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Cover illustration: Wall painting (end of 15th century) of the Virgin Mary, Orans between the Archangels Michael and Gabriel from the Church of the Monastery of Christos Antifonitis, Kalograia (on the apse's conch) after it had been destroyed, following the 1974 Turkish invasion and occupation. Used with permission of the Ministry of Transport, Communications and Works, Department of Antiquities, Lefkosia, Cyprus.

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Supporting the Automatic Extraction of HBIM Elements from Point Clouds

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Abstract. The purpose of this paper is just detailing a state-of-the-art procedure for the automatic recognition of specific 3D shapes from point clouds of immovable heritage assets supported on a tailored tool using PLY, PTX and PTS formats as input files. To make this tool functional and widely used, it is currently developed as a plug-in for the well-known and representative REVIT BIM software package.

The procedure is particularly applied to the Castle of Torrelobatón (Valladolid, Spain) to allow the automation in cataloguing of required elements, as illustrative example of the defensive architecture from the Middle age to the Renaissance in Europe, reason why it is one of the pilot sites of the INCEPTION project. Thus the HBIM process is enhanced, which is continuing right through to provide better services to technicians, scholars and citizens.

Keywords: HBIM · Façade parsing · BIM for existing buildings
Point cloud

1 Introduction

Many in the Architecture, Engineering and Construction fields will see new buildings as the main application for BIM, but a considerable percentage of projects are part developments or refurbishments of existing buildings, within heritage is included for sure (European Commission 2015). According to Arayici et al. (2017) and the Historic England report (2017), the built heritage poses two major issues: (1) the requirement to 3D record and retain many architectural features; (2) how the existing structure is brought into the BIM process.

3D surveying technologies (laser scanning or photo-based scanning) are probed as adequate in the heritage field for a significant number of years (Tommasi et al. 2016), but still today, the data, although collected in 3D, are delivered to the Architects and Engineers as 2D drawings across Europe. A number of factors drove this at the time:

- Pure restoration remains the major consideration to ensure heritage sustainability.
- Limited understanding of point cloud data (3D surveying output) and the capability to handle large data sets.
- Stakeholders' ability and familiarity working with as-built parametric models.
- Software capabilities to deal with point clouds and models simultaneously.

As the awareness of the benefits of BIM is increasingly growing and software and hardware resources are intensified, a greater understanding of the tools available and their application is becoming clear as long as new tools are demanded (Bruno et al. 2018). Due to the recognised wide professional body specification to face an inclusive heritage approach, working with each other into collaborative BIM platforms is a must to understand particular requirements. Thus BIM specifications are essential to bring the existing data into those platforms by developing complementary processes and tools to define the family structure and the delivery method from point clouds.

There are precedents of semi-automatic feature extraction on 3D models with further exporting to *AutoCAD* (Martín et al. 2010). The question now is just widening to the BIM paradigm. It is a real demand for HBIM from point clouds, but it is still relegated to research due to the difficulty of practical realization.

Authors such as Wang et al. (2015) are restricted to the extraction of planes and their intersections to define walls, floors, ceilings, doors and windows for geometrically very simple buildings. Zolanvari and Laefer (2016) detect doors and windows by horizontal and vertical sectioning of a point cloud. Li et al. (2017) make a height based segmentation and labelling to define prismatic volumetric forms by intersection of planes. Although approaching a Cathedral as an example, the most complex parts are discarded.

Many projects concerning the protection, conservation, restoration, and dissemination of cultural heritage are being carried out through commercial BIM software, i.e. *REVIT*, *ArchiCAD* and *Tekla*. According to López et al. (2018) *REVIT* is an efficient BIM platform to accurately model irregular surfaces as well as geometric anomalies of the different elements. Moreover, the *REVIT* platform lets users to add new functions or *plug-ins* based on the application programming interface (API). The programming languages that could be used to code the *plug-ins* are C++, C# and Python.

There are some commercial plug-ins for efficiently using as-built point cloud data captured by laser scanners directly within *REVIT* to ease the BIM modelling of existing buildings. These plug-ins are conceived to let users get all the advantages of a high-performance point cloud application directly within *REVIT*, but restricted to specific point cloud formats according to brand and model of the laser scanner. *LEICA CloudWorx*¹ is a representative example, providing tools for accurate fitting of steel, flange, automatic pipe, and 2D lines mainly oriented to retrofit design and lifecycle asset management of the building. Also provide a virtual visit within *REVIT* with a complete view of the captured reality. In any case, such a kind of plug-ins are only oriented to 3D laser scanning data on recent building and civil works, but not to the built heritage, so they do not expressly meet related needs.

