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# TOWARDS A MULTI-FUNCTIONAL HBIM MODEL

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**Abstract**

In Europe the number of existing buildings is greater than new ones, therefore it is necessary to improve built heritage management through suitable IT tools. Actually, BIM is an innovative methodology to optimize building lifecycle. Since BIM was born for new buildings, there are difficulties in using it for historical architectural heritage. Thus, the purpose of the research is to describe a possible strategy to develop 3D parametric models that can be easily used for many uses through a set of rules based on the description of construction components oriented to different objectives, e.g. restoration, energy saving, structural monitoring, healthcare facilities. This paper aims to discover a possible approach to implement a generic HBIM model which can be developed through the combination with a model based on intelligent agents (ABM).

**Keywords**

HBIM, ontologies approach, data management, 3D modeling, built heritage, healthcare.

## *1. Introdution*

Representing building data within healthcare facilities is always a research field both for users' needs and for improving the efficiency of facilities. This paper aims to describe a possible strategy to develop 3D parametric models that can easily be used for various purposes using a set of rules based on the description of building components oriented to different objectives e.g. restoration, energy saving, structural monitoring, facility management.

In these terms, the selected case study for this paper is "Virgo Potens" healthcare structure located in the municipality of Moncrivello (Italy) and composed of several buildings developed in different times, starting from the XVI century (Fig. 1).

As this case study is an historical building that was renovated during history, changing its function from a seminar to a health residence for the elderly, the goal of developing a virtual building closer to the real one is one of the research challenges.

The interaction between construction industry and health sector allows the identification of an innovative methodology to create a virtual model of the building that is able to collect heterogeneous information in a several objects rich of geometrical and alphanumeric characteristics depending on the model uses. For these reasons, digital modeling has required the use of computer technologies that have made it possible to extend the use of digital models, in addition to aspects strictly related to graphic visualization, to complex information systems, in order to correlate information of different nature, producing real digital archives that can be used for the management of Cultural Heritage (Donato, 2018).

Since the advent of Computer Aided Architectural Design (CAAD), a wide number of researches have concentrated on the development of digital methodologies to support built heritage representation with particular attention to digital acquisition and virtual reconstruction and communication of historical artefacts (Kalay et al., 2007; Affleck et al., 2005).

The introduction of laser scanning and photogrammetry technologies allowed to reach accurate reality-based levels of representation, both in CAAD and BIM environments (Garagnani et al., 2013). Among the others, GIS is currently considered the most capable system able to integrate the geometrical representation of the artefact (i.e. data collected through laser scanner or photogrammetry technologies) with the related semantics, allowing actors and users to


**Fig. 1:** Case study overview

interrogate virtual 3D model to gain data and information. Nevertheless, while this system can be useful in representing consolidated information about the artefact after the construction process, several limits arise when it is applied to real time information management in heritage investigation and intervention activities (Simeone et al., 2014).

The starting point of this work was to propose a simplified methodology to connect BIM and GIS fields creating a tool for users who operate for the real estate management (i.e. public administrations). To do this, critical issues of this research were analyzed to identify possible links between same types of buildings built in different historical periods to create an "informative detailed model" able to be queried directly in a GIS system, through an user-friendly interface.

## 2. *State of Art*

Building Information Modeling (BIM) is composed by a set of processes applied to create, manage, derive and communicate information among stakeholders at various levels (Osello, 2012). Building information models allow to define parametric elements enriched by data and able to establish topological relationships among three-dimensional objects (Eastman et al., 2011). Therefore, BIM was born for the efficient management of architectural projects and, thanks to its internal database, allows to generate cognitive models of existing architectures, exploiting the interoperability among actors involved to perform specific analysis. In this contest, the implementation of BIM in the historical context is a research field studied especially by Murphy (Murphy et al., 2013) that express well its limits and potentialities.

As BIM requires 3D objects which compose the virtual model, BIM object libraries represent data sources where these components are stored, developed and implemented relating to historical heritage. This aspect opens new questions about the development of 3D objects, considering their historical and architectural value.

