IMAGE-BASED MODELING TECHNIQUES FOR THE CREATION OF HIGH-QUALITY TEXTURE IN LASER SCANNER MODEL: A CASE STUDY IN FRESCOED VAULT

ISABEL MARTINEZ-ESPEJO ZARAGOZA[1]
GABRIELLA CAROTI[2]
ANDREA PIEMONTE[2]

ABSTRACT

The new survey tools used in studies aimed to preserving architectural heritage often show some dilemmas. Several studies have been able to confirm that laser scanner surveys allow to obtain three-dimensional models of high accuracy in morphology and topological level. However, nowadays the quality level of colour obtained with laser scanners is not acceptable for high quality texturing. Moreover, high quality colour medels can be obtained through techniques of Structure from Modeling, but feature a lower precision of mesh, even though results obtainable by Computer Vision programs, make this approach increasingly viable. In this context, a case study is proposed on a vault located in the Palazzo Roncioni (Pisa, Italy) decorated with a important fresco painted by the painter Giovan Battista Tempesti in the second half of the eighth century. In this case, different tests will be carried out by Structure from Modeling techniques to have a high resolution texture applied to the model obtained with laser scanner, thus obtaining a model with high resolution texture and high quality mesh. This model allows to generate an accurate documentation of the vault for digital preservation and restoration studies.

Key words: Image-based modeling, Texture Mapping, Structure from Motion, Scanner Laser, Photogrammetry

1. INTRODUCTION

The new technologies for three-dimensional architectural survey - 3D laser scanner, Structure from Motion, etc. - allow the creation of highly faithful virtual models which, when applied to historical-architectural heritage, provide a rigorous documentation of its state as regards geometry, construction techniques and materials used. Applications of such new technologies are now widespread and well established in the framework of interventions aimed at restoration and preservation, as well as in widespread monument enhancement and promotion (virtual tours, digital communication projects, etc.) (Biosca Taronger et al., 2007; Wenzel et al.,

[1] PhD Student of Pisa University, Department of Civil and Industrial Engineering, PISA
[2] Prof. Dr. Pisa University, Department of Civil and Industrial Engineering, PISA

2013; Guidi et al., 2010; Benedetti et al., 2010; Juan Vidal and Martínez-Espejo Zaragoza 2011; Merlo et al., 2013).
Besides, the potential of documentation and investigation has been increased by the development, in recent years, of new sensors and instruments, capable of either independent or integrated implementation; high performance digital cameras, multispectral, hyperspectral and thermal cameras, with ever increasing resolution, radar, etc. in fact, allow to gain a considerable amount of information, each one related to models derived from laser scanner which, after appropriate processing, are in fact an integrated platform for high-density information (Guidi and Remondino 2012; Adembri et al., 2011; Verdiani 2011).
These new investigating technologies are extensively used both globally, for the survey of the historic architectural complex as a whole, and locally, for the survey of the decorative and architectural details. Among them, the painted decorations (frescoes, surface paintings in general, etc.) are perhaps the most significant, but certainly more fragile, elements, receiving the constant attention of all the figures that in various capacities are involved in the planning and implementation of restoration and conservation (architects, administrators, engineers, art historians, restorers, etc.).
If in the past restoration techniques for pictorial work were based on a traditional inquiry by view, nowadays, with the advent of new digital technologies it is possible to achieve objective, three-dimensional, geometrically accurate data, to which all results of different types of investigation can be referred. New technologies have therefore given a strong boost to digital cataloguing, documentation of and monitoring of preservation state of painted decorations, so that availability of virtual models is now an essential tool in the development of heritage rendering.
It seems clear, therefore, that it is exactly in the phase transition from cognitive and investigative to operational that new technologies are required to interface and integrate with traditional techniques and methods of intervention.
For these reasons, restorers need to have a high quality documentation not only for metric purposes but also for colour. In this context, this work proposes a study of various techniques to apply high quality colour textures to laser scanner based models featuring high precision for topology and morphology.

