3D MODELING OF THE ST.ANTHONY ABBOT CHURCH IN S.DANIELE DEL FRIULI (I): FROM LASER SCANNING AND PHOTOGRAMMETRY TO VRML/X3D MODEL

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ABSTRACT

The paper describes the steps of the 3D modeling of the Church of Saint Anthony Abbot in San Daniele del Friuli (I), from the laser scanning and photogrammetric integrated surveying to the final VRML/X3D photorealistic model. This church keeps the most beautiful and harmonious cycle of Renaissance frescoes of the region, painted by Pellegrino da San Daniele: the virtual model is intended also as an instrument to help visitors or studious to better understand the narration meaning hidden in the fresco episodes.

For the inner and outer surveying of the church, the Riegl Z390I system integrated with a Nikon D200 photogrammetric camera was employed: 18 different point clouds for about 33 millions of points and 163 digital images were automatically collected.

Data processing carried out by RiSCAN PRO® software (Riegl) allowed the scan registration, the 3D surface reconstruction and the image texturing with satisfactory results. Particular attentions have been given to the 3D surface of the interior of the church, before in its construction by partial Delaunay triangulations and later in its smoothing and decimation for an efficient management of a 3D model with "few" (hundreds of thousands!) triangles but anyway preserving a high geometric detail.

New images have been later acquired with the metric camera without laser scanning system, to substitute the original ones having illumination troubles: these new images have been externally oriented by natural points on the surface and then textured onto it.

The 3D model and the image textures have been imported in the VRML/X3D space, where six thematic tours will be available. The model is structured in different *LoD* (Levels of Detail) for the model geometry and textures resolution, and each frescoes scene and figure is linked by means an *Anchor* with the corresponding card of the web *Regional Information System of the Cultural Heritage*.

1. INTRODUCTION

Once we have crossed the threshold of the Church of Saint Anthony Abbot, we feel astonished and overcome by the plenitude of colours and figures which fill the frescoed walls. This often leads the less expert visitor to give himself in to a whole quick look giving up, instead a more attentive watch as well as the appreciation of the stylistic and technical details, so risking to make fall into oblivion the spectacular apparatus of scenes created for us by Pellegrino da San Daniele.

This suggestion of F. Rizzatto gave us the definitive motivation to conduct a complex laser scanning and photogrammetric surveying for the creation of a photorealistic VRML/X3D model of the church. In our intention, this should give support to the visitor or the studious to truly understand the meaning of narration hidden in the fresco episodes and to recognise leading characters from supernumeraries of a pictorial world so far from us. This model is indeed mainly thought for a use via web, as a first case study of the regional project "*Computer Sciences for the Cultural Heritage: mobile and 3D innovative services for tourism*" of the University of Udine, later better described.

The church dedicated to Saint Anthony Abbot is located in San Daniele del Friuli (Italy), an ancient village on a hill not far from Udine. The first mentioned writings about the church go back to 1308, but the earthquake of 1348 damaged it seriously. In 1441, as the brotherhood Confraternita di Sant'Antonio was in flourishing economic conditions, they decided to make it longer and more beautiful. Thus they lengthened the nave, built the choir and perhaps rose the truss roof. In 1469 the decoration the under roof bows were achieved with either sacred or secular allegoric figures. In 1470 the works on the late Gothic Istria stone façade were finished with a magnificent rayed rose window, housing the *Virgin with the Child*, and the portal with a readable inscription on the architrave as well as the *Saints Anthony Abbot*, *John the Baptist and Anthony from Padua* in the lunette with *God* upon them.

The principal façade is depicted in Figure 1 in form of vertical prospect/orthophoto produced throughout this work, as well as the figures of Chapter 2. The art historians can well observe the scenes and subjects frescoed, while the surveyors may discover the small geometrical irregularities and direction misalignments.
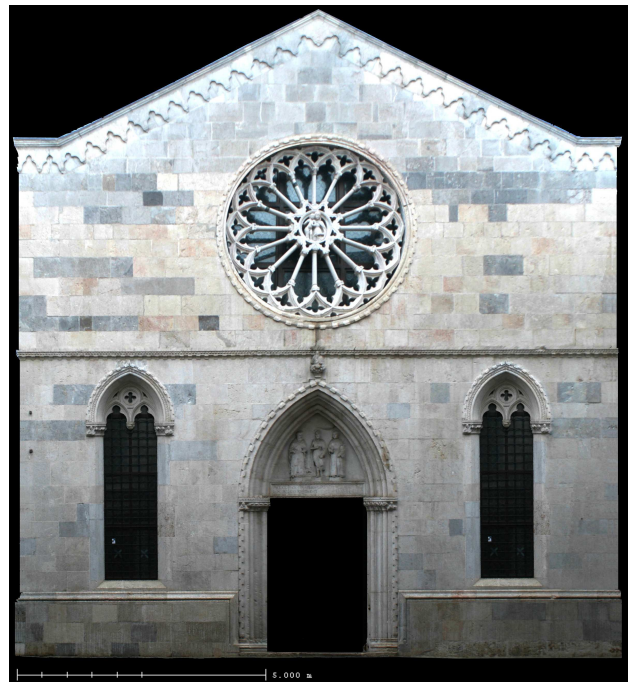

Figure 1. Orthophoto of the St. Anthony Ab. Church façade.

2. THE FRESCOES OF PELLEGRINO DA SAN DANIELE

The church houses the most important Renaissance frescoes in all over the Friuli: they were made by Martino da Udine, better known as Pellegrino da San Daniele (1467 or 1472 - 1547).

That is why this pictorial cycle has always risen a great interest and it has always been accurately studied. It was firstly named in the artistic historiography by Giorgio Vasari and it has been found in the documents and chronologies since the XIX century thanks to Fabio di Maniago and Giovan Battista Cavalcaselle, who analysed the paintings scene by scene, underlining their technical features and their precarious state of preservation. Anchise Tempestini (1979) gave important historical and artistic contributions about the character of Pellegrino. Also the work by Massimo Bonelli and Rossella Fabiani (1988) is essential if we want to go throughout the historic preservative events of the pictorial cycle until 1976, the year of the earthquake in Friuli Venezia Giulia followed by an important restoration which allowed a complete revival of the frescoes despite several "lacuna" mainly in the lower part of the apse.