In developing the model, a *shape grammar* approach was evaluated, but could only be used as a formal framework for the semantic and geometric conversion of models. Some of these models aims to develop a methodology using algorithms to automate the conversion of Building Information Models into CityGML building models, in order to create semantically enriched 3D city models that include both external and internal structures (Stouff R., 2018). This approach was not adopted in our case study because it is weighted in the model, but we took a cue on the methodology adopted to apply it in the BIM model.

Analyzing HBIM process, from data collection to the modeling phase (Oreni et al., 2014), currently the relation of HBIM models with actors involved in a building stage is one of the challenges of the built heritage digitalization. Therefore, Artificial Intelligence (AI) techniques are one of the innovative technology able to improve this link. This contribution aims to enhance the value of automatic rules generated by an AI process based on BIM object libraries management. It can be implemented as model ontologies through a logical structure in a rigorous process where classes are defined in a hierarchical taxonomy establishing meanings, properties and rules. (Acierno & Fiorani, 2017; Carrara et al., 2009).

## 3. Methodology

### 3.1 Workflow

The management of the existing building heritage can be implemented in a generic HBIM model that can be improved combining the parameterized models (HBIMs) with an Agent Based Model (ABM).

As the development of a BIM model is created to reach needs of different stakeholders (e.g. owner, energy manager), using a single BIM model for different uses is one of the key factors that enrich the value of BIM process. Theoretically, interoperability is able to ensure the correct information exchange among source software and target software to carry out a series of specific simulations and visualization tools. However, during the information exchange, data loss often occurs due to languages of communication that do not correctly transmit geometric and alphanumeric data.

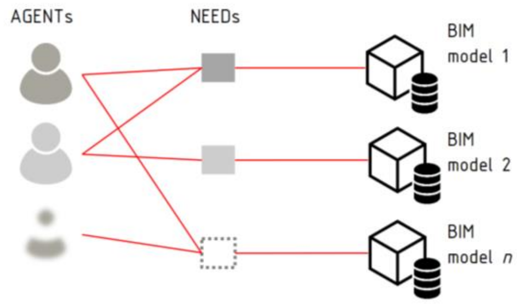


**Fig. 2** Specific BIM Model Use

Figure 2 shows a conventional workflow where several specific BIM models are usually created to reach agent needs. However, this procedure implies duplication of data during import/export process. The product of this procedure is inefficient because many models described the same entity generating data consistency problems. Therefore, this paper aims to describe a possible approach based on the creation of several 3D parametric components that can be invoked each time, depending on needs of agents.

In this way, contribution proposes the development of a source model from which specific BIM models are generated. So, specific BIM application can be automatized, creating rules based on the relation between agent needs and model uses.

In order to simulate this approach, three main steps were followed (Fig. 3):

i. modeling step: a bottom up approach was followed to develop objects of different category. A proper level of geometrical and alphanumerical detail was evaluated, creating shared parameters

