HIGH RESOLUTION DATA FROM LASER SCANNING AND DIGITAL PHOTOGRAMMETRY TERRESTRIAL METHODOLOGIES.
TEST SITE: AN ARCHITECTURAL SURFACE

M. Fabris [a, *], V. Achilli [a], G. Artese [b], G. Boatto [a], D. Bragagnolo [a], G. Concheri [c], R. Meneghello [c], A. Menin [a], A. Trecroci [b]

[a] LRG – Laboratorio di Rilevamento e Geomatica, DAUR, Università di Padova,
via Marzolo, 9, 35131 Padova, e-mail: massimo.fabris@unipd.it
[b] Dipartimento di Pianificazione Territoriale, Università della Calabria,
Ponte Pietro Bucci, 87036 Arcavacata di Rende
[c] LIN – Laboratorio di Disegno e Metodi dell'Ingegneria Industriale, DAUR,
Università di Padova, via Marzolo, 9, 35131 Padova

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ABSTRACT:

Terrestrial methodologies, as high resolution laser scanning and digital photogrammetry, are used in many applications in the field of architectural and cultural heritage surveys: they are characterized by different operative procedures and precisions.
Data deriving from acquisition of an architectural surface, "morphologically complex" but geometrically simple and regular, were used in order to compare different methodologies. The 3D laser scanning data were acquired with HDS2500 Time Of Flight (TOF) terrestrial laser scanner and Konica Minolta Vivid 910 triangulation laser scanner. Moreover, the application of traditional topography with Leica TC2003 total station provided the 3D coordinates of 70 natural points, placed in the survey area, with high accuracy. The photogrammetric survey was performed with Canon EOS 1 DS Mark II digital metric camera: with 3 m and 6 m camera-to-object distances, 13 images with 10 cm and 20 cm, respectively of base increment, were acquired. The overlap between subsequent images is 95%, but with non subsequent images it ranges from 40% to 95%. For each stereo-pair, a stereoscopic model was created with Socet Set v. 5.4 software and the corresponding digital model was extracted.
The different models were co-registered in the same reference system using control points and, subsequently, were compared: results indicated a good agreement between the data derived from HDS2500 laser scanner, digital photogrammetry and natural points. Moreover, the applicability of Konica Minolta Vivid 910 laser scanner for detailed architectural survey was demonstrated.

1. INTRODUCTION

Three dimensional methodologies as terrestrial laser scanning and digital photogrammetry, are used to extract digital models of surfaces. Laser scanner devices represent one of the most widely investigated instruments in many fields of architectural and archaeological surveying applications. In order to allow photo-realistic navigation and presentation of cultural heritage objects, 3D models with good geometric accuracy, large amount of details, different LOD (Level Of Detail) and high resolution textures are required

Moreover, the integration with classical topographic techniques allow to create a local reference network useful in the survey of control points. Thus, 3D data can be co-registered in the same reference system and, if necessary, lacunas of data generated by shadow zones can be closed. However, these methodologies are characterized by operative procedures, precisions and resolutions that have to be evaluated on the base of the instrument used, the object surveyed and the aim of the survey too.

The precision of terrestrial laser scanner mainly depends on the device used for deflecting laser beam through small rotations on perpendicular directions (generally made up of two mirrors in the configuration of optic galvanometer); on the measured range, that is the "Time Of Flight" (TOF) measure, or on the phase comparison between the outgoing and the back signal (for the triangulation laser scanner, the measurement range decreases with the square of the distance between instrument and object); on the resolution, that is the ability to detect small objects or object features in the point cloud (the combination between the smallest possible increment of the angle between two adjacent points and the size of the laser spot on the object); on the edge effects of the object: in fact, wrong points can be produced near the edges; on the reflectivity of the surfaces: generally, white surfaces will yield strong reflections whereas black surfaces absorb most of signal. The effects of coloured surfaces depend on the spectral characteristics of laser (green, red, near infrared). Shiny surfaces usually are not easy to acquire for triangulation laser scanners. Precision of terrestrial laser scanning depends, finally, on the environmental conditions (temperature, atmosphere, interfering radiations). These effects have been intensively investigated, studied and discussed for several laser scanner types (Lichti et al., 2000; Balzani et al., 2001; Boehler et al., 2003; Lichti, Gordon, 2004; Schulz, Ingesand, 2004; Kersten et al., 2005; Staiger, 2005; Pesci, Teza, 2008; Voegtle et al., 2008).

