

# LOW COST PHOTOGRAMMETRIC SYSTEMS FOR EDUCATIONAL APPLICATIONS

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## ABSTRACT:

The paper presents the outlines of a tutorial project regarding education in low cost photogrammetry systems. The project aim is to produce a package comprising both restitution software and hypertext documentation of significant cases.

## 1. INTRODUCTION

The University system in Italy does not yet provide a degree in survey sciences. Photogrammetry, geodesy and surveying courses are mainly taught in the context of a Civil Engineering degree. This Faculty comprises numerous courses in various scientific and technical disciplines, and consequently the time devoted to survey sciences rarely exceeds 10% of the total course.

As regards photogrammetry, in particular, the emphasis is on basic theory, and students are given only limited training in field work and restitution because of the demands on the instructors' time.

We have therefore decided to produce a tutorial software package for use by applied photogrammetry instructors. The field of application is close range photogrammetry; this choice has a vocational direction in so far as close range photogrammetry is used by civil engineers in their practical work.

Low cost photogrammetry systems (L.C.P.S.) are ideal for this purpose, because they are more likely to be employed in current professional activity. Moreover they enable the students, for a limited financial outlay on the part of the University, to gain experience of photogrammetry in its entirety, via a new, exciting approach: free choice of camera stations, different scale factors in photographs, bundle adjustment, 3D modelling of the surveyed object and so on.

In this paper we present some ideas towards realisation of the tutorial material.

## 2. THE TUTORIAL PROJECT

The tutorial package project is outlined in Figure 1.

The package consists of three modules: restitution module, applications module and theory module. A commercial restitution package for close range photogrammetry is linked to a hypertext document dealing both with typical applications of the software itself and with the basic concepts of photogrammetric theory.

An online help function links the commercial software and the hypertext, thus enabling the user, at any stage of the restitution process, to view explanatory material about the corresponding phase of the examples treated in the hypertext. The examples will be described in their entirety, from field work to restitution. Moreover, the hypertext can be used independently of the restitution software, as a guide to the solution of typical close range photogrammetry problems. The examples should present

as many solutions as possible: for example, for the object points, the use either of natural points or of various types of target might be proposed. From this point of view the hypertext would be a powerful teach-yourself tool for any type of operator.

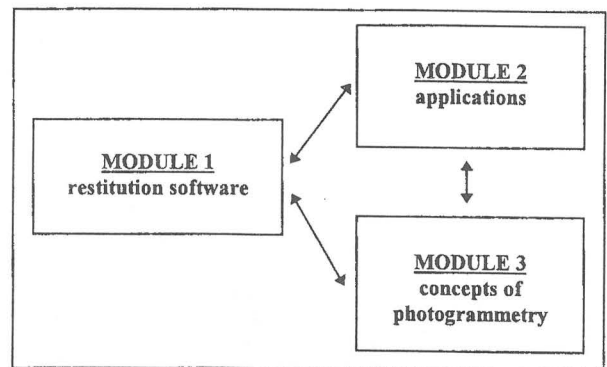


Figure 1: configuration of the tutorial package

Existing photogrammetry packages based on digital image processing (e.g. Rollei CDW or Leica Elcovision) are particularly suitable as teach-yourself tools: since the software stores all the elements required for restitution, the user can repeat his restitution of any given object and compare it with the example in the hypertext.

The greatest input in producing this tutorial package will be required by the application module. This will require careful selection of suitable examples, realisation of the photogrammetry surveys and production of the concomitant hypertext documentation.

A complete set of examples constituting an exhaustive overview of possible solutions in various fields of application would have to be collected.

In particular any example application documented in the hypertext must satisfy the following requirements:

- it must be repeatable, from field work through to restitution, with satisfactory results within the confines of an introductory course;
- it must give a concrete guide to what constitutes a professionally acceptable solution;
- it must allow the student to teach himself, with alternative solutions and varying levels of sophistication in an interactive style.

### 3 AN APPLICATION EXAMPLE

Given the importance of the application module, we have tested the tutorial concept with a photogrammetry survey intended to be the first example in the hypertext documentation.

The example describes the 3-D survey of a building carried out with a non-conventional photogrammetry system. This was assigned as practical work to a class of twenty students divided into four independent groups: A, B, C and D.

The software was Rollei MR2 PLUS ver. 4.0 running on a 486/33 PC with 4 Mb of RAM; the work station configuration included an A0 digitising table for data entry and a printer.

Figure 2 gives the structure of the hypertext, in which the example presented in this paper, outlined in grey, represents only one possible solution path in the context of the examples treated.

