

THE CREATION OF THE 3D SOLID MODEL BY LASER SCANNING: THE “OLD SACRISTY” BY BRUNELLESCHI IN FLORENCE

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Abstract:

Here we present the first results of the survey of the Old Sacristy in San Lorenzo in Florence, by Brunelleschi. The Old Sacristy is a chapel composed by two volumes, the main room and a lateral small chapel, the so-called Scarsella. It contains some high-quality bas-relief by Donatello. The survey has been carried out, in the frame of a control topographic network, by several laser scans with a Mensi GS100 fly time laser scanner. Here we discuss the operative and processing procedures that have been tested by means of two of the most popular commercial software, highlighting their characteristics and the features. They are Alias | Wavefront Spider 1.0 and Rapidform 2004. The results are surely noticeable for the point of view of quality. The survey size in fact goes from the architectural one and the one suitable for small object.

Key words:

Laser scanning, 3d solid model, alignment, decimation

1. The Old Sacristy in San Lorenzo in Florence.

The church of San Lorenzo in Florence and its monumental Sacristy (the Old Sacristy) have been designed and realised by Brunelleschi in the first half of the fifteenth century. It is one of the most remarkable examples of the architecture of the Renaissance. The original church was probably built in the fourth century. A second church was rebuilt and consecrated in 1059. In 1418 the Medici Family wanted to make it the family temple. Brunelleschi designed the Sacrestia Vecchia ('Old Sacristy' is to distinguish it from the 'new' one built in the sixteenth century in the same church by Michelangelo) as a cube surmounted by a hemispherical dome on pendentives, devices bridging the corners of the cube in the circular base of the dome. Ringed by windows at its base, the dome is partitioned by ribs into twelve webs. A smaller cube, similarly vaulted, formed the altar chapel, the so-called “Scarsella”. The construction was ended in 1429. It is dedicated to San Giovanni Evangelista. It has been restored in 1985 and 1989. It contains also some noticeable bas-relief by Donatello in addition to two doors in bronze. Two Polychrome terracotta, St Stephen and St Lawrence and St. Cosma and St Damiano are placed over two bronze doors. Door with the representation of Martyrs and with the representation of Apostles. Eight polychrome stucco are placed just below the dome. The proportions of the sacristy square became the module for the room's scheme linking plan to elevation. This environment has been regarded therefore like one of the most suitable to test the potentialities of the “new” surveying tool like laser scanning. In the frame

of a national research project we carried out a series of scans by laser scanning¹.

2. The performed scans and the control network

Twelve scans have been executed by means of a fly time scanning machine, the Mensi GS100. A four stations control network has been set up made by some targets realised by plane reflecting signals stuck on the walls and by some calibrated spheres (19 in total).

¹ This work has been financed by Prin 2002, Italian national research project

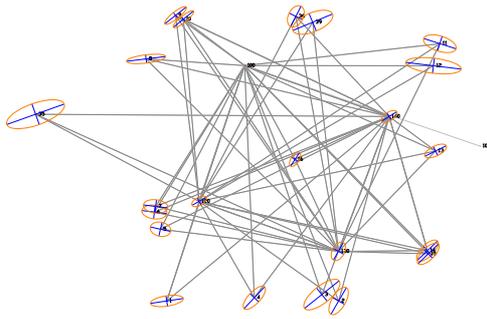


Figure 1: The Control Network

The geodetic observations have been made with a reflectorless theodolite and adjusted in a least squares adjustment programme RETE (Fangi 1994) with least constraints, reaching a sub-millimetre accuracy. A local reference system has been adopted where X axis coincides with the direction of a wall (figure 1).

3. The elaboration of the scans

We used two software packages, Alias | Wavefront Spider 1.0 and the Rapidform 2004. Both packages have a common feature, which is to create meshes from point clouds, by means of the Delaunay triangulation. Two main categories for the software can be distinguished according on the type of triangulation adopted for the mesh creation, made before the union of the point clouds derived from the single scans or after it.

Spider is a programme for the creation of mesh from a point cloud generated by a 3D laser scanner (figure 2). In particular one can import many types of formats by the laser scan. The Alias | Wavefront Spider 1.0 is able to select portions of the point clouds, to create new objects from an unique point cloud (split function), to link several clouds in an unique cloud (merge function), to create a mesh, to reduce the corners and the number of the triangles of a mesh (smooth and reduce function), fill the possible holes present in the mesh ("fill hole" function), compare with a colour map, the mesh produced with the original point cloud ("compare cloud to mesh" function), to create sections in the mesh, to measure distances among any arbitrary couple of points in the mesh.