The precision of digital photogrammetry, for normal acquisitions and the extraction of 3D models, mainly depends on the relationship between distance and base of acquisitions, on image quality (if brightness is proper, if there is smoke or

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[*] Corresponding author.

fog, if slope or vegetation are recognizable, etc…), on the resolution at ground (pixel dimension), on the grid size, on the acquisition step and interpolation method (Kraus, 1998).

In this paper, the two different approaches, integrated with classical topographic methodologies, were applied for the 3D survey of an architectural surface morphologically complex but geometrically simple and regular: the surface is constituted by two series of concrete blocks with different dimensions and roughness, spaced out in the centre by a concrete surface at constant curvature; the area is about 10 square meters (figure 1). For the surveys, Leica HDS2500 Time of Flight laser scanner, Konica Minolta Vivid 910 Triangulation laser scanner, Canon EOS 1 DS Mark II digital metric camera and Leica TC2003 total station were used. The aim is to evaluate if data with very different resolution can be integrated and what are the limits of applicability for these methodologies.

2. THE LASER SCANNING SURVEYS

2.1 Survey with HDS2500 laser scanner

The 3D survey of the building portion was performed with HDS2500 laser scanner. The instrument allows to measure single points using Time Of Flight technique and provide data with an accuracy of 4 mm for the distance measurement and of 6 mm for the positioning definition (measurement ranges from 1.5 m to 50 m); the accuracy for angles definition is 60 micro-rad.

The laser scanner was located at 5 m distance to the surface in two different stationing points: thus, two point clouds were acquired with a mean step of 0.5 cm from two different points of view, in order to decrease shadow zones, mainly in the areas between two subsequent blocks (figure 1).

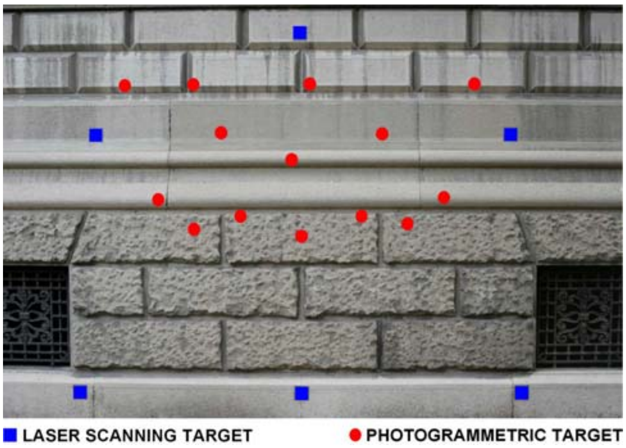

Figure 1. The architectural surface of the case – study, with photogrammetric and laser scanning targets

Before the scans, 6 high reflectivity laser scanning targets, characterized by a white circle on blue background (7.5 x 7.5 cm size), were placed on the surface. The instrument recognizes semi-automatically the targets in the point cloud and carries out a detailed scan defining with high precision the centre of the signals by means of the average of the coordinates of the acquired points.

Subsequently, the targets were surveyed with TC2003 total station using multiple intersections: thus, for each signal, 3D coordinates of the centre, measured in a local reference system, were assigned.

Moreover, the coordinates of 14 photogrammetric targets (1 x 1 cm size) and 50 natural points (mainly on the corner of the blocks) were measured: data elaboration provided a dataset of 70 3D points in the same local reference system with precision in the order of 1 mm and useful in the subsequent comparison.

