Experimental BIM Applications in Archaeology: A Work-Flow

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Abstract. In the last few decades various conceptual models, methods and techniques have been studied to allow 3D digital access to Cultural Heritage (CH). Among these is BIM (Building Information Modeling): originally built up for construction projects, it has been already experimented in the CH domain, but not enough in the archaeological field. This paper illustrates a framework to create 3D archaeological models integrated with databases using BIM. The models implemented are queryable by the connection with a Relational Database Management System and sharable on the web. Parametric solid and semantic models are integrated with 3D standardized database models that are finally manageable in the public cloud. The BIM application's work-flow here described has been experimented on the Roman structures inside the Crypt of St. Sergius and Bacchus Church (Rome). The experiment has highlighted capabilities and limitations of BIM applications in the archaeological domain.

Keywords: BIM, Archaeology, Semantic modeling, Data export, Web documentation.

1 Introduction

In the last few decades, the Information and Communication Technology (ITC) has been strongly supporting Cultural Heritage (CH) documentation activities, providing even more advanced methods and technologies to record, manage and process related data. In the archaeological domain, digital archives, image-based 3D modeling [1] and virtual and augmented reality [2], [3] have allowed to record a large number of heterogeneous data and to describe via 3D models also very complex and not always accessible archaeological sites [4] and historical buildings.

Recently, various experimental applications have been performed to define conceptual models and procedures in order to integrate 3D archaeological models with external

M. Ioannides et al. (Eds.): EuroMed 2014, LNCS 8740, pp. 490–498, 2014.

related databases [5], [6], [7]. The main aim is to provide three-dimensional descriptive systems of objects from archaeological contexts and to make them suitable to the complexity of real-world contexts. As these 3D reality-based models are integrated with database, they are able to increase the informative potential of the archaeological resource, not only by 3D visualization, but also by 3D data recording. In this context, BIM (Building Integration Modeling), a three-dimensional modeling technique based on a conceptual model and associated with databases [8], [9], is considered of very great interest. It was originally applied in the AEC (Architecture Engineering and Construction) field to urban contexts: its purpose was describing new buildings' structures and life-cycle inside a cooperative environment, but recently its application has been extended also to historical architecture [10], [11], [12]. In this respect, HBIM (Historical Building Integration Modeling) is an interesting example of BIM specifically directed to Digital Heritage. This technique has been widely described by Murphy as a novel prototype library of parametric objects based on historic architectural data and a system of cross platform programs for mapping parametric objects onto a point cloud and image survey data [13], [14].

As BIM allows representing and analyzing historic buildings via 3D models [15], it is considered an advanced tool for recording and managing CH data. Moreover, it is a useful support for further activities as restoration, enhancement and communication.

This paper illustrates an experimental framework that GISLab has defined to produce BIM-based 3D archaeological information systems, shareable on the web. In order to test the validity of the method, it has been applied to the Roman structures inside the crypt of St. Sergius and Bacchus Church (Rome). The spatial DB is structured in accordance with the Central Institute for Cataloging and Documentation (ICCD) criteria related to archaeological artifacts and sites [16].

The study has highlighted capabilities and limitations of BIM in order to solve some specific problems of archaeological contexts: the description of ancient structures characterized by irregular geometries; the synchronic and diachronic representation and querying of different chronological phases; etc.

2 BIM

BIM technology is supported just by a few software (*e.g.* Graphisoft Archicad, Autodesk Revit Architecture, Nemetschek Allplan and Bentley Microstation). It provides 3D models in which geometry is associated with semantic data. Models are visualizable, navigable, measurable, queryable and analyzable through semi-automatic selection processes and specific queries based on ontological schemes [17].

BIM is mainly composed of “Families”. They are predefined entities, which are also parametrically modifiable [18] and linked to data tables that can be expanded. Families are included into “Categories” (general groups by constructive element) and, in turn, include “Types” (further specific groups inside a family). Families contain both direct data, related to the object to be described, and indirect information (*e.g.* eventual topological relationships among the object and other components).

