Integrated survey methods to obtain interpretative models aimed at cultural heritage conservation

INTEGRATED SURVEY METHODS TO OBTAIN INTERPRETATIVE MODELS AIMED AT CULTURAL HERITAGE CONSERVATION

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ABSTRACT:

New tridimensional models can be useful for programs of conservation of cultural heritage. Models make easier the understanding and the communication of particularly shaped architectonic structures, through a synthetic vision.
Our aim is to integrate different survey techniques (with their own accuracy) with computer graphics technologies, to create a dynamic 3D model representing phenomena and processes to be considered for preservation and restoration planning.
We show some experiences of survey on different periods structures, stressing the close relationship between survey techniques and conservation problems:

- Some buildings of "Borgo del Valentino" (Torino), a neomedioeval complex, with structural problems that make an accurate survey necessary in order to restore it;
- Povil Casaforte (Aosta), a medioeval building, in which metric survey has been a support for stratigraphic analysis of the complex wall texture;
- Villa Raggio (Asti), a 1900's villa, where we used a digital direct photogrammetry (control points are only used to verify the results).

The model obtained can combine two different needs. On the one hand it had to be accurate in order to guarantee the usability for different technical purposes such as following the reconstruction projects or to schedule the routine maintenance and simulating technical installation. On the other hand it had to be photorealistic and user-friendly for an easy and effective representation, useful in virtual reality and other similar application.

1. INTRODUCTION

Every science needs to survey data end every scientific experiment needs to organize them; this is true also in the investigation of old buildings. As everyboby knows the survey has a gnoseological and epistemological function and it doesn't exhaust itself in the knowledge of geometry and in the measurement operation. Different geometries exist of the same object; we need to know what kind of geometry and what kind of measures are enough to describe, in exhaustive way, cultural heritage: this is a *critical* operation. The next step is how to connect the specific measure with a theory of observation: this involves *methodological* aspects. Finally there are *rapresentation* aspects to evaluate how to describe the same geometry. So, despite the accuracy raising and the new techniques that allow us to acquire the greates amount of data as possible, e.g. laser scanner technology, the survey assumes specific connotates in function of different aims; the result is the inability and uselessness of an objective and complete survey.
Therefore is required an act of conscientous and complex evaluation, that is not reduced to a definition of the measurament, but that is finalized having total knowledge of the object to be explored, deciding on the information that is to be obtained by means of observation.
The primacy of geometry and of the measure does not complete the whole praxis of the survey.
There are other measurable components: materials, patologies, colors, phisical and chimical phenomena in general, that need to be rapresented on the geometric base.
Furthermore, these particular objects cannot be read and studied applying a stereotype that locates symmetries, orders, hierarchies, classification, repetition and series: cultural heritage needs a case by case study, in accordance with the aims, rappresentation scale and accuracy. The general criteria is that all the data must be verifiable.
This implies the exact procedure and instrument description to give objectivity to the entire work.

Interdisciplinary character of the acknowledgement process orients the data acquisition procedures and in order to comply with requirements of the specific case of study involves different survey techniques and different measuring instruments.
New possibilities and new questions have been brought to light using the ever increasing scientific and technological innovations in the field of surveying, imaging and database management: for instance, the introduction of laser scanner in architectonic and archeological survey.
Pending the knowledge of the real usability of the laser scanner data model with some work in progress, here are presented three different metric approaches of heritage knowledge will show in order to meet three different requirements: survey to describe historic evolution and support restoration procedures; survey to higthlight stratigraphy and materic consistence and rapid survey in emergency cases.

2. DATA COLLECTION

For this purpose, instruments were used that would allow us to have satisfactory results linking the advantages deriving from the modern topographic method (having a very "detailed" measurement programme of the form) to ones deriving from the use of digital images (both for the photogrammetry and for the qualitative characterization of the surface).