The alignment of the two point clouds was carried out with Cyclone v. 5.3 software using Survey Registration procedure: each scan was roto-translated directly on the local reference system imposing the coordinates of the targets of the scan: thus, the two point clouds were georeferred in the same system with maximum error of 1 mm obtaining the 3D model of figure 2.

In this case, the 3D model describes correctly the morphology of the surface also in the areas between subsequent blocks.

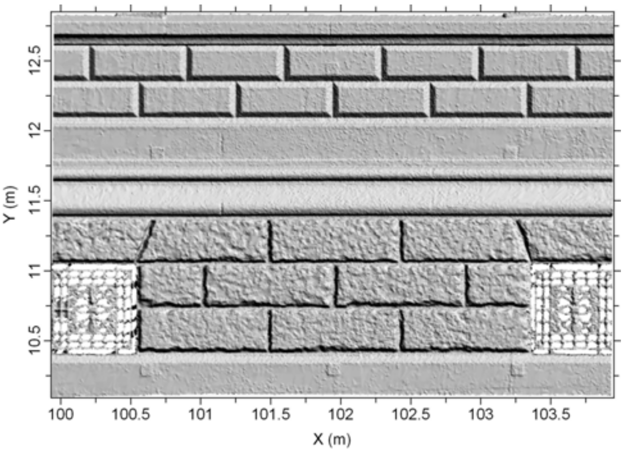

Figure 2. 3D model obtained by the aligned scans (HDS2500 laser scanner) (shaded relief representation)

2.2 Survey with Konica Minolta Vivid 910 laser scanner

The Konica Minolta Vivid 910 triangulation laser scanner provides data with resolution from 0.17 mm, depending on the lens used and the laser scanner – object distance (included in the interval 0.6 m – 2 m). In this case, the laser beam is projected on the surface from a window at the bottom of the instrument, while on the upper window is the receiver of the returning signal (CCD element). Knowing the laser source – CCD camera distance and the emission and reception angles, the distance instrument – measured point is estimated by means of triangulation.

The triangulation laser scanner is used in the framework of reverse engineering, industrial design and cultural heritage for very high resolution 3D reconstruction of small objects. In fact, using the three different lenses (“wide” with 8 mm focal length, “middle” with 14.5 mm focal length and “tele” with 25.5 mm focal length), the acquired area for a single scan ranges from 11.1 x 8.4 cm to 120.0 x 90.3 cm. Thus, even the alignment of more scans produces 3D reconstruction of limited areas.

However, the applications in architectural field could be carried out for detailed analysis of small portions, such as decorative elements and for definition and monitoring of slits, thanks to the high resolution of Konica Minolta Vivid 910 laser scanning data.

In this case-study, different acquisitions were carried out using different lenses and different instrument – surface distances.

In the first case, the instrument was located at 2 m distance from the surface and a lens with 8 mm focal length was used: 10 scans, with an overlap of about 40-50%, were acquired and a resolution of 2 mm circa was obtained. The alignment, in the same reference frame, was performed with PET (Polygonal

Editing Tool) software: the co-registration was performed by measuring homologous natural points to make scans closer and, subsequently, by applying the ICP (Interactive Closest Points) algorithm to improve the alignment (Chen, Medioni, 1992; Besl, McKay, 1992; Rusinkiewicz, Levoy, 2001). The global model was generated with maximum error of 0.71 mm.

In the second application, the same lens was used, but with the laser scanner located at 1.5 m from the surface: 12 scans were acquired with an overlap of about 40-50%, obtaining a resolution of 1.5 mm circa: the alignment was carried out with the same software obtaining a maximum error of 0.38 mm.

The last application involved a lens with 14.5 mm focal length and the laser scanner placed at 1.5 m distance from the surface: in this case, 16 scans were acquired with an overlap of about 40-50% obtaining a resolution of 1 mm circa. Besides, using PET software, the alignment between the different scans was carried out with maximum error of 0.37 mm.

