INTEGRATION OF 3D CLOSE RANGE SURVEY APPLIED TO THE WOODEN ART RESTORATION WORKS

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ABSTRACT:

The restoration of wooden artworks often requires high resolution 3D close-range elevation models. This work shows in that context some experience developed for the survey of Donatello's wooden statue "La Maddalena". A conventional close-range photogrammetric survey was carried out for the post elaboration of 3D high resolution cloud points data obtained by a fringe interferometric system device; this was applied to get a correct correlation between the various data areas of the statue. A controlled high resolution DEM of the articulated surface morphology was obtained; for an easy reading and editing of the complex survey results a software integration data was implemented facing to particular needs of art-restorations experts.

1. INTRODUCTION

1.1 Surveys for the restoration of wooden artworks

Within the scope of the larger problem of surveying plastic works, the study of wooden artworks assumes particular significance when referred to the non-linear ways this material behaves, given the physical nature of wood fiber, which is not homogeneous and is particularly sensitive to thermo-hygrometric variations. As known, in order to unequivocally correlate the deterioration analysis with the definition of adequate operative intervention, it is vital to have information gathered from interdisciplinary investigations on registration of the work's form, documentation of its consistency, and identification of the static, dynamic and climatic parameters to which it is normally subject. The elaboration of this type of data requires obtaining volumetric measurements which are accurate to a fraction of a millimeter and integrating a variety of survey techniques and investigative methodologies. In the following images some high definition close range survey developed by the D.I.C. topography and photogrammetry laboratory in Florence are shown to represent some real problems involved in this kind of study. (see fig. 1 to 12)

a)

b)

Fig. 2 Etruscan flutes; an interesting under see discovery due to an ancient wreck near the Giglio isle.
a) contour lines b) a turntable platform with its own control point reference system was employed for a fast take of the stereo pairs to reduce time outside the provisory habitat of conservation (a sea water pool) (W.Ferri, D.Ostuni)
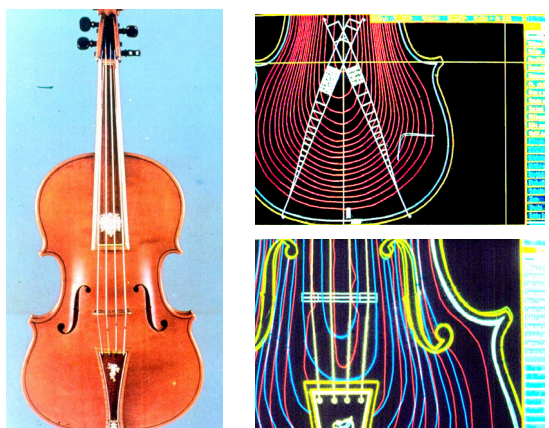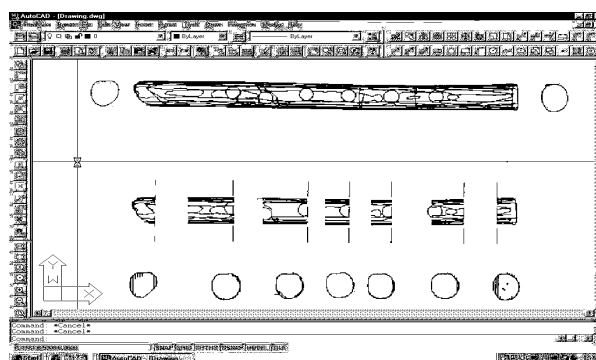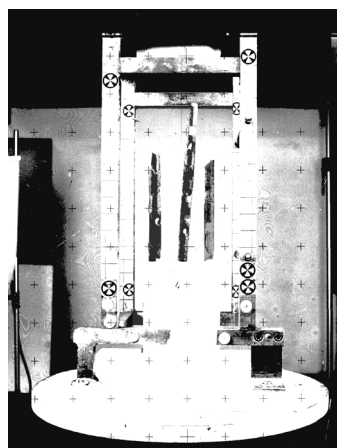

Fig 1 The Viola Medicea by Antonio Stradivari. Some life-time effects are shown in the asymmetry of the bottom contour lines and in some deformations of the frontal harmonic table; here in correlation with a modern and more regular copy (D.Ostuni)
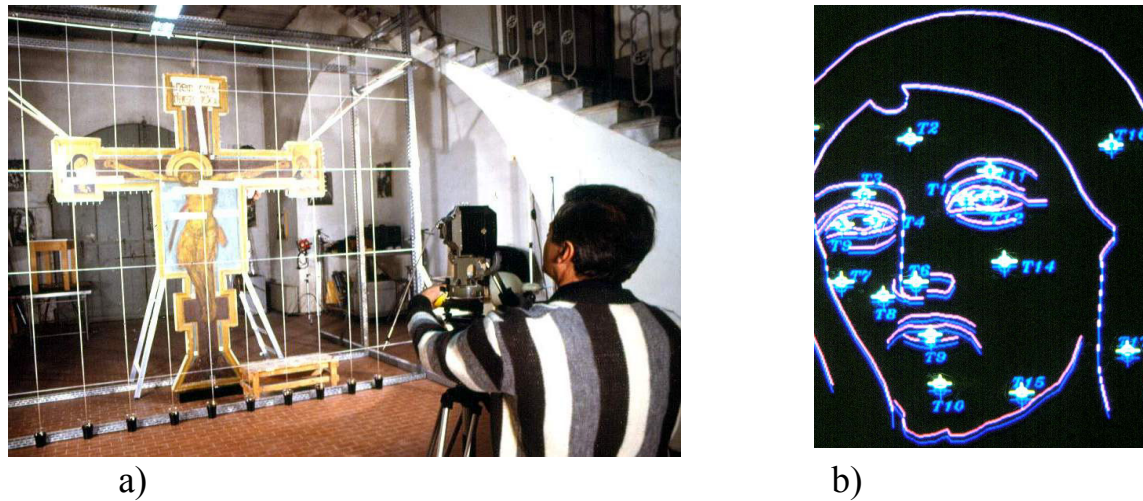
a)

