A NEW TOOL FOR ARCHITECTURAL PHOTOGRAMMETRY: THE 3D NAVIGATOR

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ABSTRACT

People involved in restoration and conservation of architectural goods make use of manual or digital drawings (traditional products of a photogrammetric survey) in order to get some simple information such as point co-ordinates, distances, areas, volumes etc.
Digital photogrammetry gives new opportunities. All the images of a block, previously oriented, can be explored as a unique large stereo-model. In fact, when the operator moves from a stereo-pair to the adjacent, the system can automatically swap the images and the user has the illusion of moving in one virtual, continuous 3D space. This new digital product simply consists in taking the images (by means of a digital camera or a scanner) and in carrying out the triangulation of the block, in order to get the orientation parameters of each photo. The result could be named "stereo-photomap"; it is stored on a CD-ROM (or a DVD, in case of very large blocks).
A new instrument, named 3D NAVIGATOR, suitable for exploring the stereo-photomap, has been realised by using a standard, low-cost PC, equipped with a simple stereovision device (an active polarised filter on the screen and passive polarised glasses).
In architectural applications, this instrument allows one to "navigate" around a building (or a statue), with the possibility of measuring continuously X,Y,Z co-ordinates of points, distances, areas and so on. The operator has access to the information offered by the images, without any need of a preliminary restitution: he can select and measure directly only what it is interesting for his study.

1. INTRODUCTION

A complete architectural survey requires a metric survey of the object of interest; the detail of the needed metric description depends on the goal of the survey: e.g. restoration, conservation, archiving.
Among the different techniques available for carrying out a metric survey, photogrammetry always played a basic role, mainly due to its obvious advantages such as the construction of a photographic archive and the possibility of measuring and drawing the needed elements only when necessary.
The never solved problem in metric architectural surveys is that an expert photogrammetric operator knows well "how" to measure, but he does not know "what" must be measured. Another problem is the cost of a complete photogrammetric survey.
Analogue photogrammetry did not solve these problems: the use of analogue stereoplotters required well experienced operators, used in producing cartography but not competent in selecting the basic elements necessary to describe an architectural object. Furthermore, the instruments (metric cameras and analogue stereoplotters) were very expensive. Analytical photogrammetry has allowed a remarkable reduction of costs. Reseau-cameras, non-metric cameras, simplified analytical stereoplotters have given satisfactory accuracy at lower prices. But one problem still remained unsolved: the expert in architectural survey and the photogrammetric operator have too different professional skill.
Digital photogrammetry seems to offer the ideal solution. The required hardware for digital acquisition and restitution units are available in the widespread and inexpensive market of the DTP scanners and PCs. Automation in the most phases of the photogrammetric process, such as interior and exterior orientations and collimation of homologous points, really allows the end user to become easily a skilled photogrammetric operator.

2. THE STEREO-PHOTOMAP

In analytical photogrammetry, once the orientation parameters have been determined, the X, Y, Z co-ordinates of a point are quickly obtained, simply collimating the homologous images of the point and measuring their fiducial co-ordinates.
In digital photogrammetry, the procedure is even simpler: measures are implicit, due to the pixel position in the image matrix (nr. of row and column) and the two homologous pixels of the point of interest can be automatically identified.
In fact, it is well known that the homologous of a selected point can be carried out by means of a "matching algorithm": for the first time in the history of photogrammetry, the human stereoscopic view is not essential for an accurate identification of the homologous points!
The reachable accuracy is similar to the one obtainable by an experienced operator, even if a low resolution of 800 dpi is used.
Therefore, an oriented stereo-pair can be considered as a complete metric survey of the represented object: the user himself can select, among all the image points, the points of interest, without the need of being an experienced photogrammetric operator.
The above described properties of a single stereo-pair can be extended to a strip or a block of photos.
The whole oriented stereo-pairs representing an object could be called "*stereo-photomap*". *STEREO* because it is observed in 3D; *PHOTO* because it appears as a photographic image; *MAP* because it contains all the metric information, like a traditional map, in a single 3D reference system.
In other words, the stereo-photomap can be considered the three-dimensional evolution of the traditional ortho-photomap: a correct 3D geometry is directly connected with a not interpreted photo image. The use is similar: the final user observes and measures the points of interest, according to his particular needs and applications.
The stereo-photomap can manage at the same time, in a common reference system, aerial and terrestrial images. This is an interesting and powerful tool of investigation, when the object of the study is an urban area: the user can shift from aerial to terrestrial 3D views and *vice versa*, in an unique geo-referenced environment.