2. STATE OF THE ART

2.1. Modelling

The last decade has witnessed the emergence of the laser scanner as a consolidated methodology to produce accurate high-resolution three-dimensional models (Lerma et al., 2011; Marambio et al., 2009; Dore and Murphy, 2012; Juan Vidal and Martínez-Espejo Zaragoza, 2011). In particular, this methodology has been applied in many case studies on historical, archaeological and architectural heritage with excellent results (Martínez-Espejo Zaragoza and Juan Vidal, 2012; Caroti and Piemonte, 2012; Bevilacqua et al., 2012; Caroti and Piemonte, 2008).
Compared to earlier methods (traditional discrete points survey with reflectorless total stations, 3D classic photogrammetric survey with manual stereo-rendering, ...),

laser scanning has allowed to obtain very detailed models with reduced field time. By contrast the cost of the instrumentation, both hardware and software, is high and office-based postprocessing is burdensome (a texturized mesh model requires about nine days of data processing every one day of field survey).

Lately a new technique, whose main data are sets of photographs of the object to be surveyed, is proposing to replace or supplement laser scanning methodology: Structure from Motion (SfM). This technique stems from computer vision sciences and is well integrated into the established procedures of classical 3-D photogrammetry (Lerma et al., 2010; Koska and Kremen, 2013; Guidi et al., 2010; Guidi and Remondino 2012; Rodriquez 2012), from which the techniques of optics calibration and the good practice of planning a rigorous geometric structure for pictures takes were borrowed (Wenzel et al, 2013; Alsadik et al 2013).

On the other hand, computer vision legacy includes the algorithms for the automatic detection of homologous points, in order to solve the collinearity equations and, therefore, to define the orientation parameters of the cameras.

However, even if software evolution in this field is very fast and the solutions are gradually higher performing in terms of processing time, amount of manageable data and obtainable precisions, SfM methodologies may not always be considered reliable. In fact, they show non-homogeneous precision, strongly dependent on the pattern present on surveyed objects, as well as the difficulty of having little control of the achievable accuracy at geometric and morphological levels (Guidi and Remondino, 2012; Appollonio et al., 2014).

As regards the latter, we can state that SfM systems fail to compare to laser scanning in terms of homogeneity of accuracy. So, if a metric strictness typical of very large scale (eg. 1:20 or greater) is required, the laser is probably the most suitable surveying tool for the time being.

In general, whether using laser scanning or SfM techniques, it must be emphasized that, if very detailed models at very large scale are needed, it is essential to proceed appropriately introducing different levels of detail (LODs) (Guidi et al. 2010). The idea of LODs originates from the concept of optimization of the model according to the intended purpose.

2.2. Texture

In many cases, particularly in the context of architectural survey, good quality, photo-realistic textures must be used to apply to the model.

These textures are not meant solely as aesthetic completion of the model but as an added tool allowing to better identify the details when using the model as an object of measurement.

In fact, after a texture has been applied to surface models, from the perceptual point of view the collimation of points is driven by the texture itself rather than the underlying geometry.

Applications involving the use of laser scanner or SfM models may require textures with the same level of geometric precision of the models they will be applied to.

These requirements are met by a few different surveying and rendering methods.

Many of the laser scanners have built-in cameras, whose relative orientation is calibrated by the manufacturer, which allow direct true colouring of the point cloud.

These textures are characterized by a high geometric accuracy, but the photographic take system usually does not achieve good results in terms of resolution and colour fidelity (Apollonio and Remondino 2010)

Simplified, realistic-looking models may not suffice for restorers, who require rigorous rendering in both morphology and colour information.

In these cases, it is essential to resort to a dedicated photographic campaign, taken with high quality cameras as regards optics, sensor size and post-processing graphics.

