DIGITAL STATEMENT AND 3D MODELING FOR THE RESTITUTION OF THE ARCHITECTURAL HERITAGE

3D virtual model for architectural restoration

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Abstract. Heritage specialists (architect, historian, conservator, engineer, archaeologist, etc.) often face significant problems of representation and simulation assumptions restitution of monuments. The traditional graphic means cannot fulfill all the needs which are done day in the patrimonial restitution. That is why it is necessary to consider the services that digital technology can do, and think about their use in the representation of monuments in their environment. It can also be used to restore and to preserve heritage using digital statement which allows reconstituting numerically damaged parts or disappeared from historic buildings. The virtual model of restitution constitutes a solution which makes it possible to show the restitution of the site (or part of the site) without materializing it physically, using graphical means. The virtual restitution can be materialized in the form of digital restitution in 3D, but also by the use of drawings or others graphic techniques. In this paper, we present two techniques for digital statement: The Photomodelling and 3D laser scanning, which are used in the field of modeling heritage. Then we present case studies which were carried out within the framework of our teaching activities and research at the School of Architecture of Paris La Villette (ENSAPLV).

1. Introduction

The practice of restoring parts damaged or disappeared from historical buildings began at the 15th century in Rome (Santacana J. and al., 2008), even if the goal of these restitutions, far from that of the current restitutions, was not necessarily to preserve the historical heritage but sometimes to use it at private ends. We consider the current restitution as an interpretation of architecture, made from the development of hypotheses.

These interpretations can be represented in different ways and on various media, without necessarily leading to material restitution. Indeed, restitution can be also shown in the form of a digital representation.
At the origins of the archaeological restitution developed in the 19th century, *Viollet-le-Duc* recommends the total reconstruction of the ruins: *"Restoring a building, it is not to maintain it, repair it or to remake it, it is to restore it in a complete state which can never not have existed at a given time"* (Viollet-le-Duc, 1868). This model obviously had implications for heritage sites, but this debate about the reconstruction of the ruins grew especially in the field of architecture.
The virtual model of restitution constitutes a solution which makes it possible to show the restitution of the site (or part of the site) without materializing it physically, using graphical means. The virtual restitution can be materialized in the digital form of restitution in 3D, but also by the use of drawings or others. This virtual model is based on the digital statement which has obvious assets for the statement of architectural objects. This approach consists of two parts: The first which is based on techniques of Photomodelling starting from images; the second, on the modeling of architectural knowledge starting from a 3D laser scanning.
The Photomodelling, or three-dimensional reconstruction from one or more photographs, covers various areas of research: photogrammetry, vision, robotics and CAD (Van den Heuvel F. A., 1998). She uses photography techniques; the architectural objects are modeled and determined using overlapping images taken with cameras calibrated. The 3D laser scanner statement is comparable to 3D photographs of architectural object. It has obvious advantages for the statement of architectural objects (Dekeyser F. et al., 2003). In a few minutes, it is possible to raise millions of 3D point with precision. The major drawback of this method is, however, the time required for the modeling from 3D point clouds.

2. The Contributions of the digital reconstruction of the heritage

The primary objective of any digital reconstruction of the heritage is the study and the conservation of the architectural objects and the archaeological monuments. Once established this principle, it is true that the digital reconstruction can fill of other functions and utilities from the point of view of research in archaeology, of teaching as well as valorization of the heritage.

2.1. CONTRIBUTIONS IN THE EDUCATION DOMAIN

The digital restitution of the heritage has obviously applications in the field of education in architecture and archeology. As part of my teaching activities within *the school of architecture of Paris La Villette France (ENSAPLV)*, we propose teaching in cycle master degree entitled *"3D reconstruction"*. This teaching has been developed in synergy with the research in our laboratory *AHTTEP UMR AUSSER n°3339 (Research Group Architecture Technical History Territories Heritage)* on the problem of 3D reconstruction and early modeling in architecture (Ciblac T. and al., 2006).
The principal objective of this teaching is to lead the students to control the theoretical and practical tools for reconstruction of three-dimensional objects starting from their projections (perspective, photographs….) and of known constraints (parallelism,…), then to apply these tools to the digital reconstruction of architectural objects. This teaching is divided into 4parts:
- Reminders and deepening theories 3D reconstruction.

