TRANSPORTABLE 3D ACQUISITION SYSTEMS FOR CULTURAL HERITAGE. REVERSE ENGINEERING AND RAPID PROTOTYPING OF THE BRONZE LIONS OF THE SAINT ISIDORO CHAPEL IN THE BASILICA OF SAN MARCO IN VENICE.

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ABSTRACT:

This research illustrates the experimentations accomplished in the field of Cultural Heritage aimed to the determination of the "total form" of the objects with a high resolution, using a simple and transportable acquisition technology. The aim of this research is to identify the process and the methodology for the acquisition of geometric information of three-dimensional objects which are situated in area that can be reached with a great difficulty. In some cases the traditional laser scanner equipments can't be used in the lack of visibility, of space and on instable surfaces. Transporting in an easy way a small equipment can become an operational advantage that can't be ignored in term of costs. This study puts together various advanced experiences from different fields and reverts them for the field of Cultural Heritage to obtain an approach methodology for the study of the "total form". The objects of our experimental applications are some bronze sculptures collocated in the chapel of Saint Isodoro in the Basilica of Venice.
The operational phase of this project has interested the Politecnico of Milan and the Procuratoria di San Marco in Venice. In the actual state, has been acquired high resolution scan (0.2mm) of the both sculptures of the bronze lions with the portable system HandyScan 3D and the elaborations have been realized with VxScan and Rapidform Xo-Scan. The scanning system requires reference targets which have been situated on the interesting surface with a grid patch that various from 20 to max 100mm. These targets let the instrument to self-determinate its own position in the space doing in the real time a space resection on at least three targets. In addition to the spatial position of the points during the acquisition, is also automatically generated the mesh of the surface. The phase of acquisition ends writing the points or meshed files for examples in the standard .stl format.
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1. MANUSCRIPT

1.1 Introduction

This research study has focused on the application of new methods of 3D acquisition with scanning systems that allow an approach to the object of study that uses methods other than the traditional methods applied to reverse engineering.
While technology is consolidating methods of acquisition widely experimented on in the field of survey of Cultural Heritage, especially as regards active optical systems (structured light systems, interferometry systems, laser scanner systems), at the same time, instruments are being introduced that bring in new innovations, especially in terms of applications but also in terms of how they work and their positioning with respect to the reference system.
When it is necessary to analyze objects of a certain complexity, which can only be rectified through an extremely accurate acquisition - millimetric or finer - and these objects cannot transported or cannot be reached using traditional fixed station instruments, we had to contend with many difficulties and at times excessively high costs.
The problem of shadow areas in the scans due to sub-squares, variable or articulated geometries - such as in sculptures, beading or decorations, as well as in fields of industrial interest such as in automobile bodies - which can be overcome only with different scans made around an object or from several perspectives - where this is possible - or with contact systems such as NCM machines or robotic arms.
This is why many of the instruments that allow digitization of high definition and precision objects in spatial positioning cannot be used in on-site survey of architectonic elements or of objects that cannot be transported into the laboratory.

1.2 Manual laser scanner technology: operating principles

In the context of this research, therefore, the idea was to experiment on and study a type of hand-oriented 3D laser camera, produced by Creaform. The compact size of Handyscan

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makes the instrument easy to transport and remarkably versatile, being simply powered and connected to a laptop with a fire-wire cable.

Figure 1. Handyscan 3D

Its operating principle is based on the association between two *mechanisms*: a laser plotter and a system for recognizing reflecting targets that enables the instrument to automatically position itself in relation to the object being surveyed.
The acquisition is achieved by two crossed laser liner-cameras that measure in perpendicular directions, since the bodies of the cameras are slightly inclined toward the inside of the instrument.

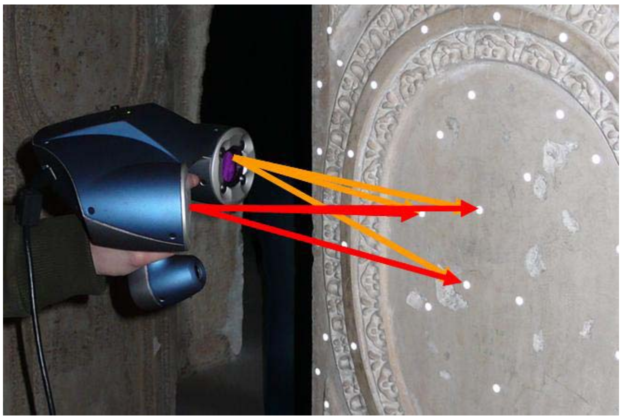

Figure 2.The system is based on association of two crossed laser liner cameras and a laser plotter

