

SEMI-AUTOMATIC GENERATION OF BIM MODELS FOR CULTURAL HERITAGE

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ABSTRACT

The building information modelling (BIM) platforms have serious difficulties to represent historical buildings and cultural heritage. These platforms have no libraries with historical parametric objects able to represent the particular characteristics of the historical buildings. One solution to represent faithfully the buildings is the use of point clouds obtained by laser scanning systems and photogrammetry. However, these clouds points, although they may represent faithfully the geometry of the buildings, are difficult to incorporate to BIM platforms because of the enormous volume of data they contain. Moreover, the particular nature of historic buildings makes it essential to incorporate semantic information including historical and bibliographic data of the analysed building.

In this article a new methodology which facilitates the modelling of heritage buildings by incorporating point clouds to BIM platforms and tackling their subsequent treatment for obtaining parametric models is proposed. The obtained models can be incorporated into libraries for later reuse, along with their historical semantic information, under the concept of heritage BIM. To do this, performing cuts, sections and views following the norms, rules and constructive patterns of the different historical architectural periods is proposed.

The proposed methodology has been applied to a real case study: the Romanesque church Santa Maria la Real de Mave located in Palencia, Spain. Moreover, the results of the digital modelling of the church are a solution for 3D modelling recurring a wide range of buildings in the same style. This is possible because the shapes and proportions of the modelled elements can be modified to adapt to new requirements without having to restart from scratch. This will allow sections, details, projections and other features to be generated automatically. We can provide quantitative and qualitative information, thus allowing detailed analysis in a remote and multidisciplinary way, within the framework of ‘Smart heritage’.

Keywords: 3D environments, BIM platforms, HBIM, heritage documentation, point clouds/historical information, Smart heritage.

1 INTRODUCTION

Heritage is considered to be everything that has a universal value, being these tangible or intangible elements. In consequence to the environmental conditions, structural instability or increased tourism, the cultural and natural heritage is constantly threatened, requiring the human intervention to performing their restoration [1].

In particular architectural heritage buildings, due to the passage of time or other problems, often lack the technical documentation about the status, shape or composition of the different elements. For this reason, performing restoration or rehabilitation works is often difficult [2, 3]. Therefore, the collection of all kinds of information about the analysed buildings is required to determine their history and current state of their construction [4].

Nowadays, a high level of automation can be achieved through the use of 3D scanning and photogrammetry technologies, which allow the collection and further processing of spatial data to be accelerated [4]. In particular, laser scanners provide a large amount of 3D data in

a short time, under the form of millions of points (point cloud), with (X, Y, Z) coordinate (Fig. 1) [5]. Moreover, colour data, (R, G, B) coordinate can also be incorporated by using digital cameras [6].

In order for point clouds to be useful, several phases must be taken, such as cleaning, filtering and softening. In addition, processed point clouds could be incorporated into building information modelling (BIM) platforms. With the use of this technology we could be able to create 3D models with parametric information of their elements, with properties of materiality, geometry, quantities, cost or any other type of characteristic necessary to request the client, thus converting a simple graphical representation into a virtual project with real condition [7]. The correct communication and coordination between the parties involved, it is essential to achieve the implementation of this technology.

BIM platforms have the ability to import and manipulate graphical and non-graphical information, referring to the data obtained from the point clouds, as well as the semantic data, that describes historically and technologically each element that composes the model [8].

The BIM platforms were designed for the virtual modelling of new constructions; for this reason, the libraries of the BIM platforms are geared primarily for the design of new buildings. The reconstruction of cultural-historical heritage has revealed some limitations of BIM, such as the unavailability of historical parametric object libraries and the need for human intervention when each architectural component is modelling, because despite the high level of the point cloud detail or precision, these are limited to the empty form of its geometry. In addition the lack of tools in BIM platforms for managing complex and irregular shapes obtained from point clouds makes it harder for the modelling works.