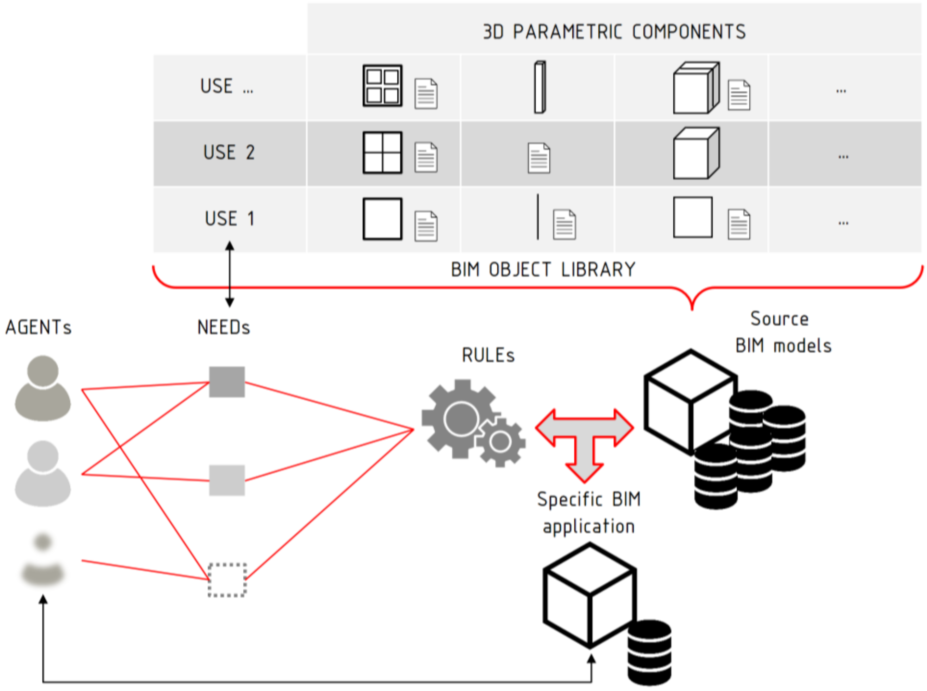


**Fig. 3:** Methodological workflow proposed for multifunctional HBIM models

to be used subsequently. These objects are created for the source BIM model generation;

ii. agent implementation step: creation and verification of certain rules which describe agents needs to allow the choice of correct 3D parametric components for the generation of the specific BIM application;

iii. creation of the specific BIM application: development of the specific BIM model oriented to achieve goals of each agent needs. At this step, 3D objects are related each other through rules of inference.

The innovative idea of this approach is to ensure the generation of an information model for each agent that is fully functional to its usage. The generation of the specific BIM model have to take place through specific rules which extrapolate a model starting from a BIM model defined in this study as Source BIM Model.

In these terms, the specific BIM model is made up of all building components that make it flexible for a use over another one, overcoming data loss during the import / export process.

Certainly, the creation of a BIM object library - which able to describe all objects categories in different ways with a large variety of model uses - is one of the starting points to automatize the specific BIM generation.

Subsequently, fixed problems and limits of BIM authoring tools, in the following scheme (Fig. 4) is summarized the procedure to be adopted for the modeling of a building HBIM trying to answer the maximum number of needs and users.

The choice of combining a Model HBIM with a Model Agent based is suitable to overcome the limits of BIM tools through the use of Intelligent Agents.

$$\forall Obj(n) \epsilon E(x) \exists ! A(n):f(Ax)$$

The function allows to describe relationships between each single object, belonging to the building and each agent (actor), starting from the assumption that there is only one model use for each need. This requires the modeling of *n* objects in relation of each level of detail and actor. So, for each object exists a single meaning that has to be defined and implemented according to agent needs associating them properties and rules. The properties can be modelled directly in the BIM authoring software (e.g. Autodesk Revit), while rules can be formalized externally in function of the specific activity and the type of user (Agent).

The formalization of the intelligent agent can be done by modeling an Agent-Based with formalized rules according to the type of agent. The ABM should interact with the BIM model (or the database of each object) to give answers to rules that cannot be formalized in BIM environment and to use Relational DataBases