Figure 2: Point cloud of a single scan

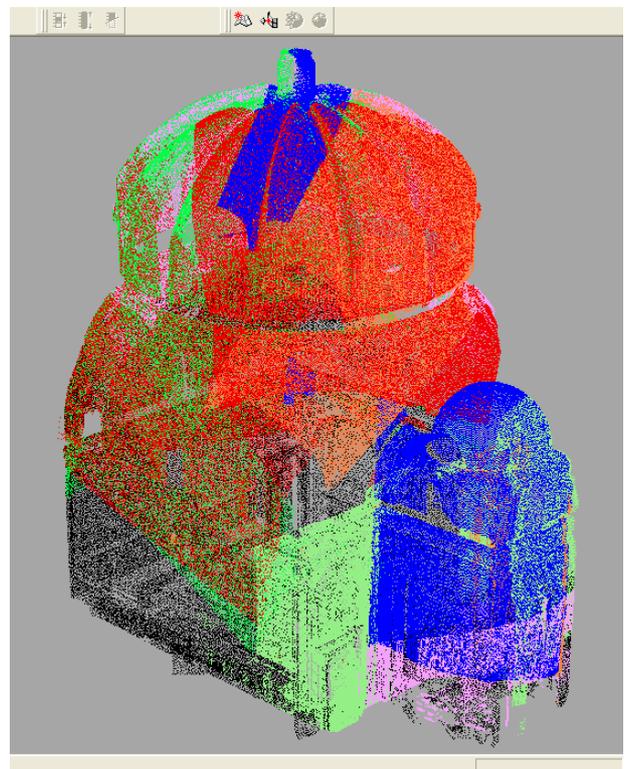


Figure 3: The point cloud by the fusion of several scans

The model derived from the simplification of the point cloud

is not without imperfections; some discontinuities can be met of the mesh (holes) (figure 2).

The software let obviously to remedy to this inconvenient with the command *Fill All Holes that* highlights in red colour the holes (Figure 4). One can, at this point, proceed manually to fill the holes (Figure 5). Alias | Wavefront Spider let in addition to create sections, and to measure distances between points inside the mesh. The limits of the software Spider consist essentially in the impossibility to roto-translate the different scans in order to fuse them in an unique reference system, but to have the need of scans already fused in their totality.

The programme Rapidform let to quickly perform operations as the registration, the fusion and the decimation of a large quantity of points.

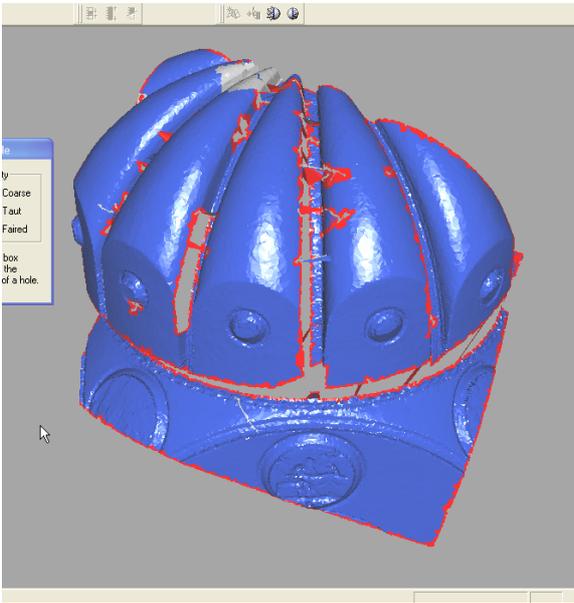


Figure 4: holes in the mesh highlighted by red colour

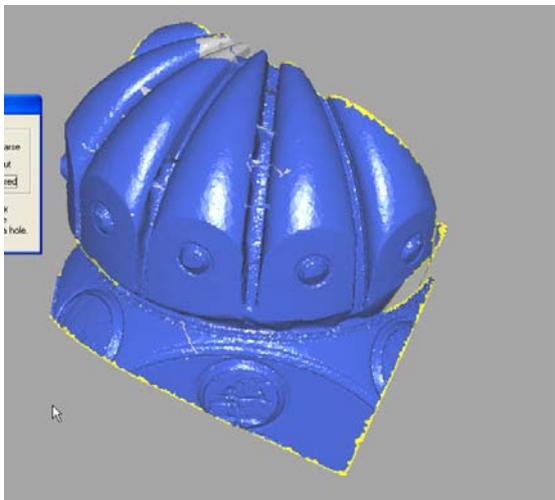


Figure 5: mesh after filling the holes

The single scans can be fused both under the form of point cloud (figure 3), and in the form of mesh (the meshes must have at least three points in common).