2.1 Topographic survey

An appropriate network has been applied in all cases of the study; vertices and topology have been projected to guarantee the collimation of all necessary points to describe form and geometry of the structure. Survey of details is an onerous phase in old buildings: the problem of measuring is moved to criteria of point selection. In the process of measurement, the elements deriving from it have enabled a location of the points and the lines in the space. The approximation grade is linked with a significance and a quality of the selected points. Very often a design attenuates or accentuates the geometry leading to formulation of the erroneus interpretation: non-respected alignments, forced or non-measured symmetries.
A total station, without reflecting prism, has been the instrument most used used in this kind of survey. Free from the requirement to signal the points to be located, it became possible to concentrate on the selection of the same; this imposes an accurate plan of measurement of a detail. In such a way it avoids the risk of not having sufficient data to describe the shapes or, on the contrary, to have an amount of information requiring costly and patient work on simplification of the graphic design. During the recognition phase, drafts have been issued with points, duly numbered and linked among them; these points should lead to a signifcant line. In the subsequent acquisition stage, the possibility of using an identification code allowed the pre-management of the data into files that group the families of the points and that have been memorized at different layers in order to facilitate the management in cad software. File management is fundamental: a subject is described by means of the points among which the linear interpolation is programmed; a descriptive structure that derives from there defines wireframe lines, so an operator decides what should be in-between the lines. The same lines are, therefore, a result of the choices aimed at the creation of a model that, as always, is a simplification and so a scheme of reality, furnished by a sufficient descriptive accuracy in order to respond to the research objectives. It is advisable to work with a very clear project with regard to a data bank that, step by step, is being implemented. In an tree shaped organisation, for example, it is possible to distinguish the lines of different nature: structural, wall apparatus, the profiles of ornaments and decorations etc..., changing the rules, already consolidated ones, of photogrammetric acquisition from the observation of the model to observation of the reality.

2.2 Photogrammetric survey

As well-known, photogrammetry has numerous positive attributes in architectural recording, however there are some limitation of the photogrammetric product that digital techniques allow us to overcome. In any case a vast volume of primary data is quickly captured and the problem of chosing what kind of data, geometric or thematic, has to be plotted, is posticipated and can be discussed in the laboratory in accordance with the users survey. Digital image processing has simplified the pratical approach to photogrammetric survey in such a way that even non experts in photogrammetry can perform the plotting and interpretation phases. So, while geometric problems can be understood by photogrammetrist, the other aspects of the survey can be performed by conservation specialists.
With digital techniques it is possible to distinguish acquisition unit (images, coordinates to orient acquired images, measure and computation to estimate orientation parameters), from restitution unit (finding interesting points, classifying information in logical levels representing results in an efficient way). All the topics of the acquisition unit requires a specific technical expertise and can be correctly designed and executed by the photogrammetrist.
In the same way all the topics of restitution units can be performed by the operators who can study other heritage aspects indipendently from the acquisition and orientation phases.
Another simplification has been introduced with a return to direct photogrammetry in which the absence of control points allows to face up to emergency survey where the necessity to collect on the field, as much information as possible, as quickly as possible, is often conflicting with high quality metric results. We present one example, as work in progress, of this direct photogrammetry application.

2.3 Image rectification

To the necessary critical selection that makes a measurement and the graphic design an instrument of immense use have also been added the valuable characteristics of a photo. A passage from analogical to digital allows, nowadays, the more flexible use of a photo imaging that releases a complete and "global memory" in camparison to analytical designs achieved by topographic measurement.
Aiming at a reduction of field work, and in order to document in the best possible way the metric difference of the surfaces, digital rectification can be used thanks to which it is possible to define in detail the values achieved outlining the areas where the contours have been measured by topographic or photogrammetric use of points. A rectified image can be used to integrate the other kind of information either in evaluation of the surface conservation state or in 3D model texturing deriving from photogrammetric restitution.
We present one example of rectified image use to furnish a base to analyze the wall texture of Povil Casaforte (Aosta) in a stratigraphic study of the facades.