The two high resolution cameras identify and photograph the targets illuminated by the LED and the laser plotter. According to the statements of the manufacturer, these cameras can capture up to the 18000 separate measurements per second, with accuracy to 0.05mm and a resolution along the Z axis of 0.1 mm.
The data obtained are united in a single scan in real time, through recognition of reflecting signals located along the surface of the object using the FAST algorithm which makes it possible to record their configuration-distribution in the 3D space and turn them into absolute reference markers for the object.

The acquisition process of an object takes place in two separate moments:

- Before beginning the actual scan of the surface, it is necessary to determine the location of the reference markers, generally located on the object, so that the laser can calculate its spatial arrangement (X, Y, Z, and the three angles of rotation).

  Each camera must be able to capture at least three targets concurrently; the number used depends on the form of the element and the possibility of surveying it in one or more acquisition volumes.
  The surface must be covered uniformly, but there does not have to be compliance of a regular arrangement geometry of the reflecting markers, while the minimum distance between them must be an average of 20 mm (for slightly curved surfaces, it can be up to 100 mm).
  For survey of particularly delicate objects, the targets may be located on adjacent planes, avoiding direct contact and making it possible for the laser sensor to determine the model of positioning.

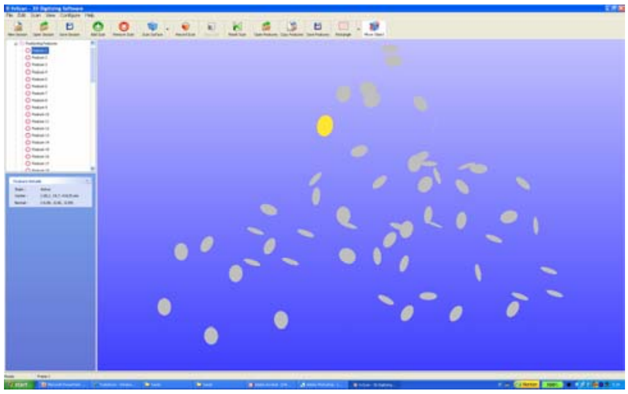

Figure 3. Reference markers location in a 3D space

- Digitization of the object of study takes place later, when the tool is able to recognize patterns of the targets and acquire the point cloud. Acquisition software (VXscan) can generate a triangular mesh surface in real time, which can produce an instantaneous 3D surface. This in turn makes it possible check the completeness of the result during actual use, preventing the occurrence of missing parts in the most complex areas.

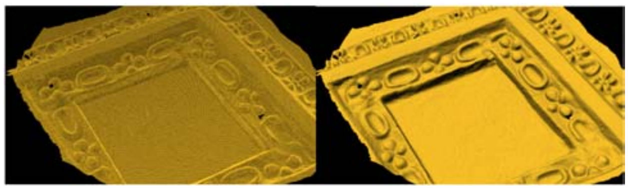

Figure 4. Triangular mesh surface created in real time during the acquisition phase

These data sets are automatically converted into an STL file, which records the x, y, z coordinates of the points measured and the normal and is a format compatible with most data CAD/CAM handling and modelling software such as Geomagic, Polyworks, Rapidform and Solidworks.

1.3 Configuration of the system

Depending on the objects that need to be measured, the instrument must be configured by defining two physical parameters, i.e. the strength of the laser and the time of exposure of the cameras, which are influenced by the nature of the object, the light, the colour and texture of the surfaces. These settings can be memorized and recovered at any time.
For objects with shiny, dark, transparent or particularly reflective surfaces, the response of the laser signal can be disturbed and end up generating noise in the data or errors in

rectification of the cloud points. The results can be improved by covering the surface of the object with an spray to create a matt effect; however, this spray can be difficult to apply in surveys of objects of a certain value or whose state of conservation cannot be altered.