¹ *LEICA CloudWorx* for *REVIT*: <https://leica-geosystems.com/products/laser-scanners/software/leica-cloudworx/leica-cloudworx-revit>.

2 Tailored Tool for the Automatic Extraction of Primary HBIM Elements from Point Clouds

A novel tool has been developed to automatically detect a useful basic set of architectural features from a given point cloud. The detected features are intended to be a common workspace where more complex and detailed objects can be added in a later stage of the digital reconstruction process for heritage immovable assets. The tool is further handled into the *REVIT* well-known BIM package to ensure functionality and actual usability by means of a specific tailored software tool (plug-in).

Suitable digital information sources are mainly 3D point clouds acquired by laser scanning or photo-based scanning. The 3D data, which is made up of geometry (XYZ coordinates) and color (RGB coordinates: real appearance), can be directly handled by the tool. The raw 3D point cloud of the building can be imported into PTX, PTS, PLY formats (ASCII or binary) to be accurately managed into *REVIT* as BIM worldwide representative software by means of a specific tailored plug-in, so called “3DASH tool”. Figure 1 describes the process.



Fig. 1. Process for automatic shaping into REVIT through the 3DASH tool.

This specifically tailored plug-in for *REVIT* is programmed in C++ and supported by the *Point Cloud Library* (PCL) as standalone, large scale, open software project for image and point cloud processing. *3DASH* is able to precisely display the detected features in a unique working project (RVT/RFA).

The *Point Cloud Library* has a wide range of statistical algorithms to detect geometrical primitives such as planes, cylinders, spheres, cones or torus. The vast majority of the architectural geometries making up the built heritage can be modeled by means of these primitives. Theoretically, a point cloud can be completely processed with the proposed library.

In order to put the efforts into a practical example, the *3DASH* plug-in has been focused on the existing primitives at the Castle of Torrelobatón (Spanish demo case). Thus, cylinders and planes are automatically detected on the corresponding point cloud.

2.1 Point Cloud Parameterization Flow Chart

The flow chart diagram of the point cloud parameterization process starts with a statistical filtering in order to minimize potential problems during later stages of cloud processing. Once filtered, a downsampling process is applied to the cloud, which

decreases the point density in the point cloud. This step, although optional, significantly reduces the processing time of subsequent steps.

The analysis of interdependence and intersection between primitives is a key topological problem. Proper segmentation of the point cloud is fundamental to make it more meaningful and easier to analyze by assigning a properties-label to every point. Thus, those with the same label share certain characteristics (Fig. 2).

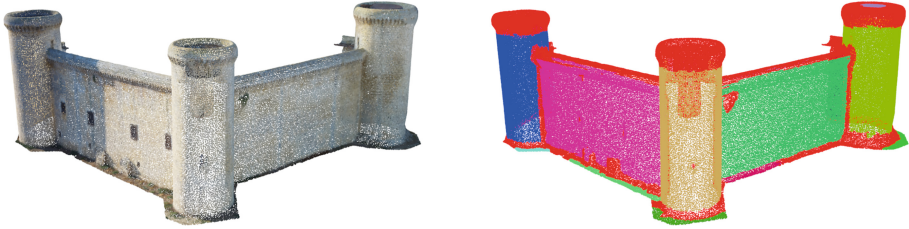


Fig. 2. Segmentation of the point cloud upon the Torrelobatón castle's wall.

In the next step of the parameterization process, the clusters of points are analyzed by a classifier in order to assign a category for each one of these sub point clouds. The clusters can fall into two geometrical categories, namely, planes and cylinders. The classification process is done through a statistical algorithm called RANSAC that determines the points of the cluster are related to the geometrical primitive used as template. It is important to note that every single point cloud can be approximate in some degree by any type of primitive. Thus, the primitive that approximate the highest number of points of the cluster is considered as the sorting primitive for the analyzed cluster. In Fig. 3(a), clusters sorted as planes are represented in red while clusters sorted as cylinders are represented in blue.

