DEM GENERATION WITH DIGITAL PHOTOGRAMMETRY AND LASER SCANNING IN ARCHITECTURAL STRUCTURES SURVEY

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ABSTRACT:

DEM generation in architecture presents well known problems when the structure is complex and has irregular and discontinue surfaces. Data acquired from laser scanner and photogrammetric systems can be employed to best represent different aspects of the same object: every survey technique is useful to register (and then to show, after data elaboration) some kind of information due to the specific capability to “read” the object surface. Photogrammetry is able to provide, according to a previous survey project, different kinds of plotting, with an expected accuracy:

- description of the object (points, lines) and main discontinuities (break lines);
- digital elevation model (DEM) with a forecast resolution of surfaces bounded by edges.

In this work we match and compare data collected by laser scanner and by digital photogrammetry and investigate their skills and weakness. Until now automatic techniques for feature extraction do not give satisfactory results in architectonic field, while DEM generation has been strongly improved by automatism developed in digital photogrammetry software. However our experience shows that DEM generated with automatic image correlation does not give a complete representation of the stereoscopic model. Poor quality images, as well as non uniform texture on the surface, should cause important lacks. On the other hand, laser scanner allows to acquire DEM with planned step and extension, closely related to the acquisition field conformation and the object features. In both cases, automatic DEM generation is not always satisfactory: unavoidable interpolation occurring when triangulation transforms points clouds into surfaces (TIN) causes typical edge rounding effects. Sometimes the 3D model could be good from the metric point of view (differences between 3D model and object are in the predefined range) but a visual inspection could be unsatisfactory. We analyzed and compared surfaces made by the same triangulation algorithm, starting from both photogrammetric and laser scanner DEM.

1. INTRODUCTION

The relevant progress both in software and hardware development allows to manage a larger and larger amount of data in very short time. The algorithms introduced in digital photogrammetry procedures, as well as in the processing of point clouds from laser scanning, enable to achieve a high degree of automation in the different stages of the generation of a digital model, capable of giving a high quality description of the examined surface.
Since the beginning of the use of laser scanning in land and architectural surveying a number of contributions have been published presenting comparisons of the results of laser scanning and photogrammetry techniques in different applications, and, in some cases, suggestions for possible integration procedures; some of these contributions are mentioned in the bibliography.
In the present case the goal is to use digital photogrammetry in order to produce, mainly with automatic procedures, digital surface models, and to compare them with the ones obtained from laser scanning data, trying to define integration procedures of the two techniques.
The survey of the transept surface of S. Francesco al Prato church in Perugia involves a number of difficult problems. Indeed, it is not a homogeneous surface: it is devoid of most of its plaster covering and exhibits wall gaps as well as imperceptible unevenness. Therefore advanced photogrammetric tools have been used in order to describe in great detail the complexity of the surface and to obtain a result comparable to the output of the laser scanning data processing. That means that a very good stereoscopic model, as regards image quality, is required, as the automatic correlation procedures in digital photogrammetry are based on image matching, whose algorithms allow to recognize signals and fixed shapes on photos, with the aim of automatically recovering homologous points; at present a subpixel accuracy can be easily attained. In order to achieve a high quality image it is necessary to choose very carefully the representation scale, to use only weakly convergent photo pairs, with good stereoscopic covering and optimal light conditions to ensure acceptable brightness and contrast, to adopt a suitable pixel size, both for images obtained with metric digital cameras and from film scanning.
Furthermore, a very precise surveying of ground points is extremely important to define a common reference frame. For all the reasons illustrated above, a very careful project of the different steps of the survey is required to obtain satisfactory results.
On the other hand, in laser scanning data processing one must be very careful in checking the different stages of the elaboration (point density choice, filtering procedure, surface generation algorithm) in order to obtain a good quality product, suitable, in addition, for further processing with photogrammetric techniques capable to provide new specific refinements. The adoption of a very critical case study allows to investigate in great detail to what extent these integrated procedures can be applied.
It is worth remarking that this approach exploits the specific capability of generating 3-D elements with photogrammetric techniques, and is somewhat different from the usually adopted