The points clouds are reduced per obtain partial 3D meshes, creating the 3D model complete with the union of the different scans. Operations of smoothing, subdivision of the meshes, filling of the holes and comparison about the accuracy of the obtained 3D models are then performed.

The procedures are the so-called Tweaking Polygon to Point Clouds, Tweaking Polygon To Polygon.

The procedure Tweaking Polygon To Point Clouds let of adapt (Fit Shell To Point Clouds) a mesh 3D created from a point cloud reduced (Figure 7) to the original point cloud previously copied, improving in this way the quality of the obtained 3D model.

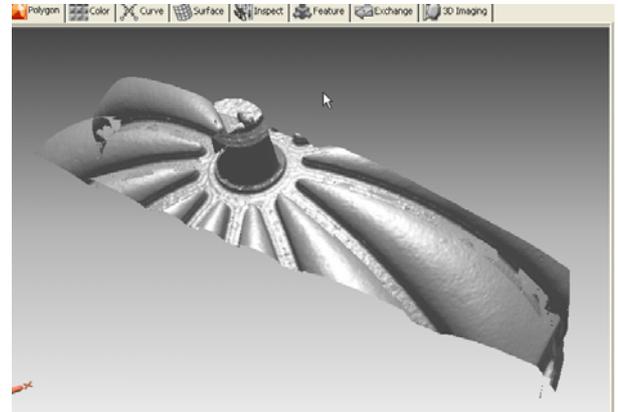


Figure 6: triangulation of the reduced point cloud

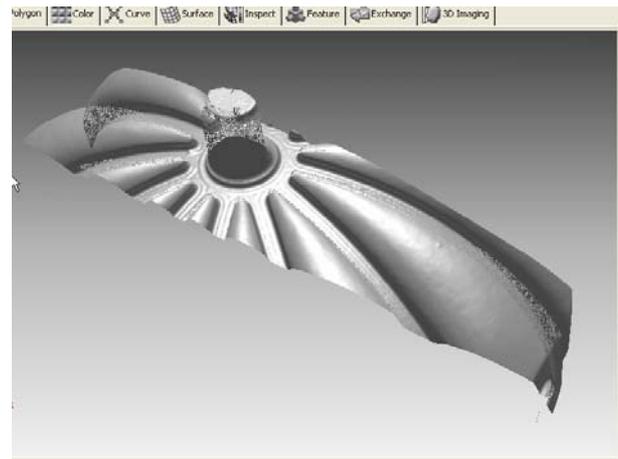


Figure 7: result of the 3D mesh after "Tweaking Polygon to Point Clouds"

The procedure Tweaking Polygon To Polygon let to adapt (Fit Shell To Meshes) a 3D mesh created from a reduced

point cloud, to the 3D mesh obtained from the original points, making in this way the quality of the model 3D obtained to be maintained, but letting us to obtain files not very heavy in memory occupation and then easily manageable (figures 6, 7).

4. The optimization of the model

To optimize the model the following procedure has been followed.

First the filtering of the single scans by means of the command *Filter Redundancy*, has been performed; then the shells have been imported in an unique file, enabling the union of the *shells* by means of the *merge* command. After this the eventual holes have been filled. Finally the *Smooth* more than one time has been completed.

The obtained results can be observed in the following figures 8 and 9.