2.1 Production of a stereo-photomap

The production process of a stereo-photomap follows the standard procedures used in a traditional photogrammetric survey: image acquisition, survey of a control network and

photogrammetric triangulation (which is the simplest way for determining the orientation parameters).
Digital images can be acquired directly by means of a digital camera or by an indirect process: a classic photo camera and a photo-scanner. As already mentioned, the orientation parameters can be determined by means of ~~a~~ photogrammetric triangulation. The bundle block adjustment procedure is recommended (ex: ORIENT by TUV), in particular when non metric cameras are used.
Specific software for digital automatic triangulation is already available on the market, both on workstation or PC platforms.
At the present state-of-the-art of the digital techniques, the price of a stereo-photomap, compared to the price of a traditional photogrammetric survey, can be estimated as about the 30%.

3. THE 3D NAVIGATOR

In a traditional architectural survey, the resulting drawings allow measurements of geometric elements, like co-ordinates of single points, distances, areas and volumes. The required measuring instrument is a simple ruler.
In a more modern approach, results of the survey are recorded in digital form: in this case, a computer and an appropriate CAD software (e.g. AUTOCAD, MICROSTATION, etc.) are necessary for such enquiries. It becomes easy to derive automatically other graphic products such as horizontal and vertical profiles.
If a stereo-photomap is available, an *ad-hoc* instrument must be conceived, devoted to the correct and complete use of this new type of "map".
In the following paragraphs this new instrument, which has been called "3D NAVIGATOR", is described.

3.1 Properties of the 3D NAVIGATOR

Considering the peculiarity of a stereo-photomap, the 3D NAVIGATOR must give the following performances:

- stereoscopic approximate collimation of homologous points by an operator even not expert, the refinement being assured by the system;
- easy movement inside the whole photogrammetric block without troubles when passing from a model to the next;
- easy exchange from aerial to terrestrial 3D images and *vice versa*;
- quick and precise measurement and recording of point co-ordinates;
- calculation of distances, areas and volume after a selection of the interested points;
- basic procedures for restitution of plots, profiles and DEM.

In order to reach the maximum of efficiency, the 3D NAVIGATOR uses many of the automatic procedures offered by digital photogrammetry.

3.2 Basic hardware configuration

The 3D NAVIGATOR has been designed with the goal of producing a low cost and a user friendly instrument. Therefore, it has been developed on a PC platform.
All the images are supposed to be recorded at a 800-dpi geometric resolution (or better) in order to give a good visualisation of the details. A true color image, medium format (6 cm x 6 cm), requires about 10 Mb. The amount of data for each image becomes 60 Mb, in case a 13 cm x 18 cm format is used (the biggest for terrestrial photos). Considering that the 3D NAVIGATOR uses only the overlapped parts of the images of a stereopair, assuming a medium overlap of 60-70%, each model requires about 70-80 Mb.
The PC used for developping the 3D NAVIGATOR prototype has the following specifications:

– PENTIUM II processor – 400 MHz
– RAM 256 Mb
– 2 HD 9 Gb each
– 21" high resolution monitor
– active polarised screen with passive polarised glasses.

The RAM size allows the management of the overlapping portions of a stereo-pair, saving a sufficient space for other purposes.
One of the two hard disks is reserved for storing the images and the other one for the software.
Even in case the 13 cm x 18 cm format is used, the hard disk can record up to 150 images: supposing the images are at 1:400 scale, suitable for a 1:100 survey, the area covered in 3D is of about 140.000 m^2!