The traditional way to obtain textures from these photos is to derive camera features from a single take, generate the UV map using the so-called texture mapping (Guidi et al., 2010; Baldissini et al., 2010; Apollonio et al., 2010) of the projection of the single-frame model and finally unite the different partial UV maps to generate the texture of the model as a whole. Textures obtained in this way allow to have 3-D models featuring high quality for geometric, morphological and chromatic respects (Fantini et al., 2012).

On the other hand, this procedure is very time-consuming, also requiring constant operator intervention in the collimation of the points on the model and on photograms. In addition, software and procedures commonly used quite often do not take into account the distortion present on photograms.

In the case of SfM software, the creation of models and textures is pretty much contextual and the procedure usually involves the camera self-calibration which also takes account of characteristic distortion parameters. In these models, textures have usually good photographic quality, although, as we said in section 2.1, the overall morphological reliability of such models is not comparable to laser derived ones.

3. MATERIALS AND METHODS

This research proposes a different way to obtain texture models with high quality levels for geometry, morphology and colour, that takes advantage of the strictness of 3D models produced from laser scanner surveys, and of the quality of textures derived from sets of photograms oriented with dedicated SfM software.

The basic concept is to use laser scanner surveys as the geometric foundation. Regarding the texture, a campaign of dedicated photographs is completed and, rather than orienting and projecting each one individually, SfM software is used not so much for the model that it generates, as for its ability to automatically detect numerous sets of homologous points and to solve the problem of calculating the orientation parameters (camera features). Finally, the model generated by the laser survey is imported in the same SfM software used for camera orientation and the images are projected on it. As a case study for this methodology a frescoed vault under restoration has been chosen.

3.1. Object of the test surveys

The frescoed surface object of the survey area is a vaulted structure in a room on the ground floor of Palazzo Roncioni in Pisa, one of the finest examples of mannerist architecture of the city (Fig. 1).

Figure 1: frescoed vault, Palazzo Roncioni - Pisa

In addition to architectural merit, the building retains a rich array of decorative painting by Giovan Battista Tempesti, active in Tuscany and especially in Pisa in the second half of the eighteenth century, the author of important frescoes among which we can mention those in the music room at Palazzo Pitti in Florence, and the depiction of the Last Supper in the cathedral of Pisa.
The root of the geometric construction of the vault in question relates to the type of italian "a schifo" vaults, set on a rectangular plan of about nine by five meters, although not quite regular. The height from the floor of the top of the vault is about 6m. The fresco is largely preserved, save for obvious, recent gaps due to environmental degradation. The vault also shows widespread injury due to a failure of structural nature. The survey of the vault was required to allow for the documentation of the fresco in view of the restoration work taking place in some portions of the building.

3.2. Laser scanner survey

LeicaGeosystems' C10 ScanStation has been used at two spots, located approximately 1/4 and 3/4 lengthwise and both along the centre across the room (Fig. 2 left). The resolution of the survey was set at 4mm at 10m, resulting in a very dense cloud (on average 70pts/cm^2). The point cloud is in true colours due to the laser scanner's built-in camera.

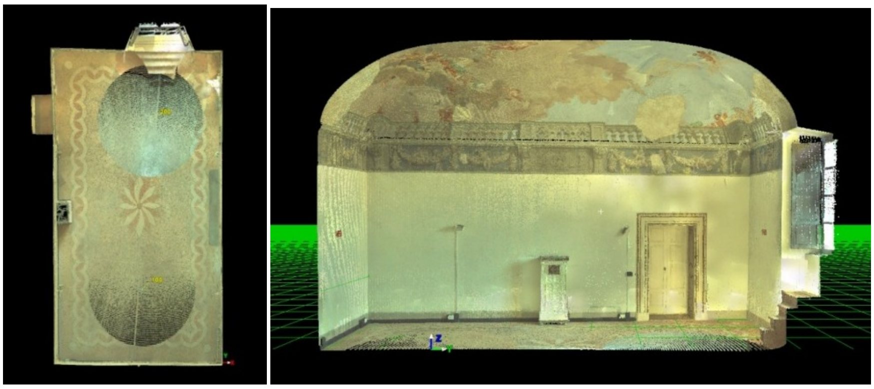

Figure 2: Plant (left) and geometric reference model derived from laser scanner survey (right)