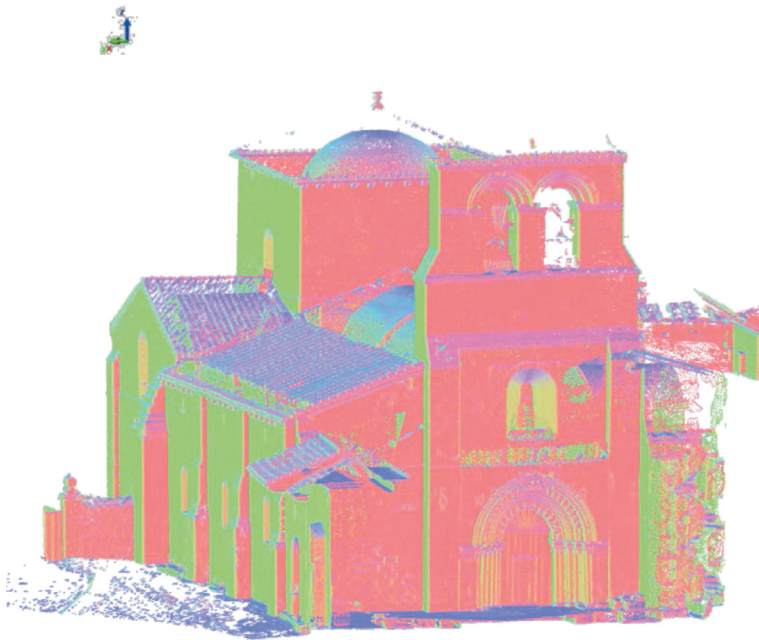


Figure 1: Georeferenced point cloud (X, Y, Z). Source: Own figures.

Therefore, once the 3D models are created, libraries of the modelled elements should be generated, thus encapsulating the concept of heritage BIM (HBIM).

The HBIM concept was first used in [9], from the Dublin Institute of Technology. According to [9–10] HBIM is a special library of BIM, where the parametric objects could be designed and modelled. For the virtual modelling of the architectural elements that would compose the historical building, the use of historical documents and the data obtained from the physical analysis is essential. Thus, thanks to the designed process, a wide range of buildings in the same style could be built simpler, clearer and quicker. This becomes possible due to the flexibility of the modelled elements that can change in shape and proportions, thus adapting to new requirements and projects without having to start from scratch.

The components of the HBIM library have the opportunity to develop details stored behind the surface of the objects regarding their construction methods and materials [11, 12]. In addition, the components of this library can be used as patrimonial visualization models, and to produce such technical documentation as floor plans, elevations, section cuts, details and perspectives in a semi-automated way.

The aim is to create a faster and semi-automatic modelling of the objects from the use of point clouds. Moreover, the proposed methodology has been applied to a real case study, focusing on a monument of the Spanish Romanesque period.

2 METHODOLOGY

The methodology proposed in this article consists of two main phases to convert laser or photogrammetric data into HBIM library. Specifically, cuts, sections, views, grids and reference lines are used, which follow the norms, rules and constructive patterns analyzed in the bibliographic data corresponding to the actual historical architectonic periods. This allows creating a faster and semiautomatic modelling of the obtained point cloud data.

2.1 Collection of historical data

This phase covers the collection of semantic information, as well as the spatial information.

Considering that, in some cases like the Romanesque architectural period (14th century), the information and technical documentation of the old buildings are scarce or non-existent, any historical source that describes the norms, rules, patterns and architectural proportions of the construction period that the building belongs to can be used to support the parametric object modelling [13].

In Fig. 2a we can observe a figurative plant obtained from [14]. Modules and proportions obtained from [14] can be seen in Fig. 2b. Figure 2c shows the section of a system of repetitive modules obtained from [15]. In Fig. 2d we can see a drawing of the Romanesque capital proportions [16], and Fig. 2c shows a prototype of a richly decorated arch, typical of Romanesque entrances [16].

Another key aspect is the graphic or spatial information data is collected from the laser scanners that can provide a point cloud that spatially demonstrates the visible parts of the (internal and external) surfaces of a building.