The three global digital models were georeferred in the local reference network by means of 12 natural points (figure 3).

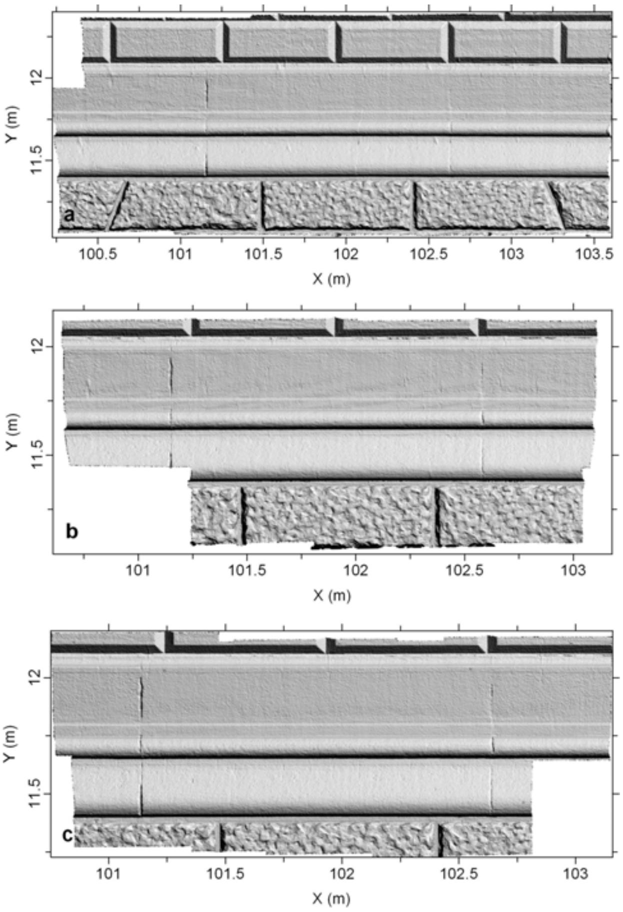

Figure 3. 3D models obtained with Konica Minolta Vivid 910 laser scanner: a) 2 m instrument – surface distance and lens with 8 mm focal length; b) 1.5 m instrument – surface distance and lens with 8 mm focal length; c) 1.5 m instrument – surface distance and lens with 14.5 mm focal length (shaded relief representation)

Figure 3 shows that the reconstructed area, obtained from the alignment of more scans, is smaller when compared to the HDS2500 laser scanner one (figure 2).

Further acquisitions were performed with laser scanner – surface distance of 0.8 m and 1.2 m, using the lens with 8 mm focal length. The last scans were carried out with instrument – surface distance in the advised range for many applications. Also in this case, each scan was co-registered in the local reference system using natural points.

3. THE PHOTOGRAMMETRIC SURVEY

The terrestrial photogrammetric survey was carried out with Canon EOS 1 DS Mark II digital metric camera, providing images at 16.7 Megapixel resolution. The acquisitions were performed with camera – surface distance of about 3 m and 6 m, with lens of 53 mm focal length and using a calibrated bar. Thus, the perpendicular condition between the axis and the base of acquisitions was guaranteed. The survey was carried out in a cloudy day so that light conditions were the same for the first and the last acquired images.

The images were obtained with an overlap of 95% to reduce shadow zones, mainly in the little areas between two subsequent blocks: for this reason, basis of 10 cm along a single strip were used with camera – surface distance of 3 m. The disadvantage is due to the bad relationship between the distance and base of acquisitions (Kraus, 1998). Finally, 13 images were acquired, obtaining different overlaps between different images: if the overlap between subsequent photos is 95%, the overlap between the first and the third image is 90% and, thus, the overlap between the first and the last image is 40%; in this case, also photogrammetric targets were acquired.