The 3D object chosen was one of the ancient gates of the city wall of Ferrara (figure 3): this is an isolated monument of obvious historical significance and with at least 2 prospects of architectonic interest. Following the solution path of figure 2, after choosing the type of photogrammetry application the students must decide whether to use natural object points or targets (angular and/or reflective), and whether to measure object points distributed over one surface only or over all the available surfaces. The hypertext has the task of guiding the student in his choice of options given the instruments which he wishes to use or has access to for the object point survey, and depending on the precision to be achieved. Clearly these choices influence the morphology of the 3D reference point network.

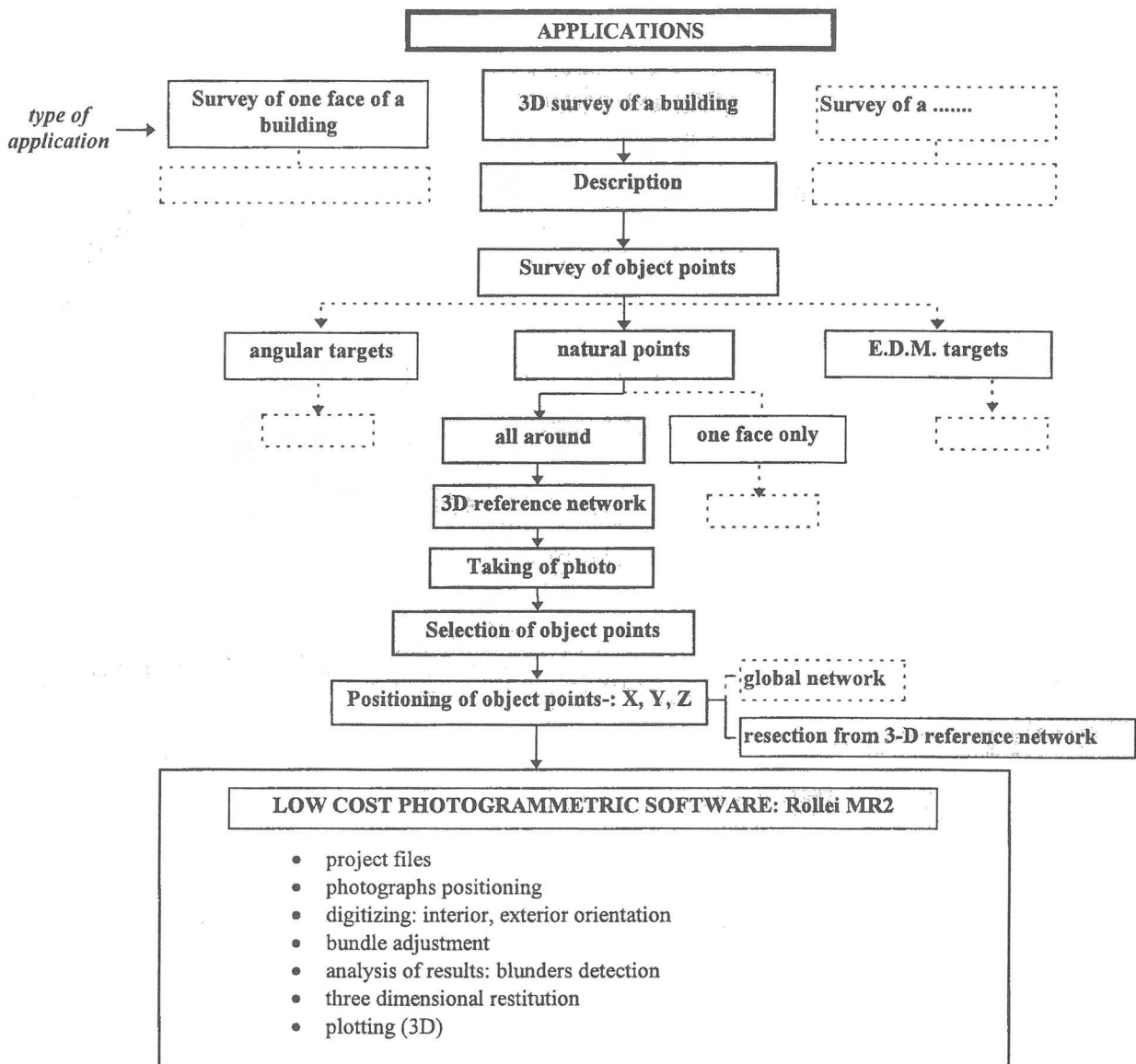


Figure 2: the example described in this paper is only one of numerous cases to be described in the hypertext