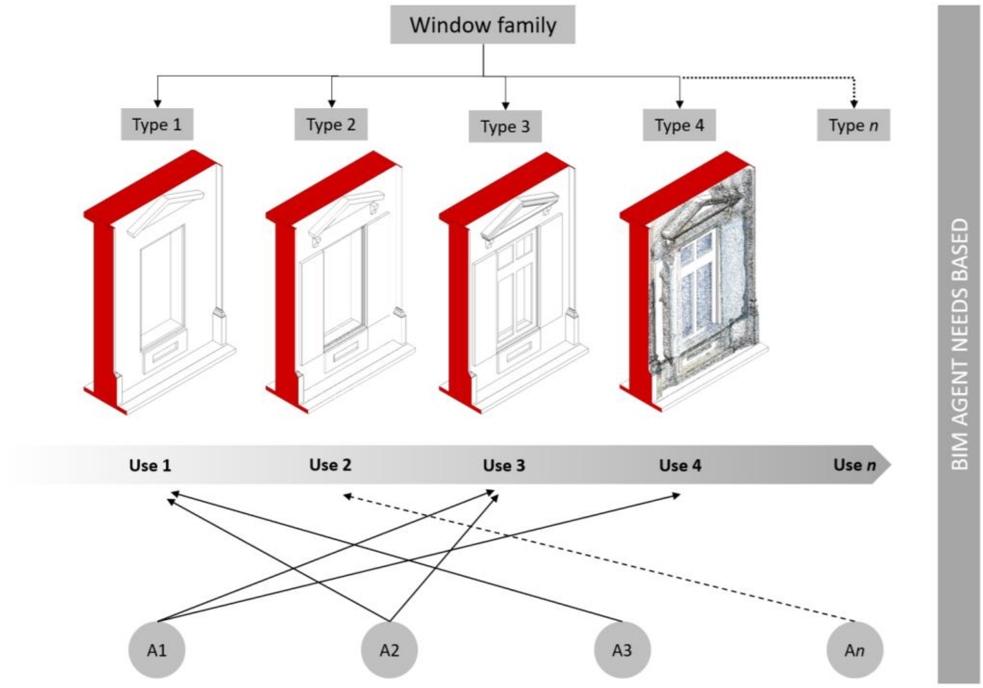


**Fig. 4:** Methodological schema with the relation between agent needs, model uses and BIM components

Management (RDBM) systems to create more complex rules.

These procedures can be applied to different building objects which are part of the case study such as *Windows, Vaults, Walls, Spaces*, etc.

The intelligent agent should work using an algorithm that allows to find the LOD (Level of Development) of interest that best suits to Agent needs.

### *3.2 Case Study application*

For this study, starting from each agent needs, an HBIM model was generated using many 3D parametric components developed in various ways for different uses. For this reason, proper LODs were defined considering the need to maintain building components and manage the structure and its functions. For the development of LOD, particular attention was given to the historical value of the building and to the specific goal of *Virgo Potens* as occupational therapy facility.

Starting from a geospatial survey, the prototype of *Virgo Potens* the building façade was developed describing the same building component (e.g. windows), reproducing many times the same component with different level of geometrical and alphanumerical detail. The development of the BIM model was occurred using a BIM authoring tool, able to manage 3D components into *Categories*.

As the purpose of the paper, the creation of the first model of the building is considered as a source BIM model.

The overlay of the point cloud to the HBIM model allowed its development closer to reality, analyzing modeling issues, evaluating possible enrichments with further details. Certainly, the single object element is no longer an exact copy of the real one but derives from the simplification process due to the fact a certain '*slenderness*' has to be guaranteed within the digital model itself.

Considering the amount of actors involved in the building process, a proper LOD was determined in relation to the type of activity to be carried out (Uses). For the purposes of experimenting modeling with Revit, 3D building components of *Virgo Potens* building have been reproduced starting from window metric family, generating different family types. The right choice between the creation of several families with one type and one single family with different types, is one of the challenges for the optimization of the modeling step. Several families of window were developed, defining different family types varying graphic visibility settings of the individual nested components. This choice needs to be evaluated subsequently to understand the better solution in terms of speed and standardization of modeling operations relating to the development of HBIM models. As visible in figure 4, each window family type of *Virgo Potens Building* is generated based on each agent needs. Therefore, each BIM component can be invoked every time in different way, according to agent needs to develop a BIM specific application. At the end of the proposed approach, a prototype of BIM model was developed as visible in figure 5.

For each *Window* object, a certain use can be connected to an intelligent agent which can also have other connected uses depending on the performance to be reached and to the analysis that they have done.

An agent ($A_n$) is modeled with a goal that is a function of the type of activity to be performed on an $Obj_n$. Each $A_n$ has to manage *n* Rules that can be activated if necessary. So, the model based on Agents can be inserted in a Model based on Ontologies in which for each object are assigned *meanings, properties and rules* (Carrara et al., 2009). *Meanings* are implemented through an algorithm for the development of the taxonomy used in the *Context Knowledge Model* definition (Gargaro et al., 2015); *Properties* were defined in the BIM model though the implementation of *Parameter*; *Rules* were modeled as *general* or *specific* ones, *general rules* were implemented for all agents and can be used by all the agents involved in the design process, instead *specific rules* were modeled for a specific agent use.

The assumption for the agents is the condition *All Diff*, i.e. each agent created is unique.

