Carmine Gambardella

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INDUSTRIAL HERITAGE, THE *FABRA I COATS* ENGINE ROOM IN BARCELONA: A TERRESTRIAL LASER SCANNING POINTCLOUD CLASSIFICATION

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Abstract

This paper is divided into two parts: the first seeks to compare the results of two surveys made with a time of flight scanner, Riegl z420i, and a phase based scanner, the Faro Focus[3D]. These surveys were conducted inside an industrial heritage building, the Fabra i Coats boiler room (built between 1910 and 1920). The complexity of this construction allowed us to make a comparison between technical characteristics of the instruments, settings, data collection and lighting conditions. The second part develops a classification workflow for this information. Architectural parts and installations were separated in relation to three topics: historical construction, function and architectural program. A high density point cloud model was generated, over 1.300 million points in a building volume of 7.000m³. Finally, advantages of this process in relation to the diffusion of heritage, conservation documentation for the proper understanding of the current state are discussed as well as the representation of its historical evolution in an interactive real-time point viewer.

Keywords: Laser Scanning, Industrial Heritage, Digital Preservation, Classification, Point clouds.

1. Introduction

Although there are several techniques for cultural heritage documentation, terrestrial laser scanner (TLS) technology allows a survey of very complex sites in short periods of time without compromising precision. Standard workflows are required in this type of surveys for a better understanding of the building. It is a complex task to propose a unique methodology, given the technical characteristics of instruments, the complexity of the objects and the piping facility, and the diversity of materials in these scenarios.

An example of this methodology is presented for the classification of a high density point cloud of an industrial heritage interior. A structure for the database is proposed to facilitate the access to existing information and documentation generation by users involved in the process of heritage conservation, in terms of planning, interdisciplinary communication, evaluation of outcomes and as a dissemination tool [4].

The case study is the Fabra i Coats engine room, an industrial heritage icon of Barcelona, where boilers supplied the energy for the textile factory to work, first by coal and later by gas. This room is part of a larger complex consisting of several buildings built in different periods, the oldest dates from 1890. The complex has witnessed the history of Sant Andreu de Palomar (the old town where he was born) before its annexation to Barcelona. The Fabra i Coats, textile factory represents an exceptional moment in the city's development and industrialization process which Catalonia lived in the XIX century.

This study covers different levels and scales of detail, ranging from machinery cables to brick walls that compose the main body of each boiler. A comparison of the technical characteristics between two different laser scanners is made relative to the survey proposed, looking to improve the process in relation to the data needed to identify the classified elements for a proper documentation and the time required for each survey. In this process, a comparison between two technologies is also made; a time of flight, Riegl z420i, and phase scanner, Faro Focus[3D], is discussed.

The paper is organized as follows: section 2 describes the case study and section 3 is a comparison of the results of the two surveys in terms of data acquisition, resolution, accuracy and density of points. Section 4 presents the workflow in the segmentation/classification of the point cloud model in relation to the data density and the complexity of the geometry. Finally, section 5 focuses on the structure of the database, designed to communicate the historical evolution of the different engines, data accessibility and its interactive visualization.

2.   Case Study: Fabra i Coats engine room, Barcelona

In the nineteenth century, Catalonia was a major player in the Industrial Revolution, leaving its mark in history by changing the traditional craft production structure for the organization linked to the factory. With an urban and productive progress so fast and intense, many industrial buildings ceased to exist, others continue abandoned until further use or where destroyed. Fortunately, others have been rehabilitated. Today, these buildings are part of the identity of Catalonia; they are part of the rich urban and architectonic heritage of Barcelona, as well as a representation of the collective memory [2].

One of the most prominent examples of these processes is the rehabilitation of the industrial complex of Fabra i Coats, cataloged as Architectural Heritage of Barcelona with the "C" level [1]. Being a building that meets historic, artistic and aesthetic values, it has a relevant urban impact in the area where it is located. The Barcelona City Council bought it in 2005, turning its main buildings into a Cultural Center. It is a group of warehouses, currently under construction, with resources for the creation, practice, and dissemination of multi-disciplinary art, and the flagship project for the "Fàbriques de Creació" program.

The survey with the TLS was focused on a central chamber of the industrial complex, built between 1910-1920. It consists of a boiler room, a power plant room and a pump room. These last two rooms are located on the ground floor of a four level building. The construction has a brick structure, with English laminated profiles as columns and beams.