b)

Fig. 3. a) A stereo pair for a Giotto's cross in the 80th b) Color and *X ray* stereoplotter mapping info for the medieval cross of the Sarzana Dome. (I.Chiaverini, D.Ostuni)
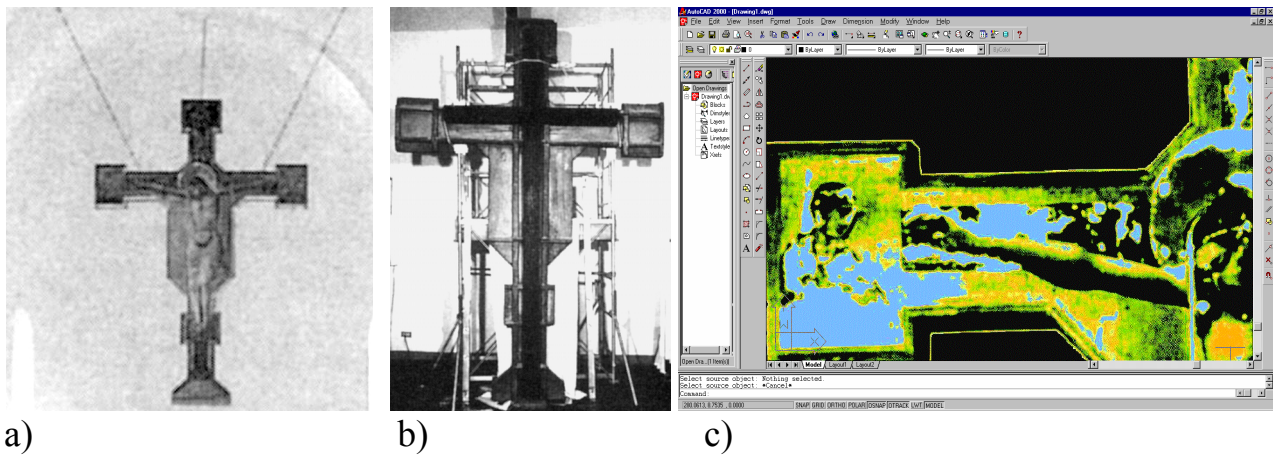

a)   b)   c)

Fig. 4. Agnolo Gaddi medieval cross in Sesto Fiorentino. An initial stereo pair of the cross suspended **(**see **a)** was correlated during the restoration works with a new stereopair of the same cross (in **b)** layed vertically on the floor as projected by Gaddi. **c)** paint lacunae after the suspention period (from 1966 to 1990)