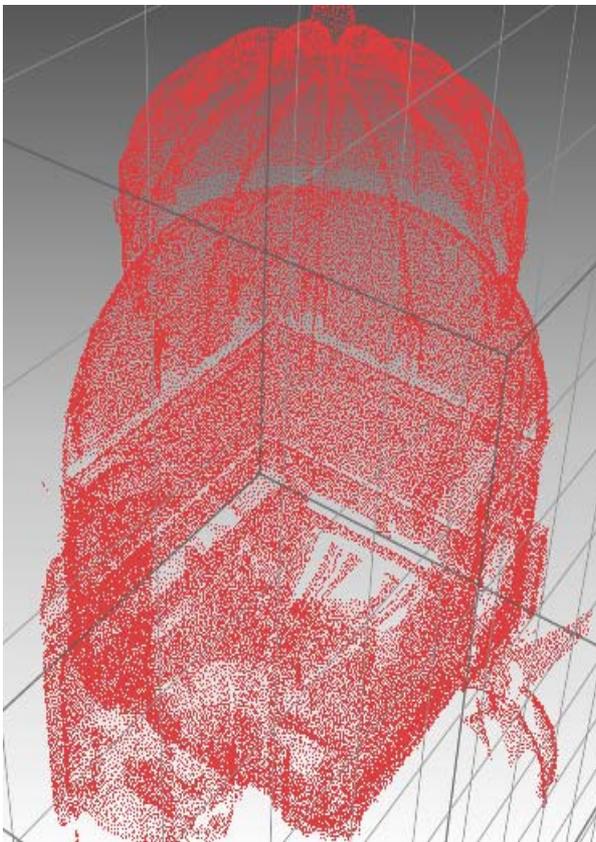


Figure 8: Filtered point cloud of the whole model

Since the software *Spider* with the command “*SPLIT*” enables a fast subdivision of the *shell*, we divided all the scans in smaller meshes. After their processing we unified them again in an unique mesh. This procedure is due to the need to make the operations of triangulation, and filling of the holes, faster and easier to manage. An example can be seen in figures 11 and 12. The polychrome terracotta over the door has been elaborated separately from the rest of the wall and after then fused.

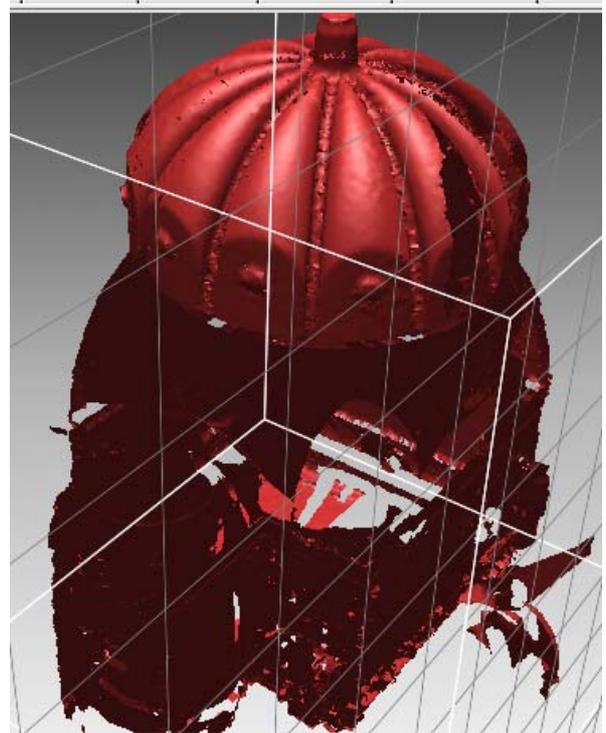


Figure 9: The model after the triangulation

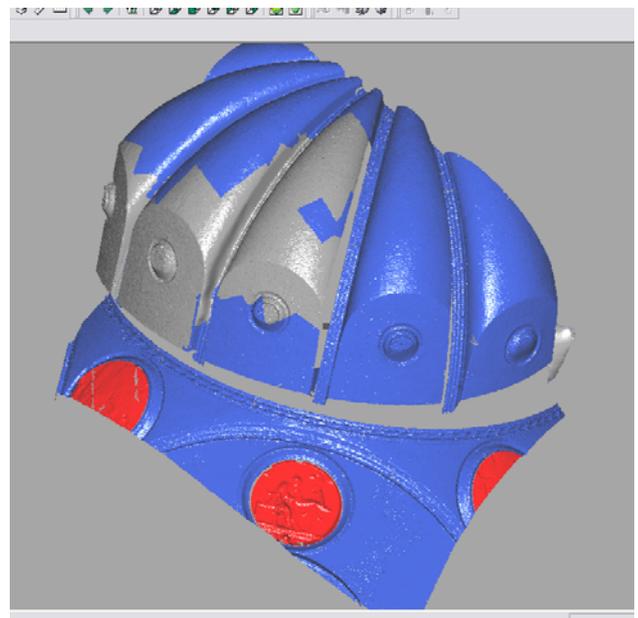


Figure 10: triangulation with Spider of one scan

The eight polychrome stuccos have been therefore cut out

and elaborated separately. Some of them are highlighted in figure 10.