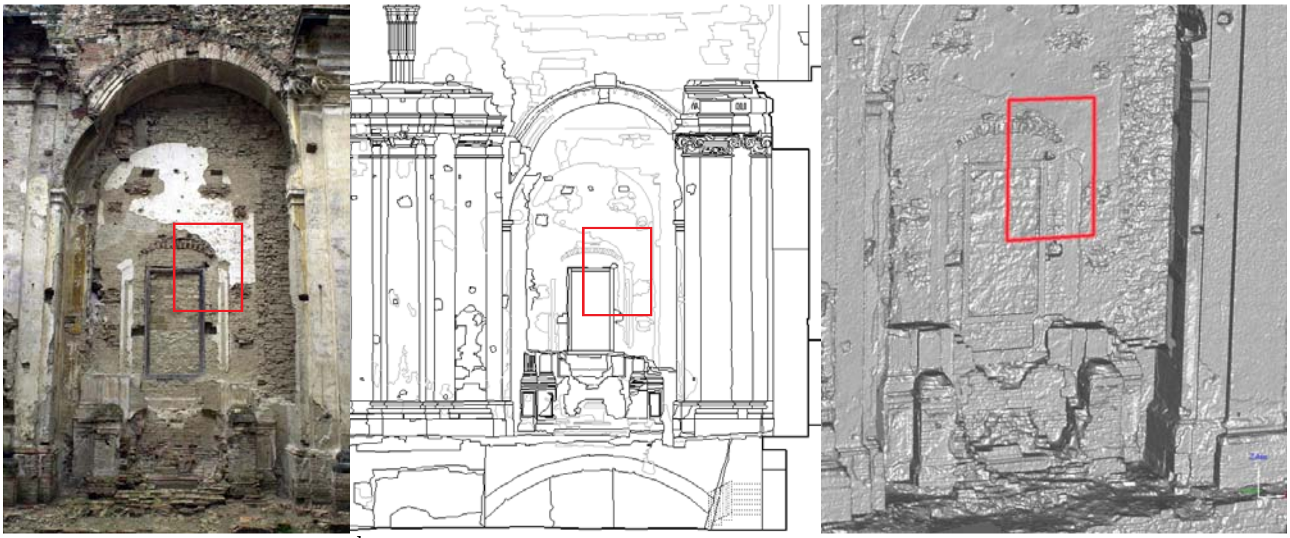

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Figure 1. A wing of the transept of S.Francesco al Prato church in Perugia : a – photograph of the present situation (test area is inside the red frame); b – photogrammetric plotting; c – triangulated model from laser scanning data.

integration procedure of photogrammetry within laser scanning surface generation, i.e. photographic texturing by projection of a photographic image onto 3-D surface model, with more or less accurate techniques according to the complexity level of the surface.

Anyway, also this kind of applications gives an important contribution to the full understanding and interpretation of a 3-D object, as regards the details described by the radiometric content of the photographic image. In this field too some developments have been carried out and implemented in commercial software in last years, to improve the metric accuracy of the correspondence between image pixels and 3-D points from laser scanning. To this aim, some of the most recent results of photogrammetric analysis, as high-precision orthophotos, the so-called 3-D orthophotos (where radiometric information is associated to a 3-D object independently of its viewpoint, that can be arbitrarily changed as in interactive exploration systems), solid images (where distances from projection center are associated to each pixel) are exploited [Dequal et al., 2001; Biason et al., 2004; Bornaz et al., 2003]. Starting with a surface generated from a very dense point cloud from laser scanning, a very accurate matching with image points obviously relies on a suitably high number of control points on the photogrammetric model, and can be satisfactorily attained only for reasonably smooth surfaces. In the present case, these techniques may be important to exhibit the details of masonry texturing, thickness variations due to the detachment of plaster portions, state of conservation of stone blocks (see figure 7).

2. DATA COLLECTION

2.1 Topographic survey

First of all, a small control point network has been measured with a total station Leica TCR703; a least-squares adjustment has been carried out. At the same time, both targets and natural control points have been collected to orient photogrammetric stereoimages. Specific Cyrax targets on the entire scene have been surveyed in order to define a reference system for range images.

2.2 Photogrammetric survey

The images have been acquired by a semimetric camera Rollei 6006 (f = 40.87 mm). Twelve stereocouples have been acquired on the transept at about 1:250 scale (longitudinal overlap = 80%, transversal overlap = 40%).

