



A proposal of a 3D segmentation tool for HBIM management

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Abstract

There are several studies related to the cultural heritage digitization through HBIM (Heritage Building Information Modelling) techniques. Today, BIM (Building Information Modelling) software cannot represent old buildings with complex prominent and particularly detailed architecture perfectly, and multiple software are combined to obtain the buildings' representation. In this paper, in order to find an alternative way of replicating the complex details present in antique buildings, a new methodology is presented. The methodology is based on a process of direct insertion of various 3D model parts (.obj), into a BIM environment. These 3D model elements, coming from the points cloud segmentation (from UAV and Laser Scanner), are transformed in intelligent objects and interconnected to form the smart model. The methodology allows to represent detail of the objects that make up an element of cultural heritage, although not standardizable in shape. Although this methodology allows to ensure a perfect reconstruction and digital preservation and to represent the different “defects” that represent and make unique a particular object of cultural heritage, it is not however fast compared with the traditional phases of point cloud tracing and more software are necessary for data processing. The proposed methodology was tested on two specific structures' reconstruction in Reggio Calabria (South Italy): the Sant'Antonio Abate church and the Vitrioli's portal.

Keywords Photogrammetry · HBIM · Segmentation · Cultural heritage

Introduction

Throughout the years, cultural heritage in Italy has undergone numerous restoration and maintenance works; sometimes, without documenting the projects, making future restorations or maintenance a particularly complex task (Dore and Murphy 2015).

The chance to apply the BIM (Building Information Modelling) approach to historical buildings heritage (HBIM) is an interesting challenge in the management/valuation of the buildings and their 3D modelling.

HBIM allows to represent historical buildings in a digital environment, satisfying all the updatable documentation in

addition to geometric information, along with the various restoration activities performed.

The surveying of the existent cultural heritage requires a first phase to acquire geometric information useful to plan the restoration work (through photogrammetry or terrestrial laser scanner).

The cultural heritage buildings are unique also thank to the friezes and particular “construction faultiness's presence”, so, an accurate modelling requires the importation of all these details into a digital model. As already mentioned, BIM is a software that was created for the design of new buildings; therefore the processes for the reproduction of those elements are not immediate.

The main challenge in BIM modelling phase is well known requiring the development of simple methods to produce BIM models that can ensure accuracy, precision, and quality consistent with the captured data. In addition, the model must be enriched with data and information that is not purely geometric, such as historical documentation, analysis of degradation or deformations, levels of detail not granted by the complete model.

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In this way, the existing structures' reconstruction on BIM models could allow the correct and precise preservation and the correct restoration or partial reconstruction, especially in countries like Italy that is a seismic territory but has a vast cultural heritage. Thus, it is important to underline that management and documentation of historical building through the use of BIM for has many advantages, described as follows:

- The possibility to archive historical documents
- The possibility to have all data collected in one file
- The possibility to support technical analysis
- The possibility to support the strategy and organization to conservation and restoration projects
- The possibility to schedule maintenance interventions (BIM can contain maintenance information of each construction element in a structured database)
- The possibility to promote cultural heritage, through the sharing of models on the web or the realization of virtual or augmented reality applications
- The possibility to monitor of degradation
- The possibility to simulate the structural behaviour to catastrophic events (such as earthquakes)

At the same time, once the virtual model has been built, it can be shared so that interested tourists may explore the varying parts. In fact, some software allows for a real time model rendering during the inside tour of the model (Banfi et al. 2017).

In terms of preservation, it must be underscored that, even if the HBIM model is considered as a catalogue of the building used to plan the cheapest and least invasive maintenance, by keeping track of all changes made over time, whilst at the same time it can be seen as a database that would allow for a possible restoration or renovation of the proper condition in case of damage (earthquakes and vandalism). In addition, it is important to highlight the importance of chronicling all cultural heritage site's details to ensure effective methodologies that value and guarantee the correct representation of details and particularities.

There are numerous ways to focus on the issue, although the major hurdle remains implementation timing. The lack of shared regulation and standardized workflows, coupled with considerable difficulties in the modelling phases and in the information's retrieval, cause:

- Uncertainties on construction techniques
- Difficult sequences of construction and reconstruction
- Presence of non-standardized elements not referable to library presets

So far, the process of a HBIM model realization for classical elements involves "tracing" of the points clouds and

the insertion of parametric objects; it involves the use of a shape elaborator for the modelling of particular shapes. Nevertheless, those processes have the tendency to simplify and to recreate environments by applying thought principles and were developed for new buildings. Therefore, the authors' concept is to realize a smart model in a BIM environment, by importing "piece by piece" single objects—building elements or friezes (or through the segmentation of the cloud of points or through the cut of the model)—detected through classic geomatic techniques. This will result in their transformation into smart objects which are then reconnected.

In order to solve the highlighted issue, a new methodology is proposed. It is based on a process of inserting 3D model parts into a BIM environment (.obj), transforming them into intelligent objects which are interconnected to create the smart model. This methodology was applied on two cultural heritage sites, situated in Reggio Calabria (a town in the south of Italy): the St. Anthony Abate church and one of the last structures of the ancient city and Vitrioli house portal that has been restored several times.

The point clouds acquired through laser scanner or photogrammetry were segmented in order to classify them and extrapolate "the pieces" that form the model. The "pieces" were imported into the HBIM, for the interconnection and subsequent matching of material and physical parameters.

The logic process for the BIM building is different from what is present in literature and although it allows to represent the different "defects" that make unique a particular cultural heritage's object, ensuring its perfect reconstruction and digital preservation; however, it does not appear to be fast compared with the traditional phases of point cloud tracing.