From the analysis of the acquisitions carried out with a camera – surface distance of 3 m, the 12 stereoscopic models were created by means of processing with Socet Set (SoftCopy Exploitation Tool Set) v. 5.4 software: photogrammetric signals, measured in the same reference system of the laser scanning targets, were used as control points; thus, photogrammetric data were co-registered with laser scanning ones.

Using pairs of images with different overlaps (95%, 90%, 85%, …, 40%), 12 Digital Surface Models (DSMs) with grid size of 0.5 x 0.5 cm were automatically extracted. Figure 4 shows the two digital models obtained with an overlap of 95% (a) and 40 % (b).

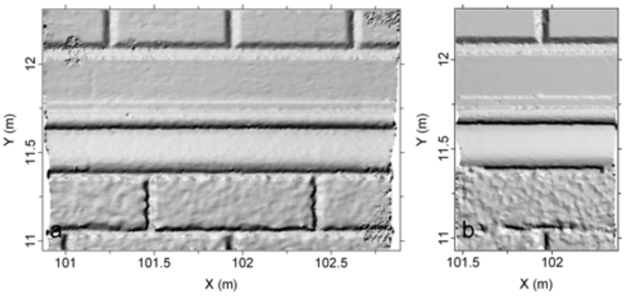

Figure 4. DSMs obtained from the stereo-pairs acquired with camera – surface distance of 3 m and overlap of 95% (a) and 40% (b) (shaded relief representation)

The automatic approach of the software for DSM extraction is provided by a correlation parameter that represents, for each extracted point, the quality of the automatic determination: it can indicate the success of the correlation or the questionability of the measurement (but the points do not need, necessarily, to be manually edited). This value is called "Figures Of Merit" (FOM). The FOM parameter provides numerical values ranging from 0 to 99: values from 0 to 32 suggest that the obtained correlation is unsatisfactory, while in the other cases, the coefficient should be proportional to the reliability of the measured data (BAE Systems, 2006; Fabris, Baldi, 2006).

Values lower than 33 correspond to a different class of approaches adopted to solve the problem of correlation failure: in all of the cases, the depth (along camera – surface direction) of each point is computed by means of an interpolation or extrapolation from the surrounding points.

In this case, the planimetric distribution of the FOM parameter, for the data lower than 33 (red colour), was overlapped to the 3D model obtained from images with 95% overlap (figure 5) and 40% overlap (figure 6).

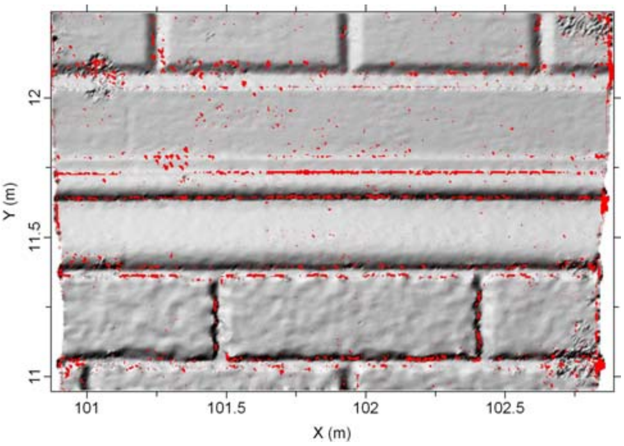

Figure 5. Planimetric distribution of the correlation parameter FOM with values lower than 33 (in red) on the 3D model (stereo – pair with 95% overlap)

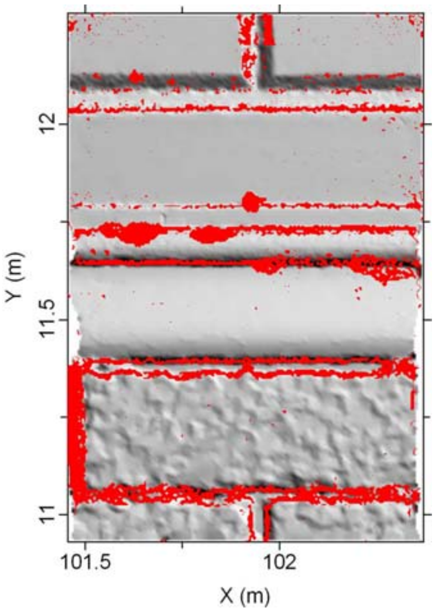

Figure 6. Planimetric distribution of the correlation parameter FOM with values lower than 33 (in red) on the 3D model (stereo – pair with 40% overlap)