3. OUTPUTS

The most commonly applied products in cultural heritage continues to be the *line drawing* produced from topographic or photogrammetric plotter, normally at 1:20 or 1:50 scale. In these products we have to pay attention to the quality of the drawing; to obtain a useful drawing for conservation requests is demanding for the operator and can be achieved in practice by working with large scales. A key change in working methods has taken place relating to the digital capture of data, making the outputs of the photogrammetric process much more flexible. Another implication of this change is that output as *three dimensional model* is now commonplace.
The *rectified photography* method continues to provide a valued product as a base for a thematic survey or as a texture for 3D model while *true digital orthophoto* (Boccardo et al., 2001) is becoming a powerful instrument of representation in architectural application thanks to a new approach which uses several images and a DDEM (Dense DEM) of the object in order to produce an orthogonal projection of complex objects. It is necessary to remember as in the heritage field, photography (image) is a record of great significance. At the very large scale extracting information is problematic and the object complexity requires personal interpretation. A new digital product, *a stereo-photomap* (Dequal et al., 1999) is now available to explore direclty the photogrammetric model. All the images of a block, previously oriented, can be explored as a unique large stereomedel. This new instrument allows the conservator "to navigate" around a building without any need of a preliminary restitution: they can select and measure directly only what is interesting for their study. Just as with the long history of photo-interpretation, direct stereoscopic

examination not only provides much information, but is a very legitimate end result in itself.

4. SURVEY AS STUDY OF HISTORIC BUILDING EVOLUTION

The Borgo del Valentino, an accurate reconstruction of an medioveal castle and village of the Aosta Valley and Piedmont, was built in 1884 as part of 1st Italian General Exibition. The most important planner was Alfredo D'Andrade, one of the major protagonists in the stylistic restoration of the post-unitary Italy.
His aim was to offer an outline of the principal aspects of civil and military architecture of the XV century in the Savoy territory.
The building complex which underwent the most significant transformation is San Giorgio tavern, our case study.
The recent maintenance works on Borgo del Valentino, gave an opportunity to apply a new surveying campaign ending up, on the one hand, in documentation and control of the restoration procedures that are in progress, and, on the other hand, in analysing the geometry of the building in relation to the construction stages and the subsequent adaptations that were made thereafter. A 3D model can help to investigate and then to comunicate how a structure is built up and transformed.

Figure 1. A view (1884) from the Po river of the Borgo del Valentino (photo: fondo D'Andrade)

4.1 Data acquisition

The first phase of this survey was dedicated to the planning and realization of a traverse to fit the whole site, consisting in total of 14 vertices, organized according to two different levels, main and secondary and characterized by high precision (points accuracy inferior to the centimetre) (Figure 2). Along with the traverse, all detail points necessary to elaborate a 3D model and photographic control points to use digital images rectification as model texture were surveyed (with a reflector less total station).

Figure 2. The plan of the Borgo del Valentino: scheme of the main and secondary traverse.

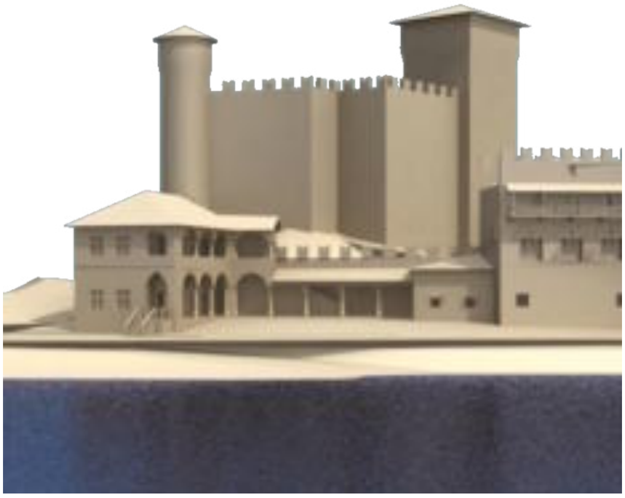
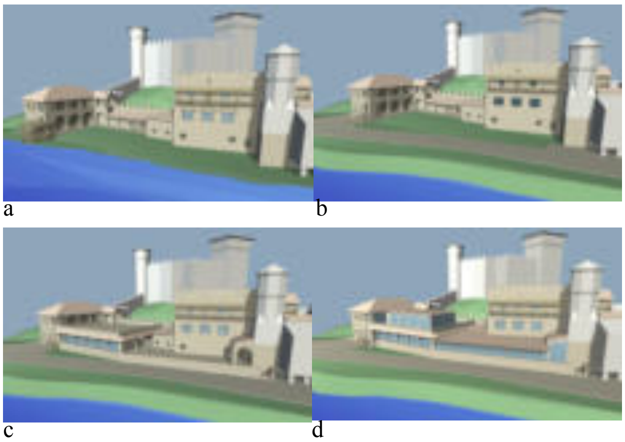