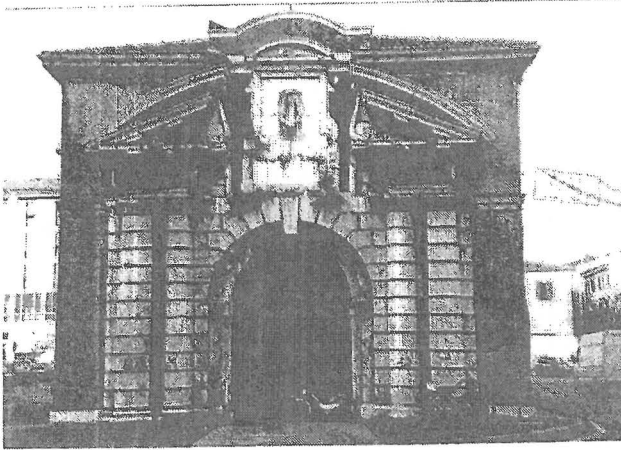


Figure 3: object of the photogrammetric survey

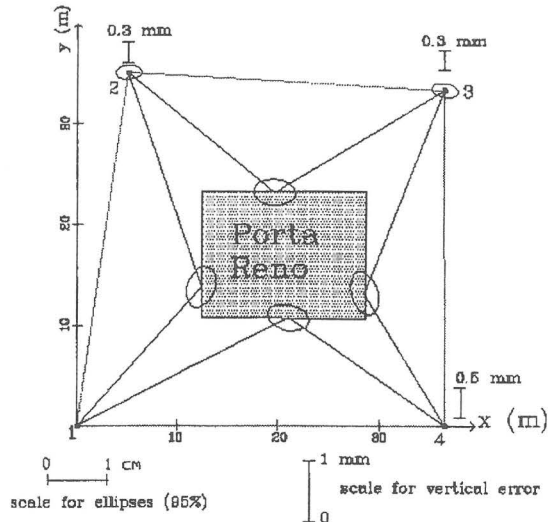


Figure 4: 3D network and object point survey by resection

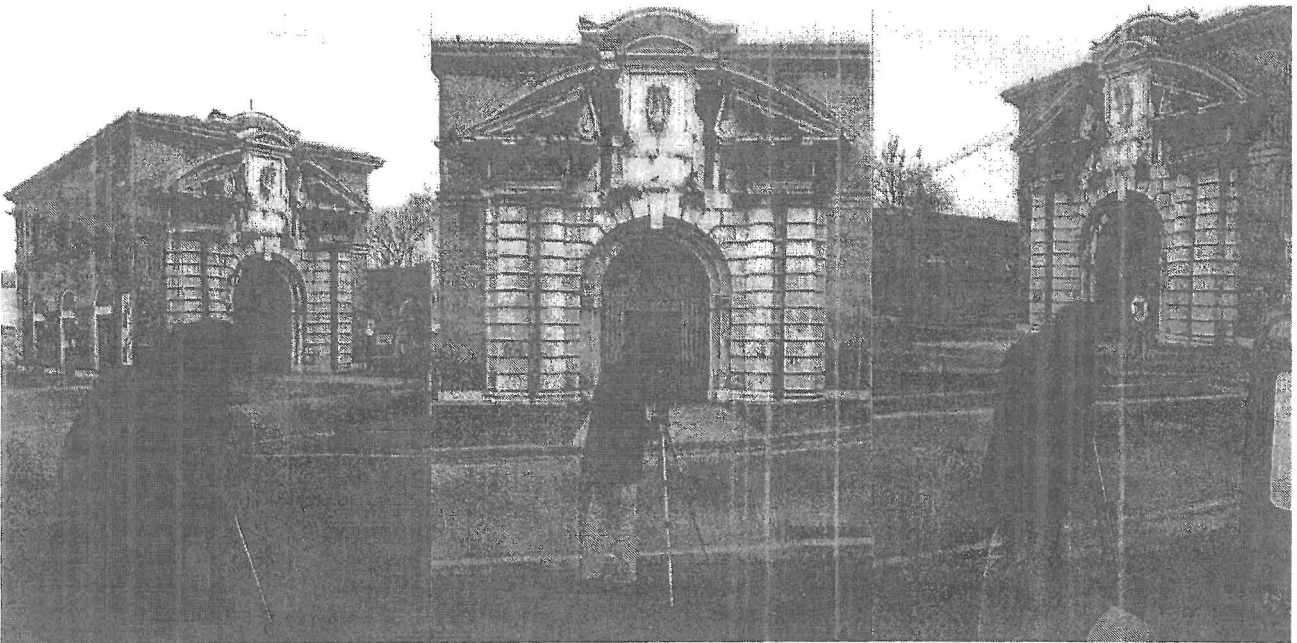


Figure 5: taking the photos

In our example, we have chosen to use natural object points distributed uniformly over the entire building and measure them by resection. The 3D reference network, installed and measured independently by the students, is shown in figure 4. The photographs were shot with a Rollei 6008 fitted with a 121 cross screen. The layout of the shots is the typical inclined axis setup typical of non-conventional photogrammetry (figure 5) with at least 3 shots per section of the building. Figure 6 gives an approximate layout of the shots.

The students' work continued with the selection of the object points, realisation of an accurate sketch (figure 7) and measurement by resection of the point coordinates.

This concludes the field work side of the project and leads on to the more strictly photogrammetric work with the MR2 software. This phase can also be subdivided into several steps (figure 2). For each step the hypertext should provide links to the theory module which, at various levels of depth, highlights the analytic and computational aspects of close range photogrammetry. The