3.   Laser Scanning Data Acquisition

As a preliminary step to the classification of the point clouds, technical questions have been raised in relation to the characteristics of a TLS survey to identify small elements in industrial heritage buildings in relation to adjustments, yields and analysis data. This data must take into account the density of points necessary to identify all elements, the optimum distance for capturing data, involvement by angles of incidence and occlusion, considering the different characteristics of both of the equipment used.

The survey of the interior of Fabra i Coats was performed with two high precision scanners:

▪   The first is based on a flight time principle, Riegl z420i, with a field of view 360º H * 80º V, accuracy 10 mm and a distance range from 2 m up to 250 m, 1.5 million points per 5-10min scan at 0.1º resolution.

▪   The second scanner is based on Phase-Shift, the Faro Focus[3D], this scanner system allows for a larger field of view 360º H * 305º V, with a range accuracy 0.6 mm @ 10 m, 0.95 mm @ 25 m (wavelength in nm 905), ≤ ± 2 mm systematical distance error at 25 m, beside intensity of reflected beam the Faro is able to acquire RGB, with an integrated camera 70 megapixels [5], 38 million points per 5-10min scan at 1/8 resolution.

At the end the resolution of the survey depends largely in the number of positions and the resolution established per scan. The importance of the registration process is key to the final point cloud resolution as every single element in the room, including the cables or lamps, is pretended to be registered and classified. An ICP method was adopted (figure 1) instead of the traditional target registration technique as it performs a validation error in the binding of each position. This process allows a great level of accuracy as all the information of the acquired data is considered, rather than only a limited number of points. The principal advantage of the ICP registration is independent to the nature of the geometric data (points, curves of different degrees of the surfaces). It is based on minimizing the distance between

two point clouds, point by point, by successive iterations. The main disadvantages of this process in its original form, is the convergence to a minimum which may be false, especially when data contains a lot of noise, and it takes a large number of iterations for the convergence of the model. A final 1.300 million point cloud model was obtained from 82 registered scan positions for the Faro, and a 45 million point cloud model was obtained from 16 scan positions for the Riegl.
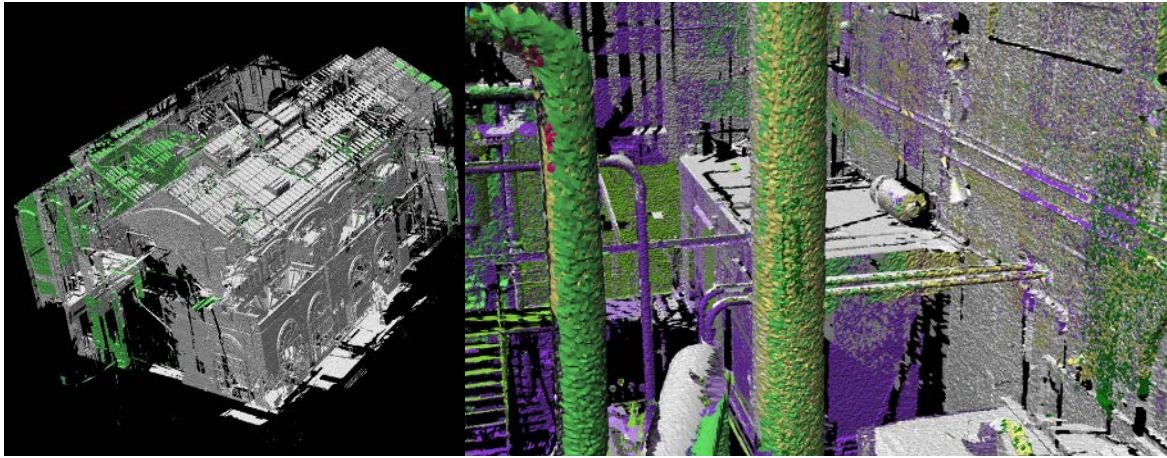

