USE OF HISTORICAL IMAGES FOR THE DOCUMENTATION AND THE METRICAL STUDY OF CULTURAL HERITAGE BY MEANS OF DIGITAL PHOTOGRAMMETRIC TECHNIQUES

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ABSTRACT:

The use of digital photogrammetry in recording and documentation of archaeological sites, historical structures and objects, offers nowadays a wide range of possibilities in terms of data acquisition (semi-metric or consumer digital cameras, digital stereo-camera systems,…), data processing (monoscopic or stereoscopic plotting, 3D model reconstruction,…) and representation (orthophotos, photo-textured 3D models,…). By means of photogrammetry is in fact possible not only an accurate geometric reconstruction, but also the collection of other important data for the knowledge of Cultural Heritage objects and structures (colors, texture and materials, damage state, …), useful also to support conservation and restoration activities.
On the other hand, restoration activities have been in some cases carried out in the past without leaving appropriate documentation, and changing some object aspects: in these cases the availability of historical images is often the only way to study and reconstruct the "past". Together with the simple qualitative analysis of some object characteristics, like for example the changes and the decay in the used material or in the decorations, the powerful tools today offered by the digital photogrammetric systems permit in fact the metric reconstruction of the object state also in past epochs, using historical imagery like digitized old photos and illustrations from books. Obviously the key phase in this process is the calibration of these images, often critical because of many problems: the low quality of the available pictures in terms of resolution and radiometry, the lack of informations about the images (acquisition period and method, camera information), the difficulty in finding accurate data like constraints or control points considered valid also in the epoch of interest, the difficulty of modeling all the distortions or deformations suffered by the images in the time course.
The paper is related to a multi-disciplinary project started in 1999, within a collaboration established between the University of Bologna and the Archaeological Superintendence of Pompeii. In the frame of this project was activated a rigorous survey, by the integration of different geomatic techniques (GPS, Laser Scanning, Photogrammetry, Visual Reality), of the most significant nymphaea of Ercolano and Pompeii (Naples); these are elements of remarkable archaeological and artistic value and presenting various geometric characteristics, needing a very accurate description of the decorative apparatus, often entrusted to particularly complex and rich mosaics.
In particular are here described the studies conducted about the *Lararium* from the "House of the Skeleton" in Ercolano.
This object is interesting for this kind of study because it presents some static problems and it has suffered during the excavations many interventions and changes, until the complete disassembly and successive replacement in situ.
Three images of the 1927-1928 periods were chosen with the aim of creating a historical 3D model of the object, comparable with the actual model, derived by the photogrammetric survey conducted in the 2006 campaign.
After an experimentation phase necessary to define the most suitable methods to perform the images calibration (single or multi photo, with the use of geometric constraints or also with the use of control points), a valid set of parameters was found and a complete model of the object was reconstructed, representative of the metric and qualitative conditions in this epoch.
The dimensional comparison between the two temporal situations (historical and actual) has also permitted qualitative and quantitative considerations about the differences, offering a very important tool for the evaluation of the past restorations and useful also to plan all the future interventions.

1. INTRODUCTION

Old maps and photographs have traditionally been a subject of study by the historians. These objects currently receive attention of scientist as well; in particular photogrammetry and digital image processing are being used to extract qualitative and metrical information from historical images. The applications are different: landslides monitoring (Chandler & Brunsden, 1995; Zanutta et al., 2006); glaciers monitoring (D'Agata & Zanutta, 2007; Kääb and Funk, 1999); coastal change monitoring; change detection in urban and vegetation studies; cultural heritage knowledge for structural purposes (Capra et al., 1999).
In the case of historical images processing, the first problem is the difficulty in finding appropriate material in good

conservation stage, evaluating its quality and making it available for photogrammetric elaboration.
After this preliminary phase, it becomes necessary to perform for each image the inner and exterior orientation procedures; a possible solution to the lack of the camera parameters and of data for external orientation, is the approach of self-calibrating bundle block adjustment techniques, with additional parameters models; starting from approximate value of unknown parameters and from control points, acquired today but recognizable also in the "past", it is possible solve the orientation problem.
In the work, results of self-calibration procedure and subsequent processing on some old images of the *Lararium* from the House of the Skeleton in Ercolano are reported.