After scans have been aligned by means of a support traverse, aided by the cloud constraint tool in the Cyclone software environment, the cloud point was processed by a reverse modelling software (Inus Technology Rapidform XOR3). In order to simplify the model where surfaces were smooth, a decimation of the points was performed, anyway preserving geometrical information that, however small, are valuable for restorers (local deformation, cracks, ...); finally, a mesh was generated. The model is constituted by about four million points and ten million triangles and is the geometric and morphological reference of the final model (Fig. 2 right).

3.3. Photogrammetric survey

The photographic survey was performed with a Nikon D700 SLR camera equipped with a focal lenght 20mm Nikkor lens. ISO sensitivity set to 400 enabled shooting at 1/25 second with 5.6 aperture, also thanks to the lighting provided by a set of two 2000 W halogen lamps with colour temperature of 5600K. The shooting distance was on average of 4.5m, that allowed single pixel coverage of about 2 mm. The camera and its lens have been previously calibrated. Table 1 shows the features of the camera and the results of the calibration.

Focal lenght	[mm]	20.62
Format size	[mm] [pixel]	36.00x23.95 4256x2832
Principal point	[mm]	X=17.95 Y=12.34
Lens distorsion coefficient	K1 K2	2.876e-004 -4.817e-007
Overall residual RMS	[pixel]	0.0854

Table 1: Sensor features and calibration parameters

3.4. Projection of individual images on the model

A methodology to provide models with colour maps consisting of photo-realistic textures is based on the projection of the individual photographs on the mesh.
Upon completion of the photo campaign, the steps to follow include the collimation of tie points in a reverse modelling software, the collimation of the same points to orient the images using photogrammetric software and finally the definition of the texture through a software for entertainment.
In the photographic take draft the surface of the vault has been divided in areas, characterized by almost constant curvature, in each of which photographic images have been acquired, keeping the optical axis close to the direction of the radius of curvature of the centroid of each area. The photograms must ensure full coverage of the object taking into account that only the central portion of each photogram is used in order to avoid residual radial distortion at the edges.
The processing procedure is the same for each photogram to be projected.
Considering the part in common between the photogram and the 3-D model obtained from the laser scanner, a set of tie points has been chosen with a distribution as uniform as possible. These are exported as coordinates in DXF format, using a point cloud management software of the laser model (eg. Rapidform XOR3, Fig. 3 left). These coordinates constitute the Control Points (CP) which the photogrammetric software (eg. PhotoModeler) uses to orient the photogram. Photogrammetric software is used to derive the image coordinates of the chosen tie points (Fig. 3 right); it is also possible to calculate the camera features along with the precision with which the various parameters were determined.

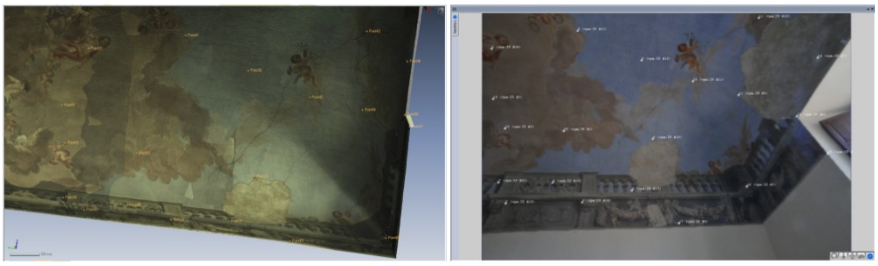

Figure 3: Homologous points on the 3D model (left) and the photogram (right)

Repeating this process for all the photograms yields the orientation parameters of the cameras, each of which is exported in a format compatible with the entertainment software used for texturing (eg. Luxology Modo - format * .fbx).
In order to texturize the model, once it has been imported into the entertainment software, the so-called subdivision surfaces model must be created (Fantini, 2012), and the related UV map is defined (Fig. 4).