Figure 1: Scan positions ICP registration

The first comparison between the two surveys is clearly the final number of points per square centimetre. The Riegl data was acquired with a 0.1° angle (1.5 million points per scan), and the survey with the Faro was acquired with a 1/8 resolution and a 4x quality (38 million points per scan). Figure 2 shows a direct comparison between instruments, scanned at the same distance, about 2,5 m from the center of the boiler to each scanner with a 0.5-2mm resolution with the Faro Focus^{3D}, and a 5-10mm with the Riegl z420i.
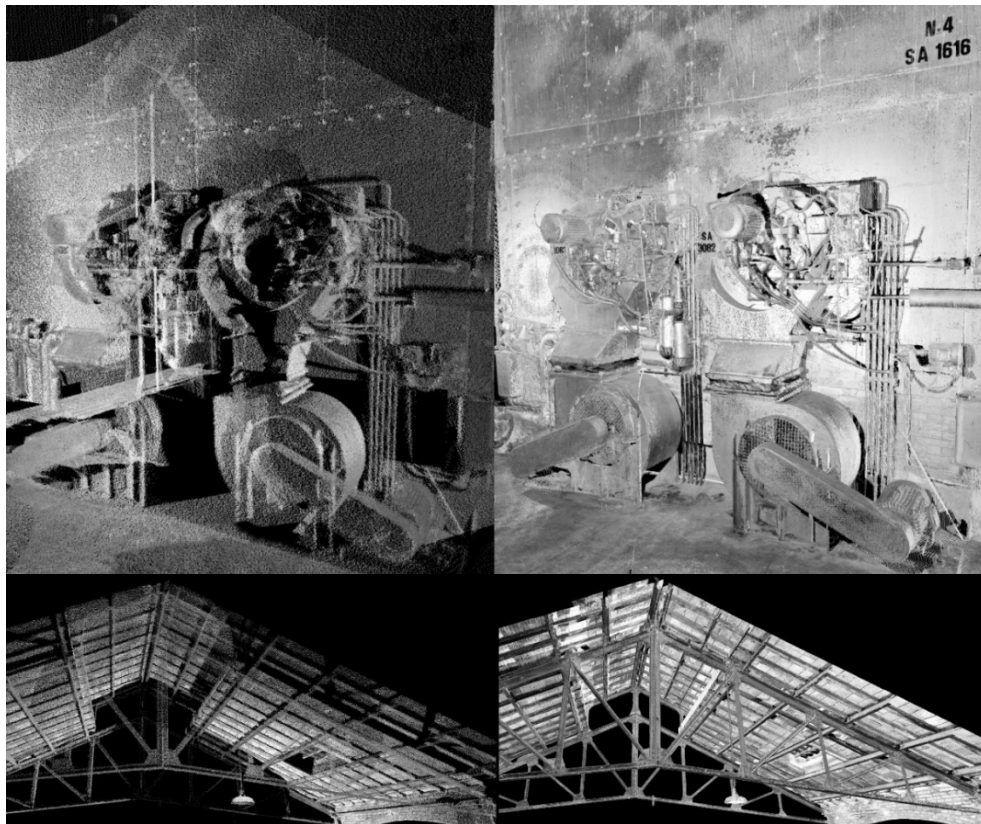

Figure 2: Comparison of resolution between Riegl z420i (left) and Faro Focus3D (right).

One of the reasons between the differences in the point cloud models are not only the number of points acquired but also occlusions. The accessibility between the boilers, the different heights, the complexity of the piping distribution allowed a limited number of scan positions, which had a direct relation with the

occluded areas (figure 3). The final point cloud model had a resolution of 0.2 mm with the Faro Focus[3D], and of 1cm with the Riegl z420i.

The density of points change between the interior and exterior in both surveys:

- In relation to the distance of the scanner and the complexity of the space-object, the scan distance in the exterior with the Faro and Riegl varied between 3 to 5 meters. A homogenous point cloud was generated.

- In the inside of the building, distances varied significantly between objects. Figure 4 shows some of the typical problems that we face in this survey. This image represents an architectural plan-section from the Riegl point cloud with a high percentage of occluded areas. As the data collection instrument is limited to an 80º angle in the vertical axis, it fails to document every part of the building. On the other hand, the Faro scanner has a 305º vertical angle in data acquisition, covering all the elements of the building, minimizing occluded areas and overlapping positions, decreasing the time in surveying and making easier the work plan. Number of positions where minimized, reducing overlapping, solves problems caused by the scanning angle, like problems with the normal of points (point direction in relation to the geometry), allowing a better illumination using the normal information.