Procedures leading to the parametric BIM modeling are: the decomposition of the building into parts and constructive elements; the conceptual classification into semantic categories (architectural component, material and phase of construction); the structuring of the model, based on families and different levels of detail.

2.1 BIM and Archaeology

The application of BIM to the archaeological heritage description can be an interesting solution to the main issues in this field: they require both a photo-realistic visualization and a 3D database storing identification, morphological, typological, constructive data, etc. This information should be related to each archaeological object represented inside its own context in accordance with specific constructive hierarchies. The database should also include: general data describing the whole archaeological area the artifacts come from; technical and administrative information on the excavations and any other useful data.

3 The Roman Structures inside the Crypt of St. Sergius and Bacchus Church in Rome

The research project here described has explored the possibilities for implementing a BIM-based archaeological information system, valuing also its capabilities and limitations.

An experimental archaeological BIM has been applied to the remains of a Roman structure inside the crypt of St. Sergius and Bacchus Church (Rome). They are two rooms created within a former space of a residential house, testimony of the life in the ancient neighborhood of Subura in Rome. The rooms, adjacent the republican atrium house successively closed off, preserve rather extensive fragments of frescoes and valuable materials (marble revetment, figural painted plaster of various styles, and floors of *opus sectile*) [19]. (Fig. 1).

Fig. 1. One kernel structure inside the Crypt of St. Sergius and Bacchus, Rome. Northern Area.

First studies on the area, based on direct surveys, identified two main building phases: a wall structure consisting of pillars in *opus quadratum* and closures in *opus reticulatum* (II cent. A.D.) and a wall structure in *opus latericium*, covered by panels in *opus sectile* style at the basement and a frescoed upper band (III - IV cent. A.D.).

4 The Work-Flow

The experimental BIM application work-flow can be summarized as (Fig.2):

a) acquisition of bibliographical and archival documentation;
b) surveys and restitution;
c) data digitizing and vectorization of graphic material;
d) integration of survey data (from phase b) with vector data (from phase c);
e) definition of a conceptual scheme aimed to subdivide the building into categories of constructive elements;
f) 3D model structuring by parts and construction phases via BIM software;
g) 3D model export using different exchange formats;
h) browsing on internet.

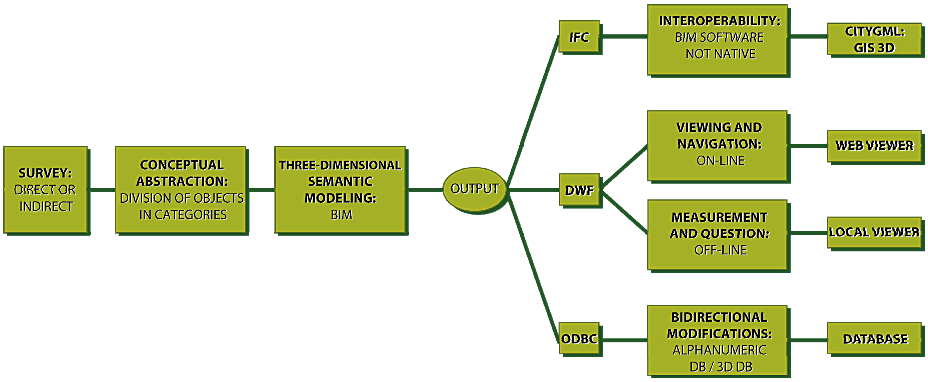

Fig. 2. The work-flow

4.1 Definition of the Conceptual Model

A 3D archaeological model firstly requires a process of conceptual abstraction and decomposition of the building into its constructive elements. They correspond to “categories” or “elements” that compose BIM hierarchical structure [20].

Each category is subdivided into “families” that differ from each other by geometry and material. Objects belonging to the same family, but having different size, can be grouped in “types”.

Properties of each family and type are defined by preset parameters. It is possible also to define “shared parameters”, customized by the user. They can be added to families or projects and shared with other families or other projects. These parameters allow adding specific data that are not preset in the family file or in the project template.

This property is useful for adding to BIM database some fields from the ICCD cataloging scheme. Data access is made possible directly, querying the 3D model.