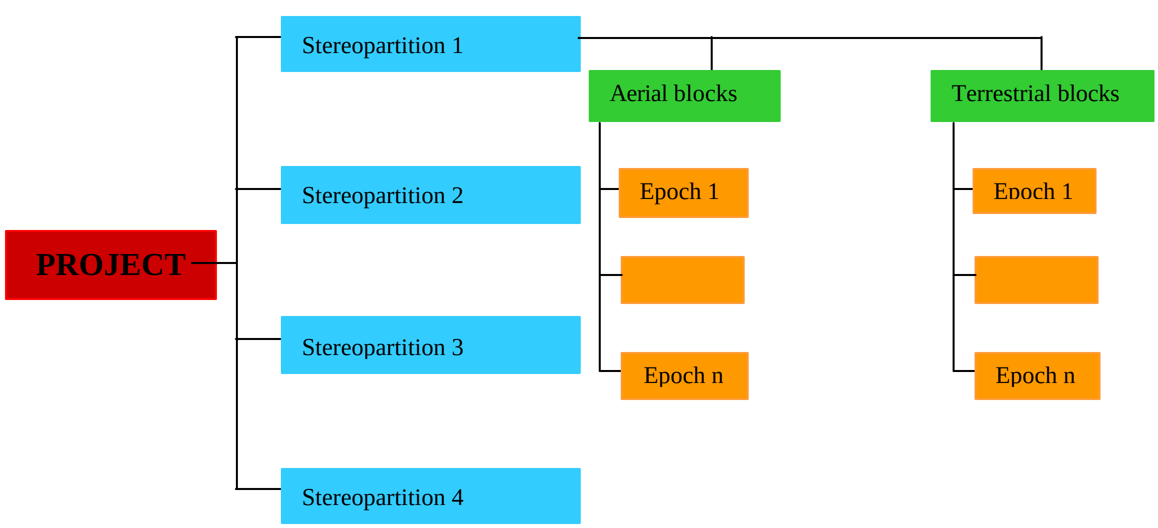

Figure 1 – Stereo-photomap data structure

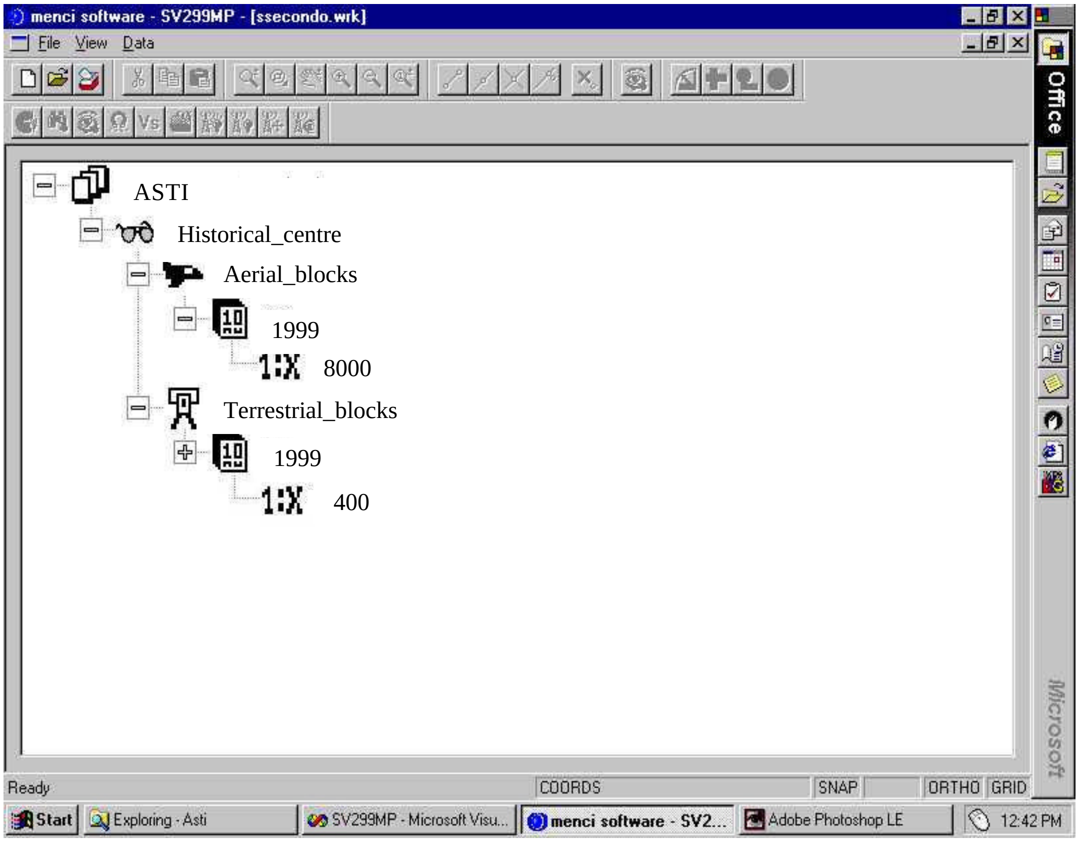

Figure 2 – Data organisation in the 3D NAVIGATOR

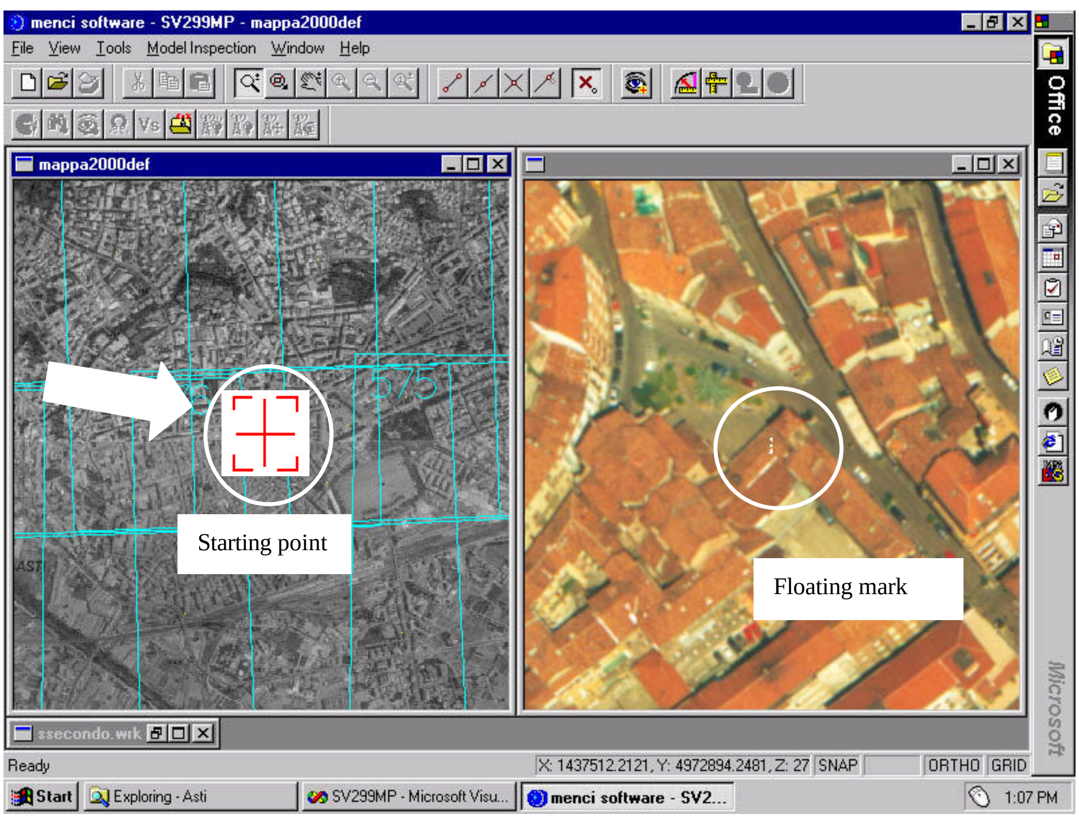

Figure 3 – Starting the 3D NAVIGATOR

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3.3 Data structure

All the data owning to a "project" (images and their calibration and orientation parameters) are organised in a hierarchical structure.
In detail, each object (e.g. a building, a monument or a statue) is recorded in a directory named PROJECT. Each project can be subdivided into subdirectories, named STEREO-PARTITIONS, containing the images of a part of the object (e.g. for a building: exterior façades, interior walls, ceilings, floors, paintings, etc.). Each stereo-partition can be subdivided into aerial and terrestrial blocks. Each of these two last directories can be subdivided again into further sub-directories named EPOCHS, in order to separate the images taken in different dates. Finally each epoch can be partitioned into sub-directories named SCALES where the images having a same scale factor are recorded (see figure 1).
This structure allows the user to choose which part of the stereo-photomap he wants to explore, optimising the way of archiving data related to the object of interest.
Figure 2 shows the structure of the stereo-photomap of the Italian town of ASTI. The aerial block (60 images at scale 1:8000, suitable for restitution at scale 1:2000) has been connected with some terrestrial stereo views of buildings, squares and roads (images at 1:400 scale, suitable for architectural surveys at scale 1:100).

3.4 Basic software configuration

The 3D NAVIGATOR software has been developed in WINDOWS environment, a world-wide known operating system. The screen can be divided into multiple independent windows, 2D or 3D: this allows one to display at the same time drawings, images and stereo-models of the object. In each 3D window a fixed floating mark in the middle of the window allows stereoscopic collimations and measurements, by using a multifunctional mouse.