- Practical of computer tools applied to the reconstruction (dynamic geometry) and specific software.
- Introduction to Photomodelling and the digital techniques of statements.
- Practical exercises to restitutions starting from documents or the interpretation of perspective sketches.

We use the software of Photomodelling *ImageModeler and PhotoModeler* for the 3D reconstruction of the examples of new and old architecture projects chosen by the student. The technique consists in taking a set of pictures of the architectural object to model, to proceed to its modeling from these photographs and the end extracting texture, then to export it to other software applications (3DS MAX , Sketchup, etc..).

At the end of the exercise, each student must provide a report which presents its choice of the project to be modeled, his approach of work and his assumptions of modeling. Finally, these educational experiments in the field of the digital reconstruction of the heritage make it possible to reinforce knowledge of the student's in the following fields:

- Understanding the difficulties related to the conceptualization of spaces and volumes.
- Analysis of the construction processes of the architectural object to model.
- The study of the different phases of life of the building or the evolution of this one.

2.2. CONTRIBUTIONS IN THE FIELD OF RESEARCH IN ARCHAEOLOGY

The digital restitutions carried out according to the criteria of archaeology have various applications in the scientific discipline of archaeology. The computer experiments carried out on digital models allow verification of the assumptions of restitution made around the archaeological monuments.

In some cases, the computer experimentation can require to go back on the field to conduct audits of the digitized model and, if necessary, the reformulation of hypotheses, that is to say that the results of the experimentation can have like consequence the modification partial or total of the assumptions of digital modeling. In this manner, the digital reconstruction makes it possible to progress in the knowledge of ancient architecture with the following experiments:

a. The comparison between the models such as it was built and the model such as it was restored numerically. That makes it possible to check the needs for maintenance for example in the case of architecture in stone, clay or wood.
b. Analysis of the materials which were used for the construction of the buildings, in order to be able to realize digital renderings which will serve for example for the restoration of materials, textures, etc.
c. Development of simulations to study for example the resistance of materials and the structures as well as the stability of buildings modeled numerically.

Finally, the interest of the restitution from the point of view of the presentation of the heritage appears obvious to us. In this way, the restitution would have interesting applications in various fields to promote the culture of the peoples and the civilizations. For example in the context of tourism activities, the digital restitution gives the opportunity to the cultural heritage of becoming for example a tourist product.

The virtual model of the restored site stimulates the imagination of the visitor, who can more easily go beyond the buildings and from the objects that it observes. In the same way, this digital restitution allows the creation of new images, which can be employed as a tourist resource from the beginning of the visit (Santacana J. and al., 2008).

3. The techniques of digital 3D reconstruction of heritage

In this part of the article we present the two techniques of digital statement used in architecture and archaeologies for the restitution of the heritage: Photomodelling and the 3D laser scanning.

3.1. PHOTOMODELING

Architectural Photomodelling allows the statement, documentation and 3D modeling of built space. Many techniques (single-image or multi-image) can be applied for the statement of an architectural object using digital cameras. There exists much software able to produce 3D restitutions or textured models from a set of digital images of an architectural object.
The photographs give a complete representation of the object to one precise moment on supports (films or image files). But a conical photography is only one projection of a three dimensional object. The use of at least two images taken from different points of view makes it possible in the general case to reconstitute the 3D object. The data obtained (points, lines, surfaces, volumes) which results from it is processed for the representation of the object by the development of three-dimensional models.
The digital reconstruction task is divided into two parts: The first consists to gather knowledge about the object to be reconstructed in 3D: catch of photographs, and the constraints on the 3D model. The second phase consists in using computer tools dedicated to the modeling and the visualization of the 3D model. The process of reconstruction of the 3D model of a building from the photos through the following phases:

1. The description of what it is necessary to rebuild using the photographs and of constraints.
2. The photographic statement of the building.
3. The acquisition of spatial coordinates.
4. The three-dimensional reconstruction (modelling).
5. The calculation of the model render and the restitution of visual appearance (texture).

3.1.1. Photographic statement of the building

All steps Photomodelling from collection of photographs, modeling to the realistic restitution of materials strongly depend on the strategy of catch of sight and the photographs quality.