In the data collection process the ambient lighting conditions were different between both scanners, for example inside the basement there was no direct lighting, only indirect lighting (specular), this affected the intensity information in the phase-shifting scanner (Faro), changing the range of intensity between levels, this problem was corrected using an equal falloff compensation for each position, modifying the current range at a distance of 20 meters for each scan and applying an auto-scale level for the intensity values, this also meant that the information out of this rage will not have a correct intensity value, and each scan needed to be distance-filtered within this distance. This range depends on the quality of the data and the distances in the space. The Riegl did not showed any significat change in the value for the intensity.
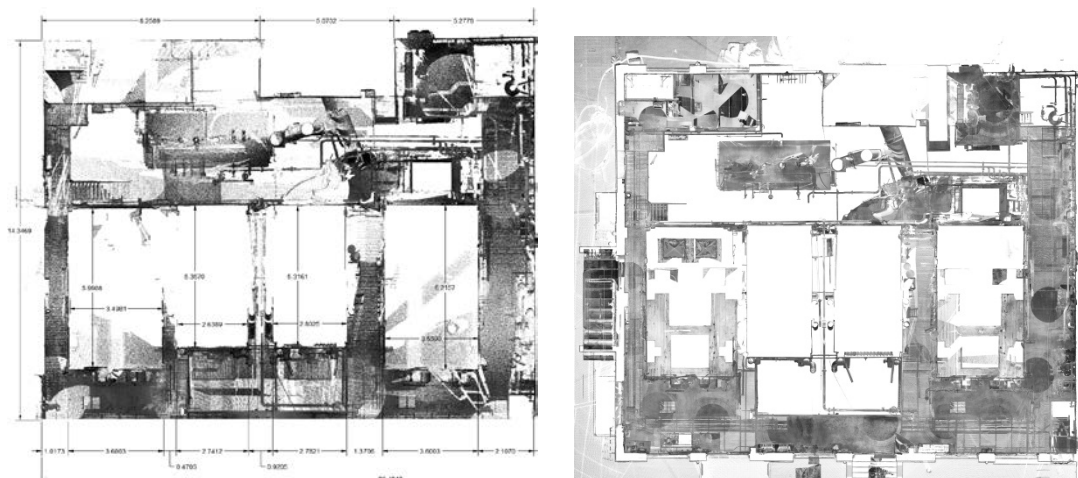

Figure 3: Architectural ortho image. Riegl z420i, and Faro

4. Classification / segmentation workflow

The high density of points in the final Faro model (1.300 million points in a 7.000 m³ volume) made a direct segmentation a difficult task. Segmentation by architectural levels was first proposed, starting with the organization of the TLS position by levels; each level was divided in three files using a predefined height, via Pointools[1] clip box tool.

The next process was the extraction of the architectural elements of the building. In this process the floor was recognized as the principal element, as without it, walls and engines were easier to identify. The area containing the floor was first extracted using a clip box tool, and then a RANSAC process in Matlab was applied for a finer selection. RANSAC considers this information a plane for the extraction, taking in to count that the data contained handrail bars on the ground.

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[1] Point cloud visualization software. *pointools.com*

After the floor was extracted, we proceeded to divide the walls from the pipes along the walls (figure 4). For this process a combination of RANSAC extraction and a manual edition in Pointools Edit software was used. The same process was repeated from the information containing the wall and the boilers, the pipes and the machinery. The segmentation between the roof, the wall and the structure needed manual interpretation, because of the complexity of these elements as they blend together, for example a structural beam can be considered either supporting element or a part of the cover.
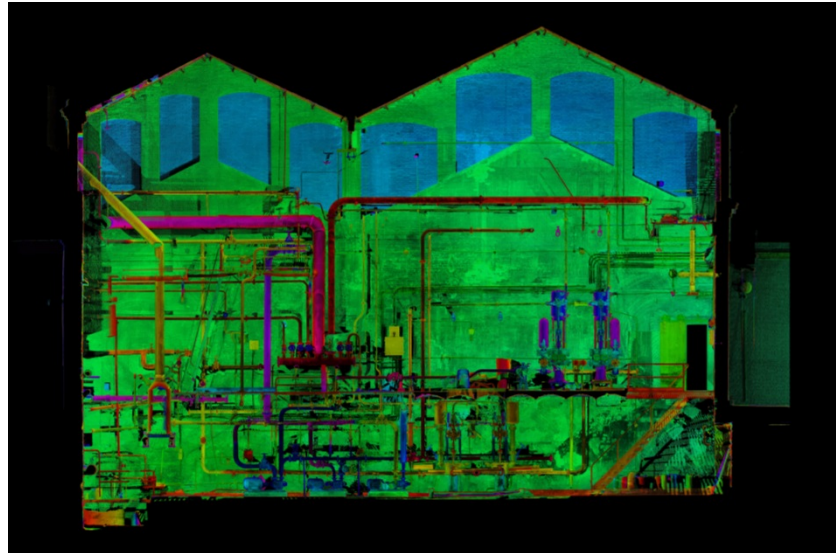