Figure 3. 3D reconstruction of the buiding complex

Figure 4. The green space at the back of the tavern is represented in one lithograpy of the period and in a 3D model render view.



a b

c d

Figure 5. Simulation of S. Giorgio tavern in four different historic phases: (a) in 1884; (b) from 1900 to 1930, when a street was constructed in order to safeguard the foundations of the buildings from the river overflowings; (c) from 1930 to 1950, after postwar reconstruction; (d) from 1950 to 2003 after next elevation.

4.2 Plotting

The 3D data obtained using this methodology constitute a valuable documentation for any future control references or subsequent modifications. Once the plotted image has been made, it would be difficult to distinguish those features that have been measured from the ones that are the result of subsequent interpretations. Therefore it is necessary to preserve accurately a file containing the justification documents: the field book, the calculations and the drafts that will allow an identification of the holes, interpolations and secure elements, and therefore allowing a later control of the validity of information. On the other hand, even thougt the

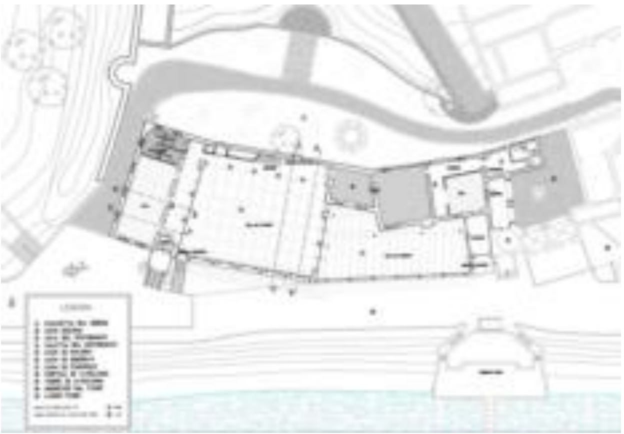


Figure 6. An example of 2D plan to link maintenance programme (1:50 scale).

acquiring and elaboration systems are able to make the 3D structures it is also true that the plotted designs that are currently requested, is a conventionally orthogonal two-dimensional drawings. Therefore, it may be necessary to return to iconic models adequate to the possible designs and to the space-time data. At present using currently available commercial CAD software it is one thing to memorize the points in 3D in order to link polylines really in 3D, but the other thing is to create a design that would satisfy the descriptive requirements to the scales normally used in documentation and in projects of conservation (Figure 6).
So, starting from surveyed 3D points, a model of the actual situation has been produced and, supported by historical documents the three phases of building have been reconstructed (Figures 3,4,5).
Rectification images will be emploied to texturize the whole model. In parallel, a set of conventional orthographic maps were produced in order to supply a base for an executive conservation plan.