2. CASE STUDY AND METHODS

2.1 The *Lararium* from the House of the Skeleton

The research here described regards a project started in 1999, within a collaboration established between the University of Bologna and the Archaeological Superintendence of Pompeii. Starting originally from the study of the house known as "of the Centenary" in Pompeii, in the frame of this project was successively activated a rigorous survey by different geomatic techniques of the most significant nymphaea of Pompeii and Ercolano (Bitelli et al., 2001, 2002; Scagliarini et al., 2002; Coralini et al., 2006).

In this paper the subject of interest is the *Lararium* of the house known as "of the Skeleton", located in Ercolano (Figure 1)[*]. The name of this house, partly excavated in the 19th century and completely unearthed in the period 1927 – 1929, derives from the skeleton found on the top floor on 1831 (Maiuri, 1958).

The house is characterized by a *Nymphaeum*, surveyed by photogrammetry during the 2006 campaign and, in a near small courtyard, a *Lararium:* a wall painting of a garden, surrounding a niche framed by an aedicula and decorated with mosaics and shells.

The *Lararium* presents today some important structural problems, as pointed out by the substaining scaffoldings, and it has suffered during the excavations many interventions and changes, until the complete disassembly and successive replacement in situ. For these reasons a study about the current state and a comparison with the past, documented by historical images, could constitute an interesting tool for the object documentation and also to plan future interventions.
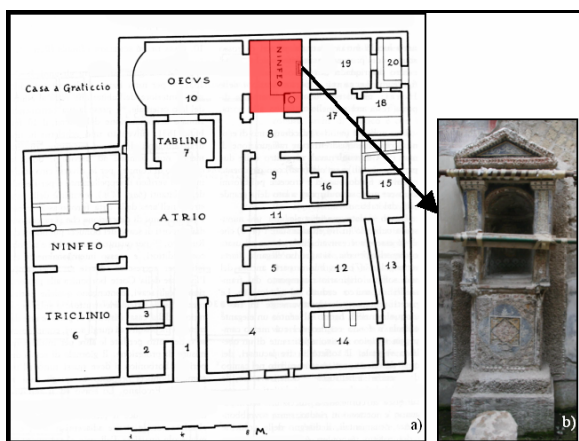

Figure 1. House "of the Skeleton" plan (a) and an image of *Lararium* (b).

2.2 Bundle adjustment with image self-calibration

An accurate and versatile orientation approach in Photogrammetry is the bundle adjustment. The mathematical basis is the collinearity model, that needs to be extended in order to take into account systematic errors that may occur during the acquisition phase, leading to a self-calibrating bundle adjustment (Kraus, 1997). These errors can be described by correction terms for the image coordinates, which are functions of some additional parameters; these are

usually in number of 10 and model the interior orientation (focal length and principal point coordinates), the scale factor uncertainty in pixel spacing (shape factor), the non-orthogonality of the image coordinate system (shear factor), the radial and the decentering lens distortions.

The extended collinearity equations assume the following form:

$$x - x_0 = -c \cdot f_x(x,y) + \Delta x$$
$$y - y_0 = -c \cdot f_y(x,y) + \Delta y \qquad (1)$$

where
- x, y = the point image coordinates
- x_0, y_0 = the image coordinates of the camera principal point
- c = focal length
- f = function that contains the exterior orientation parameters and the object point coordinates
- $\Delta x, \Delta y$ = corrections terms, functions of the additional parameters and image point coordinates

Starting from the approssimate value of the unknown parameters and from the known coordinates of some control points, it is possible to solve the adjustment, estimating the additional parameters as well as position and orientation of the camera(s) and object coordinates of all other observed points.

3. HISTORICAL IMAGES CALIBRATION

3.1 Data processing

Among the numerous available historical images of the *Lararium*, three were chosen for the processing; in particular these are dated about to the same period around the 1920, immediately after the excavations, and present a good convergence between the optical axes, important requirement for a good calibration. One image reproduces the object upper part, so it was used only to strengthen the solution, but was not calibrated, also because of its uselessness in object modeling.

The two calibrated images, realized maybe by means of different cameras, are here reported; any additional information is available.
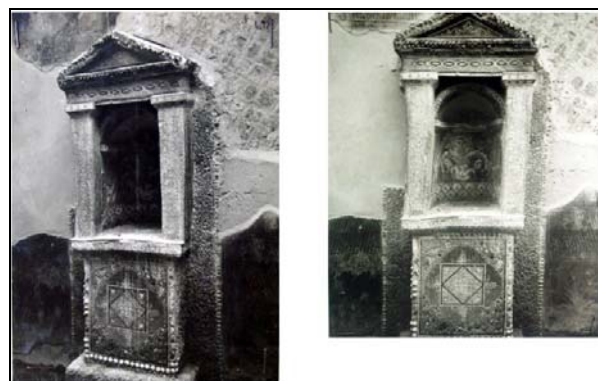

Figure 2. The two historical images.