Materials and methods

Over the last few years, Building Information Modelling methodology has an ever-increasing diffusion (Brumana et al. 2020; Pocobelli et al. 2018). BIM is a building information and characteristics' digital representation. It is a process that involves structure's life phases, from planning to maintenance; all the professionals participating in the structure's life cycle can share and upload information.

This process allows a complete analysis of the model, structural, energetic, acoustic, on brightness, on materials, etc., enabling the simulation of different scenarios, and makes these tools fundamental in the process of ordinary and extraordinary maintenance of a building. In fact, the procedure initially considered for new buildings thank to correct variation could represent a valid instrument for existing buildings; and in this standpoint, in the context of existing

constructions, the information management guaranteed by the BIM became strategic. Applying BIM methodologies to existing buildings, it is possible to manage in a coherent and tracking of building's life, facilitating the disclosure of the built heritage, improving both the methods of data acquisition and the modelling process. The 3D reconstruction in a BIM environment allows a tour within the model, applying real-time rendering systems (Paris and Wahbeh 2016), and therefore, it is easy to imagine that end users (e.g. cultural institutions, municipalities, universities, etc.) will have the opportunity to view the model in AR and formulate hypotheses of improvement.

Related to the methodologies and tools usually applied for new construction projects, the information of buildings already in existence require a redefinition of knowledge levels that often cannot be rapidly detected, because often designs and reliable data miss (Barazzetti et al. 2015).

For this reason, the results of building in existence survey (i.e., point cloud) are then related to software object libraries to check a similarity. This process allows to have lean models that simplify the data association phase for documentation or for numerical simulations. Therefore, HBIM does not mean applying BIM to pre-existing buildings, but to apply different methodologies and strategies to obtain streamlined models from a survey. Another method, defined Scan-to-BIM, involves the use of geometric components derived from the survey, obtained locally, without appeal to the already precompiled objects libraries (Stanga et al. 2019).

HBIM differs fundamentally from BIM for the type of information contained within it and the modelling approach type. While BIM helps professionals to coordinate the various phases of the construction process with the various actors who incorporate their skills (architectural, structural and planting) into the model, HBIM instead focuses on the importance of knowledge about the conservation status of places and materials, providing designers, managers, conservators, etc. with a knowledge tool to support diagnostic investigations and recovery analyses. Therefore, it is clear that, in order to make the knowledge of the architectural artefact complete, the two fundamental phases of HBIM are survey and modelling.

The implementation of an HBIM model can be summarized as follows:

- Acquisition of data from different technologies
- Creation of point clouds
- Import and adapt point clouds for semi-automatic recognition in BIM environment
- Semi-automated BIM generation of elements
- Modelling the remaining elements
- Linking all elements to obtain a complete model of the artefact

When considering the presentation of the methodology followed by the authors, it is important to observe that it is not yet possible to build an HBIM model using a single software (Pierdicca et al. 2020; Oreni et al. 2012), in fact it is necessary to use interoperability between different programs, taking advantage of file format, which allows for transfer while maintaining the largest quantity of information possible, using in certain cases plugins that connect the different platforms.

Today, the acquisition of new point clouds of cultural heritage items is only possible through the use of well-established methodologies (laser scanner and photogrammetry) that are characterized by a resolution which can be very different depending on the necessities, tools, etc. but that can reach also the millimetric accuracy.

At Present, from a point cloud, it is possible to create a parametric model that includes the greatest degree of knowledge. However, it is time-consuming to complete the process (Murphy et al. 2009). In fact, starting from the building survey, the process must accumulate as much information as possible to transfer into a model. But this procedure is variable in function of the survey reason (Martínez-Carricondo et al. 2020).

Recent research is centring on the enhancement of standard procedures and automatic processes to carry out this procedure with faster methods than manual ones. These procedures must avoid any loss of information and details, by combining the need for more details on the parts of the element inside the BIM with a better accuracy of the model.

In fact, HBIM scan process works fast and smoothly, reproducing environments without construction peculiarities caused by human mistakes or by the age of the structure. As already observed, to date, two main approaches are used: the first one that compares the point cloud with a database of objects already present in libraries searching for the most similar ones and the second procedure that uses surface information (from the point clouds) to execute another sort of classification (Micheletti et al. 2015).

HBIM processes are continuously evolving. The latest studies attempt to automate the HBIM process through the use of libraries, but it is clear that the use of parametric elements could conflict with the objective of cultural heritage. On the contrary, the authors suggest a division into different sub-elements preventing the levelling out of all elements.

This methodology is based on a process of inserting 3D model parts into a BIM environment, by transforming these parts into intelligent objects that are interconnected to create a smart model.

The point clouds acquired through laser scanner or photogrammetry were segmented to extrapolate and classify the “pieces” that form the model, and then the “pieces” were imported into the HBIM to interconnect and, afterwards, match material and physic parameters. It is important to note

that the logic process used here differs completely from other processes studied in the literature. Nevertheless, this procedure highlights issues related to the use of multiple software and to the file formats used, although it speeds the process up.

The process followed by the authors is reported on Fig. 1.

Therefore, it is possible to create a congruent and coherent model, where most of the information gathered up are contained, in an accessible digital database.

In the case study, to proceed to the 3D reconstruction, a photogrammetric and laser scanner surveys were conducted.

To acquire the digital image dataset useful for the outdoor and indoor photogrammetric 3D reconstruction, a DJI Mavic Pro (DJI; Shenzhen) UAV (Unmanned Aerial Vehicle) with CMOS 1/23" sensor and a Canon EOS 6D Body were used. The DJI Mavic Pro camera specs are Sw = real sensor width = 12,8333 mm; FR = real focal length = 8.6 mm; imW = image width pixels 5472; and imH = image height pixels 3648.