In the experimental application, only some fields from ICCD schemes were selected. They are: identifier, denomination, description, position, generic chronology, construction technique, material, state of repair, demolished parts, rebuilt parts.

4.2 3D Modeling

After the definition of its hierarchical structure, the building can be parametrically modeled by each component through BIM.

The 3D model of the Roman structures above described has been created through Revit Autodesk. Piers in *opus quadratum* have been divided into sub-structural elements (tuff blocks). As each pier is composed by four different block types (regular, protruding, trapezoidal, low), the regular one has been chosen as the constructive archetype. Therefore, all the types of block derive from it, just changing the value of some parameters. Different block types are grouped into the "pier family" (Fig. 3).

Different records related to the history of the building can be assigned to each family: that allows obtaining a 3D reconstruction of the artifact by distinct chronological phases and querying building parts that belong to the same phase (synchronic) or to different phases (diachronic).

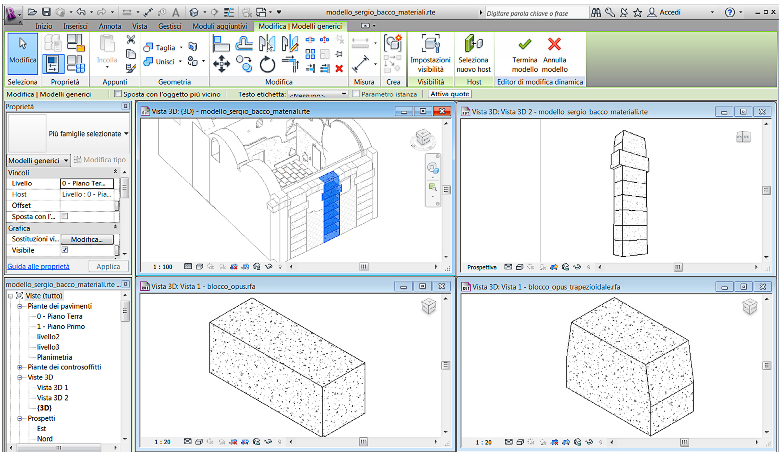

Fig. 3. View of the "pier" family and the tuff block type from which it is composed

4.3 Data Export

The model can be exported in different formats. They are:

- IFC (Industry Foundation Classes), interoperable and importable exchange format (*e.g.* Google SketchUp export using IFC2SKP plugin) (Fig. 4);

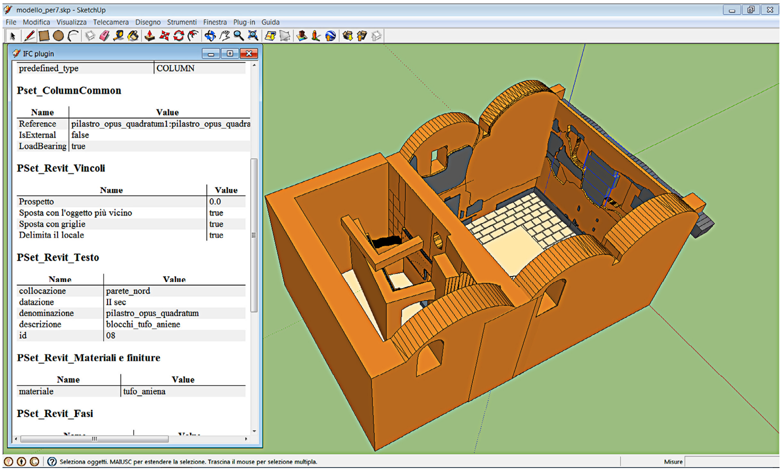

Fig. 4. IFC model imported into a non-native BIM software (*Google SketchUp* and the plug-in *IFC2SKP*)

- DWF (Design Web Format), allowing model viewing and browsing online via free web-viewers (*e.g. Autodesk 360* from https://360.autodesk.com/). It also enable to measure and query the 3D model by local desktop viewers (*e.g.* Autodesk Design Review);
- MDB format (*Microsoft*), aimed at reading DB tables by Microsoft Access through the ODBC (Open DataBase Connectivity).