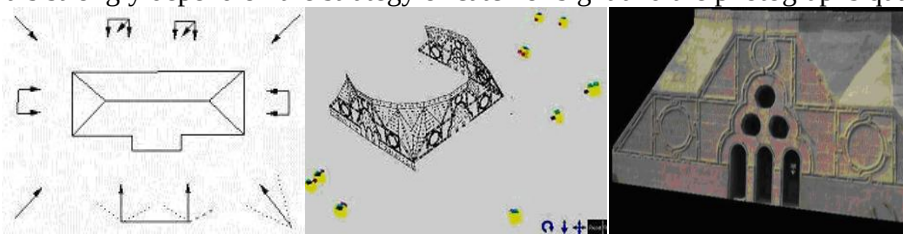

Figure 1. Principle of taking pictures of the architectural object

For the realization of the catches of sights, several rooms of catches of sights having complementary characteristics (focal length, format, etc...) Are required to take account of obstacles, the height of buildings, and lack of perspective. For a good shot, you must consider the context in which the building is located, its scale, its geometric complexity, occlusions generated the component where the object by external elements.

3.1.2. The acquisition of spatial coordinates

The type of catch of sight makes it possible to lead the calibration and the orientation of the cameras by indicating points homologous on several plans and at various levels of depth of the architectural object to model.

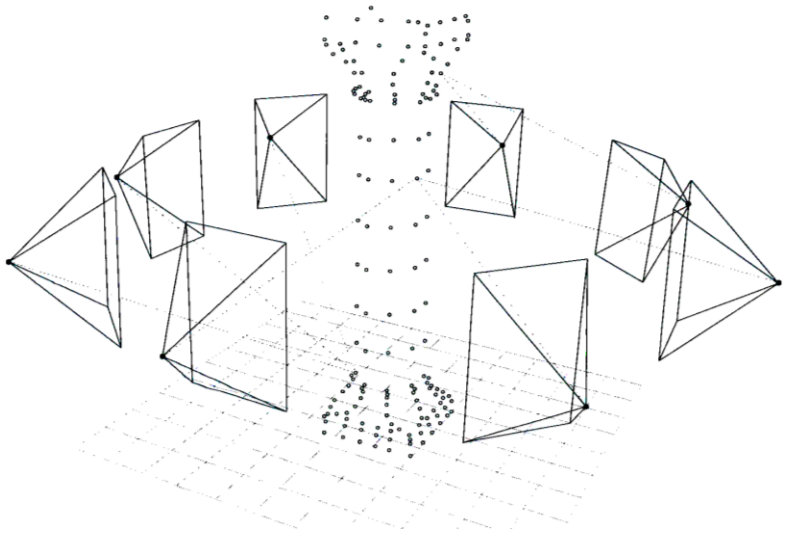

Figure 2. Principle of taking pictures of the architectural object

The calibration phase and orientation of the cameras makes it possible to establish the projective relations between the optical centers of the cameras and the points on the images and the 3D space coordinates. This allows:

- To determine the metric characteristics of the portion of space photographed.
- To determine the orientation and the position of the cameras at the time of the catch of sight.
- To position homologous points in multiple photographs.

3.1.3. The three-dimensional reconstruction (modeling)

This step is to build a three-dimensional representation of the object containing all of these points and expressing the geometrical nature of the elements of the scene photographed.

This geometrical modeling can be based on:

- Modeling from adjustment (positioning and deformation) of geometric primitives.
- Functions of extrusion of polygonal faces
- Complex Procedures for generation of parametric surfaces from profiles.

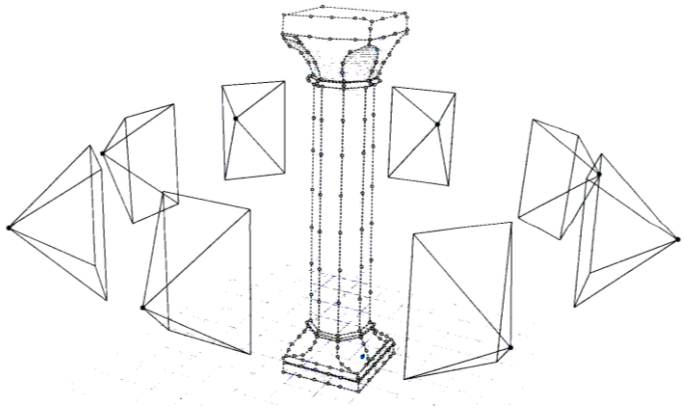

Figure 3. Principle of modeling of the object

3.1.4. Restitution of visual appearance (texture)

That consists with the enrichment of the geometry resulting from the phase reconstruction 3D by attributes able to describe the aspects of surface of the architectural object. It is a question of associating with the model 3D the textures acquired at the time of the catch of sight, which implies the extraction of the portions of image which will be then plated on the models from one or several photographs which were used in the modeling phase.