Thanks to the scaffolding set for consolidation works, it has been possible to take photos in the best condition for stereoscopic recording: base distance 2.5 m, object distance 8 m. The film has been digitalized by a photogrammetric scanner with 2100 dpi resolution, obtaining a pixel size of 12 μm. The images have been oriented and plotted at 1:20 scale with a Digital Photogrammetric Workstation and LPS software, by Leica.

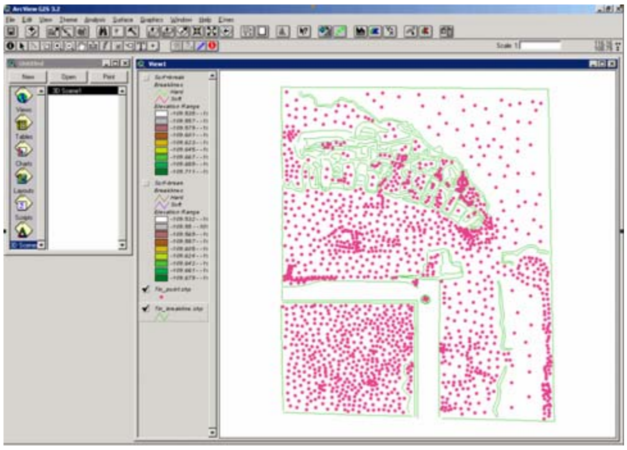

Figure 2. Visual representation of photogrammetric data: DEM and breaklines

2.3 Laser scanner survey

For the transept survey, Cyrax 2500 laser scanner (by Leica) has been used, with sampling step of about 1,5 cm. For more complex details, as for example, capital blocks, a sampling step of 6 mm has been set. In all, 20 range maps, with an overlapping of about 40% have been generated. This overlap has been performed not only to align 3D images but also to cover undercuts and hidden zones. Laser scanner has been mounted on its tripod or simply placed on the scaffoldings, at various levels, to avoid great inclinations.

3. DATA PROCESSING

3.1 Photogrammetric data processing

For digital photogrammetry data processing in the present investigation, a Leica DPW (Digital Photogrammetric Workstation) with the LPS (Leica Photogrammetric System) software has been used. Starting from the acquired photos, the camera calibration certificate and the topographic survey points, the usual photogrammetric procedures, relative and absolute orientation, are carried out to generate the stereoscopic model. For the twelve points used for the model absolute orientation, the standard deviations of the residuals of the three coordinates are of the order of 5-6mm.
Subsequently autocorrelation procedures at different sampling steps (10cm, 5cm, 1cm, 5mm) have been carried out with generation of digital models both in tin and grid format. It has been verified that the smaller the sampling step, the greater the difficulties in reading and interpreting stereoscopy, both owing to a too dense point distribution, mainly for the grid format, and because of the stereoscopic view magnification, necessary for a correct point identification in the digital model. Consequently, as a first approximation, a tin format with 5cm sampling step has been chosen for the autocorrelation model.

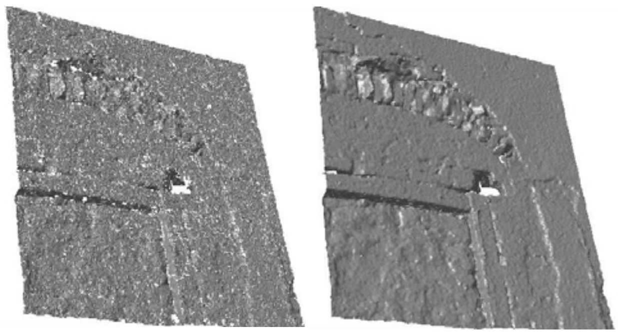

Figure 3. Detail of the surface model directly triangulated from collected data (left); detail of the surface model triangulated after noise reduction on collected points (elaboration with Raindrop Geomagic) (right)

This model has been edited correcting point depths where necessary and interpolating with successive sampling steps, until an optimal choice of a 2cm step has been obtained. Furthermore, an architectural recording of the breaklines, i.e. discontinuity lines essential for a correct interpretation of the complexity of the surface of the object, as a constraint to the surface digital model generation, has been carried out.