first steps regard project parameters, positioning the photographs on the digitising table, digitising the screen crosses for internal orientation and digitising the object points and tie points (figure 8). The application proceeds with the computational orientation phase which is done by the MR2 PLUS software in two distinct analytical steps (figure 9):

- sequential multi-image orientation (intersection + resection); uses at most 13 object points for the absolute orientation of the model and requires exterior orientation parameters, even if only approximate ones. At the end of this phase the results may be affected by systematic errors due to the sequentiality of the orientation procedure itself;

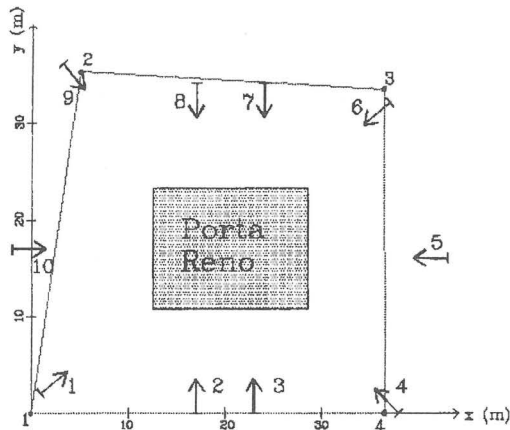


Figure 6: approximate camera station positions (required by MR2 software)

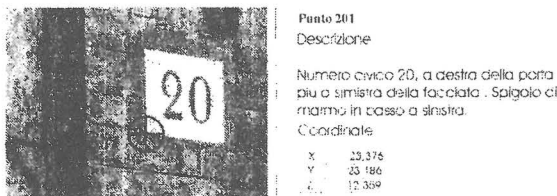


Figure 7: sketch of a object point

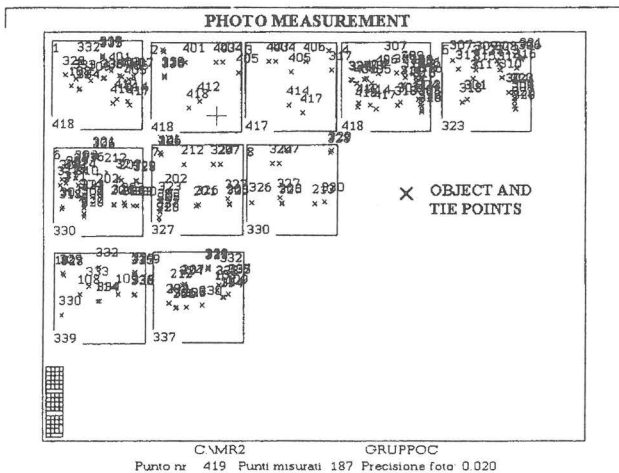


Figure 8: digitiser with the photographs used in the project: object and tie points used for relative orientation are indicated

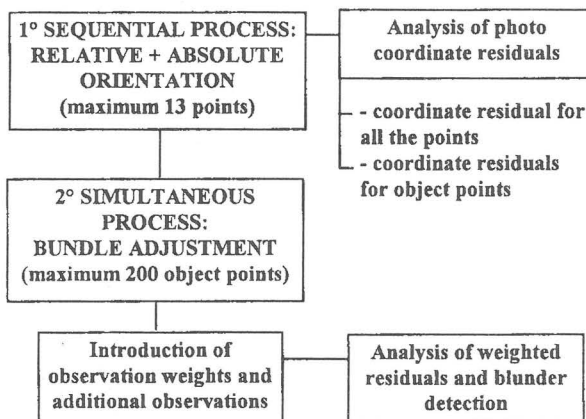


Figure 9: orientation computation

- bundle adjustment, that is, simultaneous photogram orientation with the introduction of additional observations such as additional object points (up to a maximum of 200 points), distances, control points, etc. Bundle adjustment, as is well known, yields more precise results than mere multi-image orientation, but requires that the exterior orientation parameter values be known with considerable accuracy. The latter are output by the first computational phase of multi-image orientation.