Figure 4: Complexity of classified surfaces

4.1 Classification in relation to the historical development, function and architectural program

In order to simplify user's access to the different parts of the heritage building, a classification based in architectural characteristics was required, although it can also be divided further taking into account three different variables:

- The historic development: integration of different boilers, changes in the building, evolution or modifications of the machines
- The function: coal boilers, gas boilers, electric system, hydraulic system
- Architectural program: areas were divided by different activities

The structure of the segmented point cloud to a classified one was mainly a manual process as it required a specialist interpretation to assume this differences, is not only based on geometry characteristics but rather on the knowledge of the buildings characteristics. Pointools Edit software was used for this division (figure 4). Classification order started from the first two coal boilers (N2 and N3), coal was served by hand, and supported by a system based on hoppers, supported by the bearing wall and a complementary metal structure. These boilers were modified to gas as energy source, with the addition of a burner and a steam accumulator on top.

The introduction of two new boilers (N4 and N1), forced an architectural expansion, the height of the roof and walls were raised 3 meters, reaching a final distance of 10 m height at the lowest point. The new gas boilers were elevated with respect to the previous ones from the floor by 3 meters in order to facilitate the cleaning of the used coal. The last boiler was introduced in the building by making an opening in a peripheral wall, as the tank was smaller and did not required the disassembly of the roof for installation. This last boiler only worked with gas and gave the same energy power of the four old ones (N5).

The ventilation systems associated with the boilers were modified over time, leaving at the outside of the complex a brick chimney and others metal made. Complementary to this system, two parallel systems worked together, one electric and one hydraulic. They were used to distribute energy to the other buildings through steam from hot water boilers, and to act as a fire prevention system. These combined with the boilers, generate a complex network of pipes and auxiliary machines, distributed onto walls and connected at the top with the boilers.

The architectural part is in close relationship with these machines, on the lower level with warehouses, on the upper floors with a metal frame for circulation (Figure 6), that reaches the highest point of the machines, the roof with its modifications with a metal structure trusses and a metal structure that is still being modified, as a reinforcement to the complex.
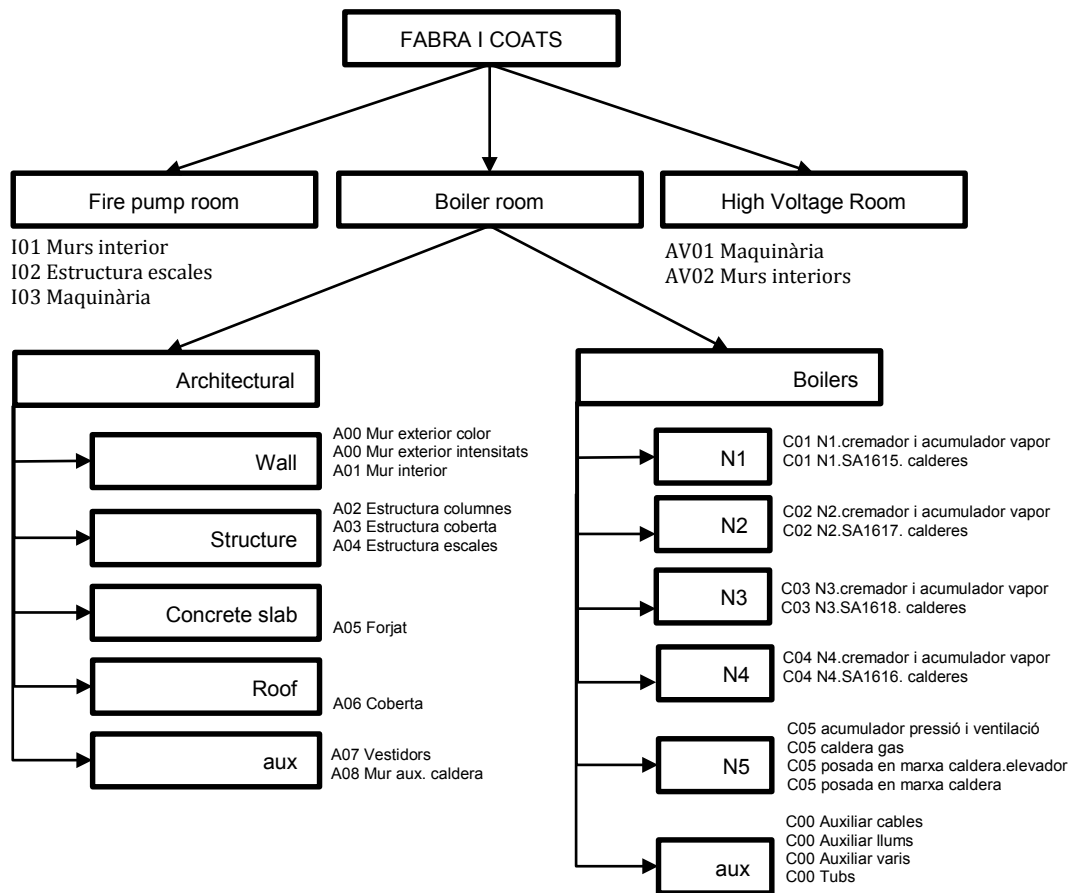

