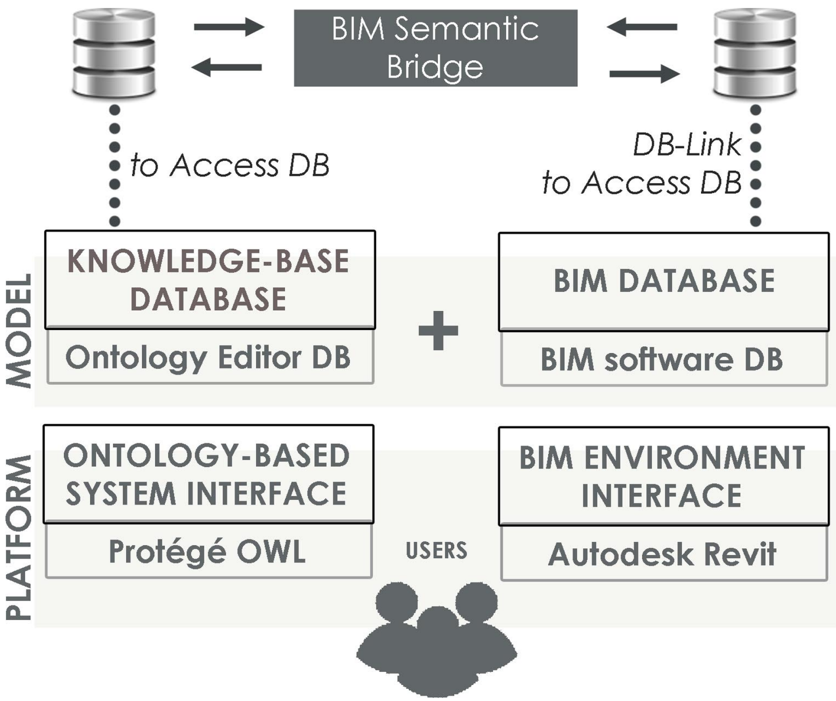

Figure 3
The model consists of an ontological knowledge base and a BIM environment; Ad-hoc software allows integration as well as the ability to perform verification operations between the two databases.

filtering" between knowledge domains for the various disciplines involved in the building design process, and how the knowledge-based approach might be integrated more effectively with that of Building Information Modeling.

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