In 1497 the Confraternita di Sant'Antonio ordered the covering of the previous frescoes which had been judged not enough devotional and unfit to rise a strong proselytism to the faith.

Of the ancient paintings dating back to the second half of 1300 and saved by Pellegrino himself, only some stories of Christ (*Birth of Jesus*, *Adoration of Magi*, *Escape to Egypt*) are visible on the left wall together with *Saint Helen with the cross*, frescoes some year older (1405) (Figure 2). Another fragment with *Jesus among the Doctors* (1475) torn by the restorer Antonio Bertolli in 1878 and preserved in the Museum of San Daniele, it is now in the left wall of the church.
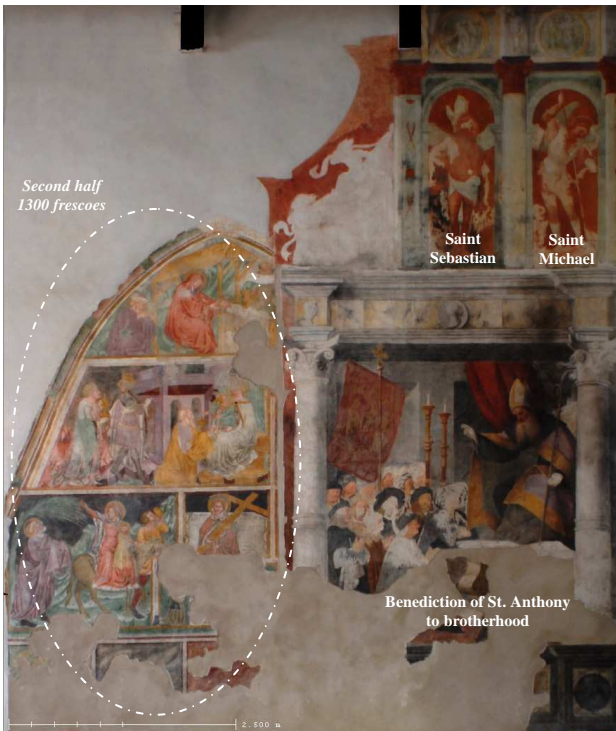

Figure 2. Orthophoto of the frescoes of left wall of the nave.

Between 1497 and 1498 Pellegrino painted the decorations of the sails of the rib vault of the apse following a precise iconographic plan probably established by the Confraternita. In the middle he painted the *Blessing Christ* inside an almond, surrounded by the four *Evangelists* and two *Prophets* on the vault limits (Figure 3). Then there was the representation in the

arc of ten busts of saint women recognisable by their attributes: *Colomba*, *Lucy*, *Agate*, *Helen*, *Barbara*, *Maria Magdalena*, *Catherine*, *Ursula*, *Rosa* and *Apollonia* (Figures 3, 5 and 6).

Figure 3. Orthophoto of the presbytery and apse frescoed dome.

In the same period Pellegrino also painted the little *Prophet* (identified by Bonelli as the young *Daniel*) in the upper part of the window release decorated with many little figures of saints and with the artist's signature and the date 1498, the year of the end of the first phase of works (Figure 5).
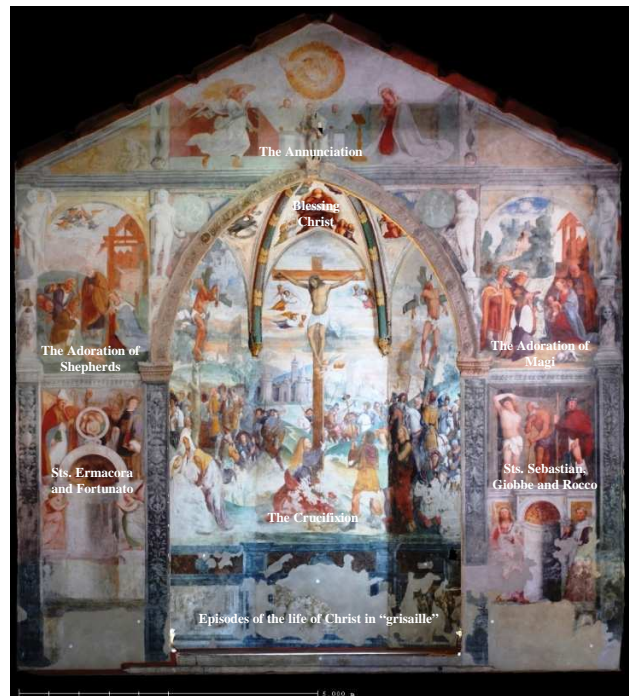

Figure 4. Orthophoto of the triumphal arch wall and apse.

After a period spent in Ferrara at the Estensi court, Pellegrino went back to Friuli and in 1513 he drew up a new contract with the Confraternita. This was a new start for the second and last phase which saw Martino busy in the execution of the decorations of the presbytery groin vault, of the lunettes and of a first part of *The Crucifixion* which takes three of the five sides of the choir wall (Figure 4).