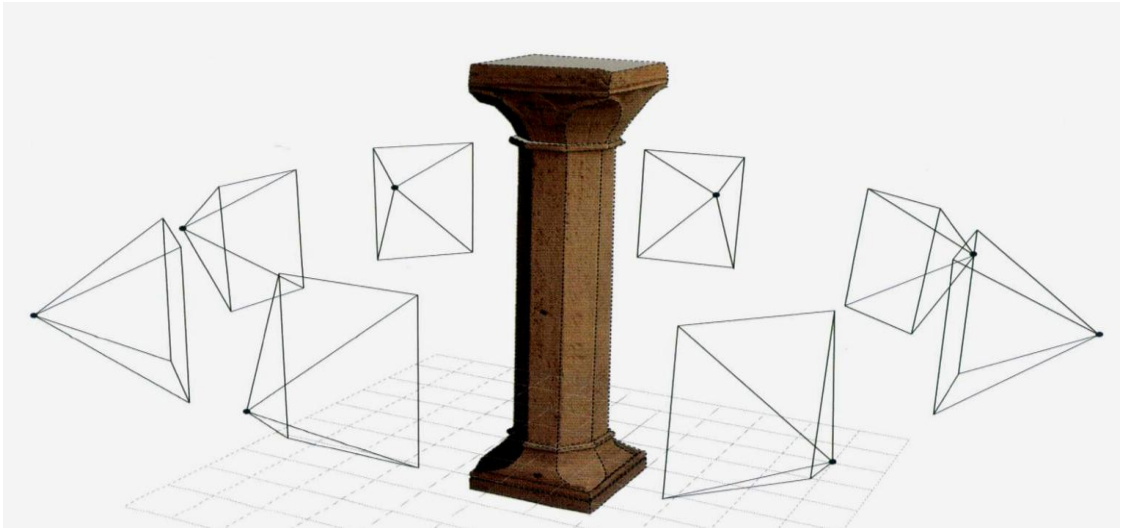

Figure 4. Principle of extraction of texture and application to the modeled architectural object.

3.1.5. Case study: Modeling of the « La rotonde de la Villette à Paris »

This case study was carried out in the course of Master 2 "*3D reconstruction*" in *ENSAPLV School*. The objective consists in modeling *« La rotonde de la Villette à Paris »*.

The constraint was the subway line that hides a major part of the facade southwest. In order to model this building, we used the constraints known on the project namely: symmetry, parallelism, and orthogonally.

Then the method was to apply these constraints to the digital reconstruction of the architectural project by using the « *PhotoModeler software* ». The following illustrations present the stages which were followed for modeling.