4.3.1 Bi-directional Database: Export via ODBC

BIM software generally allows exporting 3D databases via ODBC. The DB is composed of families' tables; each table contains as many records as the constitutive elements, whereas columns define the parameters associated with each of them.

In particular, Autodesk Revit Architecture allows the bi-directionality of actions and changes by DB Link (Autodesk Revit plug-in): every DB update corresponds to the BIM project update and *vice versa*.

5 Results

The research work above described has allowed:

1. to produce a semantic model that is compliant with the ICCD cataloging schemes and adequate to the specific requirements of the 3D model;
2. to share, view and browse online a textured BIM model;
3. to query and measure the BIM model inside the desktop application;
4. to export the BIM model in solid modeling software;
5. to export tables from the 3D model database and to make use of BIM bidirectional editing capabilities.

The system experimented still has some limitations: many BIM's default families (*e.g.* "pillar", "ceiling", "curtain wall system", etc.) regard only modern and contemporary buildings. Therefore, they are not useful to describe historical architectures, which require the creation of *ad hoc* families.

In addition, BIM software automatically applies to constructive elements some characteristics (*e.g.* the horizontality of the pavements or the regularity of the vertical surfaces) that do not regard ancient contexts. It also provides standardized features aimed to describe the regular geometries of the default libraries' objects: therefore, the asymmetric and geometrically irregular constructive elements of many historic buildings (as well as archaeological remains or fragments) are not compliant with the Autodesk Revit features. Its functions, in fact, refer to modern buildings' typical characteristics (*e.g.* serial proportions and measurements; the perfect coincidence of materials for entire surfaces; etc.). Therefore, archaeological objects' modeling requires new libraries that contain specific families: they should be able to describe this domain and its peculiar characteristics.

The experimentation has demonstrated that it's possible using BIM to describe archaeological contexts, but some additional features have to be provided for this purpose [21]. An inventory of archaeological features can be implemented, recording the different types of constructive elements available on architectural treatises and archaeological examples. That is preliminary to create new specific categories and families and produce archaeological BIM libraries. Inside BIM the archaeological database will be integrated with the 3D semantic model. It will contain tables corresponding to the families created and fields related to the main information from typical ICCD schemes.

Some limitations are due to the software currently used: it should be added also tools to describe different situation not perfectly suitable in BIM software, in fact it is not as flexible as one can be expected.

In addition, currently, BIM application is mainly related to the construction features, whereas a complete description of an archaeological context should include also the area surrounding the site (*i.e.* the transition from the architectural scale to the territorial scale).

6 Conclusions and Future Developments

As the current literature demonstrates, the issue of BIM applications to archaeology has not been studied yet, even if it represents an interesting matter.

The scientific community has been debating for decades on archaeological data standardization and data access (that would be open). In this respect, the method of semantic and solid parametric modeling can produce 3D archaeological databases that are standardized, containing all the information related, shareable in a big cloud-database. This enables a simultaneous consultation of a large data resource, shared in real-time, and allows comparing information coming from heterogeneous sources. It also increases the quality of statistical and crossed analysis [22].

Therefore, this work would highlight how BIM software, originally implemented for new buildings description and construction project management, can be successfully used for modeling archaeological artifacts and contexts. The software allows customizing the preset families, creating new ones to suit specific requirements and adding to any entity or group of entities relational or semantic parameters that can be shared or not.

Future developments should be focused on the integration between GIS and BIM: they are two similar technologies operating at different scales. In order to this purpose the use of XML-based formats - such as CityGML – could allow standardizing information and consulting meta data of both scales on the same platform [23].

The results of this study are partial, as the research activity is still in progress. Nevertheless, they have allowed experimenting methods of semantic representation that can be applied to the archaeological world's aspects of survey, use and conservation of ancient sites.

Acknowledgements. We wish to thank Rita Volpe and Carla Termini, archaeologists from the Superintendence of Cultural Heritage Capital of Rome (SSBAR), Maura Medri, Professor of Archaeology, at the University of Roma Tre, and Mirella Serlorenzi, Department Member of SSBAR, for the scientific support related to the study examined.

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