a)   b)
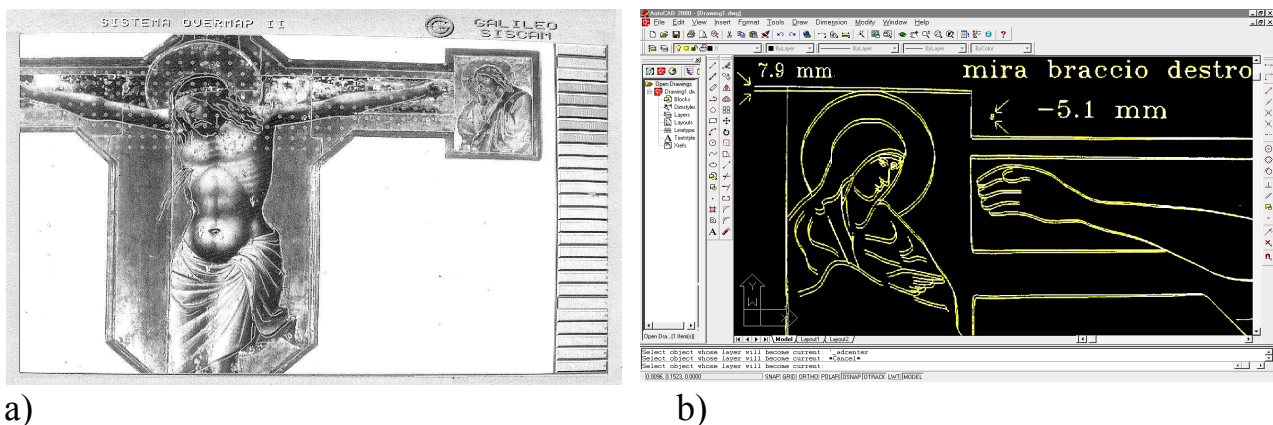
Fig. 5 **a)** Rectitied image and D.E.M., **b)** A structural correlation between image contour and targhet restitutions of the different static position of the cross show some effect of the stress applied to the cross; these deformations were pricipally caused by the inadequate back crossbar suspention support (see fig 4 b). (I.Chiaverini, D.Ostuni)
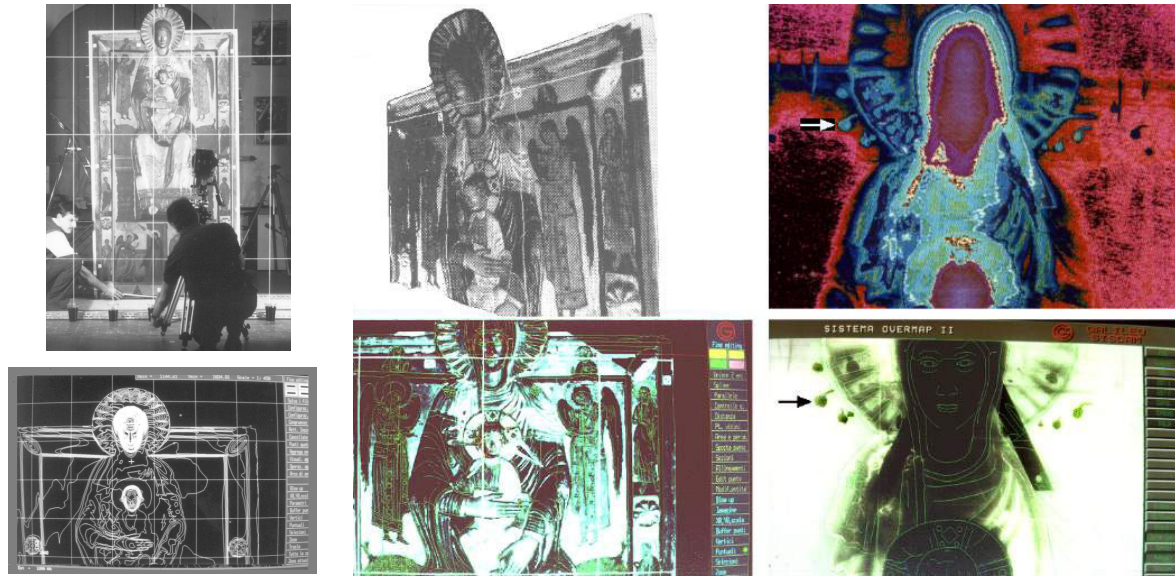
Fig 6. A wooden *Pala* by Coppo di Marcovaldo, an hibrid picture-sculpture that has required a specific restauration data base; close range, restitution, orthophoto, *X ray* and false color. (I.Chiaverini,D.Ostuni)
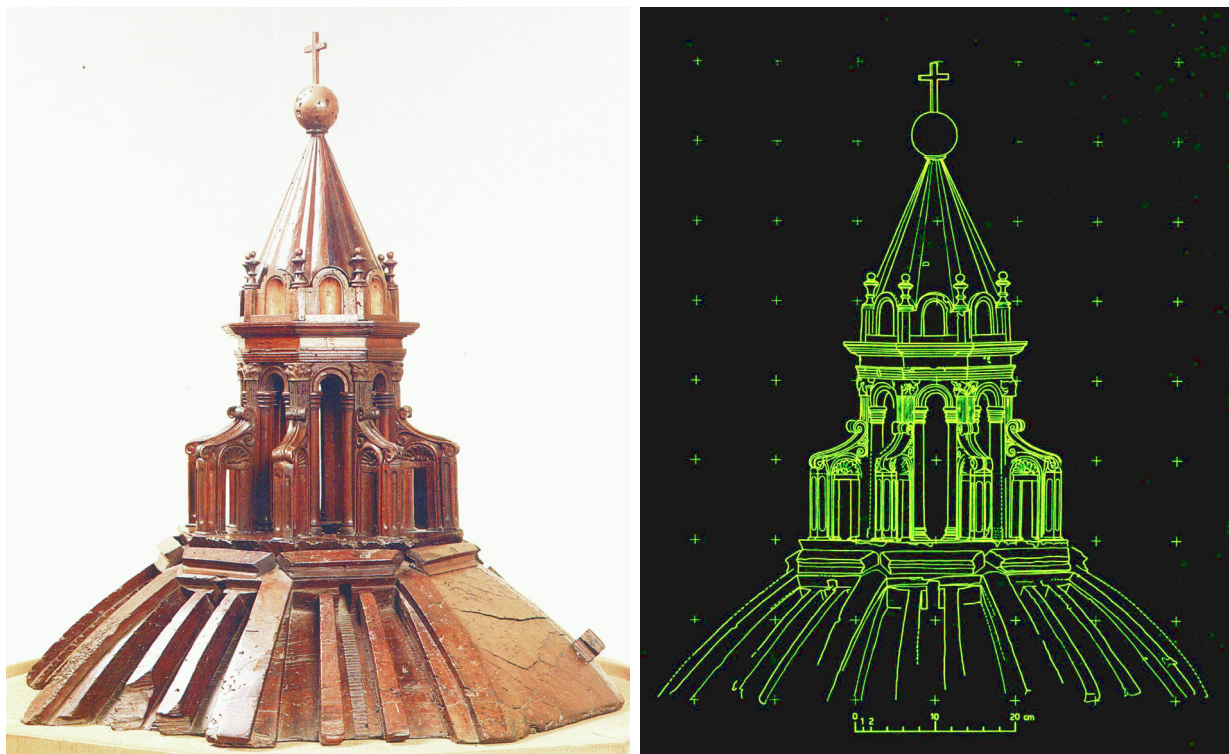