Navigation inside a block. This software allows the user to move inside the whole object space, selecting automatically the stereo-pairs of interest.
At the beginning, a general view of the selected partition of the stereo-photomap is displayed on the screen in 2D. The user just clicks on the desired start point and the software provides to load automatically the needed stereo-pair: a 3D window appears and the floating mark follows the movements of the mouse (see figure 3).
Particular attention has been paid to obtain a continuous movement inside the stereo-photomap: the user might not see the change of stereo-pairs during the navigation.
Let us consider the small block represented in figure 4: it can be explored in both the shown directions.
Along the strip direction, when the floating mark moves from model 1 to model 2, the system must swap the left image of model 1 with the right image of model 2. Following the side direction, when moving form model 1 to model 5, the system has to swap the two images of model 1 with the two images of model 5.
To avoid repeated swapping steps, the navigation software considers the overlapping area of two adjacent models (hatched areas in figure 4) and it swaps the images only when the floating mark is on the edge of the overlapping portion of the two models.
Figure 5 shows what happens along the strip, when the floating mark moves from model 1 to model 2: swapping occurs only in the case represented in figure 5a. If the mark comes back, the images are swapped only when the edge shown in figure 5b is reached.
The operator can open more than one stereoscopic window at the same time: in this way he can explore the same part of the object at different zoom levels and/or at different epochs (see figure 6).

From aerial to terrestrial blocks and *vice versa*. When required, the system shows special symbols on the aerial images (see figure 7), putting in evidence the availability of terrestrial stereopairs, or strips, or blocks. By clicking on one symbol, the user can load and explore the corresponding terrestrial images of the façades, always referred to the same absolute reference XYZ system.. Despite of this, the movements of the restitution mouse follow a local "terrestrial" X_t,Y_t,Z_t reference system: the X_t,Y_t plane fits on the façade, Z_t represents the depth from the taking point.
On request, the system comes back to the aerial navigation.

Stereoscopic collimation of single points. Collimation and co-ordinate measurements of single points can be carried out by using one of two available procedures. When the operator moves in height, the first procedure moves both the images (the so called Helava principle, or 4-control procedure).