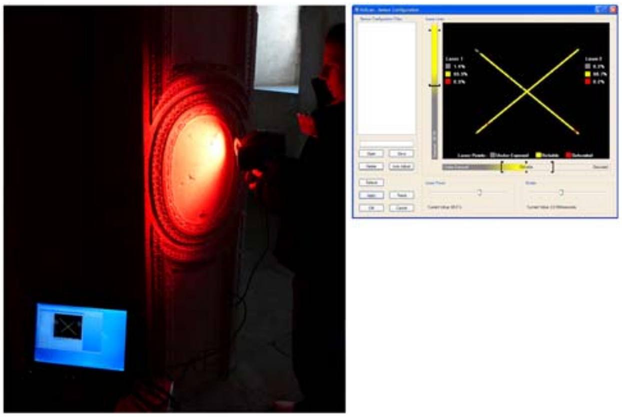

Figure 5. Configuration of the system

Another parameter to define in the structural phase of the system is the dimension of the voxel, which represents the base unit to determine the accuracy of the acquisition and resolution of the surface generated by the software.
It represents an x-y position value, in which the z component is given by the value of intensity of the signal in a 3D space, similar to the pixel which represents 2D image datum. This technology is useful for rapid visualization of the surfaces at the exact instant of acquisition.
Voxels make up the scanning volume which is a cubic box within which the operating area is defined. The smaller the operating area , the higher the resolution of the voxel.

1000 x 1000 x 1000 mm	Voxel high 1.95mm
800 x 800 x 800 mm	Voxel high 1.56mm
600 x 600 x 600 mm	Voxel high 1.17mm
500 x 500 x 500 mm	Voxel high 0.98mm
250 x 250 x 250 mm	Voxel high 0.49mm
200 x 200 x 200 mm	Voxel high 0.39mm
100 x 100 x 100 mm	Voxel high 0.20mm

Tab 1 – Volume voxel defines the scanning volume

2. APPLIED CASE. SURVEY OF THE LIONS

An applied example of this laser scanner technology involved the Politecnico di Milano and the "Procuratoria di San Marco" in Venice, for which the group participated in surveying two compact bronze sculptures of interesting artistic production.
In the realm of our research, this assignment made it possible to experiment on use of the Handyscan instrument and its versatility, in a situation of difficult mobility around the sculptures, which are located and fixed to the sides of the altar, inside the small chapel of Sant'Isidoro in St. Mark's Basilica. In addition, the mosaic decoration lining the walls of the room are currently under the process of renovation and therefore, traditional laser scanner instruments could not easily be used in the job site. It would have been impossible to survey the two bronze lions in their entirety and with the necessary accuracy.
Their attribution and dating has not been firmly established; however, their physical characteristics would indicate that they are of the same era as the mosaics in the chapel, located in the northern transept of the Basilica and dedicated to Isidoro, the Greek saint whose remains were brought to Venice from Chio in 1125 by Doge Domenico Michiel and whose ducal devotion is similar to the one for St. Mark.
The mosaics are invaluable works from the mid 14th century, when the Doge Andrea Dandolo commissioned the construction of this chapel and the baptistery in honour of the saint.
The most unusual thing about these lions is an important event in the history of the Basilica and as regards works of art in general: late last century, one of these bronze statues was stolen from the Basilica; it was recovered and replaced in its original location thanks to the laudable efforts of the local Cultural Heritage Unit of the Gendarmerie of Venice.