Fig 7. The wooden model of the *Lanterna* for the Florence Dome's by Brunelleschi; Studing this kind of manufacts in correlation with the true monument geometry give prominence to costructive details, modular project scheme, and may offer a precious evidence of old restauration works and ancient project variants. (M. Fondelli, L. Ippolito)
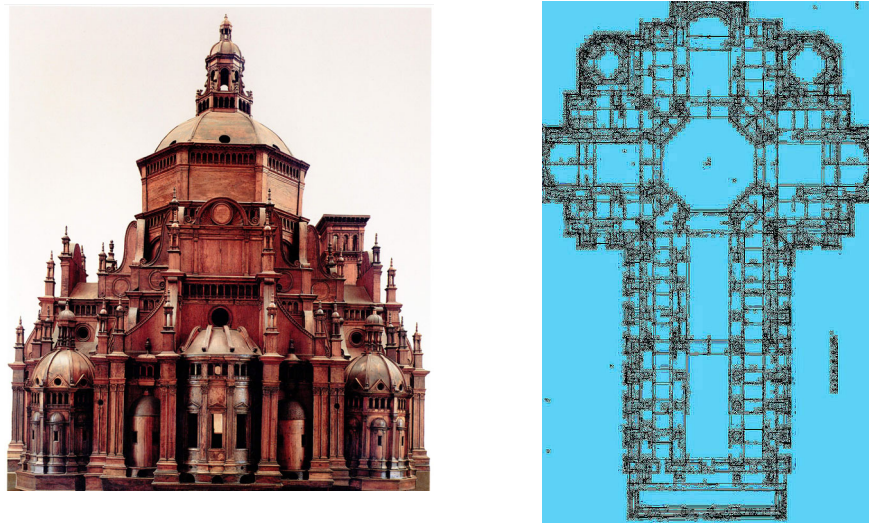
Fig. 8. The *Duomo di Pavia* wooden model by G.P.Fugazza; Photogrammetric restitutions of the plan view were used as a grafical reference database for hundreds parts in the exacting restoration reassembling work (L Ippolito)
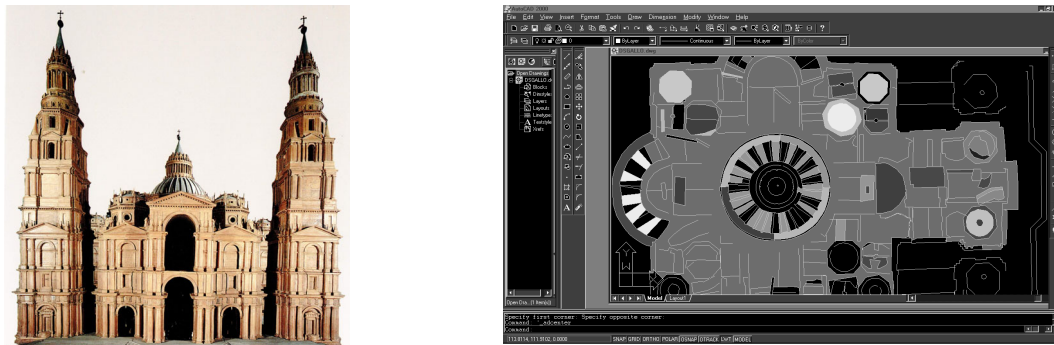
Fig. 9. The *S.Pietro in Vaticano* wooden model by Antonio da S.Gallo; Photogrammetric restitutions of the plan view were used as a 2D-3D database for the reassembling work and for some restauration info reference (I.Chiaverini, D.Ostuni)
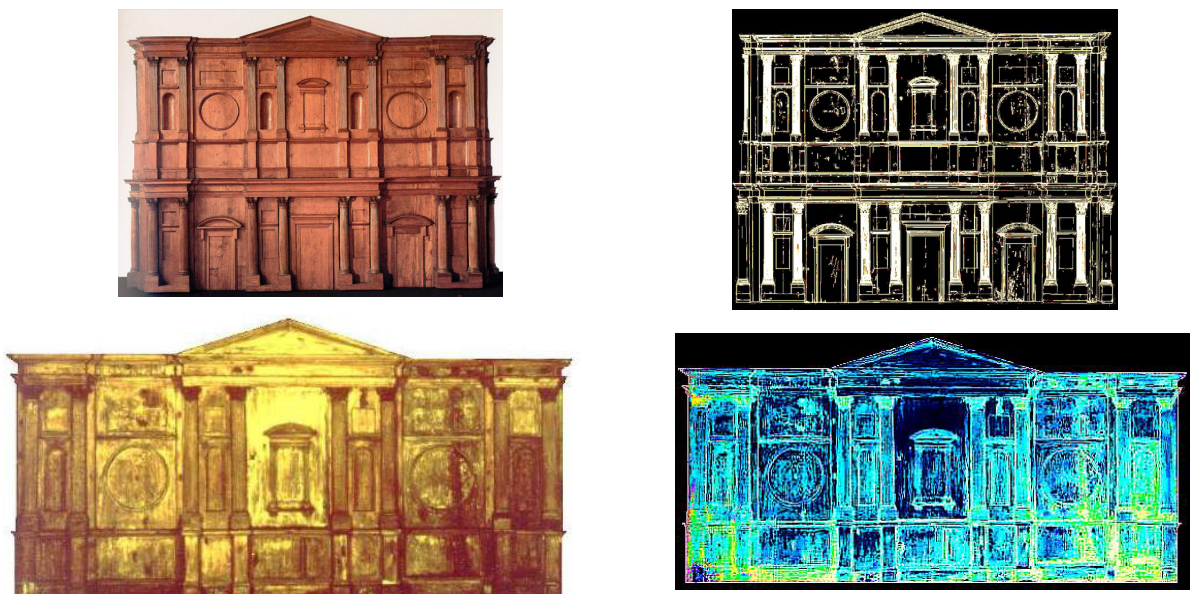