The Rules implemented in the case study are *general* and *specific* ones. The first one developed below is a *general rule* that can be used by all agents:

<<IF ∃ Decoration on the frame

THEN the building probably was born before 1950>>

If this rule is verified as in the case of *Virgo Potens,* it imposes to the *Restorer Agent* the role of *Supervisor* of other agents because the building is subject to constraint from cultural heritage. This rule imposes a *general constraint* on the model, which conditions all actors involved in the process. For the formalization of this rule is used the source BIM model, while for the formalization of the *specific rules* is used only by the specific agent in its model. As an example of *specific rule* is modeled for the *Energy Agent*:

<<IF *window transmittance*

Uw>U'w (transmittance from legislation)

THEN change window>>

Obviously, to change window in the model we imposed with the previous general rule the condition to contact the *Supervisor* because the building is a cultural asset. Another rule modeled with a similar structure is the acoustic rule:

<<IF soundproofing power window R'w>Rwlim

THEN change the window>>

As in the previous example, agent has to contact the *Supervisor* to decide together the possible solution to the problem.

The examples of rules can be referred only to the single component like those described previously or connected to other components of the model as in the case of the *Structural Agent* checks, for which the window is only a hole in the wall. In this case checks will be made on the wall

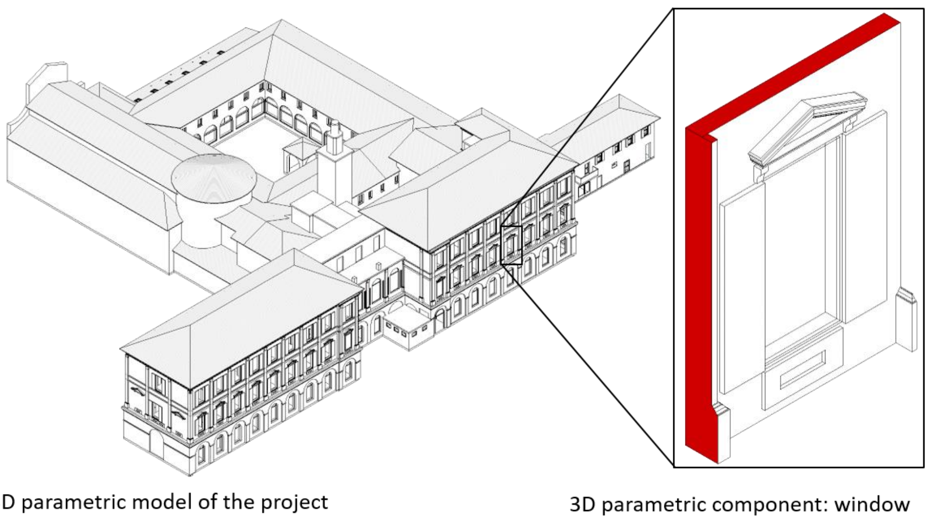


**Fig. 5**: Axonometric view of the whole model of the case study and one of the window family type

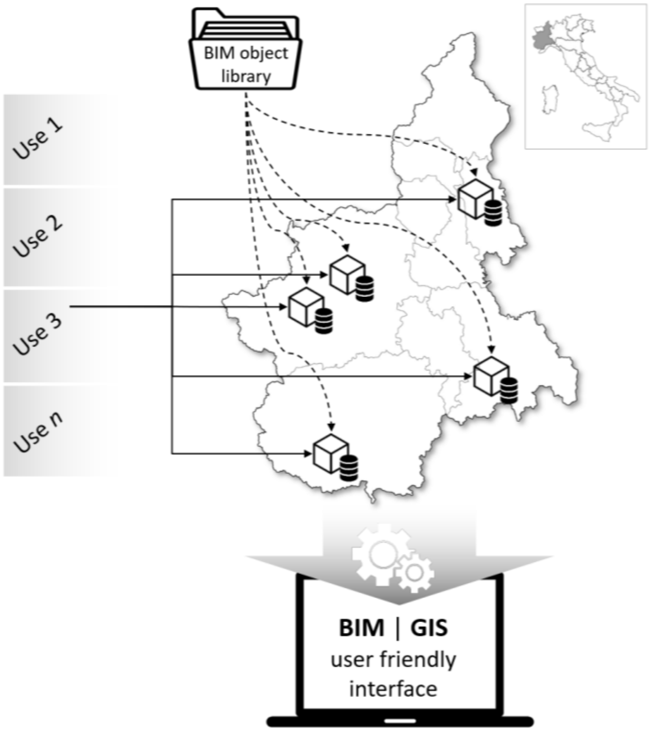


**Fig. 6**: An hypothetical BIM/GIS platform schema for built heritage management

but could also modify the window for example by placing a circle renforcement. In addition, the general rule of inference prevents the direct modification of the frame by conditioning the agent to contact the supervisor.

The application to the case study of *Virgo Potens* allowed to verify the potential of the model based on agents through the modeling of three types of agents: Restore Agent, Energy Agent and Structural Agent. From this analysis it has been possible to study how the various agents according to the use that they could make of the model could choose the specific LOD. In addition, implementing simple rules for each single agent and general rules on the model, it was possible to verify how the imposed constraints encourage collaboration among actors involved in the design process, avoiding conflicts in the development of design choices.

## *4. Results*

Nowadays, digitalization process provides different solutions to manage information that is collected in heterogeneous data sources which belong to geospatial and architectural fields. In these terms, representation of built heritage has always been deepened by human beings who is continuously looking for knowledge of places where they live through available technologies over the time (Ruffino and Del Giudice, 2018). The achievement of results of this contribution required a mix of knowledge and Information and Communication Technologies (ICTs) field that allow to improve the Architectural, Engineer and Construction (AEC) Industry.