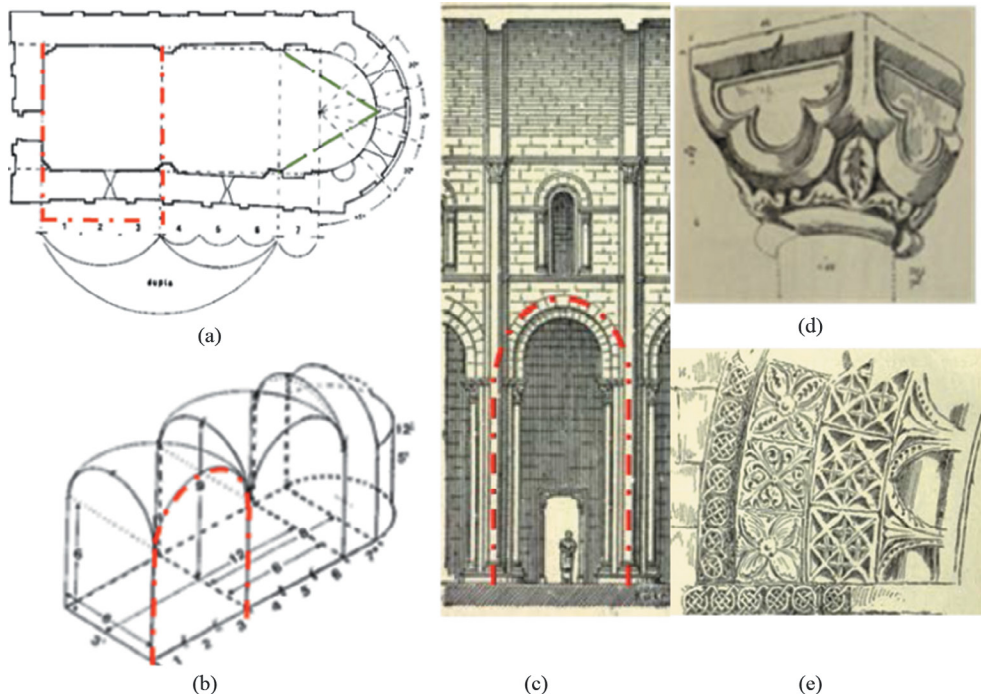


Figure 2: (a) Figurative plant about modules and proportions. (b) Modules and proportions schemas. (c) Section about a system of repetitive modules. (d) Drawing of the Romanesque capital proportions. (e) Prototype of a richly decorated arch, typical of the Romanesque entrances. Source: (a) and (b) adapted from Lorente and Francisco 2007; (c) adapted from Kimball and Edgell 1918; (d) and (e) adapted from Jackson 1920.

This feedback between the spatial and semantic data allows the complexity of the modelling process required by the HBIM library to be reduced.

2.2 Architectural component modelling

The second phase is the procedure designed for the accurate and efficient modelling of the different architectural components that make up the HBIM library of the building studied. The analysed buildings or monuments often suffer from different pathologies or deformations; for this reason, point clouds that provide the actual shape and spaces of the buildings, which is important for achieving an accurate modelling of each component, are used.

In order to address the accurate modelling of the regular and irregular surfaces of the architectural objects cuts, sections, views, grids and reference lines on the point cloud are used. The differences in implementation between the various architectural periods will be noticed when selecting the places which make these actions, because the construction method, technology, typology and materials that were implemented in every age varied through the centuries.

In our case, the analysed building belongs to the Romanesque architectural period. First, on the point cloud, the cuts and sections are made in longitudinal and transversal directions, following the divisive concept of the current architectural period. These cuts will serve to show the composition and internal layout of the building, as well as to generate an estimate of the dimensions of the various elements and surfaces.

The section planes cross the centre of the structural or supporting elements that compose the building (walls, pillars, columns, arches and vaults in the case of the constructive logic of a Romanesque monument) (Fig. 3).

After the levels were used, these levels are finite horizontal planes that constitute a reference for determining the vertical distances between one point and another. Subsequently, a set of grids are created on the planimetry. These grids are responsible for marking the outline of the cloud surfaces. Moreover, each line serves as a reference to extract the current distances.

When the geometry of a given surface is uniform and simple, the modelling will be performed using the parametric objects already in the BIM internal library, such as walls, windows, doors or columns.

On the other hand, when the geometry of a surface is irregular or complex, the modelling mainly starts with the sketch of vertical and horizontal reference planes on a 2D work plane. Subsequently, now in a 3D work environment, the use of reference lines is the key to generating the 3D virtual model (Fig. 4). These reference lines are actually useful for drawing the profile of any element. Then, the tools for creating the solid geometry of each designed element are used.

The elements modelled thanks to the designed methodology are incorporated into the design of an HBIM library. Moreover, it is important to understand that the components of the HBIM library can be used for both handling a virtual model of the historic buildings and illustrating the damage and declination of each architectural element.