At the end of each of the two analytic procedures the students learn to analyse the residuals, especially those yielded by bundle adjustment, which are essential for elimination of blunders. Figures 10 and 11 plot the residuals and weighted residuals for a single project before elimination of blunders (the peaks at points 203 and 207). Figures 12 and 13, on the other hand, plot the same magnitudes after blunder elimination: it is clear that the residuals all have comparable absolute values and all weighted residuals are below the 3.3 threshold.

At the end of the computational phase each student concludes his own project by carrying out the 3D restitution of a section of the building, which is then refined and completed by a commercial CAD package (figure 14).

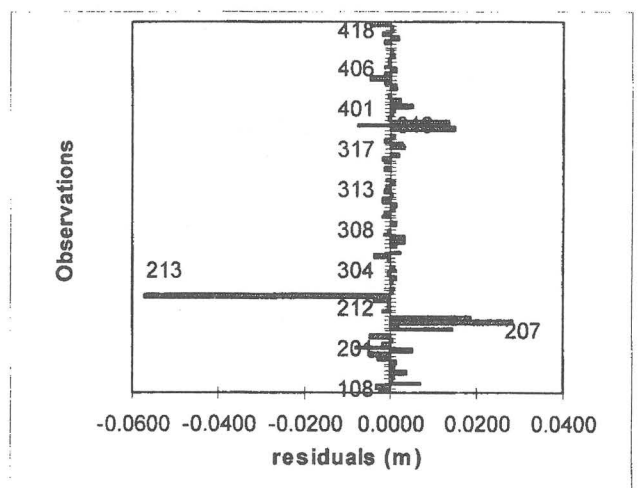


Figure 10: residuals for project group C before removing blunders

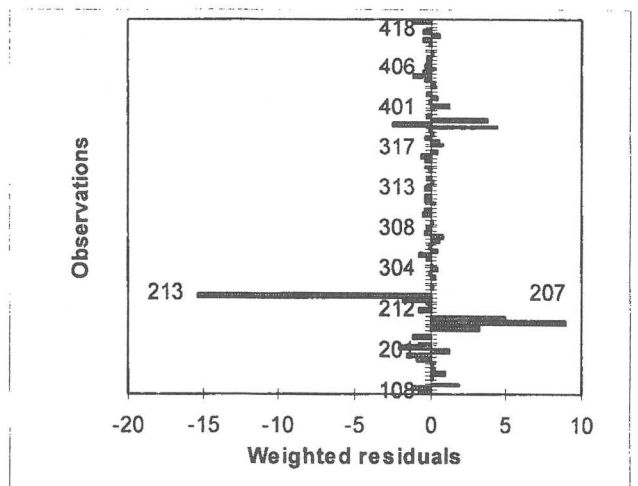


Figure 11: weighted residuals for project group C before removing blunders

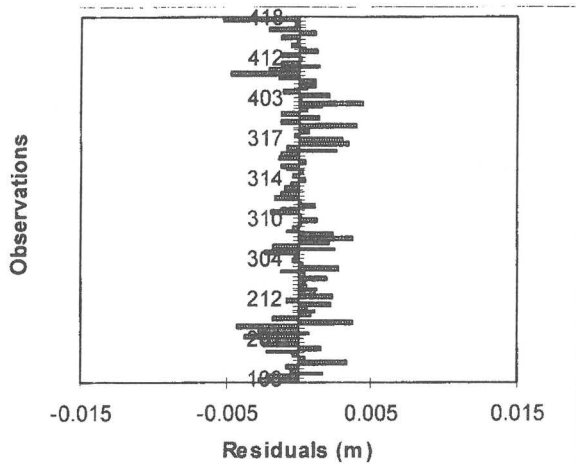


Figure 12: residuals for project group C after having removed blunders

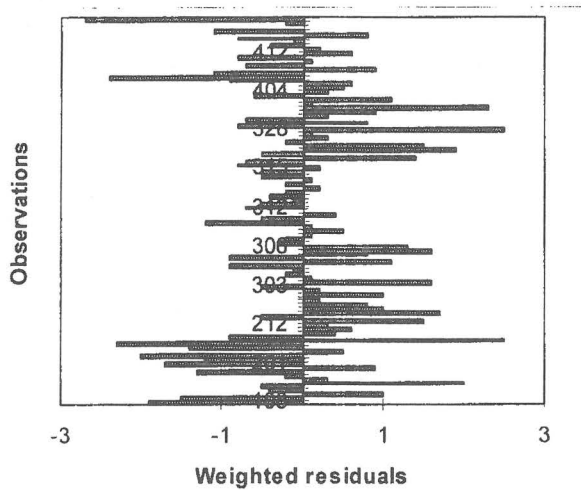


Figure 13: weighted residuals for project group C after having removed blunders

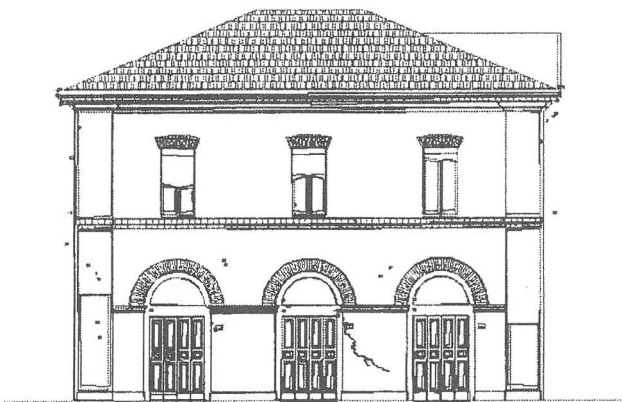


Figure 14: 3D restitution of one surface of the building

#### 4 ANALYSIS OF RESULTS

To determine whether the above example satisfies the first condition described in the second paragraph, we analysed the time it took the students to complete the various phases of the project (see table below):

Steps of the project	Time (h)
Reconnaissance, sketches, amateur photos	2
Set up, survey and compute 3-D network	6
Take photos	1