5. METRIC IMAGE AS A BASE FOR THEMATIC ANALYSYS

"Casaforte" are typical architectonic structures of the Valle d'Aosta defensive system in the Middle ages. They are military buildings or inferior aristocratic houses, but with castles characteristics. They can also be structures to protect food and to control agricultural products. Their initial planes are very simple but generally undergo great arrangement transformation. The first part is often a "donjon" with stone wall, wooden floor and particular local stone covering. Common aspects in Valle d'Aosta casafortes, between XIII and XV century, are: donjon, as first part of entire building; closed poligonal court; a series of successive buildings around the court with different use; single walls to close the perimeter. The finisch of doors, window jambs and architraves, always stone made, highlight the wish to embellish them with decorative elements. Povil casaforte is part of a well organized territory able to guarantee control and production.
The older part of Povil casaforte is the tower, built around 1200; then, other structures were made with residential and rural functions. The final arrangement is that of a complex, shaped like a horsershoe, around a rectangular court, where wall texture and decoration show different phases. An accurate metric survey is not enough to reconstruct the subsequent transformations: critical survey, supported by historic documents and stratigraphic analysis, can help us to know better this complex system.

5.1 Geometric survey

The starting point was a geometric base obtained by both topographic and photogrammetric methods, integrated with direct survey. The following were used:
- a topographic network of 10 vertices, organized in two different orders;

Figure 7. Topographic network and direct survey schema.

Figure 8. All measured details and control points.

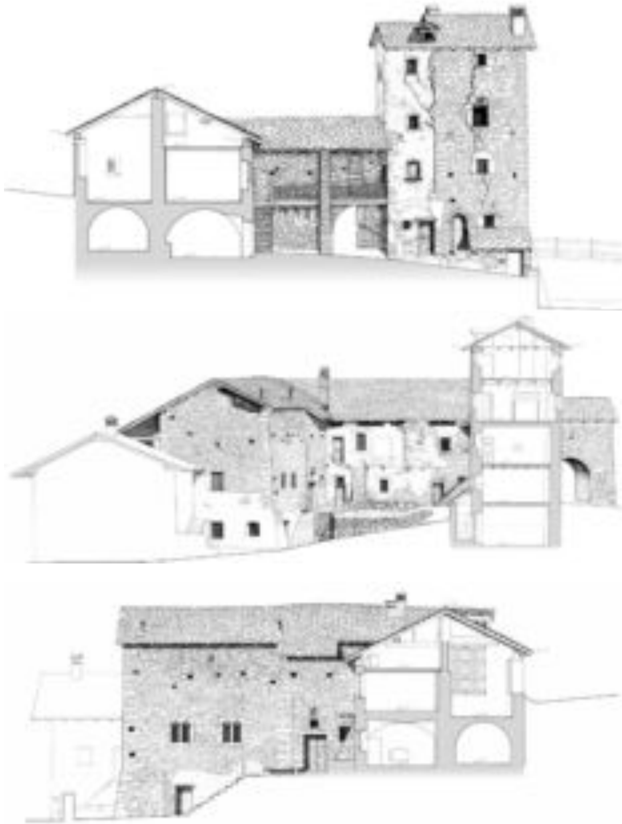


Figure 9. Some geometric sections of the Povil casaforte,

- a detailed survey of the external surfaces. We have to remember that there are a lot of irregular conditions due to static problems, materials decay and buiding transformations, so, an accurate choice of the points have been projected (Figure 8);
- a direct survey, using a diastimeter, of the interior, linked to the points on the openings, measured with a total station;
- the acquisition of control points aimed at image rectification of the facades. The survey of details and of the control points has been done using a reflectorless total station Leica TCR703;
- a photo campaign with a semimetric Rollei 6006 camera (f=40 mm).

6.1 Stratigraphic survey

This is a method taken from archeology with the difference that in architecture it is linked to the observation of what is visible; it is not a destructive analysis as in excavation. It consists of the annotation, on a graphic representation, of all building events, to

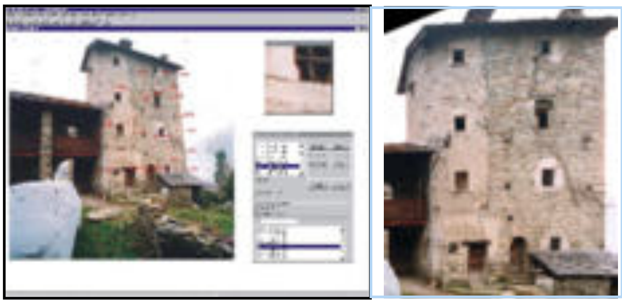


Figure 10. An example of digital image rectification; on the left are visible the used control points.