Figure 5: Database structure for the final point cloud model (31 parts).

In general the data structure is represented above (figure 5), the tree principal spaces; the boiler room, the high voltage room and the fire system room, this last one is considered as an important innovation in the industrial revolution of Catalonia.
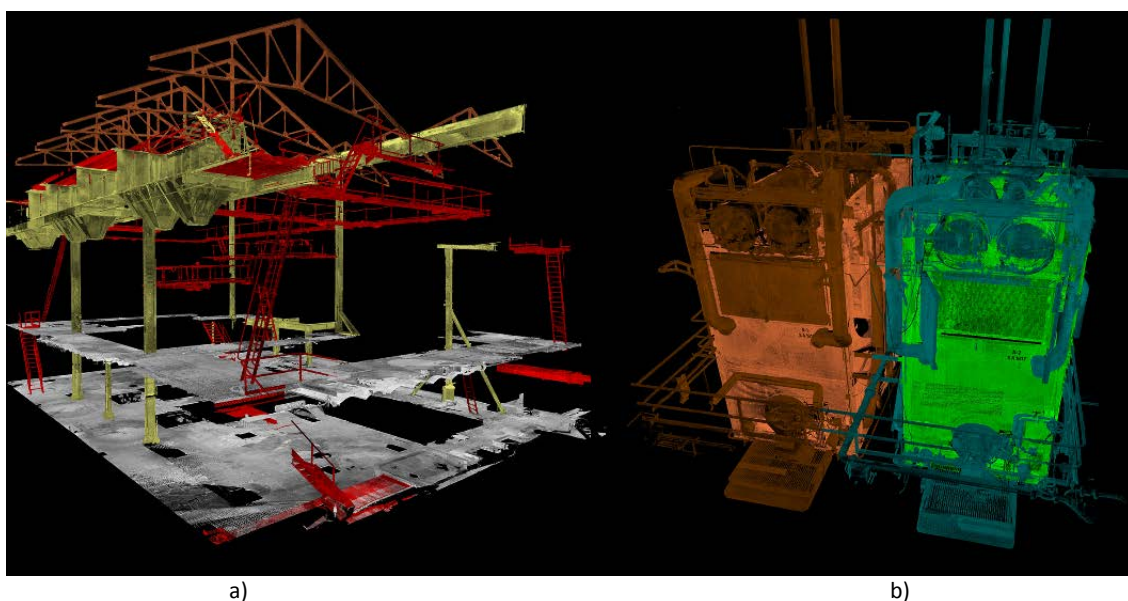

a)   b)

Figure 6: a) circulation left in red, trusses in orange, coal storage hoppers in yellow, and ground in gray. b) N3 and N2 isolated boilers