Survey object points by resection	8
Photo measurement	4
Bundle adjustment, analysis of residual	4
3D restitution	4
CAD	6
<b>Total</b>	<b>35</b>

Tab. 1: average time required by the students to carry out the various steps of the project

The average total time of 35 hours proves that this example falls within the time usually dedicated to practical work in a photogrammetry course.

As well as the time analysis, we evaluated the ellipses of error on the object points obtained by each project at the end of bundle adjustment. Figures 15 and 16 show, among the four projects compared, the worst and best results respectively in terms of ellipse dimension in the XY plane. It will be seen that in the worst case (figure 15), the major axis of the ellipses never exceeds 3 cm, whereas in the best case (figure 16) the it never exceeds 1 cm.

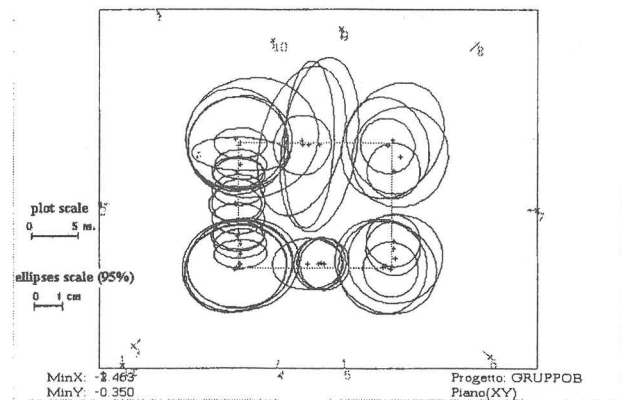


Figure 15: ellipses of error for project group B (the worst project)

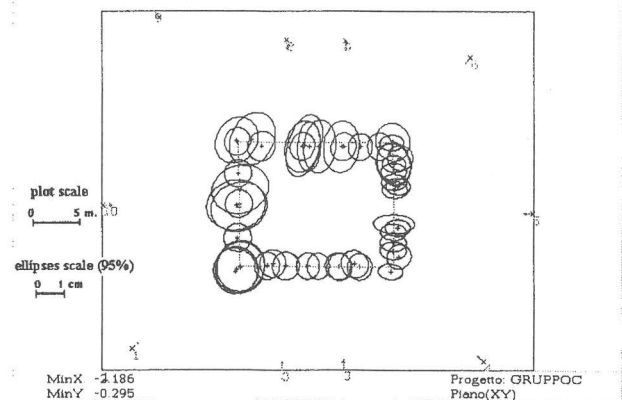


Figure 16: ellipses of error for project group C (the best project)

These results were obtained, as said above, with the choice of closed photogrammetric survey and with object points distributed over the entire building. The importance of these choices was demonstrated by re-running the best case project

analytic orientation with object points distributed over only one surface with both closed and open photogrammetric survey. Figures 17 and 18 plot the ellipses of error in the two cases: as expected, they are larger than those of the same project plotted in figure 16 and demonstrate the tendency to increase with their distance from the surface on which the object points were measured.