Fig.10 The San Lorenzo facade wooden model by Michelangelo Buonarroti; 3d restitution, rectified U.V. range image and false color elaboration implemented in the restoration works.(I.Chiaverini, D.Ostuni)
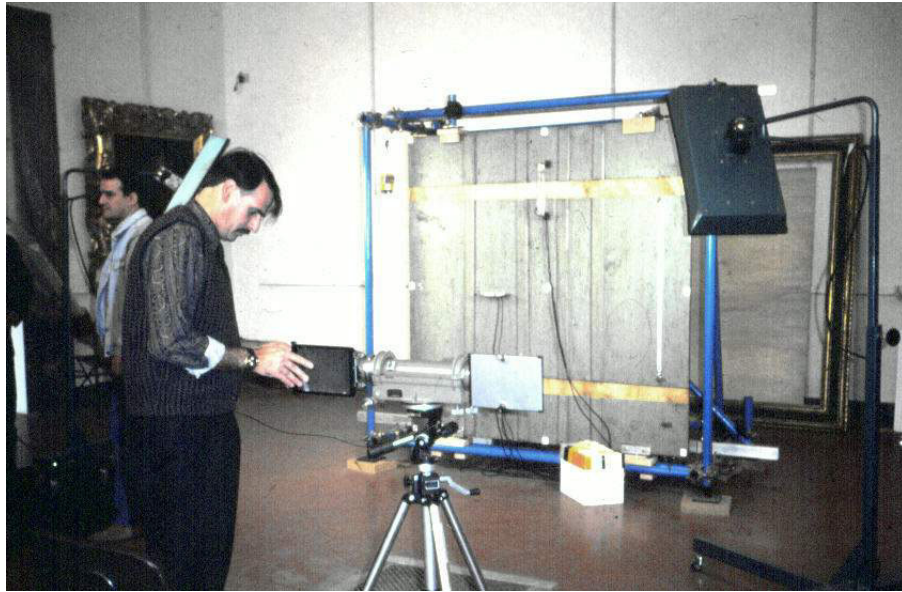
Fig. 11. Restauration works for an oil paint on wood by Baldovinetti in the Uffizi museum; close range stereo pairs were acquired before and after the removal of the back crossbar. (P.Aminti, I.Chiaverini, D.Ostuni)

CONDIZIONE PRIMA DEL DISASSEMBLAMENTO

a)

VARIAZIONI SENZA I SUPPORTI TRASVERSALI

b)

VARIAZIONI SENZA I SUPPORTI TRASVERSALI

c)

RIASSESTAMENTO STRUTTURALE

d)

Fig 12 From a) to d) Movements evolution during Baldovinetti's oil paint on wood restauration work; after a record curve of about two centimetres the artwork progressively returned in its first structural position. At that period 3d elaborations was carried out using photogrammetric stereoplotting data as horizontal and vertical referenced polylines.