On the presbytery vault he painted the four *Doctors of the Church, the Prophets* under the first arch (Figure 3) and the *Miracle of the drowned child* on the right lunette near the window (Figure 5). The scenes with *The temptation of Saint Anthony Abbot, The division of the bread,* and *The burial of Saint Paul the Hermit* in the lunettes of the left side wall, were probably ordered to some co-workers in the activity (Figure 6).
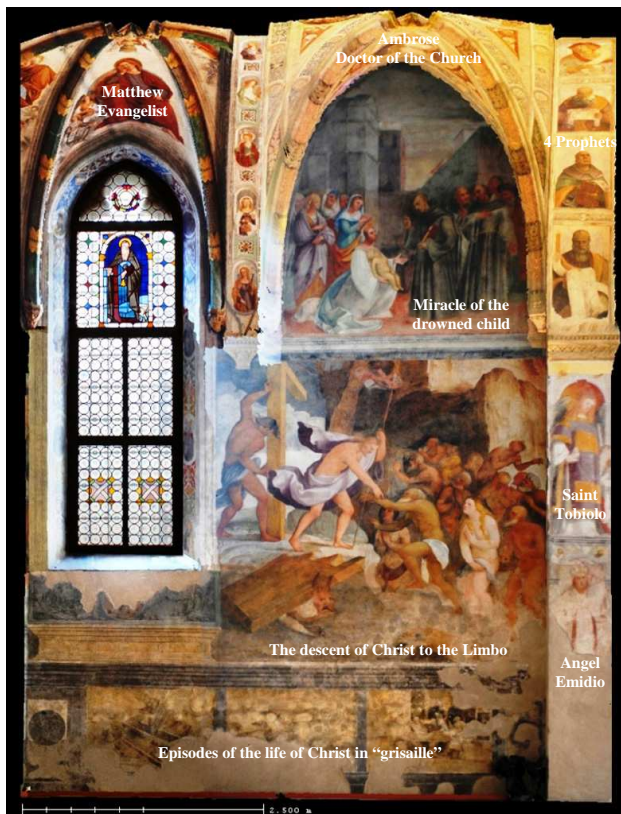

Figure 5. Orthophoto of the right side wall in the presbytery.

In 1514 the works were interrupted because of an earthquake and they stopped at the height of the feet of Christ and of the two thieves in *The Crucifixion*. Pellegrino restarted painting his frescoes by 1522 from *The Annunciation* on the triumphal arch wall of the nave and going on with *The Adoration of Magi* and *The Adoration of Shepherds* (Figure 4), and on the nave left wall with *Saint Sebastian* and *Saint Michael* (Figure 2). After only a short while, Martino could have been decorating the lower part with the *Benediction of Saint Anthony Abbot to Brotherhood* (Figure 2), and the triumphal arc with *Saints Ermacora and Fortunato* on the left and *Saints Sebastian, Giobbe and Rocco* on the right (Figure 4).

Finally he painted the lower part and the side walls in the presbytery, *The descent of Christ to the Limbo* (Figure 5), *The washing of feet* (Figure 6), and the four figures housed in the painted niches of the triumphal arch, identifiable as *Saint Tobiolo* and the *Angel Emidio* at right (Figure 5) and *Saint George* and *Saint Colomba* at left (Figure 6).

The construction yard would have been definitely closed after the episodes in "grisaille" that are in a bad state of preservation and tell some moments of the life of Christ (Figures 4, 5 and 6).
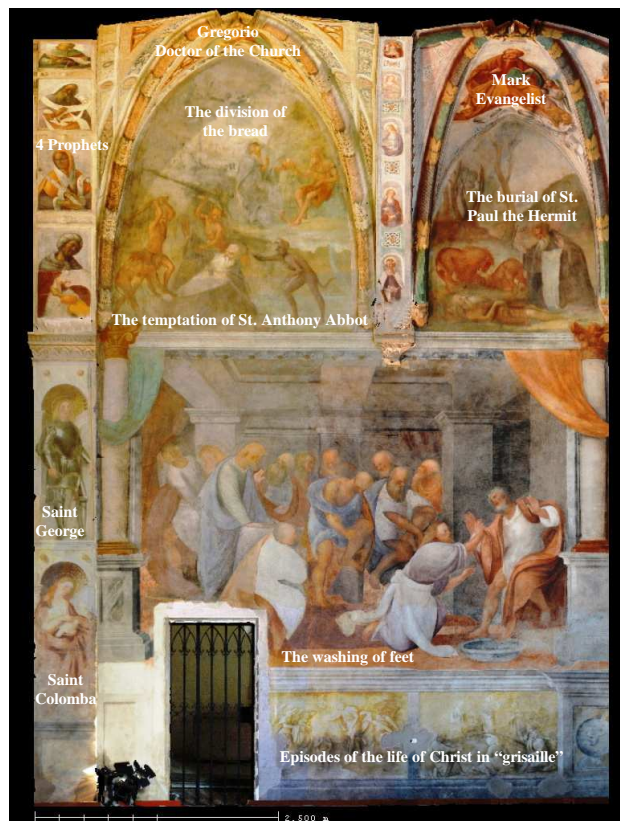

Figure 6. Orthophoto of the left side wall in the presbytery.

3. NEW STUDIES ON THE CHURCH STRUCTURE

While we have a wealth of documents and studies about the important cycle of frescoes, we have only a few pieces of information about the preservative events on the architectural structure of the church. Therefore we are interested in the study and the recovery of a still forgotten part of history by a careful exploration of the documents in the archives and we intend to throw a new light onto the historical, artistic and preservative events of the Church of Saint Anthony Abbot as an *unicum*.

From a drawing kept in the historical library Biblioteca Guarneriana in San Daniele, we learn that by the end of 1820, on the highest part of the front wall there was a bell bifora which has been later demolished and that was similar to the still existing one in the near Church of Santa Maria della Fratta. According to a document housed in the Municipal Archive in San Daniele, named but not published by Antonietta Mareschi (1978), a plan for rebuild the bell bifora was proposed to the town council but was never achieved. It was there remarked that the original stones we can still see in the church, were unfit to restore the window totally and without any integration.

From a first analysis of the documents kept in the Monuments and Fine Arts Office of Udine, we learn that the church has undergone several works through the centuries either for structural aims, to preserve the frescoes from the decay caused by the continuous water seepage, or for aesthetic and taste sake. Among all these minor interventions, we find it particularly meaningful the removal of the railing and of the step at three quarters of the nave (which can still be seen in the photos of 1906) and whose removal was made between 1927 and 1929, as well as the destruction of the old wooden compass of the door during the same intervention. Particularly interesting are the remarks on the demolition, the restoring and the moving of the stone, concrete and wooden altars during the works of 1817,

1823, 1929, 1931 and 1955. In the documents we not only find structural instructions but a wealth of news as well, such as the approval and disapproval either of the parson and the mayor which enable us to have a different and more profound sight into that distant historic period.