Figure 5. Principle of photographing the architectural project

Figure 6. Matching remarkable points on several photographs

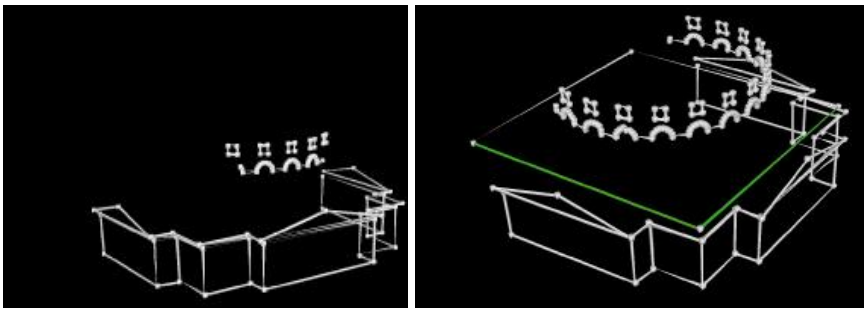

Figure 7. Modeling of the project

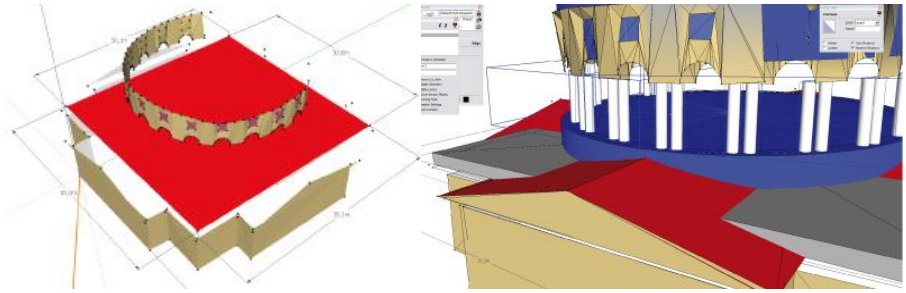

Figure 8. Export 3D model in another application software (SketchUp)

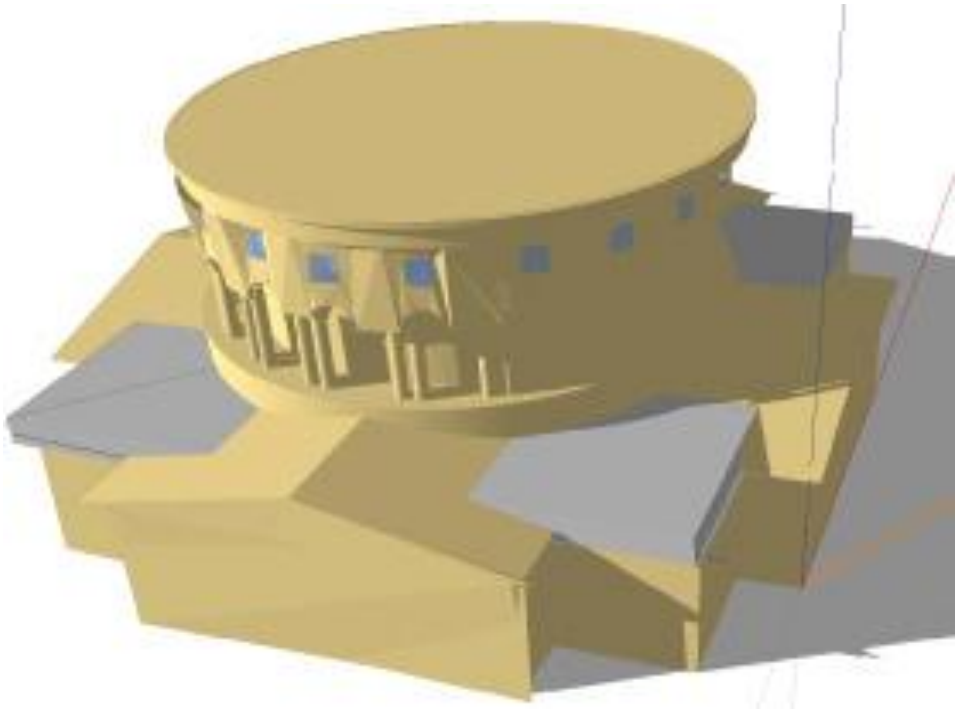

Figure 9. Finalization of the digital model of the project

3.2. LASERGRAMMETRY

Lasergrammétrie is a technology which uses 3D scanners, able to record several million points in 3D in a few minutes, with a precision of a few millimeters and a range exceeding several hundred meters (Bur D. et al., 2003). The technique of digitalization differs according to the sensors. Two types are distinguished:

- The measurement by triangulation, which projects points or visible laser line on the object to be scanned and recorded on a sensor image of these points of these lines. A mathematical calculation transforms the information into a discrete series of 3D coordinates. This technique makes it possible to obtain very precise measurements of the order of 10 mm with a scope limited to a few meters sensor.
- The time of flight measurement, which sends a laser pulse and records the time taken for the pulse to reach the object to scan and to return to the sensor. The flight time is then converted into distance associated with the recording of the incidence of the ray to be

transformed into coordinates. The accuracy is slightly lower, 5 to 10mm, but scope can exceed 500m.