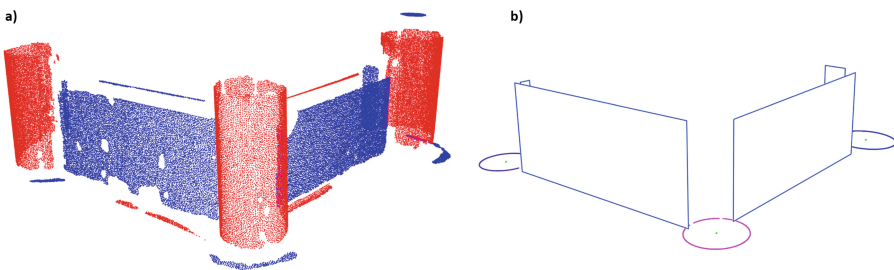


Fig. 3. Classification of the clusters of points into planes and cylinders (a) and advanced parameterization of the detected primitives (b). (Color figure online)

Once the clusters have been classified, the parameterization of the planes and the cylinders is done since the previous step only determined the general mathematical representation of the two primitives. For planes, the classifier determines the implicit equation of the plane, whereas for cylinders the point-slope equation of the centerline

and the radius are estimated. These equations define an infinity geometrical primitive in which the limits must be set. Thus, a more advanced parameterization of the primitives is required.

The advanced parameterization step determines the primitive boundaries. This step is heavily related with REVIT as the parameterization of the primitives has to match the parameterization required by the BIM software. The coordinates of the vertices of the planes are the required for the complete definition of the walls whereas the coordinates of center of the base and the radius among other parameters are required for a complete definition of the round towers (Fig. 3b).

2.2 REVIT Plug-in

Before using the *3DSA*H tool, a new project needs to be created within REVIT in order to load a set of parametric elements to be used by the plug-in later on. Once it is loaded, a specific icon is created to allow the final user modifying some of the processing steps for the automatic shape recognition (Fig. 4, left).

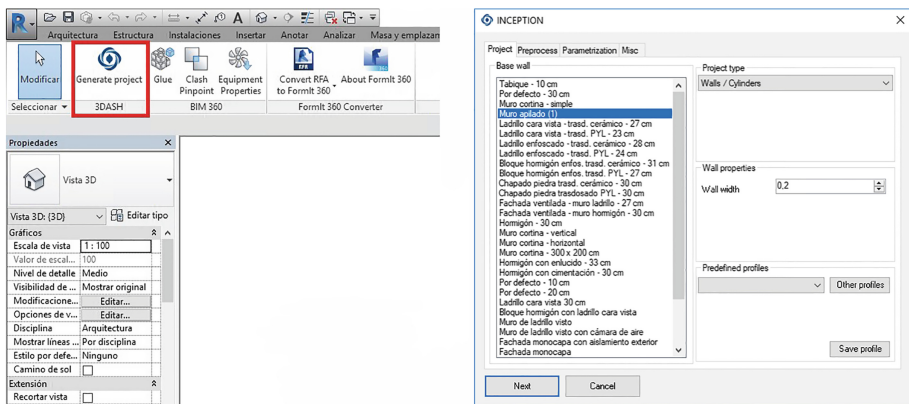


Fig. 4. 3DASH button into REVIT

Clicking on the button, all the functionalities of the *3DSA*H tool are deployed according to the configuration parameters. These parameters cover the entire work flow of the automatic shape detection process, i.e. the region growing-based segmentation normal threshold, the percentage of remaining points in the point cloud after the downsampling process or the tolerances applied while searching common boundaries between different primitives (Fig. 4, right).

Once the parameters have been set, the point cloud can be loaded. The parametric elements automatically generated by the *plug-in* (Fig. 5) are part of the *REVIT* library loaded when the new project was created. Thus, the extraction can be readily exported to IFC from *REVIT* as well.