The EOS 6D is a full 35 mm frame Digital Single Lens Reflex (DSLR) camera. It featured 20.2 megapixel full-frame complementary metal-oxide semiconductor image sensors (CMOS) and a wide ISO range of 100–25,600, expandable to L: 50, H1: 51,200, and H2: 102,400.

To build the point cloud by laser scanner, a FARO Focus 3D was instead used. The FARO Focus 3D specs are: Unambiguity interval: 153.49 m, Range Focus3D 1201: 0.6 m - 120 m indoor or outdoor with low ambient light and normal incidence to a 90% reflective surface, Range Focus3D 20: 0.6 m - 20 m at normal incidence on >10% matte reflective surface, Measurement speed: 122,000 / 244,000 / 488,000 / 976,000 points/s, Ranging error2: ±2 mm Resolution: Up to 70 megapixel colour, Wavelength: 905 nm, Beam divergence: Typical 0.19mrad (0.011°) Beam diameter at exit: 3.0 mm, circular.

Data and results

Case studies

The application of the methodology that the authors are developing was tested on two particular structures that have undergone various restorations.

The first is a church and as a building falls perfectly within HBIM modelling, the other is a portal also subject to repeated restoration that does not fall directly into the usual HBIM case studies, since it is only a small part of a bigger building. However, its modelling and hence the digital temporal archive creation, can make a major contribution to the enhancement and planning of interventions.

The Sant'Antonio Abate church is an example of medieval architecture in the town of Reggio Calabria (South Italy). The first construction phase starts on the thirteenth to fourteenth century, and the church comprised a three-aisled building with no transept, pillars and tripartite apse. In its most ancient phase, the church was placed in the Basilian-Norman architecture.

As time goes on, the church has been subject to several restorations. The northern wall was rebuilt at the beginning of the seventeenth century; and, between 1628 and 1671, the central nave arches were closed, transforming into a sacristy the nave. In the eighteenth century, the floor was raised, and the two crypts were covered with vaulted ceilings, and niches for funeral depositions were created on the walls, according to a unique monastic custom in the city of Reggio Calabria (Fig.2).

The Vitrioli house portal is one of the last vestiges of the ancient city of Reggio Calabria spared from the destruction.

of the 1908 earthquake. It was built in the XIV century and erected as a monument after the last reconstruction. Currently, the building is located within the public gardens of the Villa Umberto I (Fig. 3).

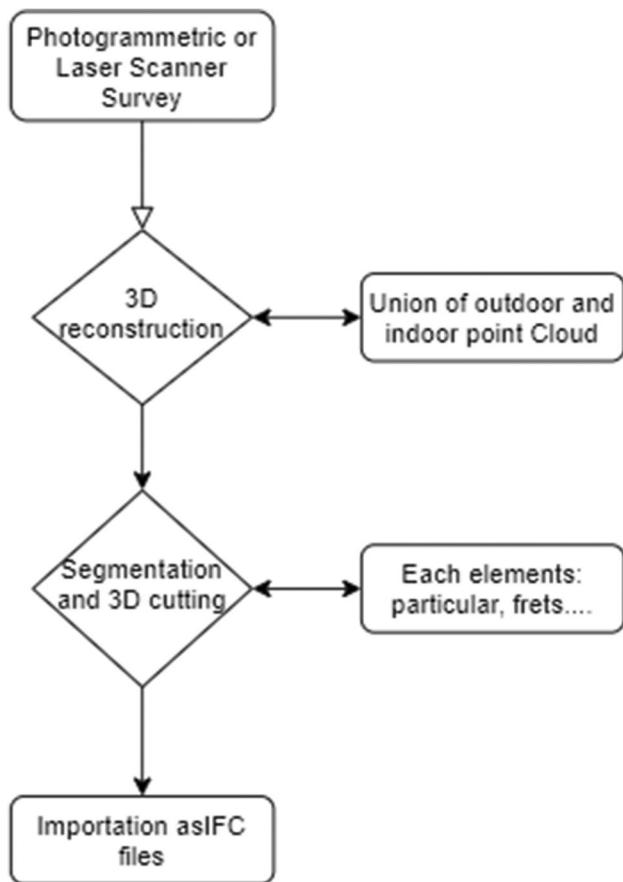


Fig. 1 Flow chart—reconstruction of Building Information Modelling



Fig. 2 St'Antonio Abate Church

Model 3D reconstruction

Starting from the internal and external photogrammetric survey, a parametric model of the St Antonio Abate church was built. A DJI Mavic Pro was used to acquire the photographic dataset of external area necessary to the photogrammetric 3D reconstruction. To obtain a model with sub centimetric accuracy and a high-quality model reconstruction, the image acquisition plan was divided into three stages: waypoint flight planning, Ground Sampling Distance (GSD) definition, and image overlap percentage



Fig. 3 Vitrioli Portal

choose. So, through a waypoint flight mission, the UAV performs an automatic flight and image acquisition.

Setting flight height (and consequentially GSD), overlap (%), and area to be mapped, the software calculates automatically the image acquisition plan and mission. To obtain centimetre precision ($GSD < 1$) at legal flight height, maximum flight height was set to 30 m for vertical flight. So, flight plan at 20, 25, and 30 m, with camera set to 70° were made. The acquired aerial images were integrated with additional images from the ground.

A Canon EOS 6D Body was instead used for the acquisition of digital images useful for the reconstruction of the indoor 3D model and to integrate the aerial survey (López et al. 2018). The parameters for the photogrammetric survey were Lens, 35 mm; Grip Surface, 3 m; GSD (Ground Sampling Distance), 0.4 mm/pixel; Horizontal point taking, 60 cm; vertical point taking, 40 cm; Side lap, 80%; and Overlap, 80%.