1.2 Generation of the 3D model

The following experience has been developed during the survey of the wooden statue "La Maddalena " by Donatello, in the museum of the Opera del Duomo in Florence. Some close range front-back stereo pairs were integrated with a set of 3D clouds point data obtained with a fringe projection scanner 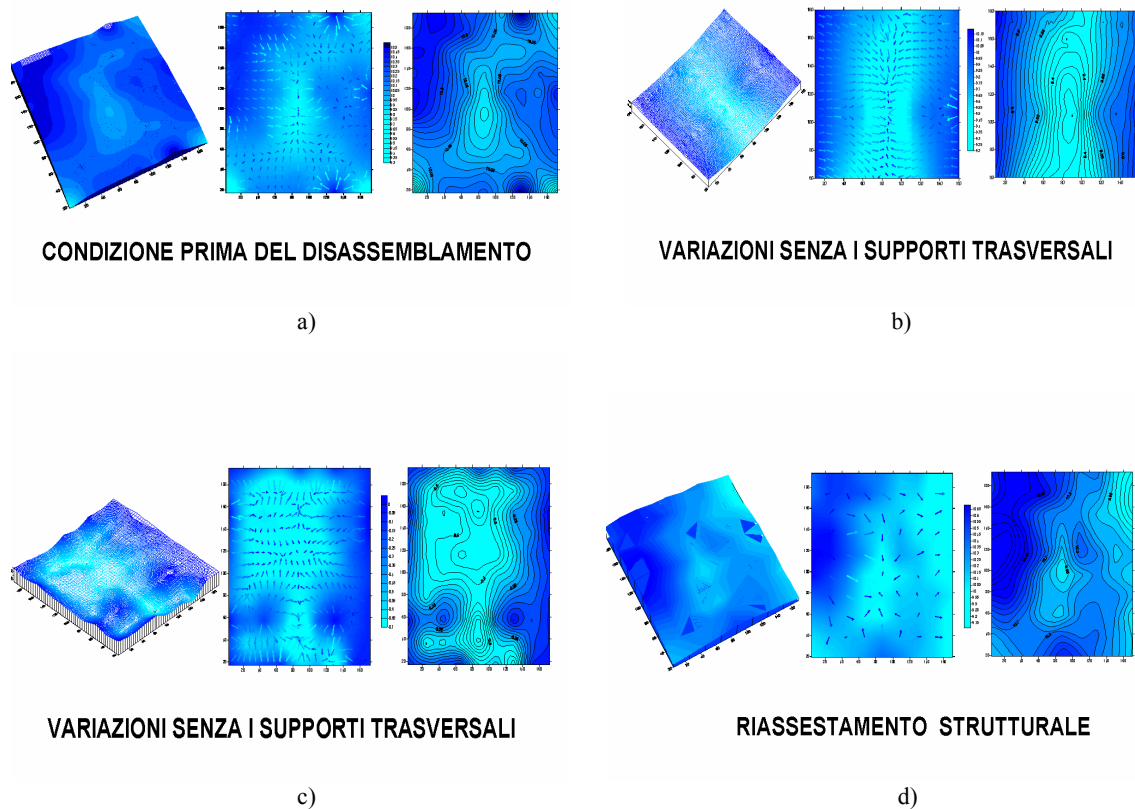system. In order to create a "high fidelity" digital model, suitable for conservation of the formal properties of the masterpiece, we decided to acquire the whole statue with a measurement uncertainty of about 70 μm. On the other hand a high number of images would have been critical due to the large size of the data set to be manipulated at once in the post-processing steps. We decided therefore to generate a "skeleton" of the model with a reduced number of images with reduced accuracy (130 μm), to be used as reference for the following high resolution step. Since in this way we used almost half the spatial resolution, we roughly reduced of 4 times the number of images necessary for obtaining a (even if not complete) closed model, reducing in this way the error propagation. The scanning process led in this phase at the acquisition and alignment of about 150 images organized in horizontal strips running around the statue. The constraint imposed by a closed area such as the one corresponding to a set of images taken by moving the scanner around the object, allowed to generate a set of well aligned "belts" that have been connected vertically to obtain the final 3D model.

Figure 13 – 3D scanning: a) relocation of the 3D scanning system around the statue; b) 3D model (F.Costantino, G.Guidi, D.Ostuni)

2. 3D scanning system

The system employed to obtain the result described in this article is a commercial product (Opto3D ranger, Optonet Srl, Brescia - Italy) which uses the 3D measurement method based on fringe projection. The technique previews the projection of various patterns over the measurement area, according to a given sequence, and their acquisition from one television camera angled respect to the projection direction. The deformation of the pattern acquired, after a proper processing, allows to gain one cloud of 3D points reproducing the shape of the illuminated object (Sansoni ET al., 1997).

By relocating the optical head respect to the object it is possible to measure various sights, until all the visible surface of the object is covered. In order to obtain the complete model, the operation of alignment and fusion of the single 3D shells can be carried out by a variety of software techniques commercially available. In our case the software Polyworks (Innovmetric, Montreal - Canada) has been used. It uses one of the various

point clouds as starting reference, and performs a rototranslation of each adjacent shell in order to align them to the reference. The procedure is repeated iteratively until all the shells from various points of view are properly aligned. The following phase is the merge of all aligned point clouds; the duplicated points in the superposition areas between adjacent images are selectively discarded and the remaining points are properly connected through a mesh representing the measured surface. Although an editing step usually follows this part of the processing, once the model has been aligned, any merge and editing does not involve further substantial modifications, so that a dimensional verification can be done just at the end of the alignment step.