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[*] The house plan is from Neurber N., "L'architettura delle fontane e dei ninfei dell'Italia antica", Naples, 1965.

In order to perform the calibration of the images, the commercial software PhotoModeler Pro 5.2.3 (EOS Systems Inc., 2004) was used; by the Inverse Camera module, it permits to determine the 5 main unknown parameters for each photograph: focal length, principal point coordinates and image format size.

Considering the possibility of a displacement during the years between the object and the standing wall, it was chosen a solving scheme that uses control points on the *Lararium* and geometric constraints on the wall at the back.

All these informations derive from the photogrammetric survey conducted in Ercolano during the 2006; in particular for the *Lararium* restitution, six images acquired by a calibrated wide–angle 8Mpixel digital camera Canon EOS 350D, were oriented and processed by the digital photogrammetric workstation Z-Map (Menci Software, Italy); the obtained final products, vector drawing (Figure 3), digital surface model (DSM) and orthophoto, present a medium scale of about 1:100.
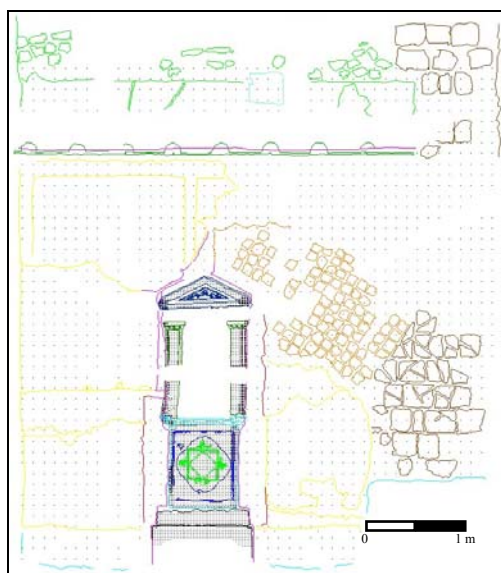

Figure 3. Vector restitution and DSM of the *Lararium* at the current state (2006 survey).

From the current 3D model, seven points contemporary visible also on the historical images were measured in stereoscopic mode, with the hypothesis of considering these points unmodified during the elapsed time period (1920-2006).

All the geometric informations used for image calibration are shown in Figure 4.

Besides the control points, a large number of tie points (84) were collimated on the three historical images, in order to permit the convergence to a good solution; distance constraints on the wall were also considered.
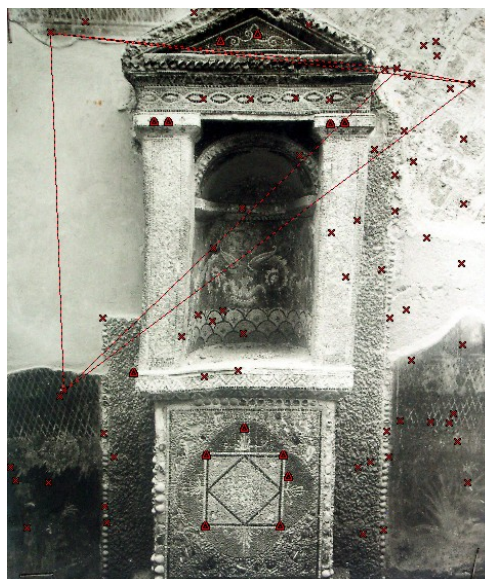

Figure 4. The geometric data used for historical images calibration (the triangles are the control points, the crosses are the tie points and the lines indicate the distance constraints).

Nevertheless the difficulties related to the discordance between the actual and the old situation, particularly for the wall pictures, the process succeeded.

The two obtained data sets are reported in the following table.