3.2 Laser scanning data processing

3.2.1 Acquisitions and registration: Range maps collected from different points of view have been tied up (Cyclone software has been employed, by Leica Geosystems), correlating the shapes of the acquired surfaces. An initial pre-aligning condition is obtained manually identifying at least three couples of homologous points on adjoining range maps. After that, a global adjustment is computed, by an algorithm that iteratively minimizes distances among a predefined number of points, until the fixed tolerance value is reached.
Special targets have been topographically surveyed and recognized on range maps (the target centre is located with an accuracy of ±2mm). Since their positions were defined with topographical measurements, we could employ them as reference target in order to determine the roto-translation transformation. In this way laser scanning and photogrammetric surveys are in the same local reference frame, as we need to do comparisons between these two kinds of data.

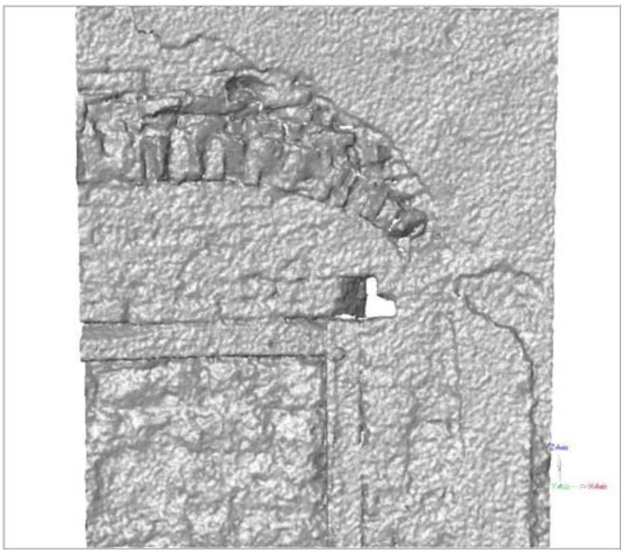

Figure 4. Example of triangulation with Raindrop Geomagic

About 18 million points have been collected to carry out the survey of the whole transept of the church. To perform the tests illustrated in this work, we considered only a small area of about 1,5 m x 1,5 m (134.000 points).

3.2.2. Noise Reduction: Noise in collected data has been reduced by the filter available in Geomagic Studio (by Raindrop). Statistical results on the test area are:
- average distance from original points to filtered ones: 1,6 mm;
- standard deviation: 1,3 mm.

Noise reduction is a fundamental step in data processing, particularly when, as in our case study, noise is comparable to scanning resolution.
Apart from noise reduction, no other data elaborations have been done to arrange the surface portion adopted as test, for the comparison of point and surface models obtained with 3D scanning and photogrammetric procedures.

3.2.3. Triangulation: As well-known, a number of different algorithms can be applied for the generation of a triangular mesh surface model.
Triangulation tests done with different softwares produce quite different results, although metric comparison between surfaces and original point sets exhibits negligible differences (standard deviation: ± 1 mm).
The surface model adopted for the following elaborations is made by a triangular mesh of 265.000 polygons. Thanks to the high resolution of data, this model describes in a very detailed way the object surface: one can easily see the most evident geometrical discontinuities, as well as the wall texture and the plaster detachments. On the other hand, to build such a high-resolution model on a very large surface (as the whole transept of the church is) implies serious problems related to the management of a very big amount of data.
As pointed out in [Tucci et al., 2003; Bonora et al., 2004], in order to obtain a complete model, a more complex data processing has been performed (cleaning of data collected on inessential elements, data partitioning in view of an easier management, applying different data reduction).