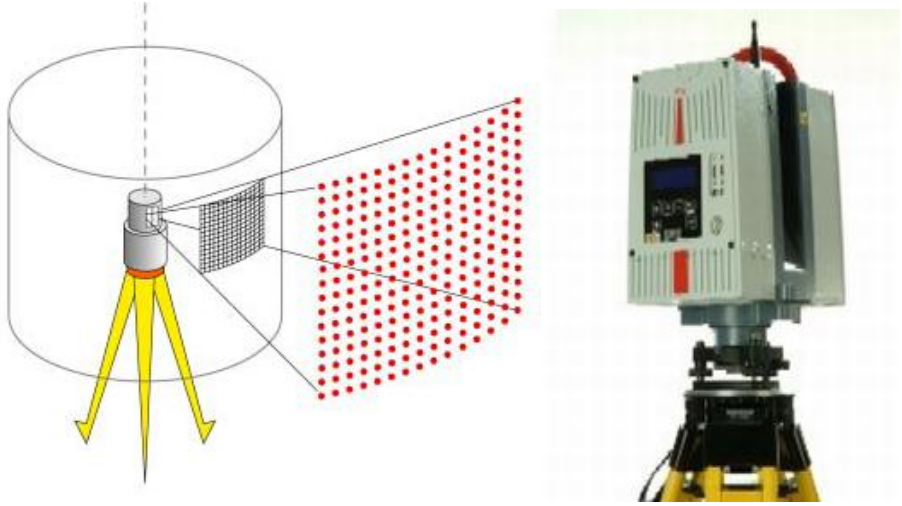

Figure 10. Digitalization technique with a 3D scanner

3.2.1. Principle of laser scanning

Like a flatbed scanner, a 3D scanner records a series of measures in rows and columns, like a digital image. Each element of the image, each 'pixel' is associated information of the distance between the camera and the digitized object. Knowing the position and orientation of the scanner, which is usually obtained by scanning known prior contact marks, can convert these pixels into 3D points. According to the devices, the field of digitalization can be cylindrical (360 ° horizontal and vertical limits, for example 80°), spherical (360° horizontal and 180° vertical) or cover only a fixed window (non-rotating sensor).

Whatever the type of sensor used, the result of a scan operation is primarily a digital file containing a set of geometric coordinates (X, Y, Z), constituting what is called a "point cloud" 3D . Sensors using the time of flight measurement can also record the reflection intensity of the signal, which may vary depending on the type of material being scanned. Finally, it is possible to couple the laser sensors of digital cameras calibrated, we can then assign the color information at each point of the cloud.

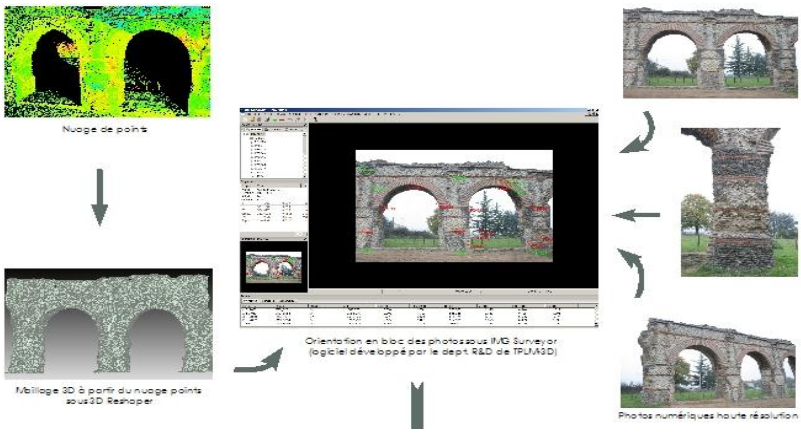

Figure 11. Example TPLM-3D: Statement of the Roman Aqueduct of GIER, France

The 3D point cloud, the intensity of reflection and digital shots calibrated and georeferenced resulting from a statement campaign, are then basic, virgin information of any treatment, being able to constitute a rough archive 3D of the site or digitized monument (Chazaly B., 2006).

3.2.2. Treatment measures and generation of 3D surface models

According to the expressed needs, the treatment of the point clouds will be different. It always requires the use of specific software developed exclusively for the management of dense 3D data. The software of treatment makes it possible to connect the points of the point clouds acquired to the scanner by triangles.

The result is a three-dimensional mesh model, a true digital skin that can reconstruct the geometry of the scanned surface. Insofar as the density of the point cloud is sufficiently large and homogeneous, the mesh model can cover the digitized object in its entirety. One has a model 3D then that some describes as model: Such-That-Build.