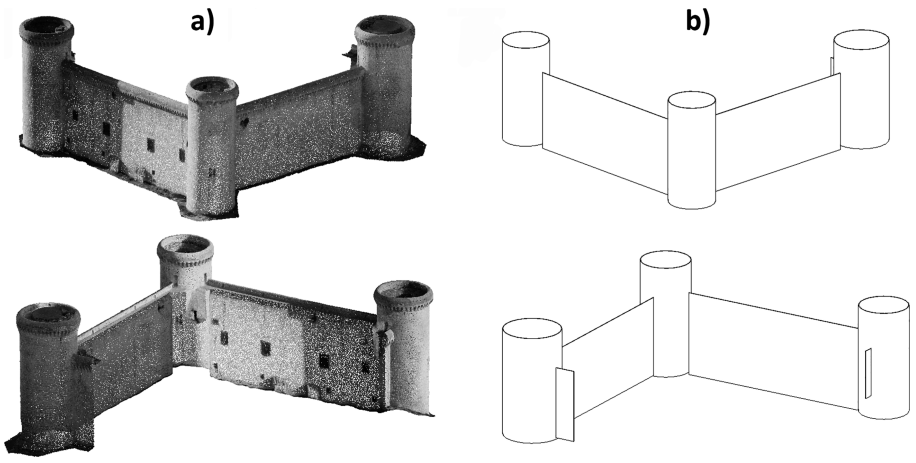


Fig. 5. Parametric extraction of walls and round towers. Loaded point cloud (a) and automatically generated BIM model (b).

The processing time to obtain the results shown in Fig. 5 was 5s in a conventional PC: Inter (R) Core (TM) i5-5200U CPU@2.20 GHz; 8 GB RAM; 64 bits OS; Intel (R) Graphics 5500. The processed point cloud dataset contains nearly 178,000 points.

The alternative result obtained using *LEICA CloudWorx* is shown in Fig. 6. A manual preliminary indication of the surfaces from which the planes and cylinders are to be extracted must be given. The joints between both figures are not completed, and the adjustment to the point cloud is far from the best-fit, with perceptible inclinations in the axes of the cylinders.

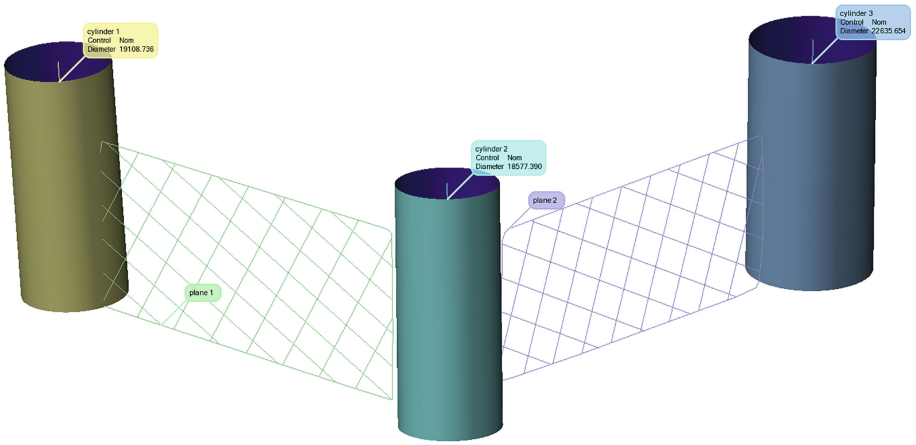


Fig. 6. Comparative result analyzed with PolyWorks 3D software solution

The complete process involving the 3DASH tool is described in a self-explanatory video at: <https://www.youtube.com/watch?v=QpYiPX7IHms>.

This tool is being refined under the INCEPTION European project of applied research on cultural heritage (www.inception-project.eu). The presented results are initial and need to be extended to the remaining 8 demonstrators to get proper feedback on user experiences and to share lessons learned.

3 Conclusions

Unlike the new-build construction sector, where BIM is increasingly applied at international level, with scores of relevant publications and online content, HBIM is a relatively new field of applied research and appears less popular in terms of adoption by heritage professionals despite strongly needing multi-disciplinary collaboration.

This is facilitated meeting specific demands as the case of tailored tool briefly explained in this paper, intended to automatically detect specific geometrical features to be part of a common workspace where more complex and detailed objects as well as semantics can be added in a later stage of the digital reconstruction process for heritage immovable assets. Therefore, HBIM documentation is favored according to the principle for non-invasive intrusions to ensure proper valorization.

Promising trends point out improving methods and tools for automatic conversion of point clouds in HBIM models, reducing inaccuracies and current severe simplifications, as well as extending the IFC standard to solve interoperability issues. The scarcity of research works reinforces the presented results and demands future developments.

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