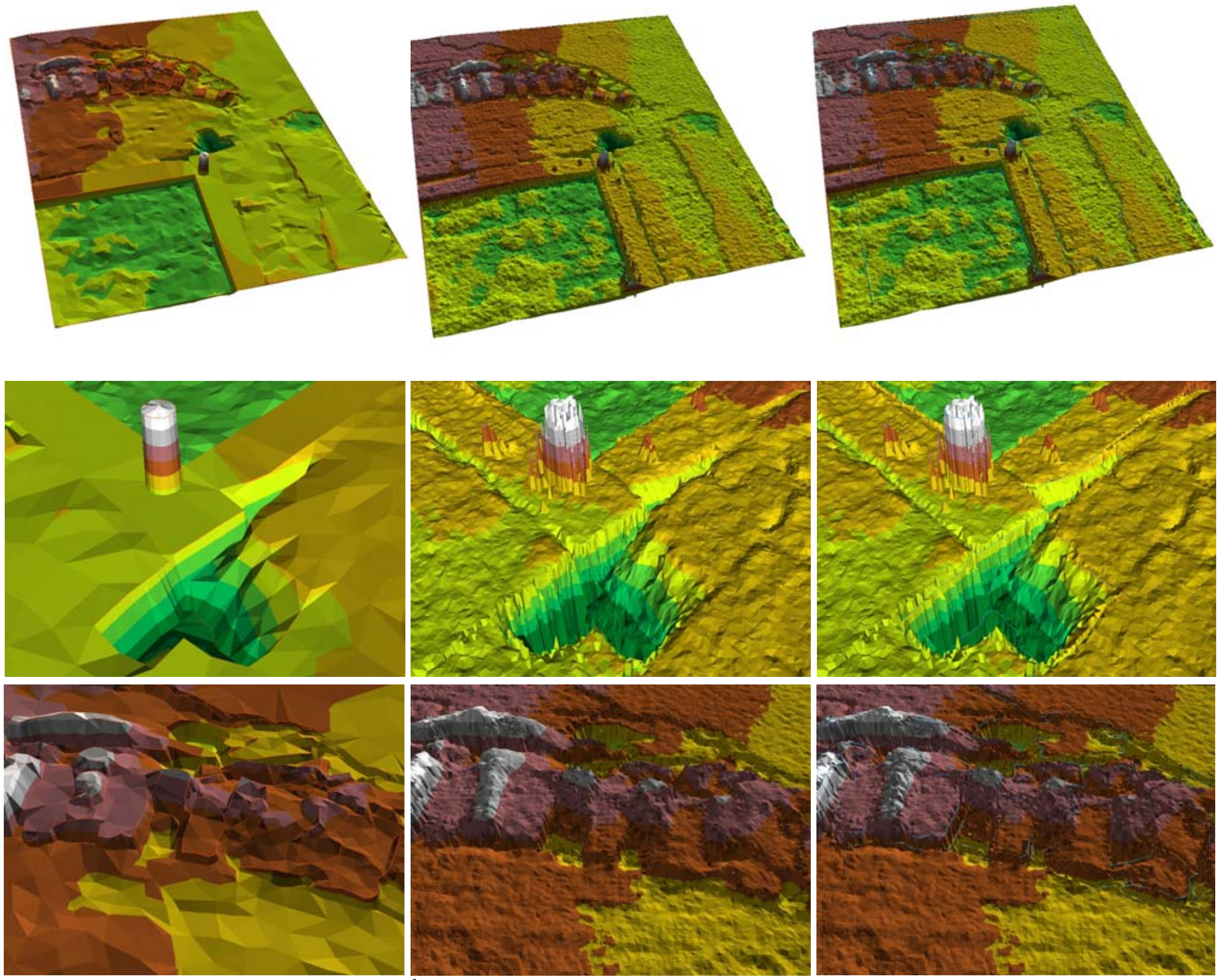

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Figure 5. Visual representation of the models carried out with Arcview (ESRI) from different points of view. a – photogrammetric model; b – laser scanning model; c – the same model with photogrammetric breaklines. Upper images represent the whole test area, whereas subsequent images represent a magnification of the most relevant portions

4. INTEGRATED USE

The experiences above illustrated are finalized to:
- compare point models generated using laser scanning systems and digital photogrammetry with automatic correlation algorithms;
- evaluate the metric accuracy of the models and their ability to give a useful surface description combining point data (with more or less high resolution) and breaklines.

Starting from DEM's of the test area, both from photogrammetry (points and breaklines) and from laser scanning (point clouds), surface models (TIN) have been generated using ESRI Arcview software. Photogrammetric and laser scanning data have been separately processed and, finally, photogrammetric breaklines have been introduced as constraints for laser scanner data.
The chosen test area does not exhibit all possible problems occurring in an architectural survey; yet, a variety of different situations is present (geometrically well-defined objects, as the wooden architrave, highly damaged surfaces, with plaster gaps and visible bricks, overhangs and undercuts due to the removal of the eighteenth century covering), and can be analyzed with the different processing techniques.