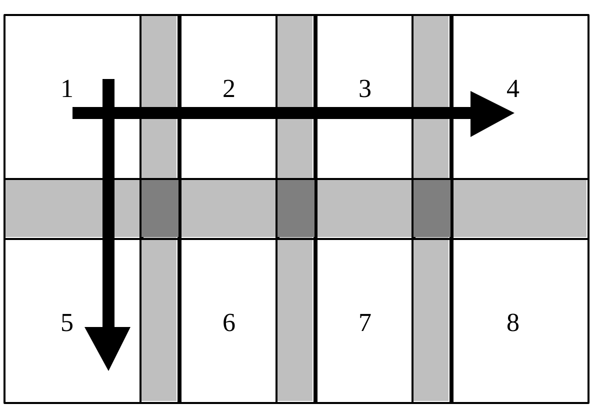

Figure 4 – Example of a small photogrammetric block

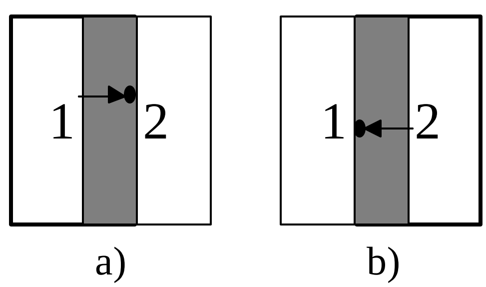

Figure 5 –Swap technique

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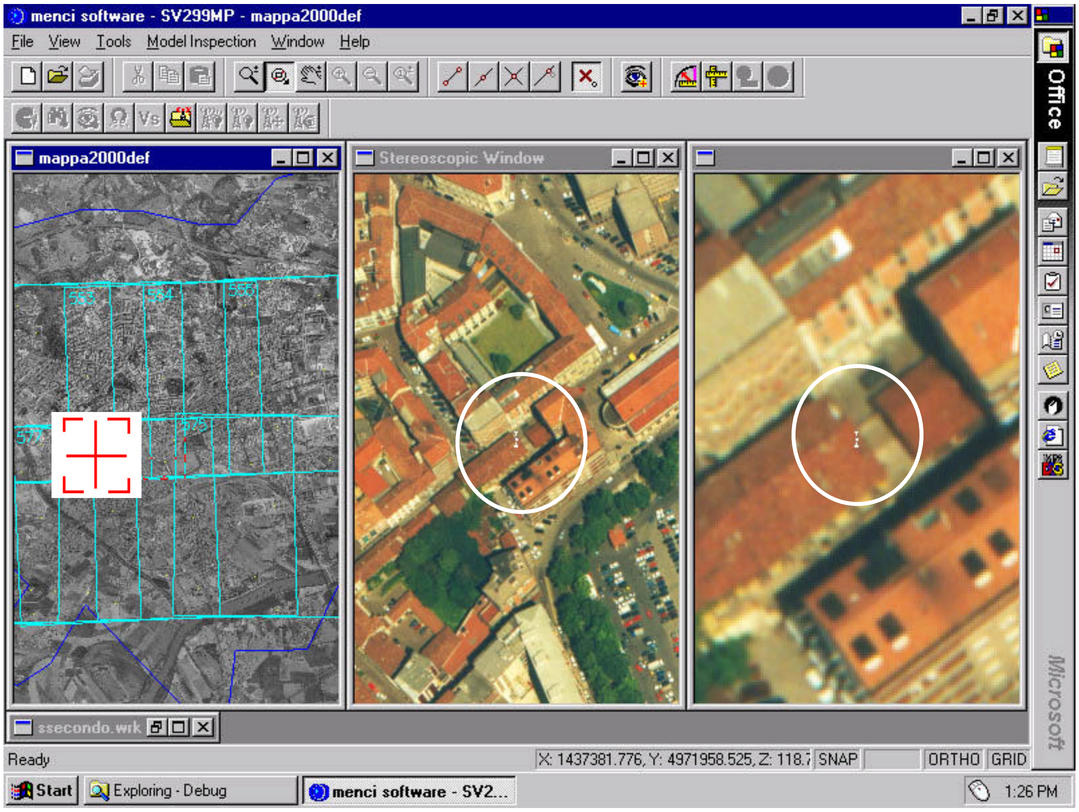