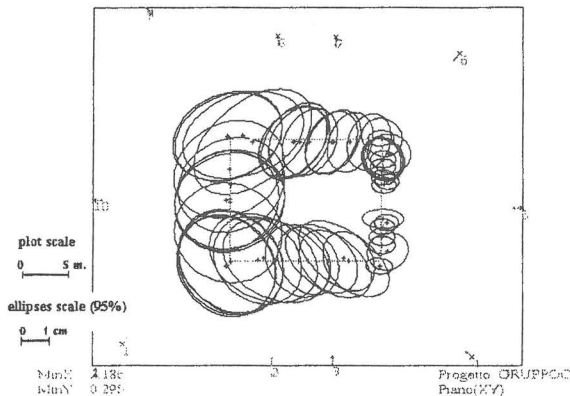


Figura 17: ellipses of error for project group C with object points on only one surface

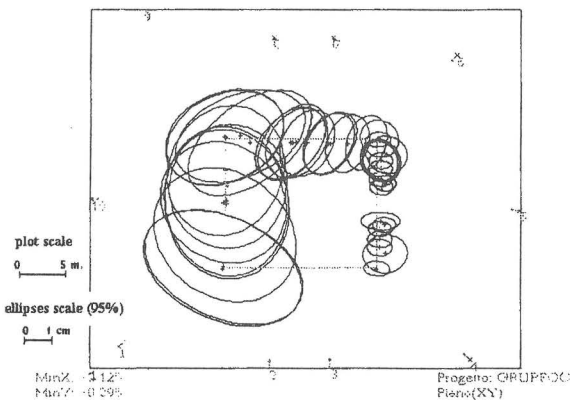


Figura 18: ellipses of error for project group C with object points on only one surface and without closing photogrammetric survey

To conclude the analysis of the results obtained, we calculated the standard deviations of the X, Y, and Z coordinates of the object and tie points for each project taken separately. Figures 19 and 20 plot the percentages of the standard deviations by axis for the worst and best project respectively. In particular, figure 19 shows that the standard deviations are greater than 1 cm on the X axis for 4.9% of the points, and on the Y and Z axes in 12.2%. On the other hand, figure 20 (the best case) the X, Y and Z standard deviations are always less than 0.6 cm, with very high percentages less than 0.3 cm.

On the basis of these results, we feel justified in saying that the students' projects satisfy the first condition both in terms of precision and time.