The quality of the triangulation is good also thanks to the command *Fill All Holes* that enables an easy filling of the holes both manual, for the larger holes, both automatically, for the smaller holes.



Figure 11: - Left portal with the bas-relief

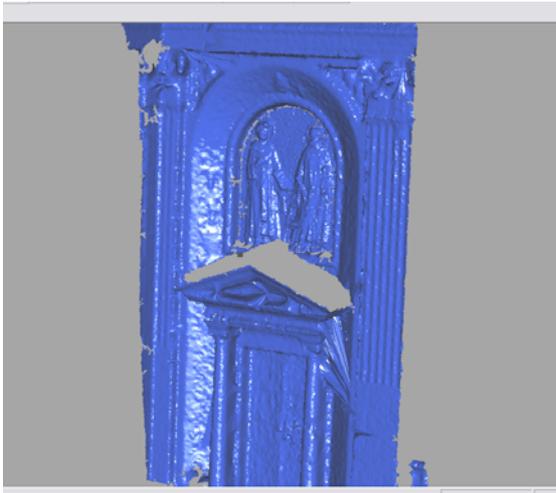


Figure 12: - Left portal with the bas-relief: union of the shells and smoothing

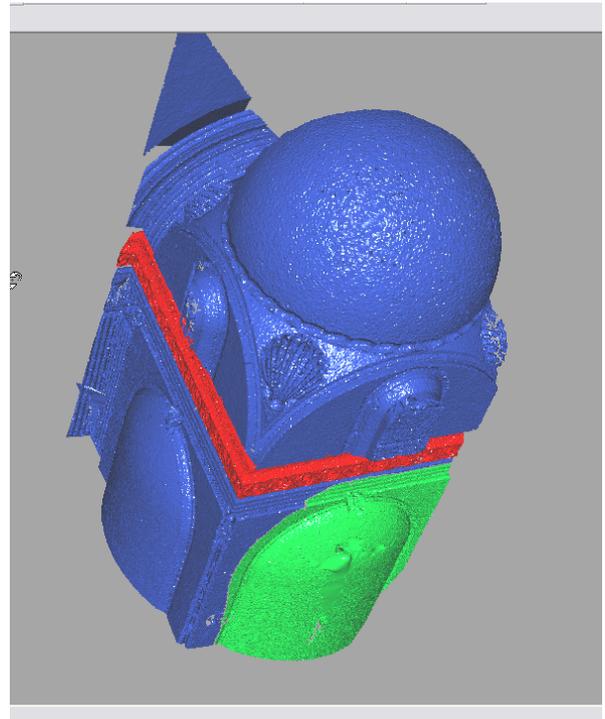


Figure 13: - The "Scarsella".

By importing the elaborations in a unique file the entire model is obtained (figure 14).

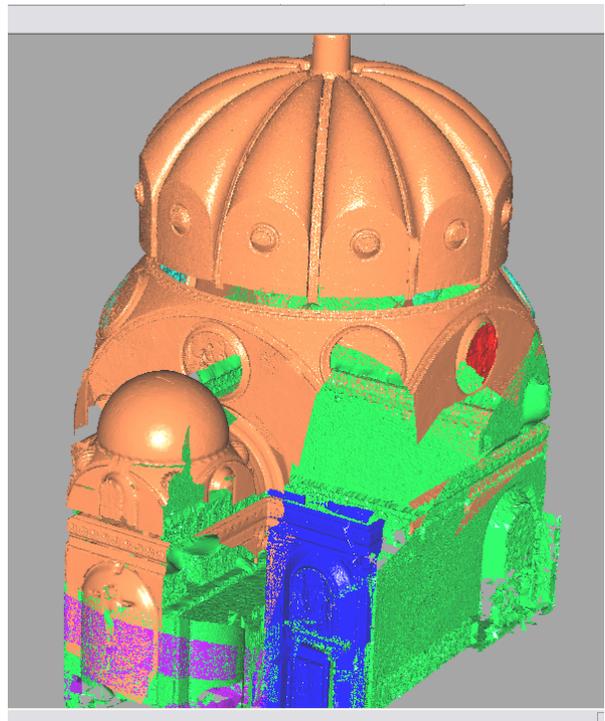


Figure 14: - The alignment of the meshes

Linking the *shells* we can read the total number of the *meshes*, highlighted in different colours.