Figure 6 – Windows showing the same area, with different zoom factors

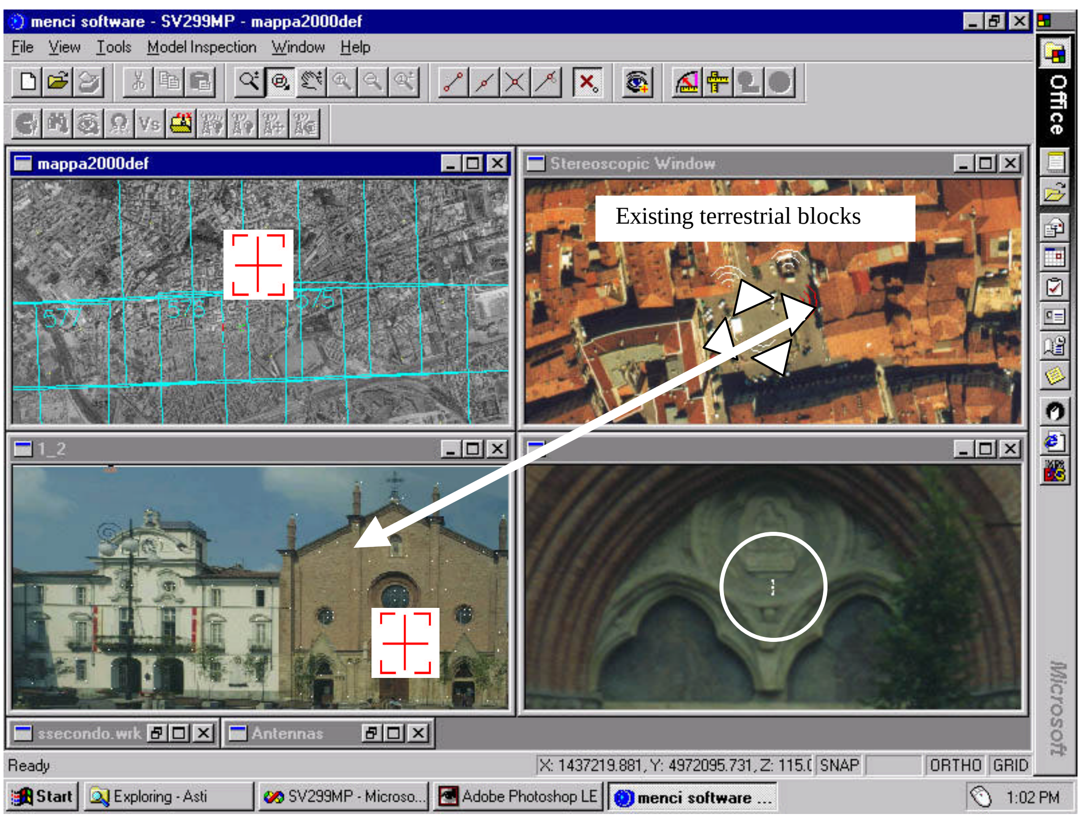

Figure 7 – Hot-spots joining aerial and terrestrial blocks

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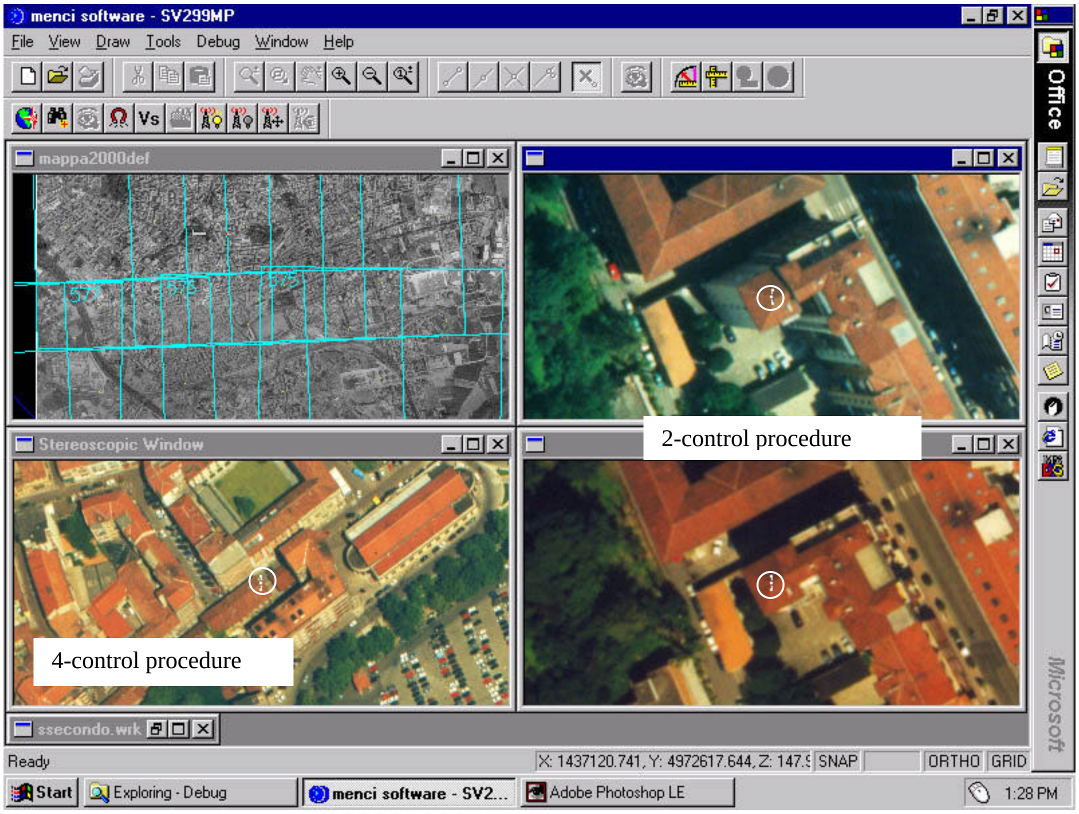