The figures 5 and 6 shows correlation difficulty in the areas between subsequent blocks: the problems are more evident with overlap of 40% due to the very different points of view of images and, consequently, the non-stereoscopic area between the blocks.

These phenomena were confirmed analyzing the images acquired with camera – surface distance of 6 m; with the same procedure, 12 DSMs (grid size of 0.5 x 0.5 cm) were extracted by means of Socet Set v. 5.4 software (images with overlap of 95%, 90%, 85%, …, 40%): the photogrammetric signals and some laser scanning targets were used as control points. Figure 7 show the digital model obtained with images overlap of 40% (a) and the distribution of the FOM parameter (b).

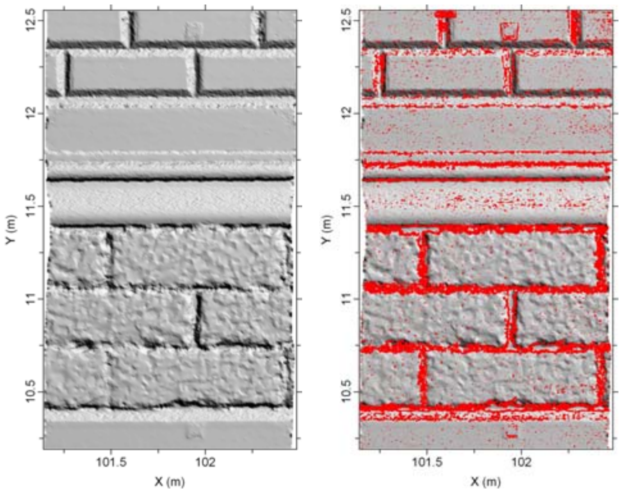

Figure 7. DSM obtained from the stereo – pair acquired with camera – surface distance of 6 m and overlap of 40% (a); planimetric distribution of the FOM parameter (b) with values lower than 33 (in red)

The absence of stereoscopic model in the areas between two subsequent blocks, generates 3D digital models with poor correlation in those zones: the final results (figure 7a) show an incorrect description of the surface morphology between the blocks: a better result was obtained adopting a 95% images overlap.

The analysis of FOM parameter for camera – surface distance of 3 m shows, generally, an improvement of the automatic correlation increasing the images overlap: in fact, the percentage of points extracted with insufficient correlation (figure 8) decreases and, at the same time, the average FOM increases (figure 9).

However, with high images overlap, the models accuracy have to be evaluated due to the bad relationship between the distance and base of acquisitions.