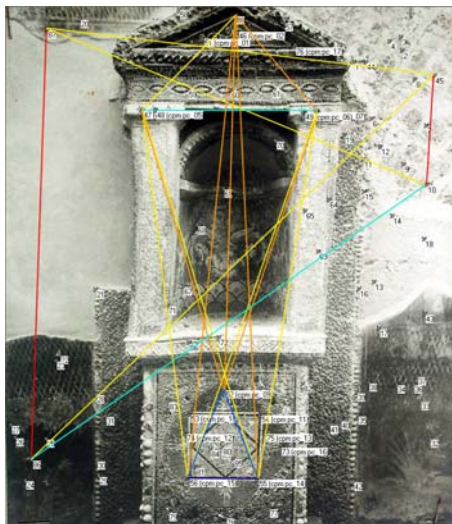|	Photo 1		Photo 2	
Focal length (mm)	63.2129		62.8682	
Format size (mm)	Width 37.1873	Height 41.9500	Width 43.6997	Height 49.2487
Principal point coordinates (mm)	X 20.3648	Y 39.1929	X 13.3529	Y 23.2701

Table 1. The obtained interior orientation parameters for the two processed images.

3.2 Data analysis and inspection

The data obtained by the calibration phase needed an inspection, in order to evaluate the possibility of their use for the metric restitution of the "old" *Lararium*. As the truth in our case study we assumed the current 3D model.

A statistical study about the differences between a large number of distances taken both on the actual and on the old model permitted a first accuracy evaluation (figure 5).

Figure 5. Graphical representation from the comparison of some differences in distances between current and old model; red and blue colors indicate problematic data in shrinkage and stretching respectively.

The comparison between the two models doesn't present particular discrepancies. It's possible to underline that the two historical images present, especially at the left and right sides, a general stretching, while in the basement central part there is a shrinkage from today to the past.

These deformations could be attributed to different causes:

- the object displacement during the periods among the shooting of the three images;
- the non-optimal geometrical distribution of the control points, due to difficulties in their choice;
- the historical digital images derive from a scanning process from book copy; the induced deformations have been not considered;
- lens radial distortion, here not solved because not considered by the calibration model adopted;
- the control points are measured in stereoscopic way on the current model, so their coordinates depend directly to the operator sensibility, and moreover they are not collected at the same time of the images.

The mean value of the differences between the most recent and the oldest model distances (figure 5) is in the order of 2 centimeters, but some large values are present due to the above mentioned causes.

4. HISTORICAL 3D MODEL CREATION

4.1 Data processing

After the calibration of the historical images, the restitution has needed the individuation of a conspicuous number of homologous points.

All the main discontinuities and some of the decorative elements have been plotted, without any interpretation or modeling by simplified geometric forms, but only measuring the visible points, with the aim of having a final product absolutely corresponding to the real state and suitable for an accurate analysis of the object.

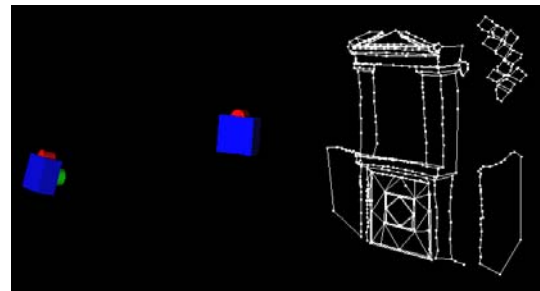The created model has afterwards been scaled by means of some distance deduced from the actual model.

Figure 6. The points and lines measured for *Lararium* restitution and the cameras position.
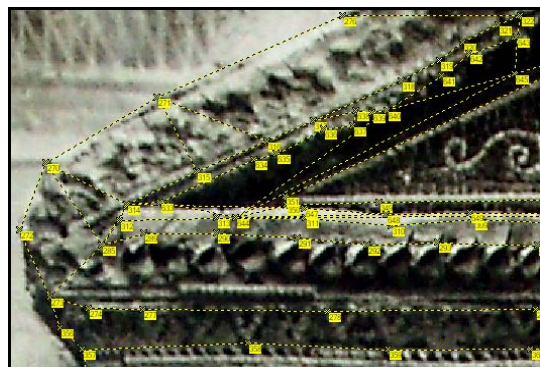

Figure 7. A particular of *Lararium* tympanum, with in evidence measured points and lines.

The problems encountered in this phase have been related especially to the low quality of the images, which don't present an adequate geometric resolution, and with the not good network configuration, that made impossible the restitution of all particulars on the object left side.
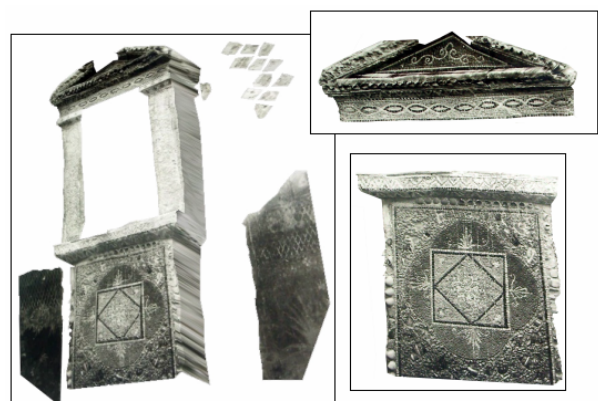

Figure 8. The whole 3D historical model and on the right side a particular of tympanum and basement.