4.2 Fine selection and extraction with RANSAC

The process RANdom SAmple Consensus (RANSAC) is proposed by Fischer and Bolles (1981) is an iterative method for estimating parameters of a mathematical model from a set of observed data. This method comes from the field of computer vision. Used as geometrical segmentation algorithm due to its ability to automatically recognize the forms through the data (planes, cylinders, spheres and bulls), despite the noise.
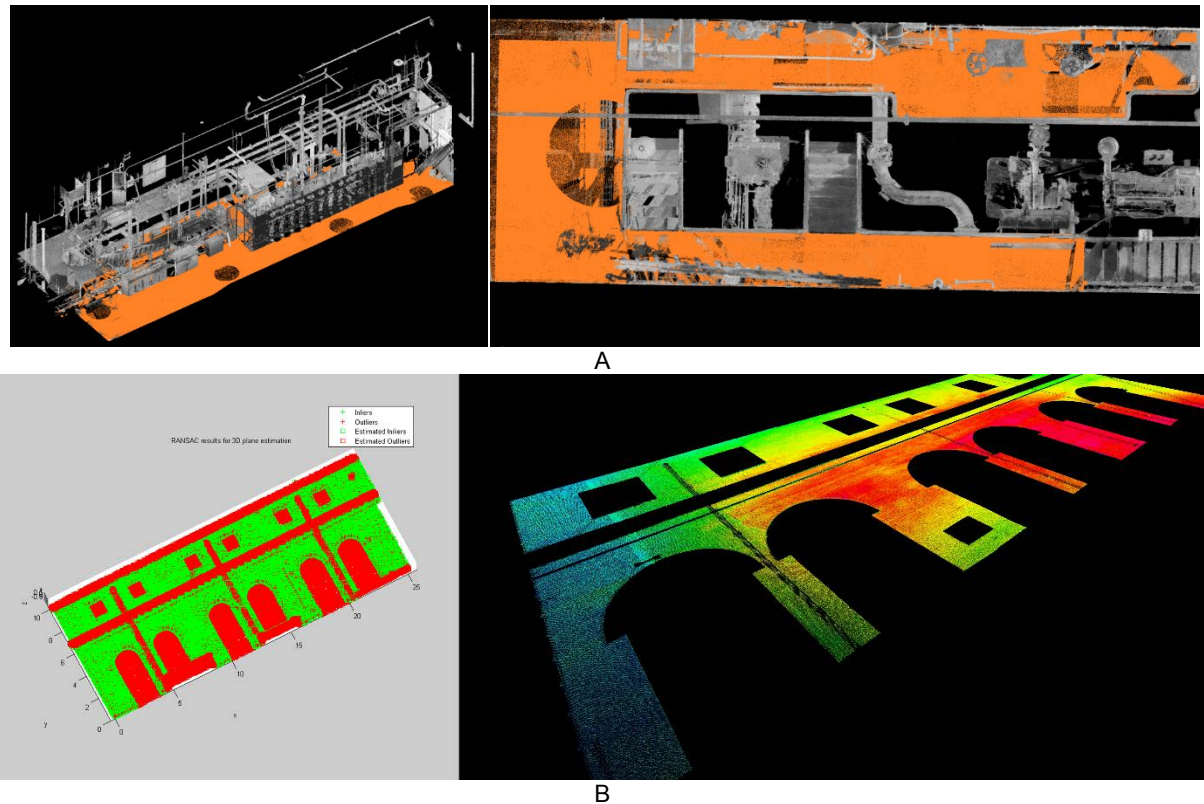

A

B

Figure 7: RANSAC detection to extract the ground and facades in complex models. A) Classified ground points. B) Example of a segmentation of the major plane in a façade.

The method RANSAC used is RANSAC.m from the RANSAC Toolbox for Matlab™ [6]. The principal options assumed are: for the scalar value of the noise variable sigma a value of 0.01m, the probability of error P_inlier 99%, percentage points to be considered as a plane 25%, we use the equation 1 for the selection of the minimal base points (m) to establish the relationship between the points and the plane. This calculation requires the P_inter (P), the minimum number of points required for the calculation (p), the fraction of abnormal values observed (outliers, ε).

$$m = \frac{\log(1 - P)}{\log(1 - (1 - \varepsilon)^p)} \qquad 8.4 = \frac{\log(1 - 0.99)}{\log(1 - (1 - 0.25)^3)}$$

Equation 1: minimal base points for the detection of a plane

The resulting shapes are tested against the original data points to determine how many of the points come close to the shapes (Figure 7). From the extraction of these data the surface can be calculated, striving to outline the geometry.

5. Diffusion of Heritage: the virtual model

The final part of the process is the appropriate diffusion of the information. We divided the final classified model into three categories: a model for specialized users, a model for general users, and a model for mass users (Figure 8).

- High resolution model: This information is the basic information for scientific-historical analysis and historic documentation, with a resolution of 1 point each 3 millimeters. This kind of information changes the heritage analysis, as the new technologies and process allows us to go deeper in the knowledge of the parts of the building, from characteristics of material (for example material

alteration of an object over time) to structural studies (like deformations analysis). New research opportunities are open describing the current state and the evolution of the heritage in technical terms.

- Medium resolution model: This model allows the exploration of the whole building by non-specialized users. The classification structure is maintained for data accessibility. This information is oriented to users who constantly work with this building. In this case, to the *Museu d'Història de la Ciutat de Barcelona (MHCB)* and *amigos de Fabra i Coats*, who administer the building.