The evaluation of possible measurement errors over the 3D model with respect to the true surface is a problem which involves different aspects. First of all an intrinsic error on the single scans is present. Since the evaluation of 3D coordinates is based on optical triangulation, the measurement uncertainty is directly dependent on the distance between the fringe projector and the video camera (baseline), and inversely dependent over the distance of the CCD from the object surface. During the following step further errors due to the alignment process have to be considered. In the alignment of two shells the alignment uncertainty can be roughly considered of the same order of the intrinsic measurement error of each point cloud, if unambiguous 3D features are present and the superposition area is large enough. In general, the error can be also influenced by the peculiar nature of two surfaces. For example two surfaces almost planar, where recognizable reference targets are missing, can produce large alignment errors, while the presence of bumps or extrusions allow to find much more easily the proper positioning of a view respect to another one. Therefore, when the alignment involves several 3D images, the error can be propagated in unpredictable way, deteriorating the overall measurement accuracy over the whole model in a way depending on the alignment quality. Such accuracy can be estimated through the 3D modeling software using error histograms and maps as shown in Figure 14. These are generated after the alignment of a few images and can give an estimate of the performance of the system. When the systematic errors are smaller than the random errors, then images should appear interwoven together after alignment. In overlapping regions between images, large areas contributed by the same image are signs of poor calibration.

However, in order to assess the actual overall error in the final 3D model, a complementary measurement method has to be used. As demonstrated by Beraldin (1997), a technique based on a theodolite survey can be employed. Here we chose to operate through a photogrammetric survey as described in the following section.
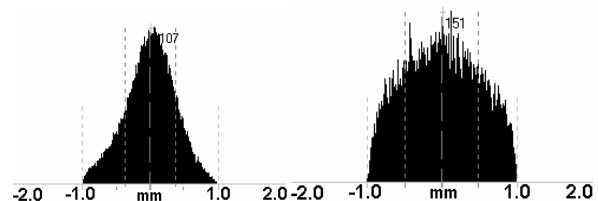

Figure 14 - Example of a histogram of residual errors after alignment of 2 images: a) best possible calibration, b) poorer calibration.

3. Photogrammetric measurements

The photographs were taken with a 150mm focal length and thanks to the format used (130 mm x 180 mm), with ten different points and a base of 80 cm, it was possible to cover the object along its entire height. Eight stereo models were derived which, at a distance of 2.50 meters from the object, worked out to an average scale of 1:20 with a relationship of base-distance of circa 1:3. The concatenation of the slightly convergent stereo models, delineates a plan with a sort of ellipse around the sculpture's vertical axis and was produced with control points placed along the sides of the statue using rigid supports aligned on its front to back axis. The collimation targets were printed on transparent acetate so that they could be easily collimated in counterpoised models and inserted in holes that had been made on four metal panels as shown in figure 15 . The accuracy in the determination of control points was ± 0.2 mm. In every model, the determination of the absolute reference system was further verified through the collimation, in terms of distance, of targets which had been arranged on an aluminum bar. On the rectangular-section bar, four holes were made, on which precision calibration with repeated measurements (± 0.1 mm) was performed. Circular targets larger than the holes were used to make them more visible and thereby facilitate their identification on the stereo models. The uniform illumination needed while the photographs were being taken was ensured by properly positioning lights. The orientation of the models obtained made it possible to measure the relative distances between fully identifiable key points visible in stereoscopy, which it was possible to compare with the values measured on the model obtained with three-dimensional scanning.

Figure 15 - Photogrammetry setup: measurement targets nearby the manufact: a) front view; b) rear view

4. Comparison between photogrammetry and 3D model: methods

The main purpose in the work presented was to verify through photogrammetry the results obtained in the modelling of structured-light projection techniques in order to refine the procedures used for acquiring digital models that will allow us to obtain a global accuracy consistent with the scanner instrumentation used. To obtain in the final model a good correlation of this kind of high resolution data, all series of 3D cloud points data need a complex post-elaboration and a number of overlapping control points. For this purpose conventional topographic and photogrammetric techniques were implemented to get a general set of high precision 3D target data. The experiments performed with both techniques gave two sets of measurements defined in a couple of different reference systems. Therefore, in order to avoid the problem of aligning them, we chose to measure some distances between

points clearly recognizable on both the 3D shells and the metric photographs, employing, as targets, features present on the statue's surface such as wood-worm holes. We tried to reduce the operator selection error employing 3D scans at resolution higher than that used for the "skeleton" model, such as the metric images at the maximum optical zoom level had a scale similar to the one of the single high resolution 3D images. Also, from the latter set of scans, we chose the ones taken in the same direction used for the stereo photogrammetric survey. Since raw 3D images have their own reference system, unrelated to the one of the whole model, we aligned each high-resolution point cloud on the "skeleton" model through the "Polyworks" software, producing in this way a rototraslation matrix for each aligned image, which allows to map the spatial coordinates of the raw image in a common reference system for the whole model. We developed a specific piece of software to operate a pixel selection on the bitmap image associated to the point cloud, which stores the 3D coordinates and transfers them into the reference system of the model, producing also a bitmap file with a well visible target superimposed on the gray-level image. Once a couple of raw points has been selected (even from different 3D acquisitions), the same software calculates the distance between them in the model reference system. A couple of "stamped" images, as the two in Figure 16, are then passed to the photogrammetry operator for the following manual selection of the corresponding points.
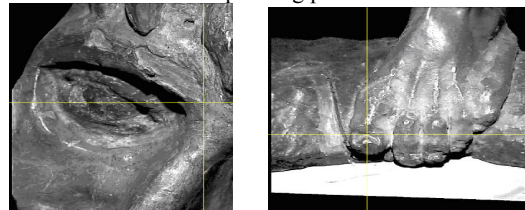

