Monitoring of a Historical Building by Low Cost Photogrammetric System

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ISPRS Commission VI, Working Group 3

KEY WORDS: Close range photogrammetry, Architectural object, Low cost system.

1. OBJECT OF THE SURVEY

The objet of this study are the Tower and the Walls of Maximian in Milan (Archaeological Museum, C.so Magenta 15). The polygonal tower and section of wall that bound the garden of the Archaeological Museum are the imposing ruins of the walls that girded the city of Milan at the end of the third century AD.

In that era, Emperor Maximian ordered the renovation and expansion of the city walls dating from Republican times (mid-first century BC) to meet the planning and defence needs of Milan, which had become a seat of imperial government.
The tower and the walls were built on massive foundations; their conglomerate core was covered with brick facing, which is now partly in ruins due to the stripping away of

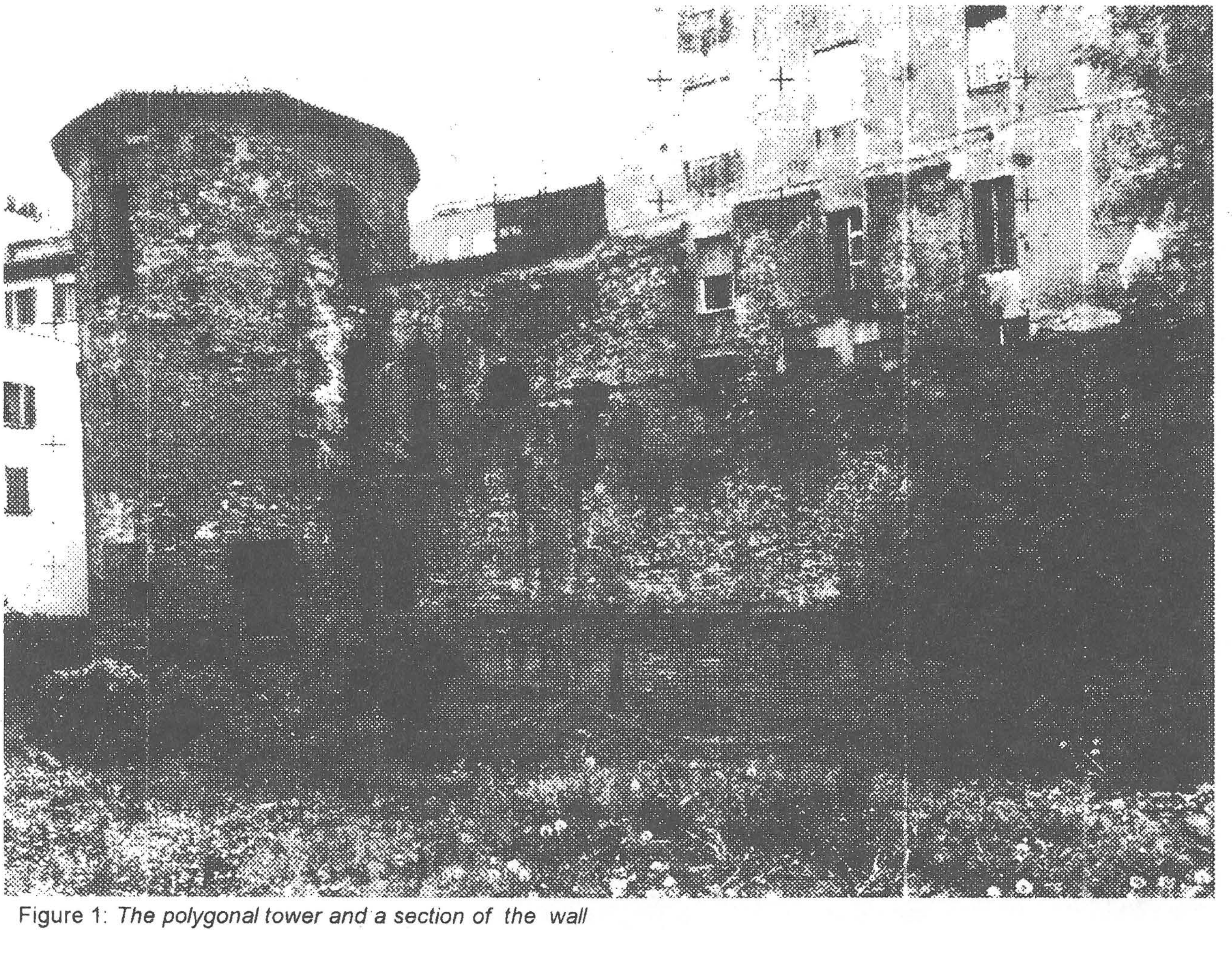


Figure 1: *The polygonal tower and a section of the wall*

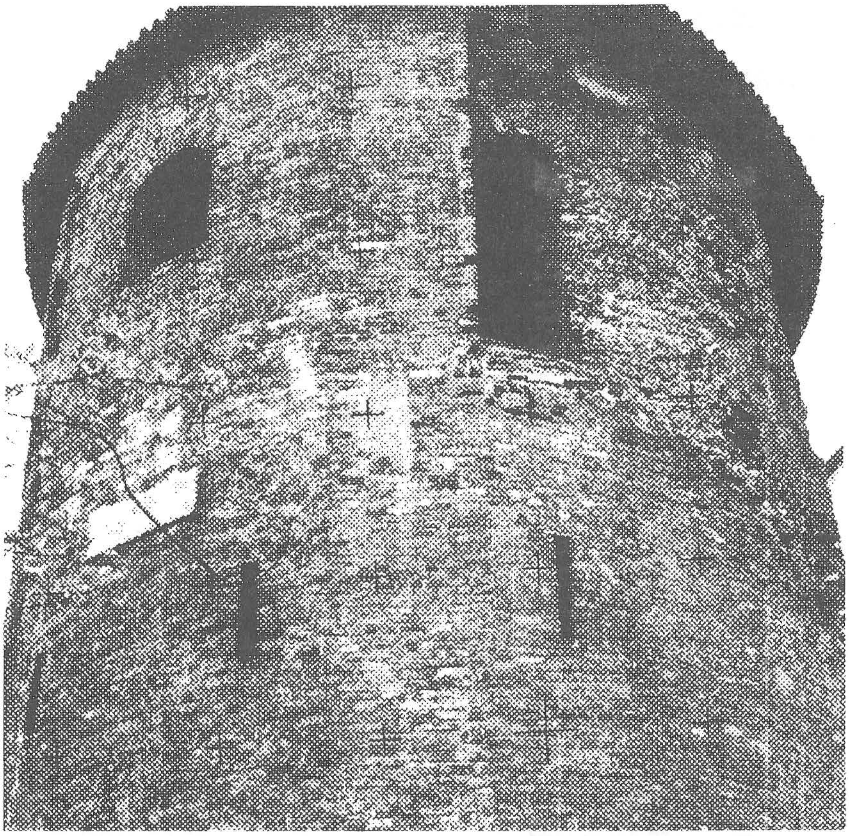
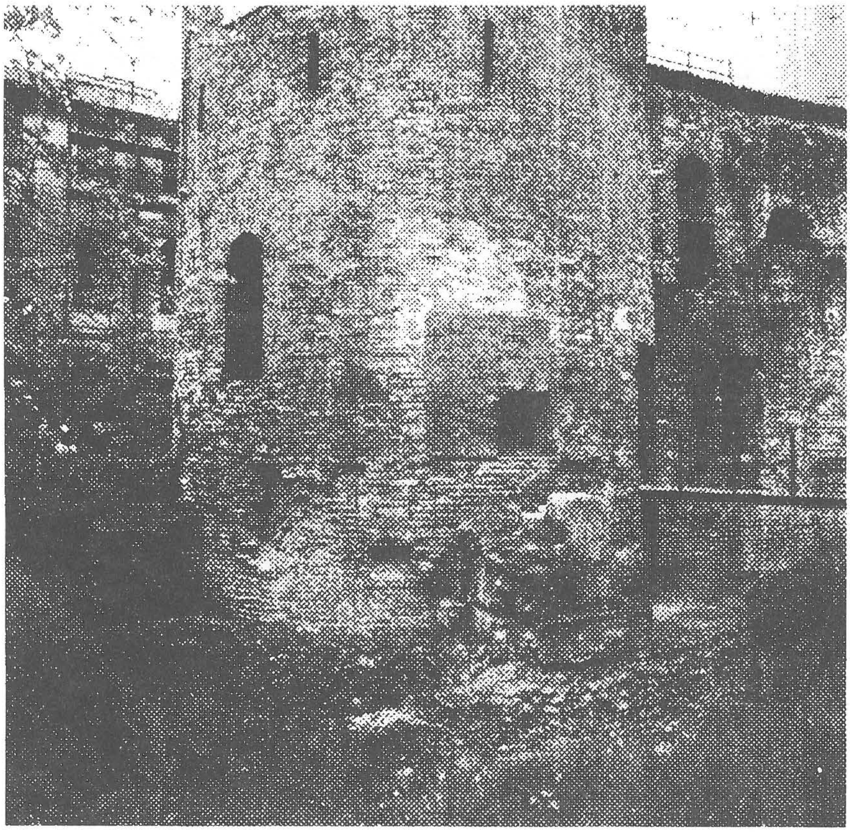


Figure 2, 3: *Examples of photograms obtained with Rollei 6006 semimetric camera*



building materials through the centuries.

The poligonal tower

The polygonal tower is located into a large courtyard generated by one of the ancient cloisters of the "Monastero Maggiore", by the ground which hosted the grape cultivation, and by another smaller cóurt which today is surrounded by the building where the Technical School for Tourism "Bertarelli" is.