4.2 Comparison between historical and current models

The two obtained models, historical and present, have been compared within a CAD platform, in order to make considerations about possible displacements or discrepancies. A similarity transformation with a scale factor of 1 has been applied to the historical model, in order to make coincident the *Lararium* basement, in particular the central decoration; this on the base of a qualitative analysis on the available images, that let think that the basement is the only part that doesn't suffer any re-movement during the restorations.

As shown in figure 9, the historical model is well scaled, with only a little discrepancy on the right pilaster, resulting translated and lightly longer (2 centimeters on the entire length, 17 centimeters instead of 15).

Regarding the depth, a good check is possible on the basement and a little difference for the tympanum; besides for the pillars, it is evident a rotations, homogeneous in absolute value; the right holds out of 3 centimeters and the left comes within at the same value.
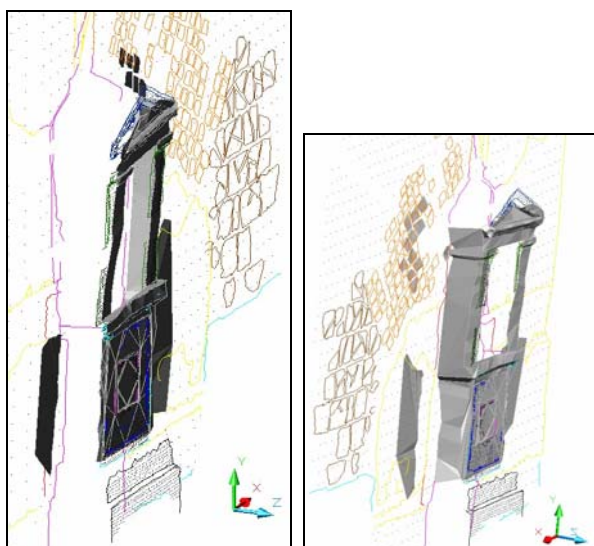

Figure 9. Superimposition between historical (gray color) and current (colored vector drawing) model (left view and right view).

An analysis between the restituted portions on the wall was not possible, due to the not good accuracy of the points collimated in this area, presenting high residuals.

Considering that the orientation phase has pointed out errors in the order of some centimeters, it is difficult the attribution of the found discrepancies to a real object displacement, even if the qualitative analysis of the images seems validate the idea that the *Lararium* upper part has been taken off for restoration and then re-placed, while the basement presents evident decay, especially in the decorative apparatus.

5. CONCLUSIONS AND FUTURE WORKS

A standard methodology of survey and representation was realized for the *Lararium* of the house known as "of the Skeleton", located in Ercolano, (Naples, Italy). Restitution was carried out by stereoscopic procedure by means of a digital photogrammetric workstation, that produce numerical and raster elaborates with high degree of detail. This photogrammetric survey has constituted a datum to orient and use, in metric way, historical photos of the same object, covering a time span of almost 80 years.

Several were the problems to solve related to the limited number of historical images available and the difficulty to identify control points or to test geometric constraints on the multi-temporal photos.

In spite of the considerable limitations in terms of amount and quality of the information, a metric model relative to the past has been obtained.

The comparative analysis of elaborates evidenced, from the qualitative point of view, a progressive deterioration of the lower part of the *Lararium* and the decorations, and a decay of wall paintings, in the bottom.

From a metric point of view, comparing historical and actual model, it can be observed a correspondence of the bottom of *Lararium* and a rigid rotation of the pillars in the top that evidence a probable non accurate re-collocation after the restoration procedure.

The case of study on which the archival photogrammetric technique has been applied, rather than having only an archaeological interest, has to be considered an approach to understand the metric evolution of objects of architectonic historical interest.

Better results can be clearly obtained when more data are available. In this sense, all the experiences oriented towards the creation of image databases constituted by different kind of photographic and photogrammetric material realized in the past by institutions and private (e.g. tourists) must be encouraged (amateur photos, scanned books illustrations, old surveys, etc.).

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