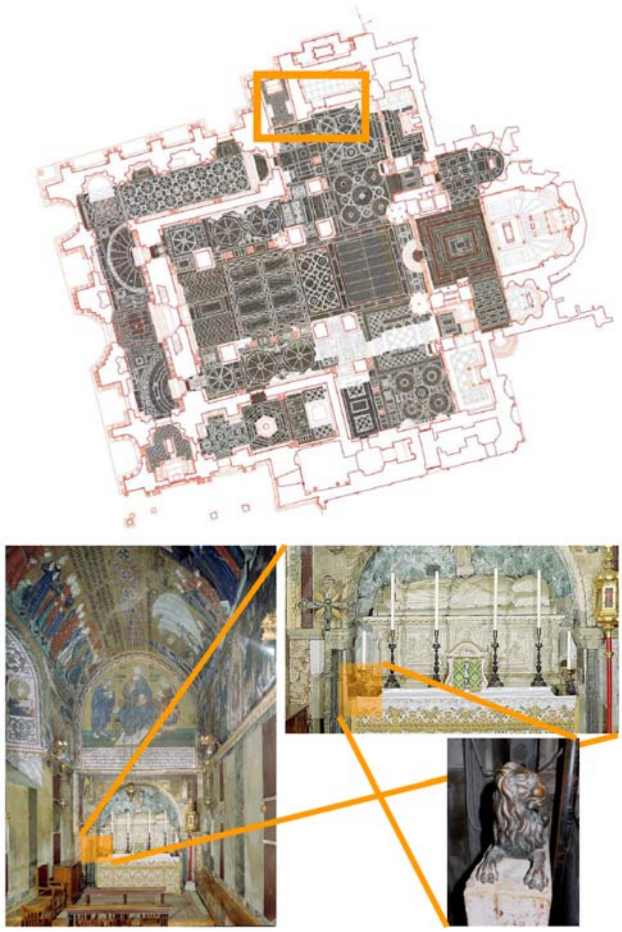

Figure 6. The bronze lion localization into st.Mark's Basilica Venice - Italy

2.1 Surveys

To date, ultra-high resolution (0.2 mm) scans were acquired of both sculptures using the HandyScan 3D portable system and the results were partially realized with VxScan software and partly by RapidformXo-Scan.
The clouds, made up of 850000 total points, were surveyed in two acquisition boxes of 200 x 200 x 200mm with the basic unit of voxel of 0.39mm. Seventy-four reflecting targets were located on the bronze lions.
After initially processing the data in a VxScan environment, the vertices of the surface created instantaneously by the programme were imported into Rapidform in the STL format,

for further processing and for subsequent creation of the final model of the bronze lions.

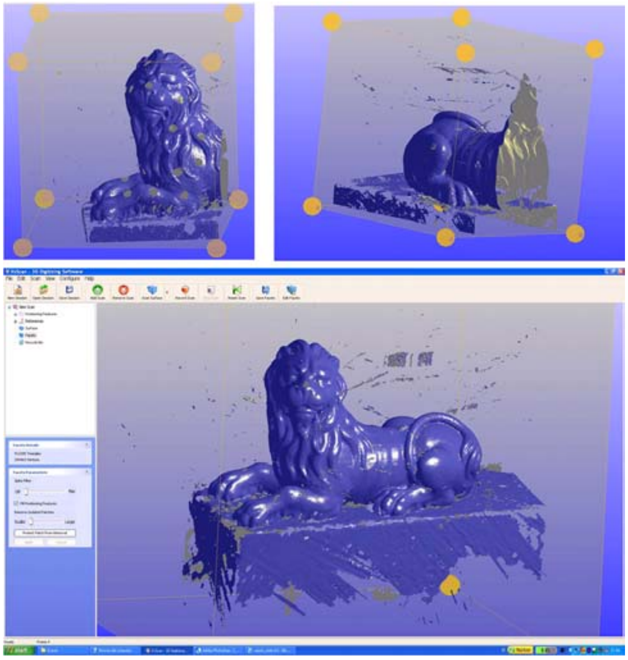

Figure 7. Both lions were acquired in two boxes of 200 x 200 x 200mm with the basic unit of voxel of 0.39mm. The dimension of each lion is around 171 x 138 x 269mm

This step was necessary to make a more accurate control of the result due to problems related to the noise that is created in surveying objects in metal, reflecting and dark materials. One of the objectives of the research was to test to what degree unfavourable conditions had an influence on the initial processing done by the proprietary programme, in addition to the fact that it was not possible to treat the sculptures with matt pain, for conservation reasons.

2.2 Modeling

The RapidformXo 2006 modeling software has been integrated with classic data filtering systems to eliminate outliers, i.e. points identified by the software as measured incorrectly, and eliminate redundant data, overlapping vertices or which after an initial measurement of the minimum distances between points appear below a certain tolerance. Other procedures used to process data involve a reduction of the number of points which takes account of changes in surface curvatures and smoothing point clouds, to reduce its "wrinkles".

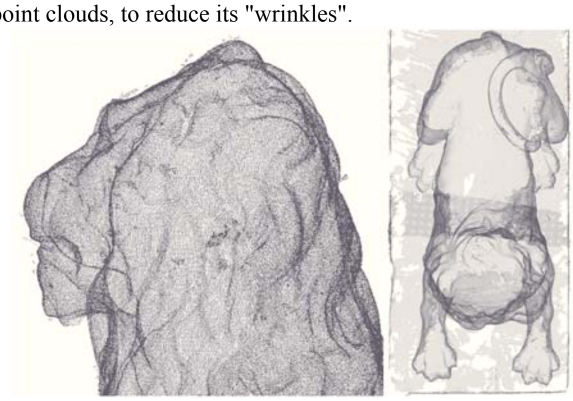

Figure 8. The point clouds are filtered in RapidformXo 2006 modeling software

Next, continuous surfaces of the model were created by volumetric triangulation, through generation of uniformly distributed polygon faces and calculated by measuring the distance between the vertices of the cloud and voxel nodes.