- Low resolution model: This model is made for webcasting purposes, in the process of building a virtual museum buildings online (figure 9 b). With resolutions of 5 and 10cm, with no classification, mainly use for navigation purposes.
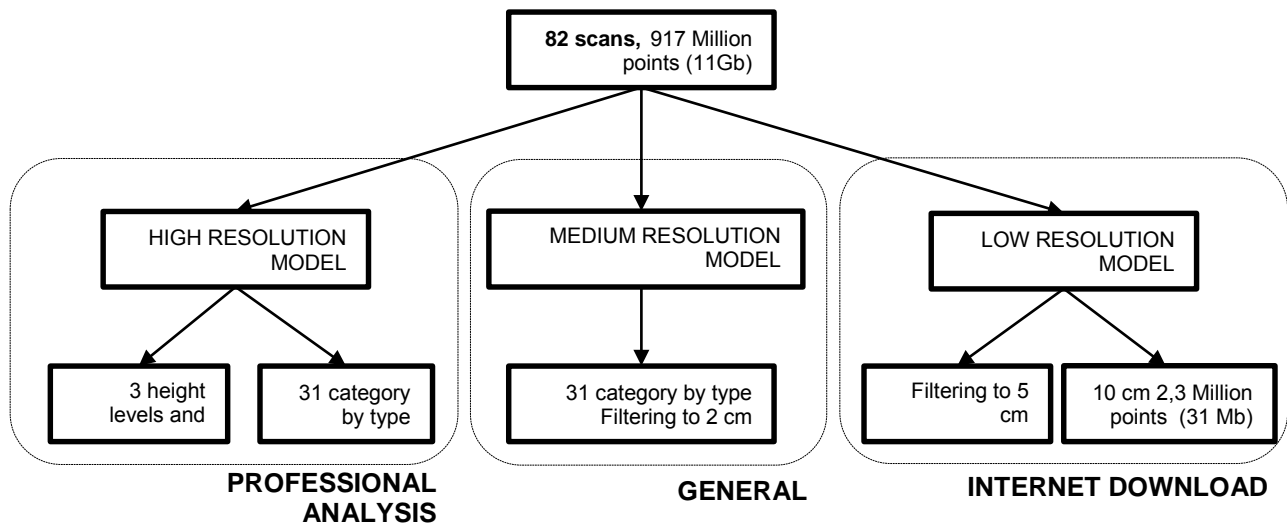

Figure 8: Tree levels of information for diffusion

Figure 9: a) High Resolution Model: 917 million points, b) Low Resolution model: 2,3 million points

Point Cloud model viewers are increasingly growing in the industry, as professionals fell more comfortable working directly with points rather than mesh models. We recommend both Meshlab[2] and Pointools software for visualization purposes. Web point cloud viewers are starting to appear such as

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[2] MeshLab is an open source, portable, and extensible system for the processing and editing of unstructured 3D triangular meshes or point clouds. *meshlab.sourceforge.net*

cloudcaster[3], or XB point stream[4], all of them allow point cloud navigation and simple measurement in the basic interface.

6.   Conclusions

Riegl Laser scanner, time of flight scanner, is not an appropriate scanner for detailed interiors surveys where data obtained is in the 2 to 10m range, as a larger number of points per position are necessary for high detail acquisition. On the other hand, Faro's portability and high number of points in short period of time is the appropriate tool for this type of interior surveys where a measurement every 0,5cm is needed to extract every object detail.

Changes in lighting conditions affect the intensity value directly of the Faro scanner, as well as distance to objects, making this information useless when scan positions are registered. This is not the case while working on single scans information. Riegl intensity value does not have a sensitive change if lighting conditions changes or as to the distance to the objects. Incorporated RGB camera in the Faro scanner, as it cannot be controlled by the user, provides unwanted color images. Texture value coming from these images is very important for a correct 3d interpretation.

Obtaining a high density point cloud model is nowadays a fairly simple task. The discussion needs to focus in two main aspects: how this model needs to be subdivided for an agile and appropriate use, and how many different models need to be delivered for different users and applications. The subdivision of the model presented is far from an automatic classification, as it needs to respond to historical, architectural or program needed. This step is necessary as it adds accessibility to the model. On the other hand, different resolutions are necessary to be generated for the accessibility of the model for different users.

[3] High Definition Point Clouds in the browser. *cloudcasterlite.com*
[4] A cross-browser JavaScript tool which emulates Arius3D's PointStream viewer. *https://github.com/asalga/XB-PointStream*

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