The process begins through a semantic reading process of the architectural elements, which allowed to identify and prioritize elements starting from the modeling of a window, arriving to the conceptualization of a method applicable to a case study.

One of the objectives of this study was to obtain an *'Architectural Knowledge Model'*, composed of objects organized according to hierarchical criteria identified by a precise taxonomic vocabulary, useful to the various actors involved during the building life cycle.

The approach proposed has been applied to our case study getting a BIM model (Fig. 6) usable for many different functions. The HBIM model is a prototype of the theoretic BIM agent-based model and it needs to be improved subsequently.

Certainly, one of the most significative results of this research are: i)discovering informative modeling rules to define a formal definition of BIM object library and agent needs; ii) evaluating the role of BIM model that can be enriched and transformed several times using standardized rules to be managed for specific applications; iii) proposing an alternative strategy to overcome issues derived from interoperability due to data loss; iv) establish a description of a virtual building in a formal way to extend its contents at urban and territorial scale with a link to the GIS field.

The main difference with the most conventional methodology is the possibility to overcome common interoperability difficulties among different software. Since any components are modelled according to Agents needs, when BIM model is used for a specific application, the management of data loss is more efficient. However, this method implies a great modeling effort for BIM object library generation.

Output benefits presented above can be implemented through a user-friendly interface which, using specific ontology-based rules, take advantages by interaction of BIM models at territorial level (Fig. 6). In particular, considering this last aspect, the proposed approach allows data management optimization of architectural heritage, digitalizing each building typology through the development of HBIM models. This approach is able to provide an operative tool for the definition of policies that actors involved (e.g. public administration) could adopt in terms of energy saving, structural monitoring, facility management and optimization of healthcare environments.

## *5. Conclusion and Future work*

Currently, building industry is crossing a transition phase oriented to digitalization based on interdisciplinary approach starting from information models. The proposed approach highlighted the creation of a BIM object library as a data source oriented to model uses. Managing large amount of data with HBIM approach to describe building components is one of the next challenges to be faced for the optimization of built heritage. As future step, 3D parametric objects could be generated through active and passive sensors, appropriately integrated by historical manuals (Apollonio et al., 2016; Ippolito, 2015; Biagini & Donato, 2014; Brumana et al., 2013, Apollonio et al., 2012).

An interesting perspective is the possibility to consult all models by *n* Agents for *n* Uses.

As already mentioned, this step has to be done outside the BIM authoring environment creating a user-friendly interface conceived as a common platform where heterogeneous data can be invoked for specific queries.

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