Figure 16 – Images generated by the point selection procedure.

5. Integration and elaboration data

Other kinds of problems concerning the acquisition methodology and specifically correlated with the survey object were encountered. The "Maddalena" statue was originally laminated in gold, and here and there some residual portion of the golden surface has caused some bad light reflections; in that limited zone it was impossible to obtain a correct 3D scanning data. Similar problems occurs with conventional photogrammetric survey methods, but the restitution work pass in this case through the human interpretation and generally the different impact of the incident light in each image of the stereo pairs offer the possibility of an acceptable reading of that unclear data. Undesirable light reflections are usual in a similar close range survey and may occur also with other kinds of scanner instruments and a feasible strategy for limiting this kind of problems may involve the parallel use of photogrammetric survey. In post editing the introduction of sections and contour lines will support the correct integration of 3D cloud point lacunae and may help to correct the excessive smoothing of the discontinuity records forcing the TIN routine to respect the *wire frame* contour lines in the compilation of a 3D model surface. The final model can be easily menage by several software modules for a fast exploration in any 3D point of view; in addition orthophoto overlay offer measuring and drawing utilities for edit conservation and restoration themes. Has to be observed that restitution of generic 3D points with a 2D monitor environment may be affected by parallax phenomenal error. In our case of study the two acquiring methods has offered the possibility to verify the correct representation of details by

correlation with some 3D vectors recorded with a conventional photogrammetric stereoplotter workstation.(Galileo Digicart 40)

6. Digital Photogrammetry test

When object quality aspects are more important than quantitative aspects, a 3D model generation can be performed using some low cost digital photogrammetric software. For this kind of use we have first performed some tests in our laboratory. A high precision system of targets simulating a close range survey was used to verify the degradation between a photogrammetric-analytical stereoplotting procedure and its digital transfer. With a commercial Umax scanner (MirageII 1400 dpi) a stereo-pair were converted to obtain a digital stereo model; calibration and stereo digital plotting was performed using the two programs: Stereoview-MenciSoftware and Stereometric-Siscam Software. In our tests we have encountered about a factor 10 of degradation in the accuracy data (from 0.2 to 2 mm s.q.m; d=2.5 m) A relevant additional noise factor must be considered for the production of a 3D model (DEM) with the auto correlation procedure; for a better result, introducing some sections and contour lines captured from the digital model may improve the final quality. Obviously, as shown in the following images, the model appearance isn't comparable to 3D clouds points data, but it could be acceptable for a requested accuracy of some millimetres.
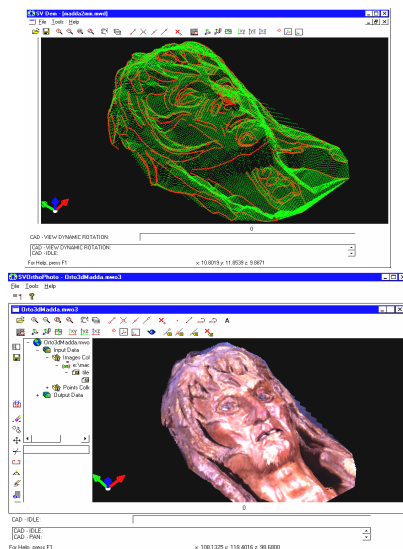

Fig. 17 D.E.M, contour lines and 3D orthophoto (F.Costantino)

7. Conclusions

Stereo photogrammetry in conjunction with a 3D scanning system characterised by versatility, speed and resolution has offered in this work a complete set of high quality results with a low cost procedure. Photogrammetric 3D data were used to arrange a general set of high precision reference points for all the different cloud point data, to reduce smoothing during the 3D TIN texture elaboration and then to verify some critical elements in the final model. Low cost digital cameras increase rapidly their performance; promoting their implementation in close range survey is a work in progress with an expansive perspective. Similar evolving situation can be found in the constant evolution of 3D software management systems and testing new products may help to solve the well known problems of compatibility between old and new data formats in the perspective of an interactive management of 3D cloud point data, orthophoto and digital stereo photogrammetry in a single work station software. As a general approach in the actual scientific world, system and methods developed in the technical background of different scientific discipline become closer and tend to form interdisciplinary sector of study; technical needs of final users evolve rapidly and old approaches to survey problems are renewed by the new instruments and in this scenario new methods have always to be found to reinterpret some useful consolidate procedure.

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