The 3D reconstruction was executed using Agisoft Metashape (Agisoft, St. Petersburg) photogrammetry software. The elaboration process is composed of different phases (Tucci et al. 2019; Pierdicca et al. 2020):

1. Photo alignment: a phase that identifies the tie points with common characteristics in order to be adequately superimposed in the various photos.
2. Build dense cloud: this phase allows to build a dense cloud using dense image matching algorithms.
3. Build mesh: it consists in generating a polygonal model based on the newly created dense cloud.
4. Build texture: this phase allows to generate a two-dimensional raster image in a way to apply a photorealistic colour to the mesh.

The obtained 3D models are represented in Figs. 4 and 5.

Figure 5 shows the Vitrioli 3D arc.

The laser scanners proved to be very useful tools in the field of Cultural Heritage, since they are not invasive systems which allow us to carry out a deep inspection of the sites without damaging their historical, cultural, and economic value.

In order to get an indoor and outdoor 3D model of the church and of the arch from the laser scanner, a FARO Focus 3D laser scanner was used. Then, the traditional elaboration of data through the commercial programme FARO scene v.4.1. software was conducted (Brumana et al. 2013).

The survey was carried out in a single day. Once the desired scanning parameters had been set (4x resolution and 2 million points accuracy), the instrument was positioned in the pre-set positions recreating the orthogonality conditions where they were necessary, acting on the instrument support tripod, so that the internal electronic bubble could check the limits within which the compensator can operate to obtain perfect horizontality.

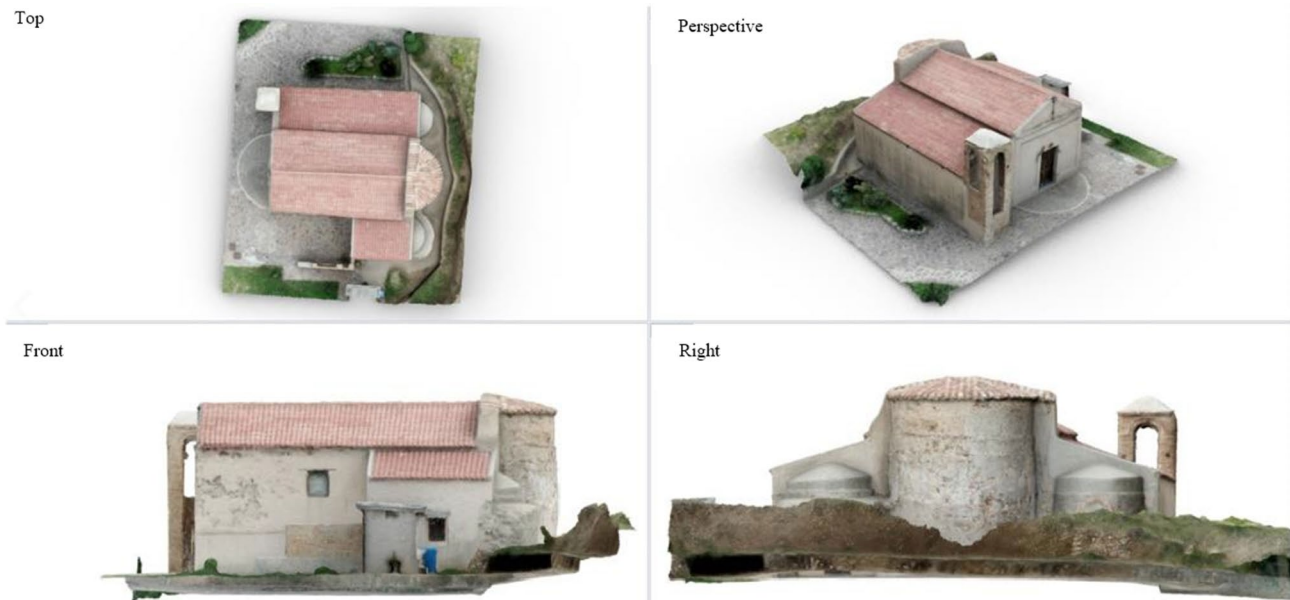


Fig. 4 Perspective view of the reconstructed Sant'Antonio Abate 3D Model—outside



Fig. 5 Vitrioli house portal 3D Model

The selected setting to obtain a resolution was one point every 4 mm in the two directions. The raw data obtained from the instrument were processed by the software FARO SCENE.

The registration phase was then developed in two parts.

In the first part, the point cloud was considered in their entirety in the face of high alignment errors. After following a process to eliminate the unnecessary or false points in the clouds, the procedure was repeated, checking the errors obtained. In particular, the clouds were aligned, trying to maintain overall geometric information acquired from each scan. The alignment errors returned by the software in the various attempts were found to be between 3 and 7 mm.

For this reason, a manual phase of editing was conducted, involving the elimination of unsuitable points.

The collimation and recording operations were carried out by recognizing characteristic points of the detected structure (vertex spots). It was verified that the three-dimensional model obtained has a high metric reliability since the errors found were contained between 1 and 3 mm.

Fig. 6 shows the reconstruction of the 3D model of the St Antonio Abate church indoor.

Once the point clouds (acquired through several methodologies and instruments) were created, before to merge the internal and external clouds to establish a single 3D model (in the church case), a comparative analysis of the accuracy of the different methods was carried out. The procedure allows to verify the quality of the surveys made, to achieve a better integration of the different clouds (Martínez-Carri- condo et al. 2020).



Fig. 6 St'Antonio Abate 3D Model—inside

Table 1 shows the comparisons (Δ_{RP} Δ_{RL}) and the related precision (σ) between real measurements (R) of length (L) for the church and (b) for the arch, and the heights (H) for the church and (h) for the arch, of parts of the building (church or arch) and measurements acquired through the corresponding models obtained by photogrammetry (P)

laser scanner (L). As expected, the deviation between the measurements and the related precision highlights a higher reliability of the laser scanner methodology. Therefore, those clouds were chosen for the following phase of mesh of the indoor models, while leaving aside the cloud obtained by drone.