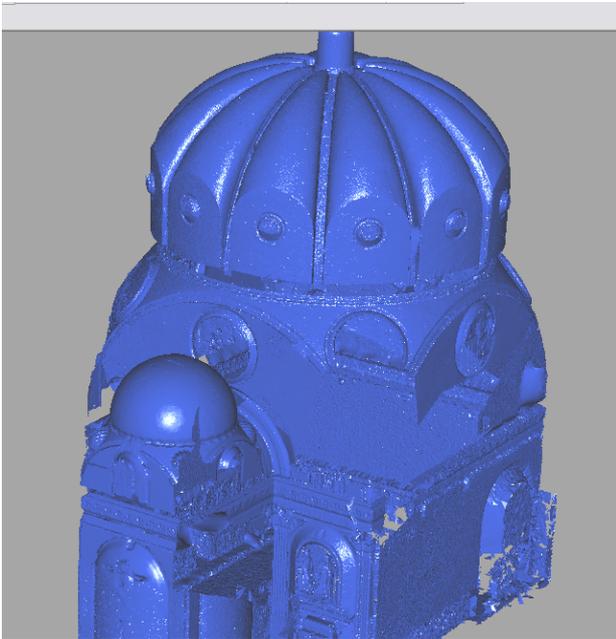


Figure 15: – the 3d solid model of the Old Sacristy

In the figure it is possible to see the sections of the cupola

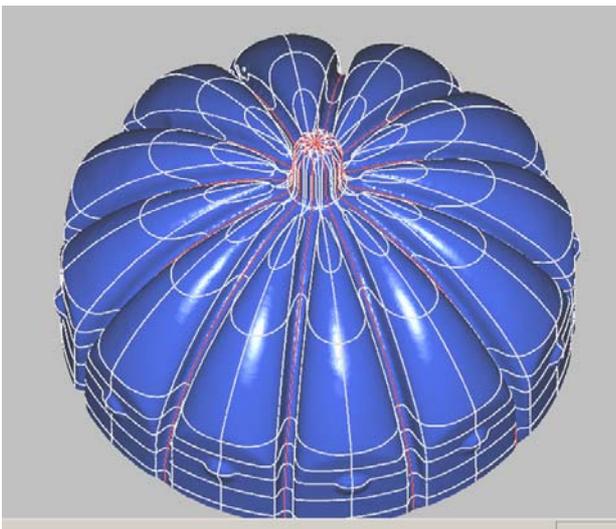


Figure 16: Horizontal cross sections of the cupola

The following steps are the division and the filtering to pass later to the triangulation.

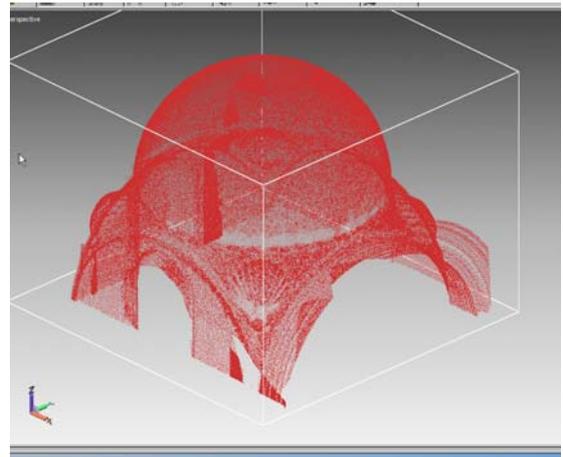


Figure 17: Integrated point cloud of the “Scarsella”

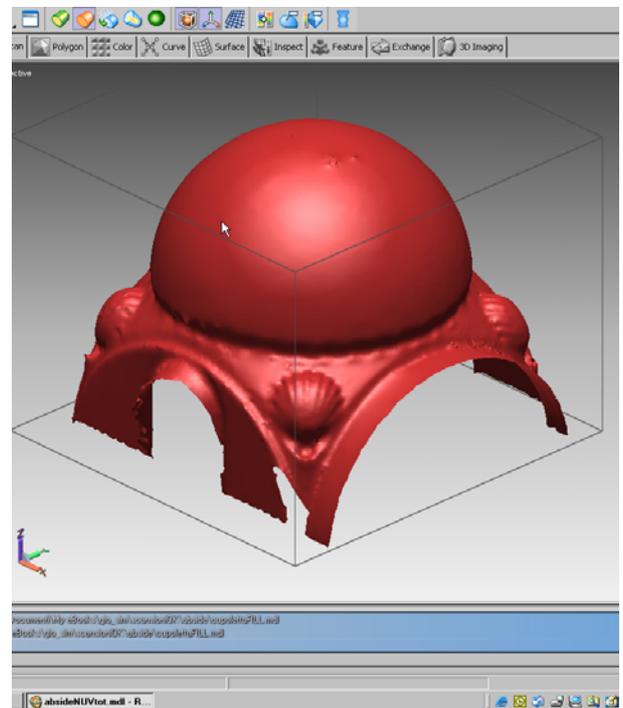


Figure 18: – The 3d solid model of the “Scars Ella”

The model has been subdivided in small portions characterized by the homogeneity (cupola, walls abside, etc):

At this point, we can modify all the vertices in red of the surface, with some options like “Patch Network Edit”.