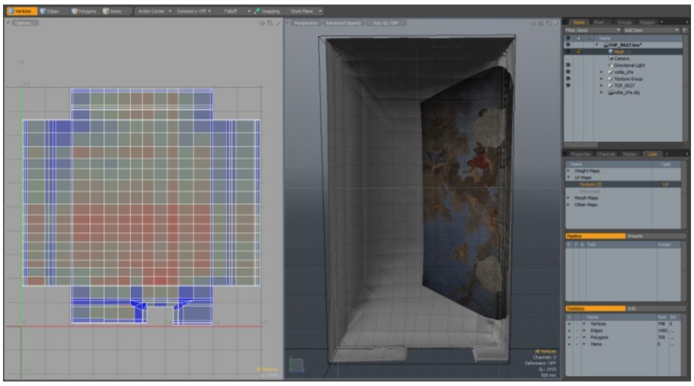

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Figure 4: UV map of the subdivision surfaces model with projection of a single photogram

By projecting individual photograms partial UV maps are obtained for each one (Fig. 5 left) where colour is applied only to the framed part of the vault. At this point, all partial UV maps have to be reprocessed with a photo editing software (e.g. Photoshop) merging them into a single image (Fig. 5 right). In this operation the different images must be processed to produce uniform brightness, contrast and saturation and select the portions of UV partial map that correspond to the central portion of the respective photograms to reduce the influence of the residual radial distortion. Finally the overall UV map is projected onto the laser model using entertainment software.

Figure 5: Partial UV map of a single photogram (left) and total overall UV map (right)

3.5. Creating a model with SfM software

Generation of the model through the SfM software was performed by means of a dedicated photogrammetric campaign. This is necessary because, while for texturing as described in the previous paragraph the photograms are just required to cover the entire surface ensuring a low mutual overlap, SfM software requires an overlap

between photograms of at least 70% in both directions. In this respect, SfM software differ from classic photogrammetric software, where the processing is carried on by strips, and a greater overlap for adjacent strips is required only in the longitudinal direction. The new photo campaign was carried out with the same camera and the same optics as the previous one. The SfM software used in this test was Agisoft's PhotoScan 1.0.0. The development followed the steps provided by all software of this type: camera calibration, image orientation, dense point cloud generation, surface generation and texture mapping and visualization (Manferdini and Remondino, 2010).
The result of processing is a 3-D, high colour resolution model (Fig. 6 left), but with a lower quality mesh as for morphology and geometry (Fig. 6 center) compared to that obtained from processing of the laser scanner survey (Fig. 6 right).

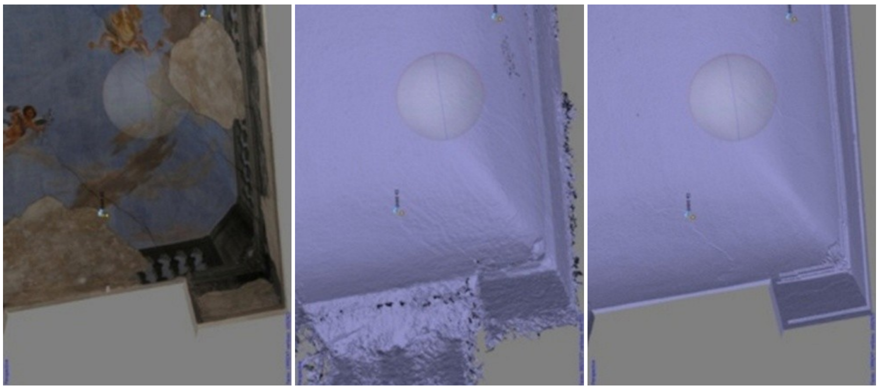

Figure 6: Texture from SfM (left), model from SfM (center) and model from laser (right)