In order to obtain a single point cloud, the internal and external clouds were then combined using common key points detected on both point clouds (i.e., main entrance, pavement, wall). Then, the complete mesh inside and outside model of the church was elaborated, and a complete 3D model (mesh and texture) was achieved. In addition, a control network and ground control points were used to connect the photogrammetric survey to the real size and orientation. As ground control points (GCP) were used a clearly identifiable point in the raw image, a GCP determines the relationship between the raw image and the ground by associating the pixel and line image coordinates to the x, y and z coordinates on the ground.

Table 1 Comparisons (Δ_{RP} Δ_{RL}) and the related precisions (σ) between real measurements (R) of length (L) for the church and (b) for the arch, and the heights (H) for the church and (h) for the arch

Elements	Real measurement	Photogrammetric measurement	Laser Scanner measurement	Points	Δ_{RP}	Δ_{RL}
L1	15.9	15.8	15.9	1	0.1	0
L2	5.1	5.1	5.15	2	0	0.05
L3	5.4	5.5	5.45	3	0.1	0.05
L4	3.5	3.4	3.45	4	0.1	0.05
L5	10.5	10.4	10.4	5	0.1	0.1
L6	8.6	8.6	8.5	6	0	0.1
H1	5.75	5.7	5.65	7	0.05	0.1
H2	5.7	5.6	5.65	8	0.1	0.05
H3	4.5	4.4	4.55	9	0.1	0.05
H4	3.6	3.7	3.62	10	0.1	0.02
H5	5.7	5.8	5.76	11	0.1	0.06
H6	5.6	5.6	5.64	12	0	0.04
b1	1.78	1.8	1.81	13	0.02	0.03
h1	1.17	1.2	1.15	14	0.03	0.02
b2	1.76	1.8	1.78	15	0.04	0.02
h2	1.18	1.2	1.19	16	0.02	0.01
b3	1.76	1.8	1.76	17	0.04	0
h3	1.17	1.2	1.2	18	0.03	0.03
b4	0.8	0.8	0.83	19	0	0.03
h4	1	1	1	20	0	0
b5	1.72	1.8	1.75	21	0.08	0.03
h5	1.18	1.2	1.21	22	0.02	0.03
b6	1.2	1.2	1.23	23	0	0.03
h6	1.8	1.8	1.78	24	0	0.02
b7	1.25	1.2	1.29	25	0.05	0.04
h7	2.8	2.7	2.84	26	0.1	0.04
				σ	0.04458	0.01954

Fig. 7 Sant'Antonio Abate Church – Union of clouds



Thus, the union and the recording of the two point clouds allowed us to precisely identify the shape and the thicknesses of floors and slabs in all their extensions.

In Fig. 7 a screenshot of the “tour” between the two-point clouds in Autodesk recap.

HBIM reconstruction

The modelling of an historic building (HBIM) presented all the issues highlighted in the paragraphs above, such as the actual difficulties of modelling, irregular sections of walls, in particular the height and thickness and with unknown stratigraphies and with architectural details which are difficult to model (Barrile et al. 2019a; Barazzetti et al. 2016).

Therefore, in order to obtain a BIM as close as possible to the architecture of the original historic building, that is able to preserve the original defects' presence and the diversity of the shapes that make it up, the methodology presented in Subsection 2.1 was used.

The methodology is based on a process of direct inserting various 3D model parts (.obj), into a BIM environment, transforming them into intelligent interconnected objects to form a smart model. The point clouds acquired through laser scanner or drone were segmented in order to extrapolate the pieces to import into HBIM and to interconnect and afterwards assign material and physic parameters.

In this regard, two different procedures can be used in the methodology proposed by the authors, in relation to the extrapolation of the “pieces” that make up the model: segmentation phase or the model cutting phase, which does not automatically generate an intelligent model.

In regard to the segmentation phase, it is noted that at present, point cloud analysis is in its infancy, and today different techniques and algorithms to treat this type of data

exist (Barrile et al. 2018); segmentation and classification of point cloud are very active research topics. Segmentation is the process of grouping point clouds into multiple homogeneous regions with similar properties (such as geometric, radiometric etc), while classification is the definition and assignments of point to specific classes, called “labels”, according to different criteria. These two processes allow the extraction of relevant information from the acquired data. Moreover, outlier elimination, spatial analysis and object simplification are another active research field.

To extract relevant information from point cloud, it is necessary to segment and classify the interested objects inside the acquired scene. There are multiple research studies related to these two topics, driven by specific needs provided by the field of application (cultural heritage, building modelling, heritage documentation, robotics, etc.). A non-exhaustive review of segmentation and classification methods is presented by Özdemir and Remondino (2018).

- Edge-based segmentation uses algorithms for edge detection to outline the borders of different regions and to group points inside the boundaries to deliver final segments.
- Segmentation by model fitting is based on the observation that many man-made objects can be decomposed into geometric primitives such as planes, sphere and cylinders.
- Finally, machine learning methods are based on classification performed by machine learning algorithms (including deep learning, neural network). Machine learning is a specific discipline of computer vision which uses artificial intelligence algorithms to allow the computer to take decisions based on empirical and trained data.