In particular we can move the vertices in such a way to cover uniformly the mesh, especially in the zones of the low-left part where we do not have a sufficient information about the border.

We can also subdivide the vertices in the zones where we need a better detail, as in the zones of the tunicae of the holy men, the book, the faces etc., with the option *Subdivide*

Vertex Star.

We can also change the curvature of the curve linking two vertices with the option *Edit Edge Curve*. Once applied the changes to our surface, we have the densified surface, before the creation of the final NURBS.

In certain zones some surfaces are missing, one can intervene by means of the command Surface\Created\Blend (figures 19 and 20).

It is also possible modify the surfaces NURBS by means the command Surface\Edit\ Transform.

Some phases of the other parts of the model are shown:

One can synthesize the tips to get a good model suitable for the creation of the surfaces NURBS:

- It is better to link the scans before the triangulation to avoid an overlapping of the meshes;
- When the surveyed object is of large dimensions, as in this case, it is advisable to divide it in more than one part;
- Powerful filtering by means of the command Filter Redundancy with values from 30 to 60, chose the one letting a triangulation with less apertures;
- Filling the holes with the software Spider
- Procedure of Tweaking Polygon to point clouds
- Regularise the normal versor to the mesh.

To verify the accuracy of the model, RapidForm2004 computes the differences of the meshes with respect to the original point cloud: 97.83% of the meshes differ from the point cloud, in absolute value, for a value less than 8mm. The same type of study can be made for the difference of the surfaces NURBS from the shell of the triangles. Also the shifts of the NURBS have small values, the bigger part of the surfaces differ by less than 12mm. RapidForm2004 programme let to generate curves. These ones can be exported as dxf format and therefore in CAD software.

In addition it is possible to generate sections with the command *Messure\Cross Section*

This feature let us to study the model from the point of view of geometry.