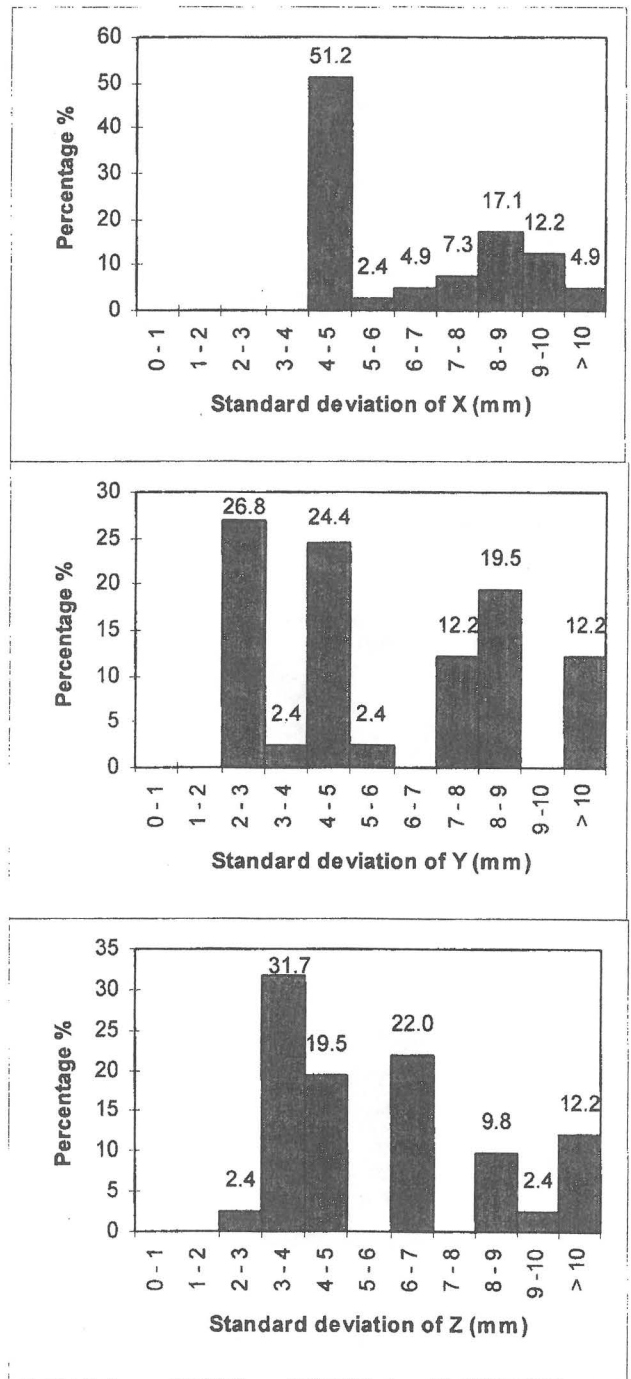


Figura 19: percentages of X, Y, Z standard deviations for object and tie points of the group B project (the worst project)

The example itself must be completed as regards 3D modelling (restitution). The whole example must then be loaded onto a suitable medium and linked with the restitution module (MR2 software) and the theory module.

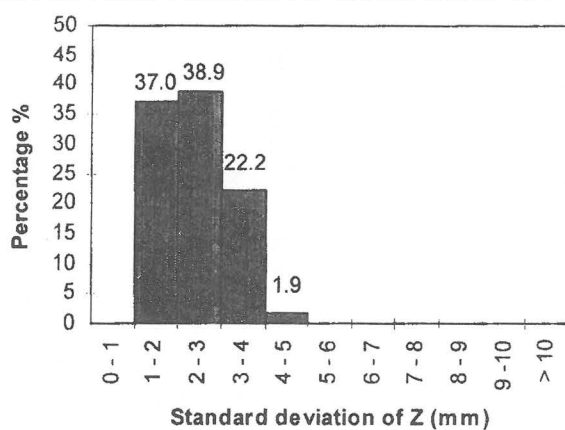
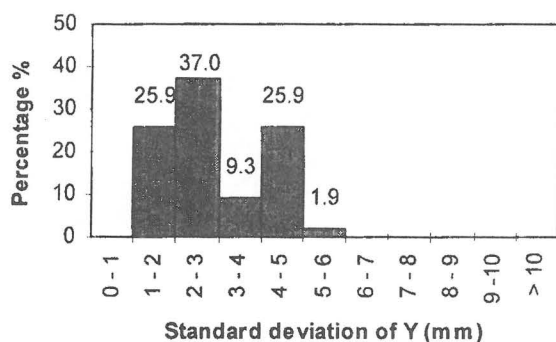
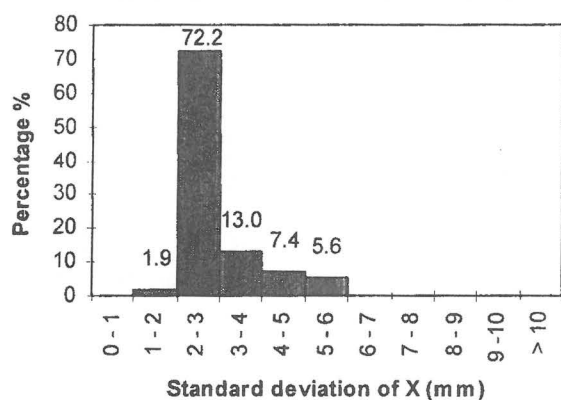


Figura 20: percentages of X, Y, Z standard deviations for object and tie points of the group C project (the best project)

## 5 CONCLUSIONS

This paper aimed to present some ideas about the potential of computers in photogrammetry education.

A restitution package for close range photogrammetry combined with a tutorial package gives teachers a powerful tool for training students in applied photogrammetry; it can lead to excellent results with savings in time and money in instruction. This is also a valuable tool for the professional, enabling him to update and refine his skills on his own with a remarkable variety of guide examples.

In this paper the package is outlined and a first example of an application is presented. This is only the first step of the work.