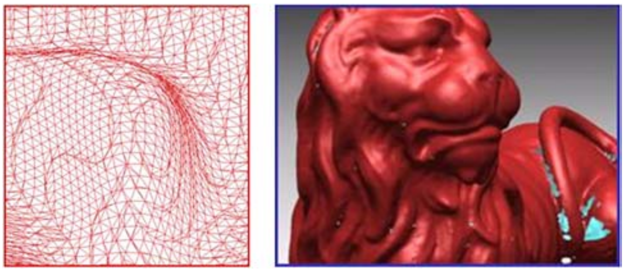

Figure 9. Volumetric triangulation

Since meshes are comprised of non-structured data, i.e. they are produced while not following a precise scanning geometry, some types of topological errors occurred during automatic creation of meshes, which included upending the normal, introduction of instable and redundant faces, etc. which were eliminated nearly comprehensively automatically by the software.

Figure 10. Topological error in the mesh

The holes found on the continuous surface after these filtering operations or due to lack of data were closed while taking account of the curvature of the edges that limited them.

After these operations, the 3D model was subjected to a geometric simplification of the number of vertices and triangular mesh that make up the surfaces, without diminishing the degree of accuracy and precision through controlled simplification. This makes it possible to greatly lighten the mass of data by decimating many of the vertices where the surfaces have a constant progression or are characterized by small variations in the angles of direction of the normal to the mesh.

After the model is obtained, many types of metric and curvature analyses can be done, in relation to a more detailed understanding of the geometry of the model and its surface.