As for the structural works, the historic sources testify that in 1856 a little channel was dug behind the area of the apse to divert rain water and reduce the wet. In 1866 two stone drainers were made as well as the first attempt to isolate the wall. In 1929 they remade the already existing channel where the water flowing from the hill on the back of the apse was conveyed and in 1954 it was then improved with a new hollow space between the outer walls and the channel itself.

Between 1971 and 1973, finally the special "RAEM" type bricks, successfully tested in Santa Croce Basilica in Florence, were used and located at the bases of the walls to have them dried and protected from water.

The most meaningful work for the static reinforcing was anyway achieved after the earthquake in 1976: in 1978 the walls were reinforced and the roof remade. Between 1985 and 1992 the floor was removed, with great attention paid to the recovery of the stone elements, which made up the door jambs, the steps and the string-courses), the foundations, a new floor with a hollow space under it to let air go about were built.

Unluckily the documents testify that during the digging works nothing was found of the first church of 1308.

On that occasion (1989) three stained-glass windows with stories dated 1487 were detached and packed and later placed again on the ogival windows of the right wall of the nave and the presbytery (Figure 5). They were ignored by the archive documents and neglected by the studies, but they will be the object of analysis and comparisons as in Friuli Venezia Giulia there are only other few cases of polychromatic renaissance stained-glass windows (e.g. two fragments in the Civic Museums of Udine).

Between 2002 and 2003 the front façade has been finally restored and cleaned from the atmospheric pollutants which had been causing its decay (Figure 1).

4. LASER SCANNING AND PHOTOGRAMMETRIC SURVEYING OF THE ST. ANTHONY AB. CHURCH

To create a detailed photorealistic 3D model of a so interesting monument, the geometric and imaging information have to be extremely accurate. A Terrestrial Laser Scanner (TLS) system with a metric camera is the State-of-the-Art surveying technique since 2002 (e.g. Boehler, Heinz and Marbs) and fulfils such requirements. The operative phases for the fully automatic data acquisition with such device are well known; the only manual operation concerns the displacement of a suitable number of reflecting targets to simplify the step of scan registration.

For the surveying of this church, the Riegl Z390I system (www.riegl.com) integrated with a Nikon D200 metric digital camera (www.nikonimaging.com) of the International Centre for Mountain Researches (CIRMONT, www.cirmont.it) was employed in September 2008. TLS system was placed inside the church in three positions "Apse", "Presbytery" and "Nave", where it was also turned for the acquisition of the higher zones (Figure 7). From these positions, eleven point clouds were collected with different TLS Z^S axis orientation and angular steps, as specified in Table 8. The cylindrical and circle reflecting targets, represented by yellow dots in Figure 7, were automatically detected thanks to their high reflectivity: thus, a fine scan per target was performed by about 30.000 laser beams, so to accurately compute their barycentre.

Figure 7. Inner TLS positions and laser points (by intensity).

From the same scan stations, 100 digital metric images of 3.872x2.592 pixel with a 20 mm focal length Nikkor objective were acquired, with a variable factor of carefulness overlap.

In the same way, the TLS and photogrammetric external surveying of the front façade was carried out, giving off out seven point clouds and 63 digital images, as reported in Table 8. Some visual difficulties arose from the very narrow porch street in front of the church; furthermore, it is surrounded by very close buildings that not allowed the positioning of the TLS for a regular surveying of the other external sides.

It must be stressed how inside and outside scans have not common points, since an informative panel describing the frescoes, visible in Figure 7, is placed behind to the entrance portal, so disallowing any inner-outer laser ray.

no	scan position	cloud	ang step [']	points	size [Mb]	no images	size [Mb]
1	Apse vert	Overview	0,200	713.216	7,5	20	64,7
2		Panorama	0,120	1.998.000	21,0		
3	Apse -90°	Overview	0,200	713.216	7,5	20	86,0
4		Panorama	0,120	1.998.000	21,0		
5	Apse +30°	Panorama	0,120	1.998.000	21,0	10	31,0
6	Presb. transv +90°	Panorama	0,120	1.998.000	21,0	10	43,2
7	Presb. +90°	Panorama	0,120	1.998.000	21,0	10	41,9
8	Nave vert	Panorama	0,120	1.998.000	21,0	10	35,0
9	Nave +30°	Overview	0,200	713.216	7,5	10	34,3
10		Panorama	0,120	1.998.000	21,0		
11	Nave -40°	Panorama	0,120	1.998.000	21,0	10	33,1
11	**INSIDE**			**18.123.648**	**190,5**	**100**	**369,2**
12	Facade1 vert	Panorama	0,120	1.998.000	21,0	21	84,1
13		Scan	0,035	2.852.255	29,9		
14	Facade1 +20°	Overview	0,200	713.216	7,5	21	85,3
15		Panorama	0,120	1.998.000	21,0		
16		Scan	0,035	2.852.255	29,9		
17	Facade2 +20°	Overview	0,200	713.216	7,5	21	82,9
18		Scan	0,035	4.155.476	43,6		
7	**OUTSIDE**			**15.282.418**	**160,4**	**63**	**252,3**
18	**ST. ANTHONY AB.**			**33.406.066**	**350,9**	**163**	**621,5**

Table 8. Summary of the scans with Riegl Z390I & Nikon D200.

Observing Table 8, let note the huge amount of TLS (33 millions of points, 351 Mb) and photogrammetric (163 images, 621 Mb) data automatically acquired in few hours of surveying! The 41 reflecting targets placed inside and outside the church were suitably surveyed with a Leica TCRA 1103 EDM station from the vertexes of a topographic network. For the mentioned independence among inner and outer clouds, only the reflecting targets topographically measured allowed to join scans together.