3.6. Projecting the image-oriented on model laser models

It should be emphasized that the lower geometric quality of the 3-D model obtained with SfM software as described in the previous paragraph is to be referred to the ability of the method to faithfully reproduce local morphological changes at a small-scale rather than its ability to render the overall geometry of the survey object. Partial results of SfM modeling have been used, i.e. the camera orientation parameters, and images have been projected on the most faithful model obtained from the laser scanner. It should be emphasized that in order to use this methodology the two models must of course be framed in the same reference system.
The laser scanner model was then imported into SfM software and had the photo-realistic texture applied. (Fig. 7).

Figure 7: Laser scanner model textured via SfM software

4. RESULTS AND DISCUSSION

4.1. Projection of individual images on the model

The procedure of projection of individual images on the model (described in Section 3.4) was followed for the orientation and the projection of eight photograms. As regards the orientation it was based on an average of thirty tie points collimated on each photogram and on the 3-D model. The standard deviation of these points, after the orientation, resulted in an average of 4 pixels. It should be emphasized that completing all the steps of the process took about five working days for one person.

4.2. Geometrical comparison between the laser and the model by SfM software

Figure 8 shows the comparison between the two mesh models, one taken as a reference, obtained from processing of the laser scanner survey, and the other resulting from SfM software.

The latter model well represents the vault in its entirety (standard deviation equal to less than 3mm) but, being strongly dependent on the pattern present on the vault, is not able to ensure a homogeneous local precision in rendering small morphological variations. Greater deviations (variables in absolute value between 7 and 10 mm), coincident with cracks or margins of plaster collapse and gaps in the fresco, are quite obvious. Full knowledge of these geometries is important for restorers planning restoration or safety implementation works.

It is noted that the calculation of the orientation exterior of the cameras done through the SfM software is substantially correct as shown by the value of the mean reprojection error equal to 0.70 pixels on an average of 9000 tie points for each photogram. It should also be noted that the manual intervention of the operator in this procedure is limited to the insertion of the Control Points (10 points input for the test) that allow scaling and georeferencing of the model in the same reference system of the laser scanner. It should be emphasized that the process of creating the model using SfM software and then calculating the orientation parameters of the cameras has required one working day for one person.

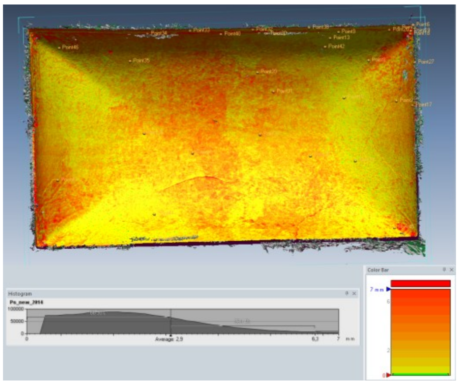

Figure 8: Distance in absolute value between mesh models obtained from laser scanner survey and from SfM software

4.3. Texture precision of final model

The laser scanner model coloured from the data of the camera integrated in the scanner itself may be considered as a reference for both geometry and 3-D texture placement. An analysis of the deviation of the 3-D position of points in the texture between the reference model and that obtained by projecting photograms oriented with SfM software has been subsequently carried out, involving a set of 20 points evenly distributed on the vault and resulting in a standard deviation of about ±3.5 mm.

5. CONCLUSIONS

The proposed methodology allows to obtain a 3-D model featuring the geometric strictness of laser scanner surveys and the quality of textures obtained with photographic survey campaigns.

The most interesting aspect highlighted by the application of the methodology proposed is considerable savings in terms of time and resources compared to the traditional methodology of orientation and projection of individual images on the model. In addition, from the point of view of positioning precision of the textures both procedures displayed roughly the same accuracy.

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