In the elaboration of the photogrammetric model the recording of discontinuity lines has produced an exhaustive, though synthetic, description of the object, possibly closer to the requirements of an architectural survey. Discontinuity lines have been inserted both in case of depth variations (for example the edges of the wooden architrave) and to bound even surface portions (plaster contours).
The laser scanner digital model can be superimposed to the stereoscopic model; then the usual operations of digital photogrammetry (editing, insertion of points and breaklines, interpolation procedures) can be carried out, with the opportunity of a direct real-time check with the aid of stereoscopic vision.
The model derived from the laser scanning point cloud has a denser sampling step. As a consequence, the complexity of the entire object should be described in greater detail; the introduction of photogrammetric breaklines as constraint in TIN generation does not involve essential changes, because of the small triangle size.
On the other hand, the processing results seem to suggest that discontinuity interpretation difficulties in the surface model generation, mostly where vertical surfaces are described, arise mainly from the high density of laser scanning data. As an example, the vertical faces of the wooden architrave are represented as highly corrugated rather than even surfaces, just because of the extreme closeness of redundant points describing the same portion of

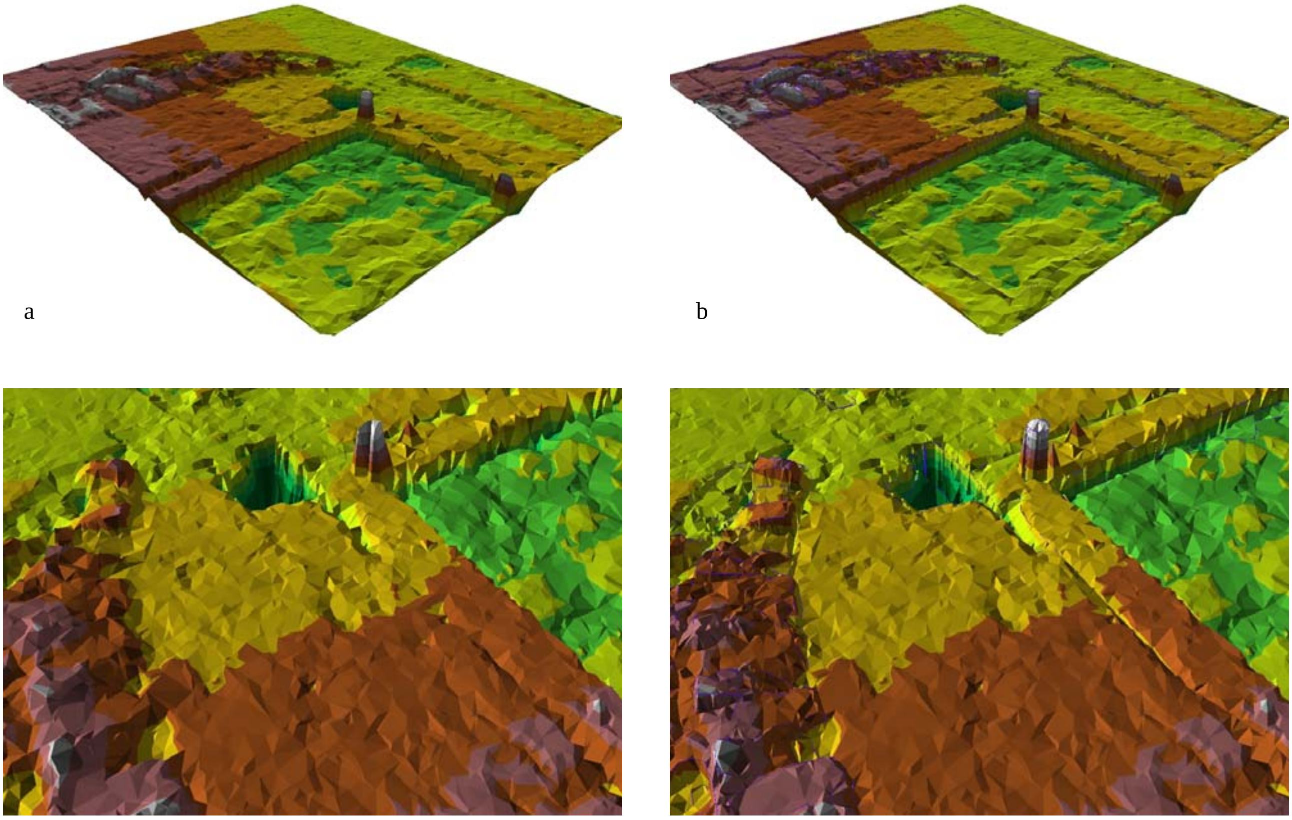

Figure 6. Visual representation of the models carried out with Arcview (ESRI) from different points of view. a – Laser scanning model decimated on the curvature; b – the same model with photogrammetric breaklines

surface. Moreover, if the point cloud is observed within the photogrammetric model, the required magnification is such as to cause difficulties in stereoscopic view.
Therefore, it has been chosen to decimate laser scanner data. The subsequent Arcview elaborations exhibit a better definition of the vertical surfaces, and also the introduction of photogrammetric breaklines provide a clearer definition of discontinuities; furthermore, the model data management turns out to be easier.