5. PROCESSING OF THE SURVEYING DATA

5.1 Registration of the laser point clouds

The first step of the data processing is the registration of the point clouds. This requires a priori definition of a coordinate reference frame, called "Project Coordinate System" (PRCS),

e.g. a barycentric coordinate system, where to roto-translate the point clouds each one defined with respect to a different "Scanner' Own Coordinate System" (SOCS). Considering a point **P** in one scan, the analytical problem is described from:

$$\begin{bmatrix} X^P \\ Y^P \\ Z^P \end{bmatrix} = \begin{bmatrix} X^P_S \\ Y^P_S \\ Z^P_S \end{bmatrix} + \boldsymbol{R}(\Omega, \Phi, K) \begin{bmatrix} X^S \\ Y^S \\ Z^S \end{bmatrix} \quad (1)$$

where:

- X^P, Y^P, Z^P : coordinates of **P** with respect to the PRCS;
- X^P_S, Y^P_S, Z^P_S : unknown SOCS origin coordinates with respect to the PRCS;
- $\boldsymbol{R}$: matrix of the unknown rotation from SOCS to PRCS, defined from Euler's (Cardan's) rotation angles Ω, Φ, K .

The six unknown are estimated by exploiting X^P, Y^P, Z^P and X^S, Y^S, Z^S "double" coordinates of at least two points **P**. The problem of pairing the same point is completely skipped by exploiting the reflecting targets, considering their barycentric SOCS coordinates, and by choosing, among all the possible combinations, the one giving out the minimum error in (1).

Following the same approach for each scan and/or considering common targets among more than two scans, three translation and three rotation parameters per scan are computed. By applying these transformations to each point of each cloud, they "move" from their SOCS to the common PRCS, so finally forming a unique cloud of millions of points.

The registration of the eleven scans of the St. Antony Ab. Church has been carried out by means of RiSCAN PRO® software (Riegl), as well as the subsequent steps of surface reconstruction, image integration, and digital representation production. Table 9 reassumes the main results of the obtained scan registration: the millimetric values of the standard deviations and the sub millimetric values of the radial, vertical and horizontal average deviations, state the numerical correctness achieved in this fundamental processing step.

no	scan position	no paired targets	st.dev. [m]	avg. radial dev. [m]	avg. vert. dev. [m]	avg. horiz. dev. [m]
1	Apse vert	16	0,0019	-0,0004	0,0000	0,0006
2	Apse -90°	6	0,0014	0,0000	-0,0007	0,0002
3	Apse +30°	14	0,0026	-0,0001	-0,0001	0,0003
4	Presb. transv +90°	13	0,0021	0,0003	-0,0002	-0,0001
5	Presb. +90°	7	0,0033	0,0010	0,0007	0,0006
6	Nave vert	25	0,0013	0,0004	0,0000	0,0002
7	Nave +30°	23	0,0017	0,0005	0,0001	0,0002
8	Nave -40°	22	0,0012	-0,0004	0,0002	0,0001
8	**INSIDE**	**126**	**0,0018**			
9	Facade1 vert	9	0,0042	-0,0012	0,0000	0,0010
10	Facade1 +20°	9	0,0037	-0,0010	0,0001	0,0012
11	Facade2 +20°	8	0,0070	-0,0011	0,0001	0,0004
3	**OUTSIDE**	**26**	**0,0049**			
11	**ST. ANTHONY AB.**	**152**	**0,0023**			

Table 9. Summary of the results of the scan registration.

5.2 Surface reconstruction from the point cloud

After having obtained a unique point cloud, and before to convert it in a surface, the removing of useless and blunder points is generally performed. For this aim, available software provide several commands and tools, implementing statistical analysis and/or geometrical criteria, to remove gross errors, *outliers* data, isolated points, duplicated points, and so on. In this way, it is possible to automatically "clean" and "filter" the point cloud, and to resample the scans with less resolution angular grid if useful, anyway keeping the high resolution scans for specialised usages, e.g. measures for restoration purposes.

Afterward, the Dense Digital Surface Model (DDSM) fitting such correct points is automatically reconstructed by means of TIN (Triangulated Irregular Network) 3D meshes, better known as *Delaunay triangulations*, or by means of regular grids. Finally, the obtained DDSM is generally *simplified*, namely it is submitted to a procedure of *smoothing*, averaging the small irregularities of the surface, and to a procedure of *decimation*, deleting and simplifying too much small triangles.

A smoothed and decimated DDSM is the simplest output of the more general process of *3D modeling from TLS data*. The final goal of the modeling should be the extrapolation, with the maximum level of automation, of the geometric shape of the architectonical elements "imprisoned" within the point cloud. In truth, this task requires a reliable *interpretation* of the TLS data and this is not a simple matter, also bearing in mind the potential infinite variability of each architectural construction: hence, we can say that the quasi-automatic 3D modeling is an open problem yet. Nevertheless, a lot of theoretical or operative procedures can be found in TLS literature. Also our research group has proposed a method for the automatic modeling based on statistical analyses of the surface curvature values: the procedure description and some numerical experiments onto just these same points are reported in this proceedings volume (Crosilla, Visintini and Sepic, 2009).

To create a DDSM by RiSCAN PRO, further one tool based on a regular grid, two commands forming TIN are available, both constructing Delaunay 3D triangles by 2D analyses of points:

- Plane triangulation: is computed from the 2D coordinates of the points mapped onto the computer screen and requires to define some settings, as the maximal length of the triangle edges, the maximal and minimal triangle angles, and others;
- Polar triangulation: is computed from the 2D angular coordinates of the points with respect to a centre point, to be defined, as well as the maximal linear, angular and radial length of the triangle edges, a depth factor, and others.

Both procedures are exploitable for the church inner DDSM, starting from about 15 millions of points respect to about 18 millions acquired. In fact, numerous useless points have been disregarded as those relating to the furniture, e.g. the chairs in Figure 7, outgoing from the windows, outliers etc.. From these points, almost a double number of triangles (30 millions!) should be constructed, if software do not crush, but such monstrous amount of 3D faces could be not handled when exported in CAD or virtual reality environments.