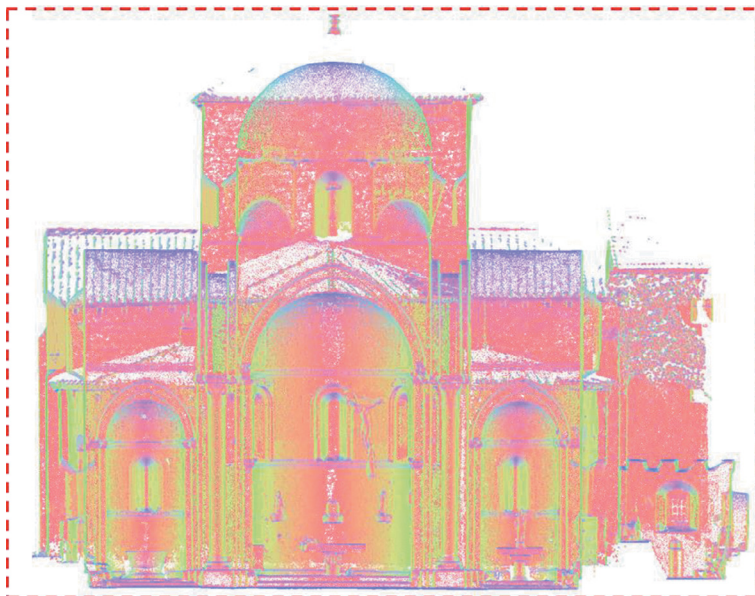


Figure 3: Transversal section of the point cloud. The section box is highlighted with a red dashed line. Source: Own figures.

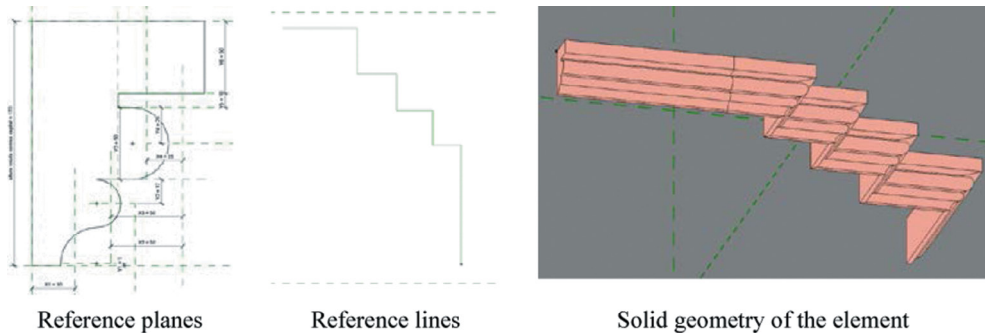


Figure 4: Construction sequence of an uneven surface: creation of one of the cornices that crowns the main entrance. Source: Own figures.

3 RESULTS

The selected building, to apply the proposed methodology, is the church of ‘Santa Maria la Real de Mave’, a monument of the Northern Spanish Romanesque period. This church is located within the monastery of Santa Maria, in the village of Santa Maria de Mave (Aguilar de Campo, Palencia, Spain) (Fig. 5).

The said church was built in the first half of the 11th century [17]. Now their appearance is the combination of its constructive history and the reforms carried out in the 16th and 17th centuries [18–20]. The current cloister was built during this last period. The church is characterized by a basilica plant, separated into three articulated naves topped each one by a



Figure 5: Location of the monument. Source: Adapted from <https://www.google.es/maps/@42.7230384,-4.2758203,334m/data=!3m1!1e3>.

semi-circular apse. The flashlight tower, which is the highest part of the building, is crowned with a polygonal dome.

Six cruciform pillars with semi-columns adjoining on every front, with the exception of the side arches, delimit the longitudinal sections of the naves and arms of the transept. The central nave is covered by a barrel vault and is separated into three sections by pointed arches.

The church has been digitized using a Leica HDS 3000 'time-of-flight' laser scanner and images have been taken using a Canon PowerShot G6 (7.1 megapixel) digital camera. A total of 31 3D scans have been taken inside and out, from an average distance of 20 m, to a 4 mm standard deviation accuracy. Over 14 million 3D points have been collected, along with 135 photographs.

The Autodesk Revit software has been used to model the building. This software is an efficient BIM platform suitable for accurately modelling the regular and irregular surfaces. Also, it allows generating the construction documents and provides all the necessary tools to implement the proposed methodology.

The regular surfaces have been modelled using the 'Architecture' tool that already exists in the Revit internal library.

Moreover, reproducing the rich ornamentation of the Romanesque architecture is hard work. Therefore, the irregular surface has been modelled externally by creating 'Component Families', thanks to the use of the aided procedure described in the previous section.

The 'Cruciform Column' has been modelled like a 'Component Families' and these parts shown in Fig. 6a. In Fig. 6b a longitudinal section can be seen where the cruciform pillars with terrace half-columns and the canyon vault are perceived.

Once the components have been modelled, they could also be used to automatically produce technical documentation, such as floor plans, elevations, section cuts (Fig. 7), details and perspectives.

In conclusion, the church has been completely modelled and each architectural component has been parameterized. The components of the 'Church' may be adapted to other monuments belonging to the same period and architectural style, thanks to their flexibility. For this reason, this family has been incorporated into the HBIM library.