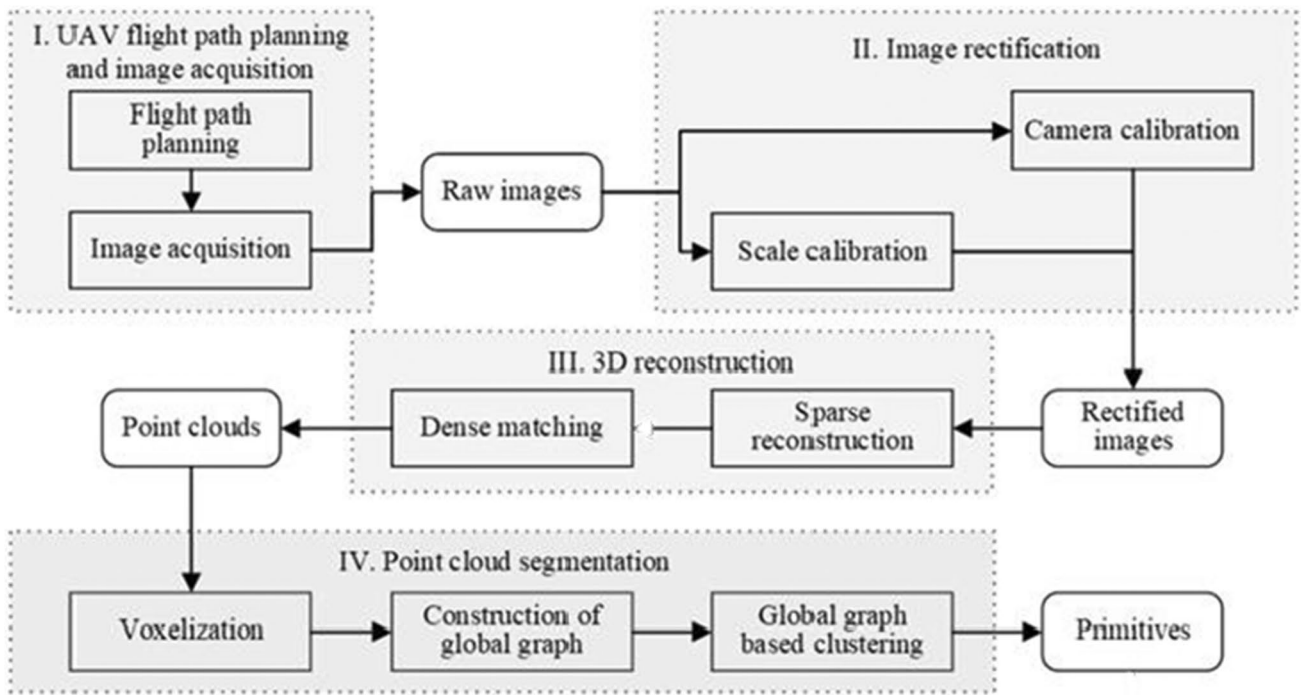
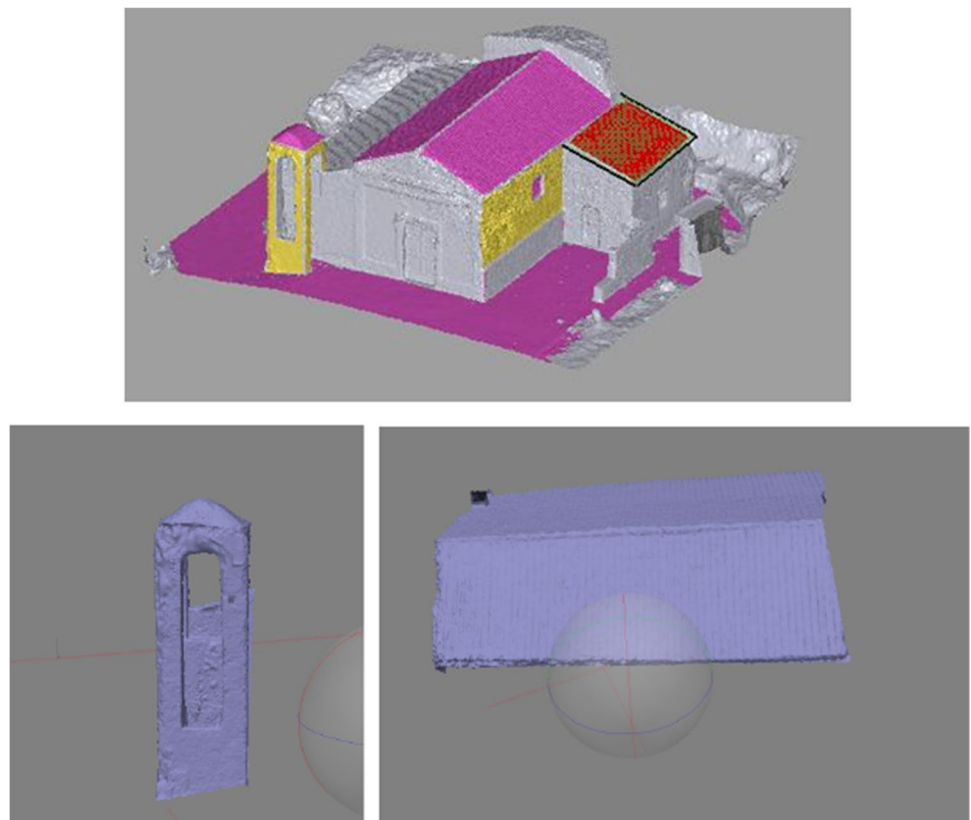


Fig. 8 Flow chart dense cloud segmentation

Fig. 9 Segmentation results using the reference data



Classification of each segmented points can be achieved using three different approaches:

- Supervised approach, where semantic categories are learned from a dataset of annotated data and the trained model, is.

used to provide a semantic classification of the entire dataset.

- Unsupervised approach where data is automatically partitioned into segments based on a user-provided parametrisation of the algorithms.