For this reason and to apply the best triangulation procedure and different settings for various church parts, the point cloud has been shared in 27 subsets, differently coloured in Figure 13. Figure 10 shows the obtained DDSM for the apse rib vault by means of a polar triangulation with a centre in "Apse −90°" scan, from where most of such points were effectively acquired.
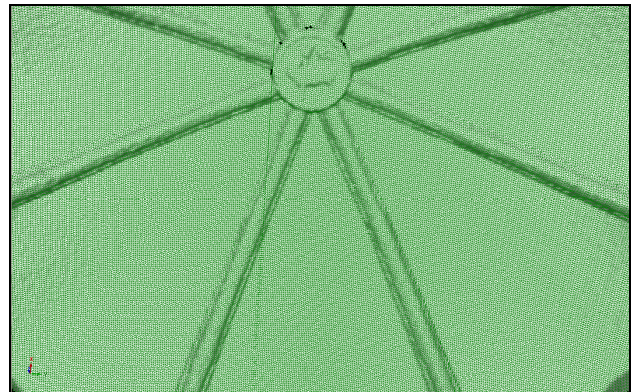

Figure 10. Apse vault DDSM (180.548 points, 357.594 triangles).

Particular cares have been devoted to suitably smooth and decimate the various DDSM, to preserve the detail of the church model also with "few" (hundreds of thousands!) TIN: this is the classical problem without unique solution, where the user has to find a best balance between such opposite needs. The DDSM simplification results depends from the values af many of parameters of smoothing (maximum angle among triangles, maximum angle among connected edges, and others) and decimation (percent of reduction, absolute error, maximum angle among triangles, split angle, and others), so different trials have been carried out. In Figure 11 a first simplification of about 71% of the vault apse DDSM is presented: as can be seen, triangles in the ribs and in the decorated medallion correctly remain smaller than those in the regular surface of the sails.
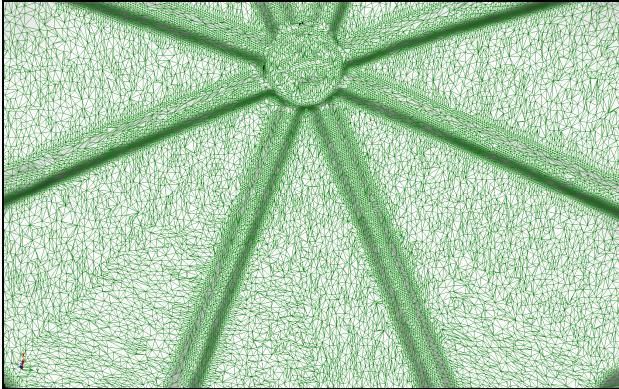

Figure 11. First simplification of the DDSM (103.454 triangles).

Figure 12 displays a further second simplification of about 90% of the DDSM apse vault: the different triangle size is yet visible.
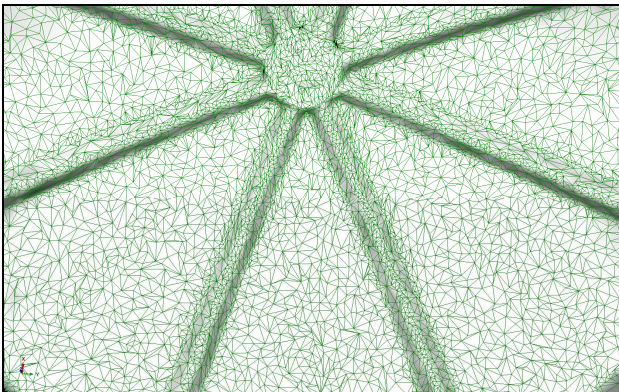

Figure 12. Second simplification of the DDSM (35.758 triangles).

Summarizing, the DDSM used for the successive steps is a simplification meanly of 55% of initial partials DDSM, but with very different amount of reduction for each one (Figure 13).
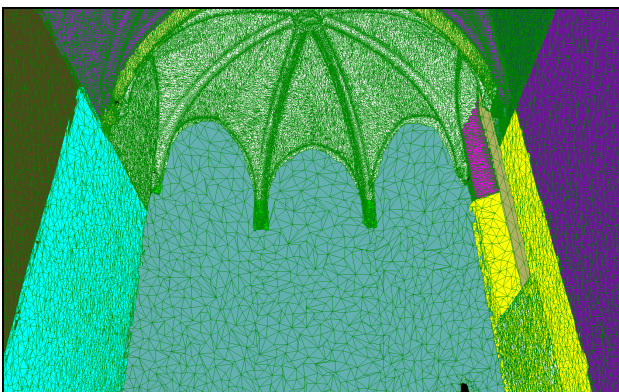

Figure 13. Final DDSM from different simplified partial DDSM.

5.3 Integration with the photogrammetric images

For a laser scanning and photogrammetric integrated surveying, TLS and imaging data can be straightforwardly joined, without the need of any user manual effort. This is possible since, unlike what happens for classic photogrammetric problems, in the following well-known equations of collinearity, all the quantities at the right to the equal are known:

$$x = -c\frac{R_{11}(X^S - X^S_C)+R_{12}(Y^S - Y^S_C)+R_{13}(Z^S - Z^S_C)}{R_{31}(X^S - X^S_C)+R_{32}(Y^S - Y^S_C)+R_{33}(Z^S - Z^S_C)} + x_0$$
$$y = -c\frac{R_{21}(X^S - X^S_C)+R_{22}(Y^S - Y^S_C)+R_{23}(Z^S - Z^S_C)}{R_{31}(X^S - X^S_C)+R_{32}(Y^S - Y^S_C)+R_{33}(Z^S - Z^S_C)} + y_0 \quad (2)$$

where:

- x, y : image (pixel) coordinates of a point;
- c, x_0, y_0 : parameters of inner orientation of the camera, known from the photogrammetric calibration;
- X^S, Y^S, Z^S : position of the same point with respect to the SOCS, known since just (!) gained by the scanning process;
- $R_{11}, R_{12},..., R_{33}$: rotation matrix coefficients from Camera Coordinate System (CMCS) to SOCS, known since the camera is fixed on TLS top and rotates by imposed angles;
- X^C_S, Y^C_S, Z^C_S : translation from the CMCS to the SOCS, known since the camera is fixed on the TLS top.