This model can then extract any geometric information: distance, slope, coordinates of particular points, radius of curvature, section, etc. The 3D surface model can also be textured in order to add color information. Finally, It can be exported in a digital format dealt with in machines with digital controls, for the realization of resin or plaster models.

3.2.3. Case Study: Modeling Romanesque chapel 11th century (St Laurent d'Agny)

The figure 12 shows the process of modeling Lasergrammetry the Romanesque «*chapel of St Lawrence Agny*», which was directed by TPLM-3D (http://tplm-3d.fr/Prestations_patrimoine.htm). A digital file of 3D point cloud containing the geometric coordinates of the project was obtained.

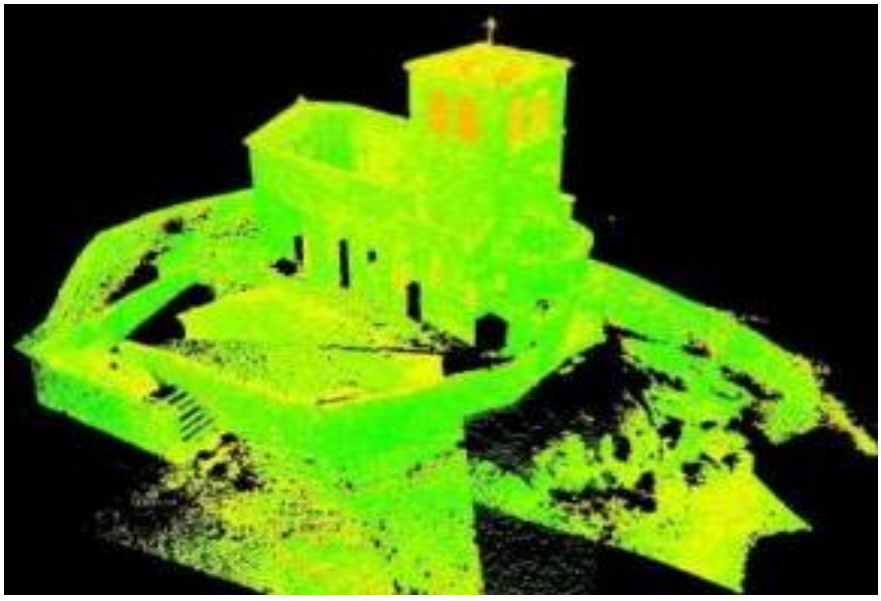

Figure 12. A 3D point cloud: Recording the Romanesque chapel of St Lawrence Agny (11th century), France. (http://tplm-3d.fr/Prestations_patrimoine.htm)

A wireframe model was created in *"AutoCAD-CloudWor"* and complex parts were modeled as a 3D mesh. The wireframe and 3D meshes were imported into "3DS Max". This model has been finalized, with polygonal modeling techniques (Figure 13).

Then, the 3D surface model was textured with the technique of "camera mapping", which consists in projecting photographs on the geometry 3D. The goal is to recreate the conditions of shooting by placing virtual cameras in “3DS Max” software (Figure 14). “3DS max“ make it possible to create an environment to supplement the visual aspect of the building, to compute syntheses images and video animations.

Figure 13. A surface model of the Romanesque chapel of St Lawrence Agny (11thcentury) France. (http://tplm-3d.fr/Prestations_patrimoine.htm)

Figure 14. A textured model of the Romanesque chapel of St Lawrence Agny (11th century) France. (http://tplm-3d.fr/Prestations_patrimoine.htm)

4. Conclusion

We presented an overview of the current state of digital techniques identified in architectural Photomodelling and Lasergrammetry that are applied to architecture and ancient heritage. Combining techniques Photomodelling and Lasergrammetry, is undoubtedly the future in the field of 3D digital modeling heritage. Within the framework of our teaching activities and research, we wish on the one hand to create at the school of architecture of Paris the Villette a teaching in Master degree 1 on the techniques of representation and theme will be "Digital Recording and architectural reconstruction" and on the other hand we think it will be interesting to develop a research program aiming at coupling the analysis of images and laser scanning , in order to model numerically an architectural project in 3D much more quickly than with the traditional methods.

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