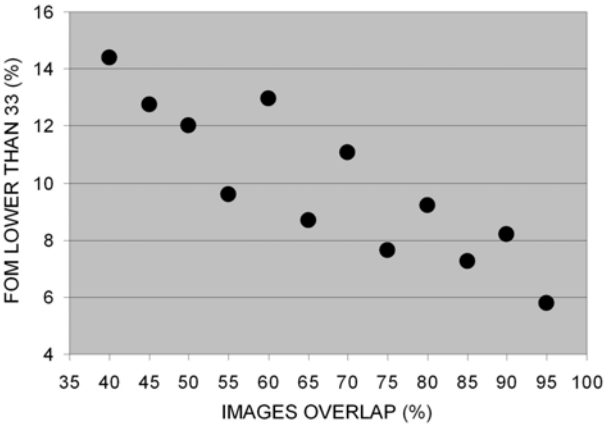

Figure 8. FOM lower than 33 for different images overlap

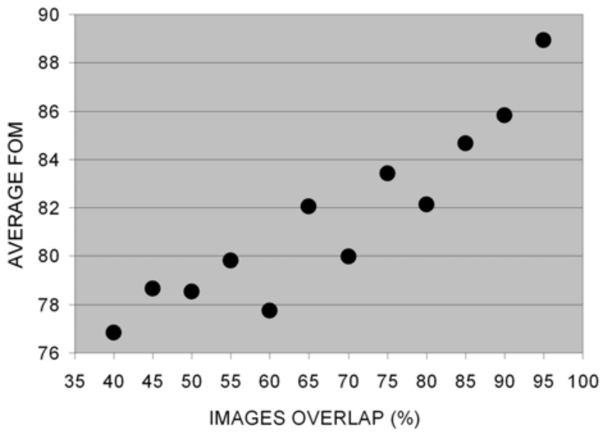

Figure 9. Average FOM for different images overlap

4. COMPARISON OF THE DIFFERENT 3D MODELS

4.1 HDS2500 laser scanner– Natural points

The 3D model obtained by means of the laser scanner HDS2500 were compared with the 50 natural points measured by means of the total station Leica TC2003 and not used neither for the roto-translation of the points clouds in the local reference system, nor for the orientation of the photogrammetric images (thus, they can be used as check points).

Residuals of differences provides average of 1.25 mm and standard deviation of 2.24 mm: the comparison demonstrated the high precision of the HDS2500 laser scanning data (value is better than the above declared) due to the lower distance instrument – surface (5 m).

4.2 Photogrammetric DSMs – Natural points – HDS2500 laser scanner

The second comparison involved the photogrammetric DSMs extracted by the images acquired with a camera – surface distance of 3 m: each automatic model, obtained with different images overlap, was compared with the natural points (figure 10 in red) and the laser scanning HDS2500 model (figure 10 in black).

The comparison with natural points provides standard deviation values of 1 mm circa for DSMs obtained with images overlap lower than 80%: this is the same precision obtained with measured natural points (located in the areas covered by the stereoscopic analysis for images overlap from 40% to 95%). For images overlap higher than 80%, the models obtained provide larger differences in the comparison with the check points due to the relationship base – acquisition distance not optimal.

The comparison of the photogrammetric data with HDS2500 laser scanning model provides higher values of standard deviation: this is due to the smaller precision of the Time Of Flight laser scanning data and the presence of the areas with different stereoscopic coverage. In fact, with decreasing images overlap, theoretical precision improves (Kraus, 1998), but also shadow zones increase, providing worse results in the comparison with the HDS2500 data. On the other hand, with increasing images overlap, a clear worsening of the theoretical precision is obtained. Shadow zones decrease and the results in the areas between subsequent blocks improve.

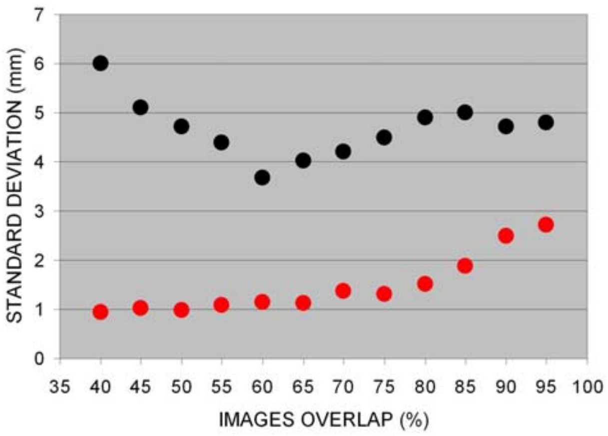

Figure 10. Standard deviations of the differences between each photogrammetric DSM with natural points (in red) and laser scanning HDS2500 model (in black)

The best results of the comparison with the laser scanning model was obtained using a images overlap of 60%, representing, in this case, the right compromise between the coverage of the shadow zones and the final precision of the photogrammetric model (standard deviation is 0.37 cm). Between 80% and 95% of images overlap, standard deviation provides similar values, not following the trend of theoretical precision expected.