Figure 8 – Stereoscopic collimation of single points in aerial block

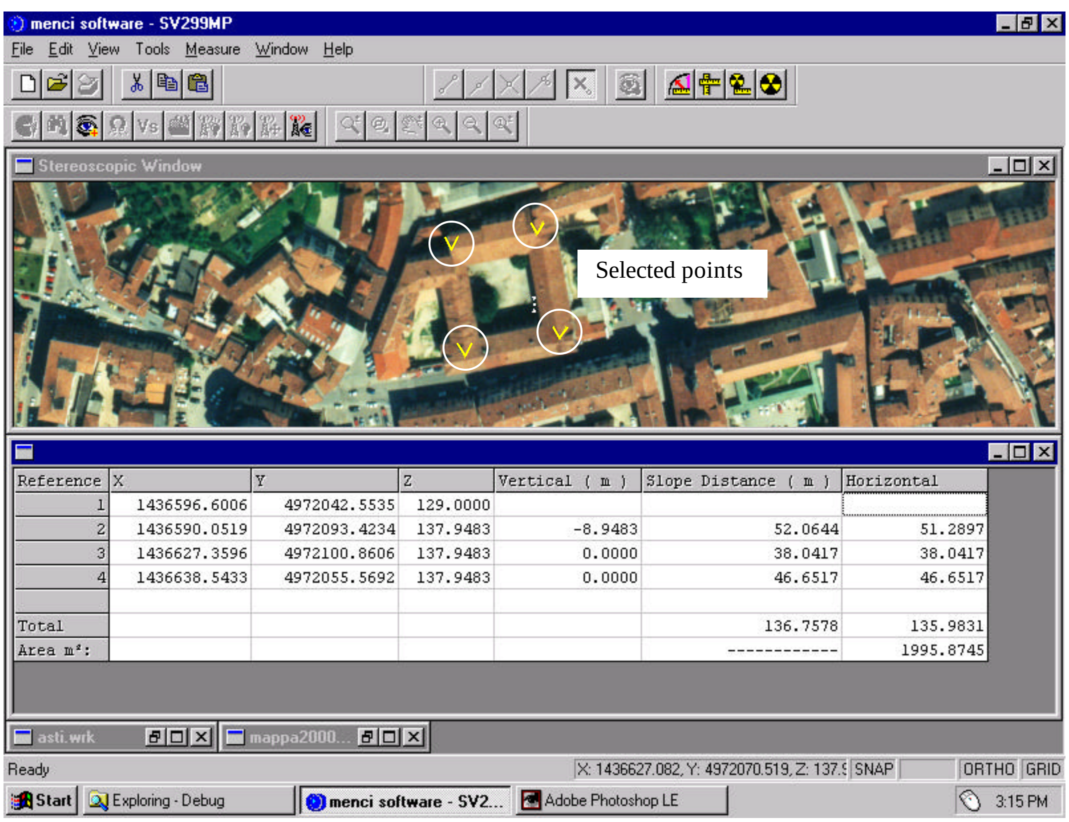

Figure 9 –Co-ordinate recording of some selected points

The second moves only one image (Inghilleri principle, or 2-control procedure) (see figure 8). This last option is easier for a non skilled operator: he can collimate monoscopically the wanted point on the fixed image and then eliminate the x-parallaxe by just looking at the homologous point on the other image, moved by the mouse.
In both cases the system uses matching algorithms, consisting in a pixel and sub-pixel correlation, in order to refine collimation and to achieve the needed accuracy in computing X,Y,Z.
When the floating mark is far away the correct height on the model, the stereoscopic view disappears and the images appear doubled: for a non experienced operator it is difficult to get the stereoscopic view again. In these cases, a “help” function is available, which makes the system to move automatically to a correct collimation of the nearest recorded point (e.g. one of the control points used to compute the orientation parameters or one of the points recorded during a previous working session).

Recording data. The X,Y,Z co-ordinates of the points selected by the operator (or X_t,Y_t,Z_t, on demand) can be recorded in an electronic sheet (for ex.. EXCEL, see figure 9); afterwards they can be used for computing required elements such as distances, areas, volumes or for generating drawings such as plane projections, perspectives, profiles, and so on.

4. CONCLUSIONS

The stereo-photomap concept and the 3D NAVIGATOR system strongly contribute to solve many of the problems arising in the metric survey of architectural goods.
The stereo-photomap represents a new way of recording architectural photogrammetric surveys. In fact, it is the right way to separate the different competencies required by a metric survey and its representation. Experts in photogrammetry have to plan and build the stereo-photomap, but they have not to take care of selecting the needed elements required for a correct reading of the object.
The 3D NAVIGATOR is an user friendly instrument able to inquire the stereo-photomap. PC platform and WINDOWS environment make the use of this new instrument familiar with everyone. Thanks to the wide use of advanced digital photogrammetric techniques, the high degree of automation reached, helps every user to become a good photogrammetric operator in short time, without any knowledge of the photogrammetric process.
The user has just to explore and select the elements needed to describe and understand the object. No care to the measurement problems is required: the experts that have built up the stereo-photomap have solved them previously.
The possibility of connecting aerial and terrestrial images is an additional performance of the system and a powerful tool of investigation for architectural applications.
The 3D NAVIGATOR, as described in this paper, is a first step towards a new generation of digital photogrammetric instruments.
Additional modules, such as stereo-plotting, DEM and ortophoto production, can be integrated in the 3D NAVIGATOR, in order to give the final user all the features available in a digital stereoplotter.
At the moment, the 3D NAVIGATOR is a “general purpose” instrument: in a foreseeable future a specialised version for architectural applications will be probably conceived.
It will allow a complete 3D navigation outside and inside the buildings, in an unique reference system.

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