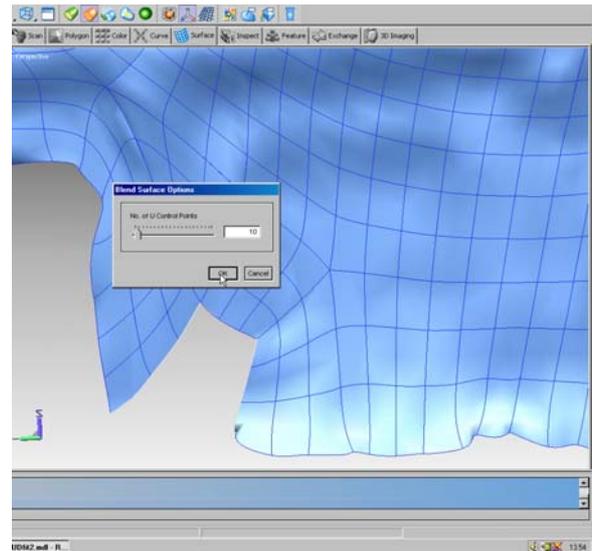


Fig. 19 – Hole to be filled

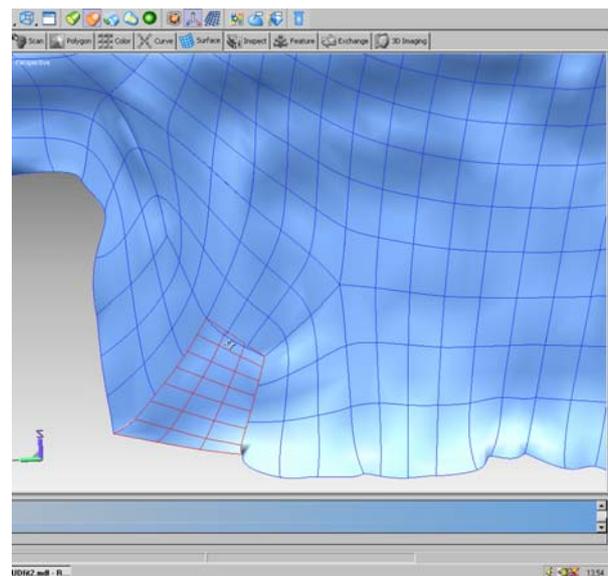


Fig. 20 – The hole already filled

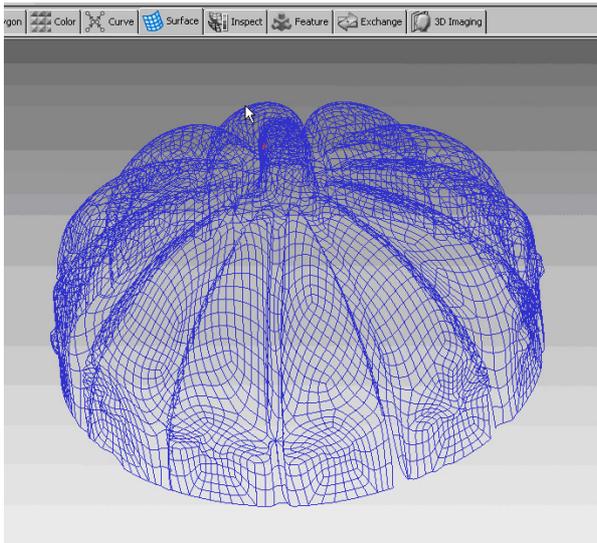


Figure 21: Nurbs of the cupola

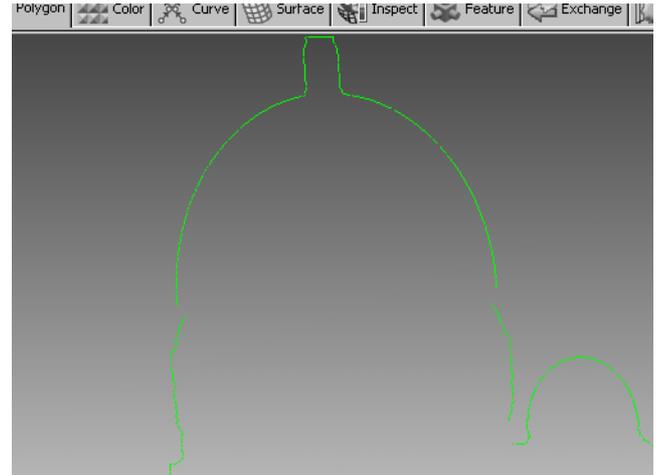


Figure 23: – vertical cross-section of the cupola

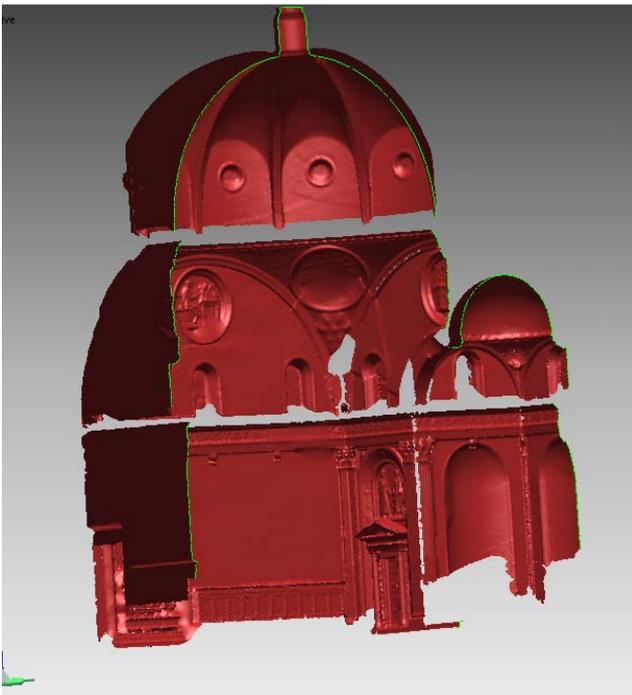


Figure 22: vertical longitudinal cross-section of the 3d model

5. Conclusions

A relatively new instrument is available nowadays. We have to learn how to get the best results out of it. In particular we hope that in the future, the machine will automatically set the resolution according to the complexity of the surface. This is not obviously in the capabilities of the operator which has to perform the decimation in post-processing mode. Moreover the operator should have a remarkable degree of skill in order to handle the scans and get good results.

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