- Interactive approach where the user is actively involved in the segmentation/classification.

In particular, the procedure for extrapolating the “pieces” that make up the model, starting from the point cloud capture phase made by drone, is described in the flowchart (Fig. 8) (Yang et al. 2019).

Figure 9 shows the result of the segmentation of some parts of the cloud obtained with the described methodology, which would allow for the reconstruction of the related mini-models of the classified elements, in relation to the church of Sant’Antonio Abate.

At this point, to generate the HBIM the point clouds which were segmented and classified, using this methodology are processed with the appropriate software for the creation of mesh and related 3D model in the .obj format, which is then imported onto REVIT (Barazzetti et al. 2015).

Alternatively, in order to extrapolate the “pieces” forming the model, one can proceed directly with the cut of the 3D model created by the whole point cloud, thus obtaining the “pieces” forming it from the model itself. Therefore, for the generation of the HBIM, the 3D model is “cut” into several elements that were imported as individual elements in the BIM software (Autodesk Revit) as .obj file, using the entire cloud as a guideline for the placement of the various objects.

The exported .obj model can be subdivided into parts through the use of cut planes. In this specific case, the

software Fusion 360 was used. The “Mesh” software work environment allows to find 3D mesh models like .stl and .obj; and through a subdivision command (Plane Cut), the models were sectioned. Through the free software Mesh-mixer, it is possible to modify the mesh formats and cut the model through the use of several commands to work on files .stl and .obj. Among these, the most relevant is the combination of two commands, Plane Cut + Separate Shells, through which it is possible to subdivide our models into several portions.

Once the objects were obtained (in .obj format) with one of the techniques mentioned, it is possible to proceed in a standard way to transform those objects into smart objects, assigning them specific characteristics and indicating the interconnection with adjacent objects. These obj were imported after being embedded with semantic information, such as materials and dimensions and were then inserted into the BIM model as “families”, i.e. categories of similar objects. Additionally, metadata enrichment can be provided.

This process guarantees a geometric and material appearance closer to the real conformation of each component by also ensuring information management (Barrile et al. 2019b).

Thus, the objects were located in the space following the obtained point cloud as guideline. Figure 10 show an overlap between the BIM and the cloud related to the church of St’ Antonino Abate.

The various elements were interconnected, to obtain the final HBIM model, which is accessible and presents all the information useful for the users. The final building information model is reported in Fig. 11.

Finally, the database of each element was enriched by entering data from different sources (technical geometry information, description of materials, historical information, cadastral data, presence of constraints, maintenance

Fig. 10 Overlap between BIM and Dense Cloud



Fig. 11 Reconstruction of Building Information Modelling

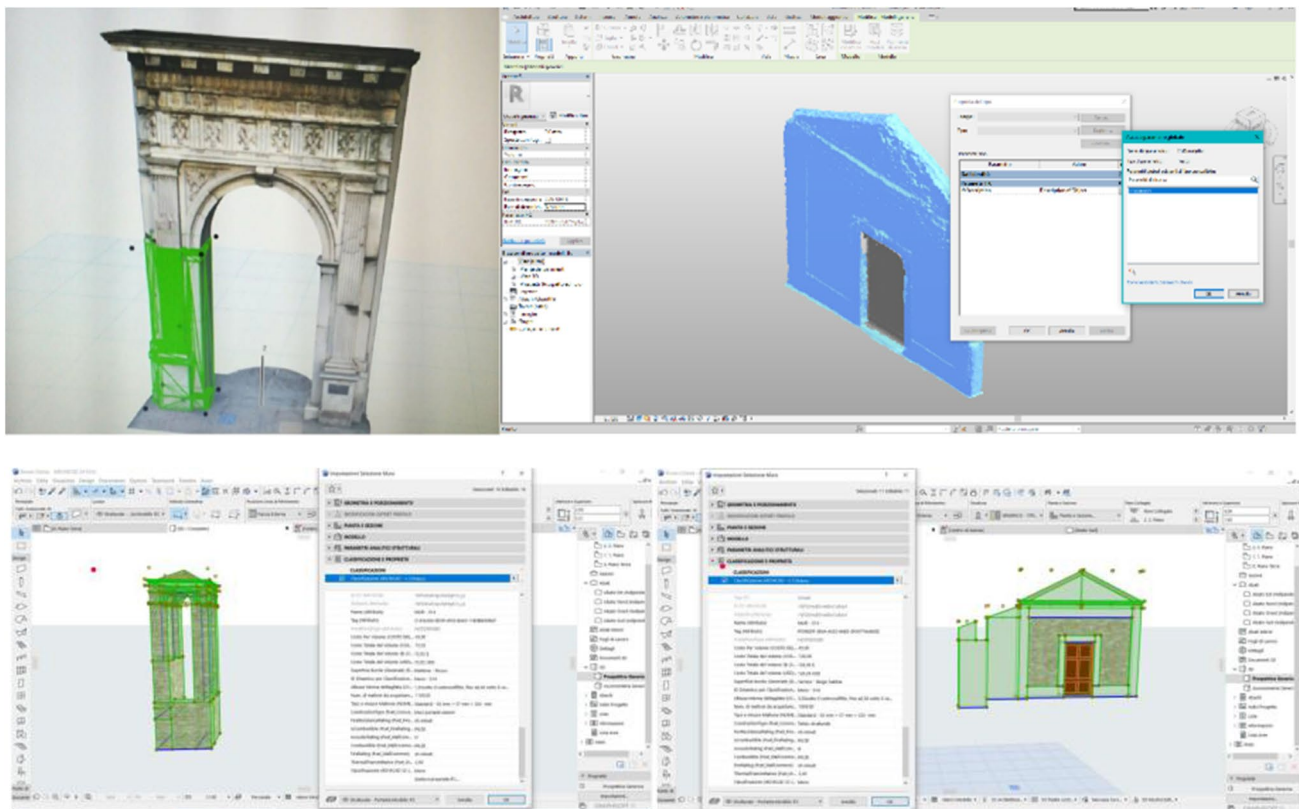
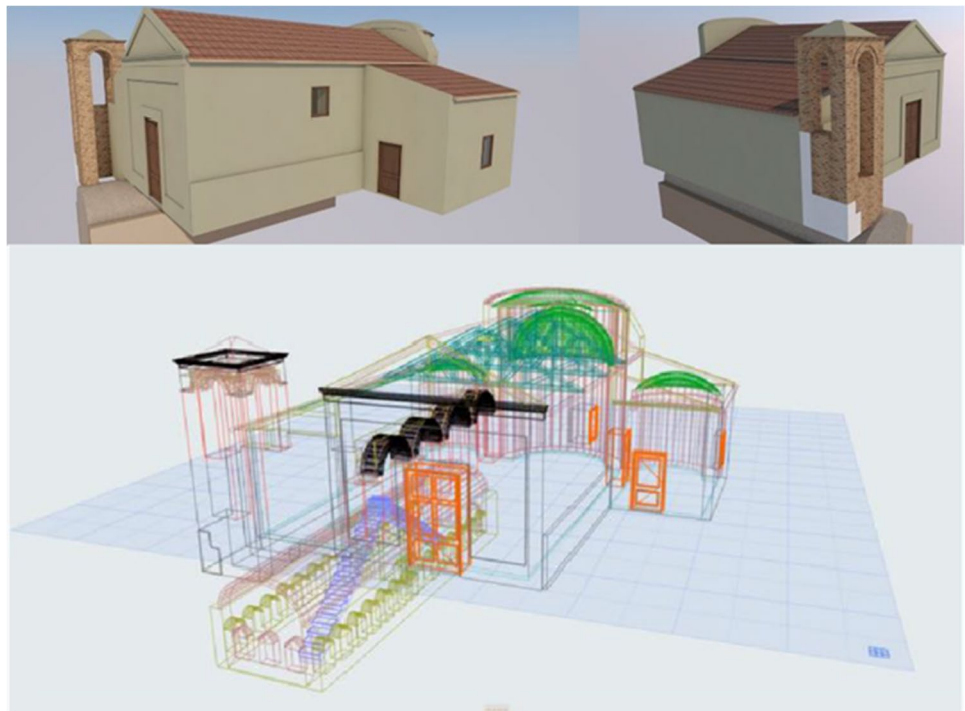