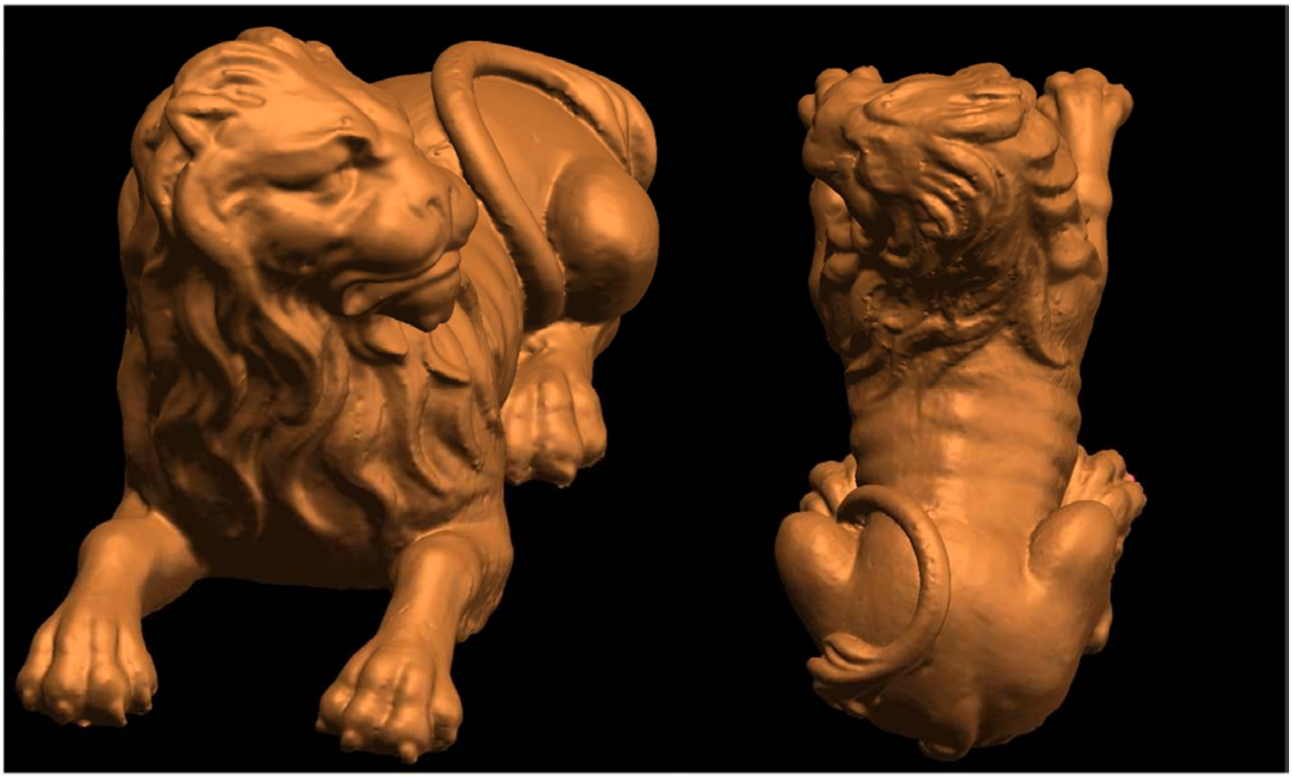

Figure 11. Lions's tridimentional model

2.3 Mapping the model

Lastly, the 3D model was texturized using the digital images produced with photo cameras, Panasonic Lumix DMC of 10.2MPixel, whose lens distortions were corrected after calibration.
For rectification of each bronze lion, approximately 10 photograms - captured from several perspectives - were applied to the model through the recognition of at least 5 matching points for each.

For each photograph captured, there is the inverse projection of the 3D model; the best portion of the photo was selected for every triangle of the 3D model (i.e., the section that introduces the least distortion) and a single texture was constructed which integrates the various incoming RGB images. In addition, potential edge discontinuities were eliminated, which were presented between a photograph and another.

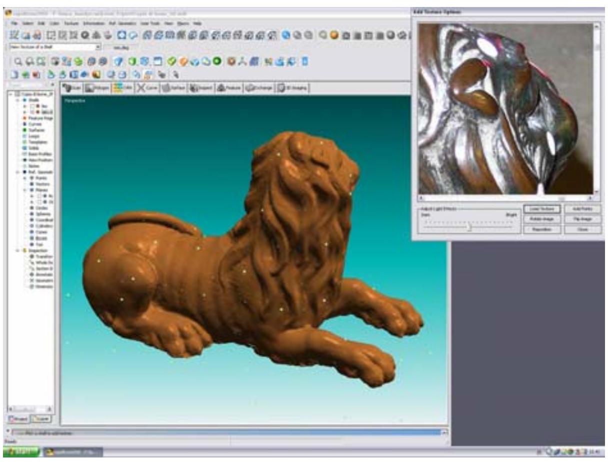

Figure 12. Texture mapping of the model

Figure 13. Each model is matched with many images, captured from several perspectives

Figure 14. Detail of the lions's head model

Figure 15. 3D Model of lions

The finished model was exported into VRLM, for management in a 3D navigable environment easily useable by various types of users.
The software used demonstrated a limited applicability in correctly mapping objects of this type, as already shown in past publications. To overcome these issues, an appropriate photographic outline had to be designed and an appropriate selection of matching points had to be designed for individual uniform areas, which is not always possible in complex 3D surfaces.
Otherwise, it would be necessary to use new 3D scanning instruments, which currently present characteristics of portability of the tested system.

3. CONCLUSIONS

In surveying cultural objects, it is frequently impossible to apply traditional laser scanning techniques, even if characterized by very accurate precisions, due mainly to operating difficulties, which can be easily overcome with next-generation instruments that are compact, versatile and portable.
Manual laser scanners use technology that allows them to automatically position with respect to the object of survey thanks to the help of reflecting targets, appropriately distributed along the surface. There are many resulting advantages: in addition to the possibility to obtain very high precision models, with errors of measurement of about 0.1 mm, this technology can overcome problems related to transporting delicate and "difficult" objects or objects that are impossible to transport from the place in which they are located. The measurements can be made by a single operator, which in the case of survey of profiles, frames, or other architectonic elements, can work from simple scaffolding.
The digital format reproduced in the modeling which is generated at the end of this process of reverse engineering provides a knowledge and conservation of complex artistic and architectonic objects or very small objects, as in case analyzed. This heritage can be consulted and used for many purposes: as a survey instrument for study of renovation and conservation; as a documentation tool to obtain spatial references and present any other type of information.

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