In more detail, six parameters of the initial roto-translation from CMCS to SOCS called "mounting parameters" are known by a calibration of the TLS and photogrammetric integrated system. When the camera rotates for the shot, only the direction angle varies from a shot to another. The corresponding rotation matrix $\boldsymbol{R}$ and the translation vector X^C_S, Y^C_S, Z^C_S are easily computed.

The RGB values relating to x, y pixel are then used to "colour" the X^S, Y^S, Z^S point. Repeating the same operation for all the points depicted in one image, the point cloud becomes a coloured point cloud. Such colouring procedure is then carried out for all the images of each scan position: this process takes only few seconds and can be done during the field operations.

As one can note from equations (2), the 3D/2D integration is performed in the SOCS frame, but thanks to the registration, the coloured point clouds "move" from SOCS to PRCS frame.

This integration allows the fully automatic texturing (*wrapping*) of the DDSM with the RGB values: from the analytical point of view, for such projection in equations (2) the X^S, Y^S, Z^S values are no point coordinates, but $X^P, Y^P, f(X^P, Y^P)$ ones obtained from the surface where holds $Z^P = f(X^P, Y^P)$.

Last but not least automatic product is the orthophoto, displaced onto a plane of interest, e.g. horizontal or vertical. It needs to know the image orientation and the surface: both are known in a laser scanning and photogrammetric integrated surveying. Equations (2) are thus exploited for the digital resampling required. Some software project the textured 3D DDSM onto the interest 2D plane, while others resample the original 2D image onto the interest 2D plane, taking into account of the different values $Z^P = f(X^P, Y^P)$ from the DDSM.

To obtain an accurate colouring of the church DDSM from the Nikon images, at first the mounting parameters of (2) had to be readjusted, anyway easily done by a RiSCAN PRO dedicated tool. Secondly new images were required since those relating the window areas were very dark for exposure troubles, as evidenced in the coloured angular 2D view of Figure 14.

Figure 14. RGB coloured scan "Apse −90°" in angular 2D view.

These new images, *ad hoc* acquired with the same Nikon metric camera but without TLS system, have been externally oriented by finding detail points in the frescoes as control points, with $X^P, Y^P, f(X^P, Y^P)$ coordinates from the DDSM textured with the original images. Nevertheless, texturing these new images, some problems of colour homogenization are inexorably arisen in the mosaicking with the old ones, later manually reduced.

5.4 Digital representations of the surveying

The automatic production of an unlimited number of 2D digital representations from the 3D model is very easy. These outputs are an intermediate result before the final VRML/X3D model, but with important utilization like *plotting sheets* as the figures presented in Chapter 1 and 2. The user has simply to choose "what, how, and from where" to represent.

"From where" query involves the direction of the view being this orthogonal to the representation plane, so rising *nadiral* and *zenithal* plans, forward, backward, left, and right prospects, etc., as well as many DDSM *sections* essentials for every technical analysis. Besides, a finite distance from the object to represent yields a perspective view (e.g. Figure 15), while an ideal infinite distance generates an orthogonal view (e.g. Figure 4).

"How to represent" question concerns the way of colouring the data. A point cloud can be painted by grey scale according to the intensity value (e.g. Figure 7), by false colours according to the distance from the PRCS or to the Z^P elevation, by true RGB colours (e.g. Figure 14), etc. DDSM meshes can be represented by *wireframe* and/or by 3D faces with smoothed colours (e.g. Figures 10÷13), etc.. By the way, a DDSM with RGB textured faces is the more photorealistic representation of the surveyed object (e.g. Figure 15 again), exactly how it appears in the default visualization in VRML/X3D spaces.

Figure 15. Perspective view of the DDSM textured by images.

Last but not least, "what to represent" affair means the opportunity to "switch on", not only the entire object or only some parts, but also any geometrically correct 3D data, like e.g. the texture of historical photos as we plan to act for this church.

6. VRML/X3D MODEL OF THE CHURCH INTERIOR

The partial DDSM with the corresponding image textures have been exported as WRL files, later merged in a unique one by VrmlPad® (ParallelGraphics) and by Vivaty Studio Beta. The main features of the achieved model are the organization in two *LoD* (Levels of Detail) and the availability of *Anchors* linking the frescoes with an external web database. In Visintini, Spangher and Fico (2007) some concepts on LoD and external links are presented, although for a VRML model of an open space as the Victoria Square in Gorizia (I) belonging to a *3D City Model* from laser and imaging aerial and terrestrial data.

6.1 Different LoD models

The organization of the model in more LoD is very interesting for a web use, where is essential to load geometric and imaging data only truly visualized in the virtual space. The model of the apse has been stored in (high LoD means low detail in VRML):

- LoD0: a detailed model with 103.454 TIN as in Figure 11 (2,1 Mb) and 43 high resolution textured images (23,4 Mb);
- LoD1: a simplified model with 35.758 TIN as in Figure 12 (0,4 Mb) and 11 low resolution textured images (9,1 Mb).
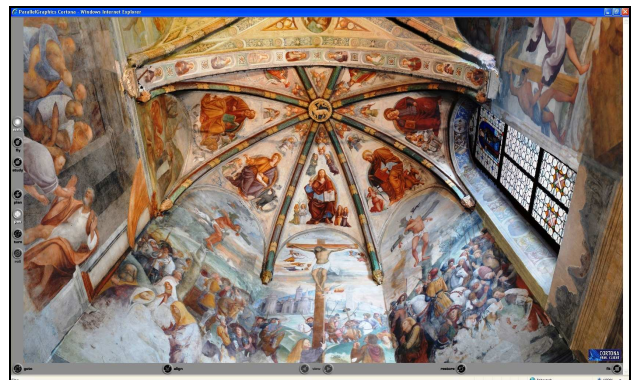

Figure 16. VRML/X3D screenshot of LoD1 model (simplified).