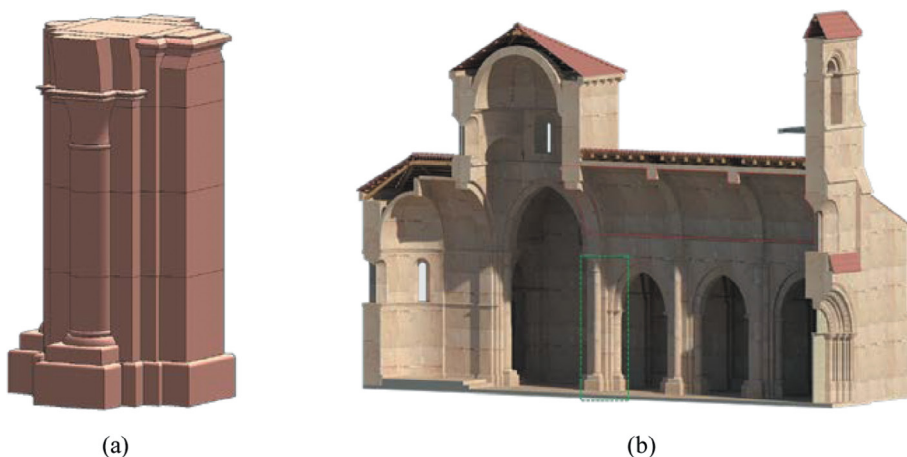


Figure 6: (a) Cruciform column. (b) Longitudinal section with the cruciform pillars with terrace half-columns and the canyon vault. Source: Own figures.

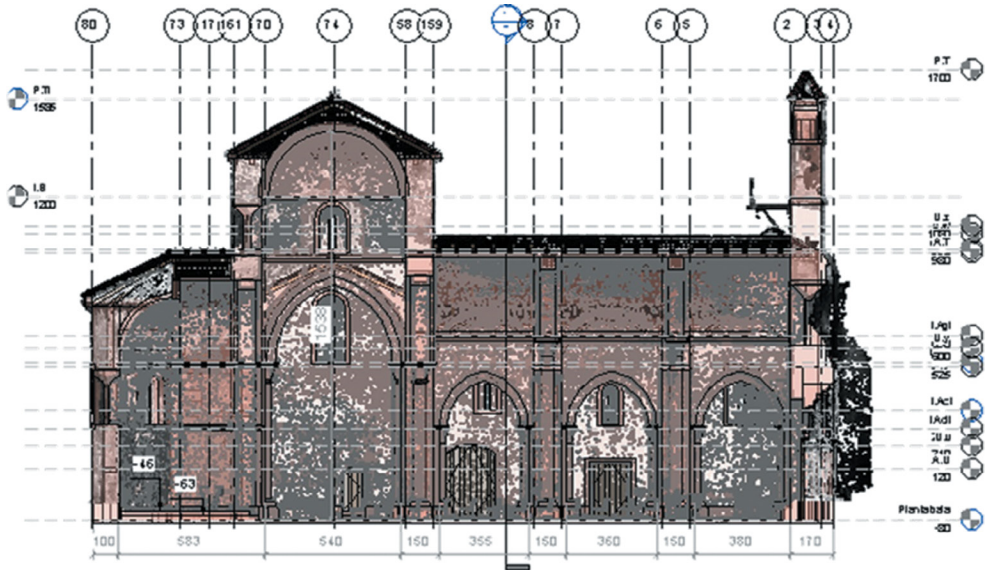


Figure 7: Longitudinal cut of the cloud of points with constructive details in transparency. Vertical gratings, level planes and dimensional dimensions are also perceived. Source: Own figures.

4 CONCLUSION AND FUTURE LINE

In this article, a reverse architecture methodology has been proposed, aimed at demonstrating the creation of an HBIM library and its benefits for simplifying the work of architects, engineers, builders and other professionals involved in architectural heritage.

Moreover, it has been shown that semantic-aware 3D models can be created in the BIM platforms, containing the construction methods and materials of each object, thus providing access to the life cycle management and simulation within various disciplines. For this reason, the HBIM library created in this work will serve as a tool for managing restoration and conservation processes, and can be reused in future projects.

Finally, the virtual models obtained in this way can be used to carry out structural, energetic, luminous and temporal analysis, as well as to interpret the different construction elements and the missing elements. This new way of working has an important social and cultural value, so its adoption will represent a step forward in heritage.

Future research would focus on the fully automated generation of parametric models of the different elements within a point cloud. BIM systems, more specifically the Revit platform, continue to grow strongly year after year, and it is expected that future versions will improve the appearance and connection to other virtual platforms, thus expanding the digital world where researchers and public can interact concerning architectural heritage anytime, anywhere and with any device.

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