4.3 Konica Minolta Vivid 910 laser scanner

Konica Minolta Vivid 910 data were compared with HDS2500 model. In fact, in the area acquired by the triangulation laser scanner, there are only few natural points (check points): the comparison with Konica Minolta data would provide not reliable statistics. Moreover, the photogrammetric data with high images overlap are characterized by poor precision while, with low images overlap, the area between subsequent blocks are not correctly described.

The comparison between HDS2500 laser scanning data and a single scan obtained with Konica Minolta laser scanner with 80 cm instrument – surface distance (co-registered in the same local reference systems by means of natural control points), provided a standard deviation value of 2.12 mm, in the same range of the comparison between HDS2500 and the coordinates of check points. Moreover, the comparison between two Konica Minolta aligned scans and HDS2500 data has confirmed a standard deviation value of 2.45 mm.

The acquisition at 120 cm distance has given the same values in the comparison with TOF laser scanner (2.31 mm) while, for laser scanner – surface distance higher than 120 cm, distortion effects of the lens camera can make triangulation laser scanning models worse.

When acquiring at an instrument – object distance ranging from 80 cm to 120 cm, Konica Minolta Vivid 910 laser scanner can be used in architectural surveys for detailed analysis of limited portions; in the case – study, the 3D reconstruction of the slit is more accurate when compared with the HDS2500 laser scanner due to the very high resolution of data (figure 11).

5. CONCLUSION

In this work, three different methodologies have been applied in the surveying of an architectural surface.

The comparison between coordinates of natural points and HDS2500 laser scanner point clouds, co-registered in the same locale reference system, has confirmed the validity of the latter methodology in the 3D reconstruction of portions of buildings.

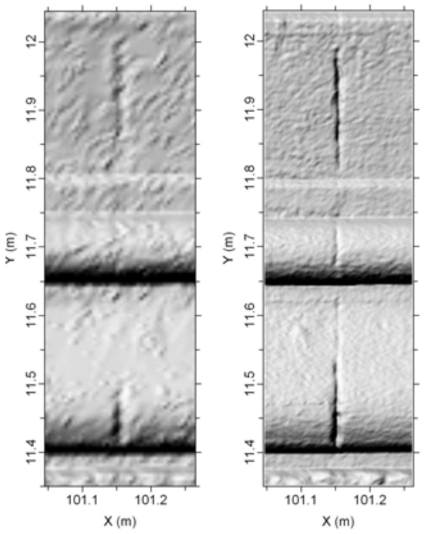

Figure 11. 3D reconstruction of a slit in the area of case – study: a) HDS2500 model; b) Konica Minolta Vivid 910 model (shaded relief representation)

Some tests about wide overlap of photogrammetric images were performed in order to verify stereoscopic acquisition of narrow and deep areas between subsequent blocks. Results illustrated a smaller precision from 80% to 95% images overlap according to the theoretical approaches: nevertheless, these overlaps can be used for the qualitative description of mentioned areas.

Finally, tests performed with Konica Minolta Vivid 910 triangulation laser scanner demonstrated the applicability of the instrument in the survey of architectural details, and in the definition and monitoring of slits, thanks to its very high resolution. In this case, it is necessary to pay attention to use the instrument in its correct range distance during acquisitions (from 80 cm to 120 cm laser scanner – surface distance) in order to not introduce optical deformations. The instrument is inadequate for survey of large surfaces that do not require high resolution: in fact, Konica Minolta Vivid 910 can acquire only small portions, moreover the alignment of more scans introduce other co-registration errors. For the survey of areas of some square meters, the HDS2500 laser scanner is more efficient. In the proposed survey, digital photogrammetry can be considered intermediate between the two laser scanners; moreover, it provides radiometric information of the surfaces together with the survey.

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