Moving the user virtual camera from the floor (Figure 16) to the apex vault, if the distance is less than 5 m, LoD1 model is automatically switched in LoD0 one (Figure 17), so anyway assuring an optimal visualization and a fluent web navigation.
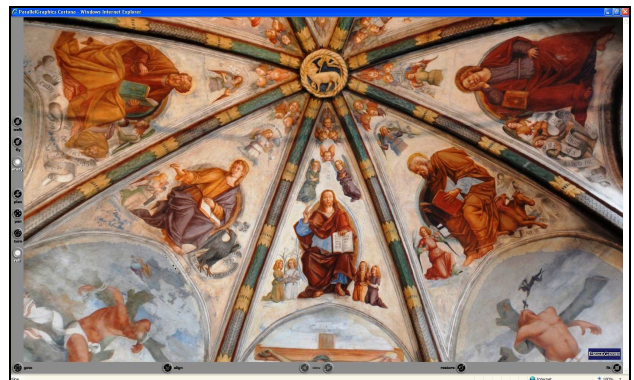

Figure 17. VRML/X3D screenshot of LoD0 model (detailed).

6.2 Links with external web databases

As mentioned at the beginning, this work of photorealistic 3D modeling fits within the regional project *"Computer Sciences for the Cultural Heritage: Mobile and 3D innovative services for the tourism"* of the University of Udine.

This interdisciplinary project exploits the different knowledge of the members of scientific and humanistic departments of the university. It forecasts the creation of a complex web GIS collecting and integrating existing and new 3D models of monuments and thematic databases, for the management, protection, utilization, and enjoyment of the historical-artistic and archaeological heritage of the Friuli Venezia Giulia region.

To develop, test, and improve this web GIS, some preeminent sites diverse for style and typology have been identified: this church in San Daniele, the Roman *Thermae* archaeological area and the Patriarchal Basilica in Aquileia (whose TLS surveying are described in Visintini, 2009), the Longobard Temple in Cividale del Friuli and the Saint Just Cathedral in Trieste.

The web GIS is thought as on open system where authorized users can also edit the database, while simple users have only tools for query and visualization of 3D models and data.

The existent databases to be linked and integrated are:

- SIRPAC: web *Regional Information System of the Cultural Heritage* (http://www.sirpac-fvg.org/index.asp);
- ARISTOS: web *Database for the History of the Historical-Artistic Objects Preservation* (http://aristos2.mbigroup.it/);
- SICaR: web *Information System for the Restoration Yards* (http://sicar.mbigroup.it/).

In the VRML/X3D model, 25 frescoes subjects are linked by an *Anchor* with the 25 corresponding cards of SIRPAC database: clicking on it, the relating web page is opened (Figure 18).
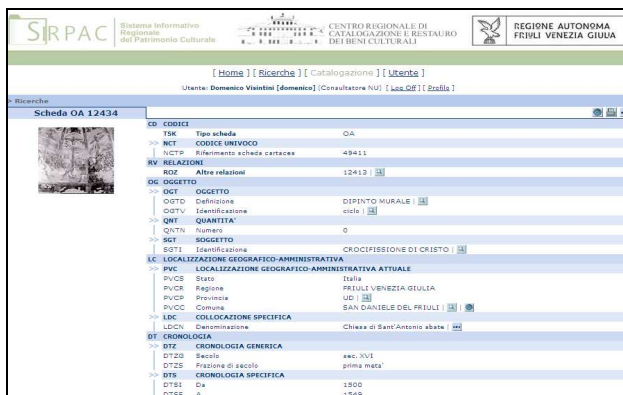

Figure 18. SIRPAC data card anchored at the VRML/X3D model.

Up to now, other two databases not contain data about this church, but is our intention to insert documents kept in the Monuments and Fine Arts Office of Udine, in the Biblioteca Guarneriana and in the Municipal Archive in San Daniele.

Further the web access to the data, other ways of query and visualization are in implementing, e.g. with a workstation located in the church (today deconsecrated) onto a fully detailed model and database, or with user own mobile phones onto simplified data downloaded by *Wi-Fi* or *Bluetooth* technology.

In the VRML/X3D model, it will be possible to choose among various thematic tours, with a virtual camera going exactly in front of the frescoed scene and subjects (without angular roll) and at a variable distance in order to wholly observe it. The next six tours are planned, whose first two have been implemented:

1. *Iconographic*: the different events and the subjects will be visualized in the order thought from Pellegrino;
2. *Chronologic*: the scenes of the pictorial cycle will be shown following two phases of draft (1497-1498 and 1513-1522);
3. *Restoration*: the different restoration work will be described and matched with the scenes they have been applied to;
4. *Technique*: the pictorial techniques and differences taken by Pellegrino among the first and second phase will be shown;
5. *Geographical*: the different stories will be related with other works by Pellegrino that are spread all over the Friuli area;
6. *In the time*: using old photos we will be able to travel in the time: the photographs dates back to 1906 and was on behalf of the Monuments and Fine Art Office of Venice.

The virtual views are particularly interesting for the scenes in the curved surfaces of the arcs and vaults, each one with a different spatial orientation. For instance, the portraits of the *Prophets* depicted under the left side of the first presbytery arc,

having an increasing inclination, are orthogonally displayed in the tours as in Figure 19. As can be seen, the four "rectangular" portraits have different proportion of base to height, geometrical aspect that can not be perceived by a visual observation *in situ*.

Figure 19. Iconographic tour: e.g. four portraits on presbytery arc.

7. CONCLUSIONS

A detailed VRML/X3D model of the Church of Saint Anthony Abbot in San Daniele has been attained from laser scanning and photogrammetric integrated data, not without manual actions described in this paper. This final model, thought for via web historical-artistic aims, is formed by progressive geometric simplifications of the automatically computed DDSM, stored in two LoD dynamically visualized. The model photorealism could be improved by new refinements: this anyway states that 3D modeling is not a "press the button" process. In any case, the original DDSM effectively constitute a *hyper-detailed* model to manage within whatever TLS editing software to take accurate measurements, to texture new very close images, and to product *ad hoc* plotting sheets for restoration and structural analyses.

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