Fig. 12 Example of single element's reconstruction on Building Information Modelling

interventions) with the same DB becoming an integral part of the model.

The model can then be saved in .ifc file per can be shared among multiple operators ensuring interoperability (main feature of BIM/HBIM).

For the Vitrioli portal BIM reconstruction, a similar procedure was used. The methodology was much more expedited than the church because only one cloud must be processed, and the elements can be extrapolated easier.

Each object contains information about its construction element classification, object identifier, renovation cycle type, structural loads, etc. These attributes can be populated and have assigned values to them. The information contained in the object as a user attribute can be later translated to an ArchiCAD property. In the ArchiCAD environment, however, the semantic data are not simple; some are inherent to the specific object type, others are general, and some can be customized by the user in order to represent a certain kind of object associated phenomena.

While Fig. 12 shows the outcome of the suggested methodology with the possibility of selecting a single obtained element as an interconnection of many parts, on the left, the base of the portal is displayed (which was not subject to any restoration phase), and on the right, it is displayed the acquisition of two mini-models of the doors and facade wall (of the church). The associated tabs report data and information acquired by the user.

Therefore, from the final models, it can be observed that HBIM is a reverse engineering process on the existing building and that the most realistic historical buildings modellation require a high knowledge of the buildings' characteristics (geometric, material, historical).

In BIM methodology, the exchange of data (between the various subjects) is essential. This information transfer is facilitated by the open .ifc format (Industry Foundation Classes), which has become an international reference standard.

Conclusions

BIM is a process that leads to the creation and management, in all its parts, of a digital model representing construction project, which contains all the information regarding its characteristics. It is well suited to the modelling of point clouds generated by geomatics procedures such as photogrammetry from UAVs.

Over the last few years, various software have been developed to view BIM files with .ifc extension. Most of these .ifc Viewers offer the possibility to control BIM models through classic three-dimensional navigation functions.

The reconstruction of BIM models for existing cultural heritage allows for the creation of databases to preserve information and to favour the eventual restoration or partial reconstruction of buildings, especially in countries like Italy affected by strong seismic events.

However, nowadays commercial BIM software is not designed and suited for the modelling of existing structures, so in reporting complex construction, surface details cannot be faithfully reported in the software. Inserting single class is too generic and results in losing that information that makes the historical building unique (e.g. different designs of capitals and columns of the same architectural style).

HBIM is a process to optimize the planning, reconstruction, restoration and management of historical building.

The reconstruction existing cultural heritage models allow for the creation of databases to preserve information and to favour eventual restoration or partial reconstruction.

The authors used a different methodology to create the HBIM model. The entire model produced by photogrammetric techniques is cut in several parts as an .ifc file. It is a particular data format that allows the interchange of an information model without loss or distortion of data or information and facilitate interoperability between the various operators. The different parts of the model are then reassembled using the point cloud as a guideline. The results are appreciable from a metric point of view, using dense cloud as a reference for the insertion of the various "cut" models (.ifc files), where there is no metric deviation.

Therefore, the creation of multi-object requires an extensive time of elaboration, yet definitely faster if there is the need to distinctly model every single element of a cultural asset.

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