reconstruct its transformations through the exam of technical and morphological features of its elements. It is important to arrange a system of graphic conventions to show the principal events. It generally needs a bidimensional graphic support and, if the object of study is planary enough, image rectification is an exellent support to annote the observations (Figures10,13).
So it is possible to highlight, directly on the image, the stratigraphic units intended as a product of an omogeneous constructive action, positive or negative, on the analyzed wall. A single unit is characterized by surface, contour, volume, each having its specifications. Particular attention is given to the edges, elevations, openings, materials, finishings, processing. The aim

Figure 11. An example of stratigraphic survey on a facade; hypothesis of chronological reconstruction of the Povil Casaforte.

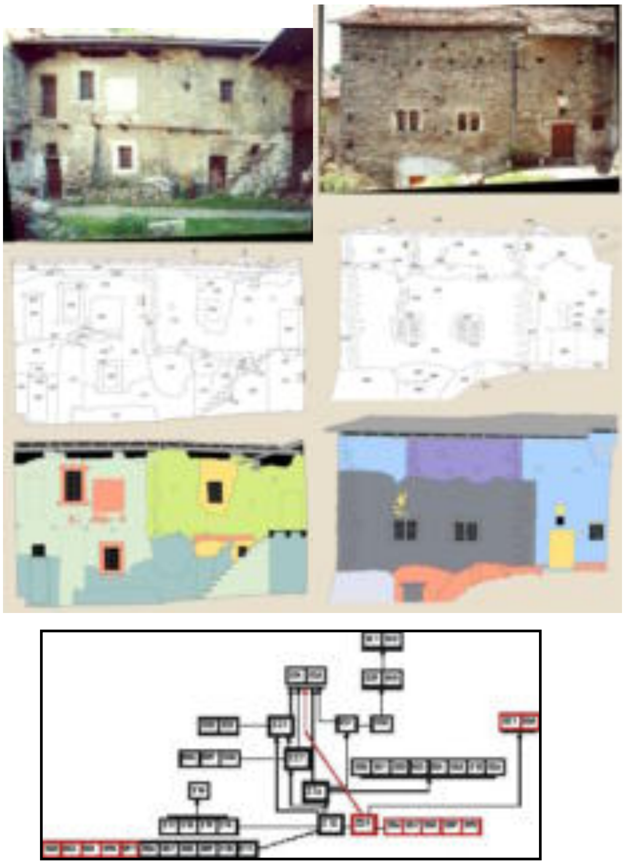


Figure 12. Stratigraphic survey on the north and west facades around the court. At the numbers are linked specifications on the single unit while different colors make a synthesis of most important constructive phases. Under them an example of matrix gives a stratigraphic sequence.

is to establish different layers in chronological sequences, and constructive actions were put in phases. It follows a Matrix (Harris) that shows the stratigraphic relations; it is really a work tool, the base on which interpretations can be carried out (Figure 12). To obtain an absolute dating it is necessary to refer either to historic documents or to direct sources: there are, for example, two types

Figure 13. The stratigraphy on the rectified image allows to see underlyng wall texture;

of windows in our case: the first one is a loop-hole, the original openings, the second one, richer and decorated, is the evidence of a transformation in a civil building. Also wall textures have been classified by taking a sample (1mx1m).
Vectorial data has been directly drafted from rectified images but it is also possible to represent them on the raster image, modifying colors or contrast to make visible the underlying texture. Another step can be to use a 3D model to show critical situations where the spatial continuity is important, for example, the edges or the relation between plan and elevations.

6. RAPID PHOTOGRAMMETRIC SYSTEM FOR EMERGENCY SURVEY

In emergency survey, the necessity to collect in the field as much informations as possible, as quickly as possible, is well known. These requirements sometimes conflict with the application of high quality metric techniques, but the research of solutions that represent an acceptable compromise must be carried out. We will show this work, in progress, using direct photogrammetry, even if the object of study is not exactly an emergency situation.