5. CONCLUSION

In order to obtain a satisfactory integration of the different techniques for the survey of complex architectural objects, a very careful project of the different acquisition and data processing steps is required, with a particular attention to the operations necessary to define a very precise common reference frame.
The main laser scanning characteristic consists in the fast automatic acquisition of a very large amount of points, with a post-processing stage of data filtering and surface modeling.
A number of acquisitions from different viewpoints, that must be inserted into a unique model space, is generally necessary in order to obtain a complete 3-D representation devoid of umbrae. Anyway, a direct acquisition of 3-D coordinates is obtained; the post-processing stage requires the use of complex filtering and modeling algorithms.
In photogrammetry the automatic determination of 3-D points is obtained in the post-processing stage. Its accuracy depends on a high precision identification of homologous points, that certainly is strongly related to the good quality of the images; in addition, in the post-processing stage it is possible to check and correct the stereoscopic model in real time, introducing new entities (points and breaklines) necessary for a correct interpretation of reality.
The main idea underlying the investigations illustrated above is the possibility of integrating laser scanning and photogrammetric techniques in order to generate a unique digital model of the surface of an architectural object, as representative as possible of its complexity, in the sense that laser scanning is used in a first stage of direct generation of the 3-D model, photogrammetry in a subsequent refinement stage.
In order to choose the optimal level of detail of a surface model describing an object, we must consider as well the aim of the model itself, as the specific characters of the object (from both a geometric and physical point of view). Consequently it is difficult to define standards in data processing. From time to time we have to adapt data elaboration procedures, in order to obtain a model able to balance satisfactorily the requirements of a complete shape description (according to the planned level of detail) and of an easy data management (implying geometrical synthesis). To try to fulfill this double requirement, our work will continue

- on one hand, evaluating how to perform substantial data reduction without damaging the model shape description;
- on the other hand, integrating laser scanning data with photogrammetric plotting.

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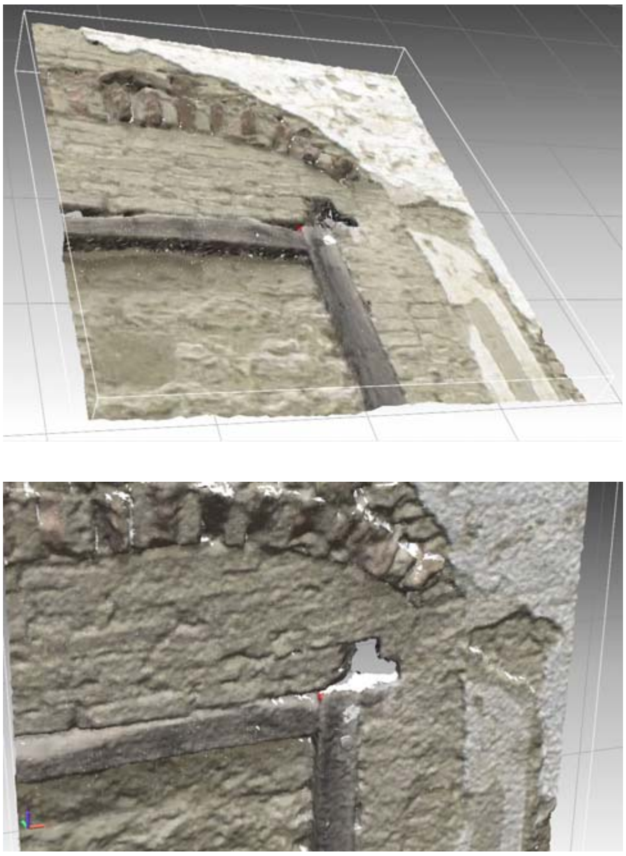

Figure 7. Texturing obtained by warping system of uncalibrate image (Rapidform INUS Tech).

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