6.1 Data acquisition and processing system

Cyclop system (a Menci Software product) is a revision of a stereometric cameras principle. It enables non experts to acquire stereoimages and to visualize a stereomodel without control points, the most demanding survey phase. This opens up digital close range photogrammetry to a great number of promising application areas, for example in small object classification, in those cases where it is impossible to signalize the object and, in general, in emergency cases. The acquisition system is an horizontal metal bar on a tripod, with a sledge run, on which it is possible to put any type of camera (Figure14). To obtain stereoimages with known base and parallel optical axis, the sledge is fixed with a

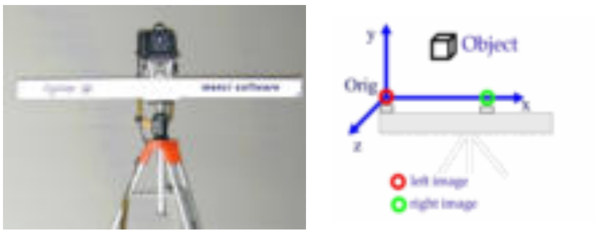


Figure 14. Acquisition unit and reference system.

calibrated distance block. This geometric configuration guarantees the alignment and the complanarity of the fiducial axis and assures the acquisition of stereoscopic pairs without height-parallax. This system allow the use of any kind of camera in order to satisfy the requirements of the survey. It is equipped with a specific software (SVCyclop) that allows the immediate plotting without orientation phases. Required data are: a couple of images, cameras distance, approximate distance from the object and camera inner orientation. Measurements and vectorial restitution are possible either in stereoscopic mode, with appropriate hardware, or in monoscopic mode; in this case one image is fixed while the other

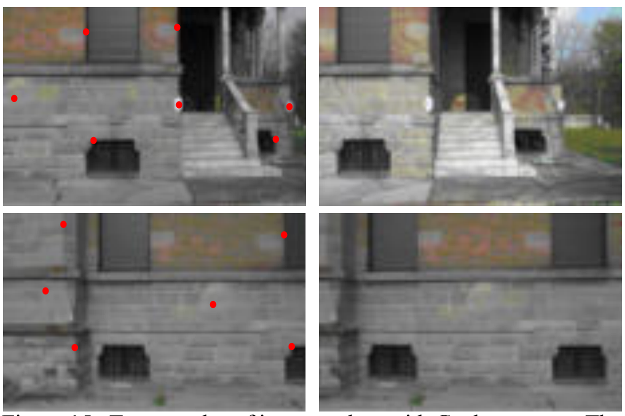


Figure 15. Two couples of images taken with Cyclop system. The points on the images, have only been used to control the results.

Figure 16. Restitution of three models with SvCyclop.

can be moved in a window with a collimation mark. Acting on the elevation it is possible to eliminate horizontal parallax, moving the second image along the epipolar line. Image matching alghoritms support the process.

6.2 An application

The system, already tested in the small objects survey (Marino, Tucci, 2002), has been used to survey the facades of Villa Raggio in Asti (Figure15). A calibrated Nikon D1 (f=24mm) has been used at different distances. To cover entire buildings, 3 strips for every facade have been acquired, obtaining different model scale. A topographic survey has been carried out to measure control points to orient the same models in another photogrammetric software (Stereoview by Menci software) (Figure16). So the restitutions obtained by Cyclop, without control points, have been compared with those obtained with Stereoview. It results that, in general, with distance inferior to 12 m, the system works well (althougth there are some problems to link different restitutions among them), and it can be used in all cases where external orientation is not possible or not required. Often, in cultural heritage the images are the only documentation that remain; this system, that can be used also by non photogrammetric experts, allows one to add a metric value at the acquired images.

We have presented three different, simple applications of a survey of cultural heritage where while the task of the measurement, “how” to measure, might usually be solved quite clearly, the question of “what” to measure remain a permanent problem and, in general, requires great expertise on the part of the operator.

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