2. THE GEOMETRY OF THE OBJECT IN STUDY

The tower assumes a 24 faces polygon external configuration with variable dimensions, from 1 to 1.38 meters each.

Internally, it assumes a cylindrical shape on three floors, separated by floors, where the second of them ruined during the bombings in 1945.

The surviving wall presents several projecting parts, with important differences in terms of thickness (to 1.50 m)

The tower is about 16.60 m. high and it has en external diameter of 10.00 m. The wall is 12 m. high, 19 m. long and its overall thickness is 2.40 m.

3. SURVEY GOALS

The final aim for this survey was to document the real conditions of the tower and the walls in order to approach them with theoretical and historical elaboration and to realise a conservation and re-use project.

Thus it was necessary to define and detail the texture of the walls with 3D data deriving from the stratigraphic tests.

The detailed survey of such a complicate structure would require long times and high costs. A selection was operated, preferring the employ of different simplified plotting methods, which needed a previous geocoding and resection phase obtained by topographic instruments, followed by a "photogram-taking" phase.

This survey was realised with the contribution of Milan Technical University (D.I.I.A.R. sect. Survey) and it's a main part of Miss.Manuela Notarbartolo degree final dissertation, which is, by now, work in progress at the Conservation and History of th Architecture of Milan Technical University. Prof. Gian Paolo Treccani presents the dissertation with the co-operation of Prof. Giorgio Bezoari and with the help of

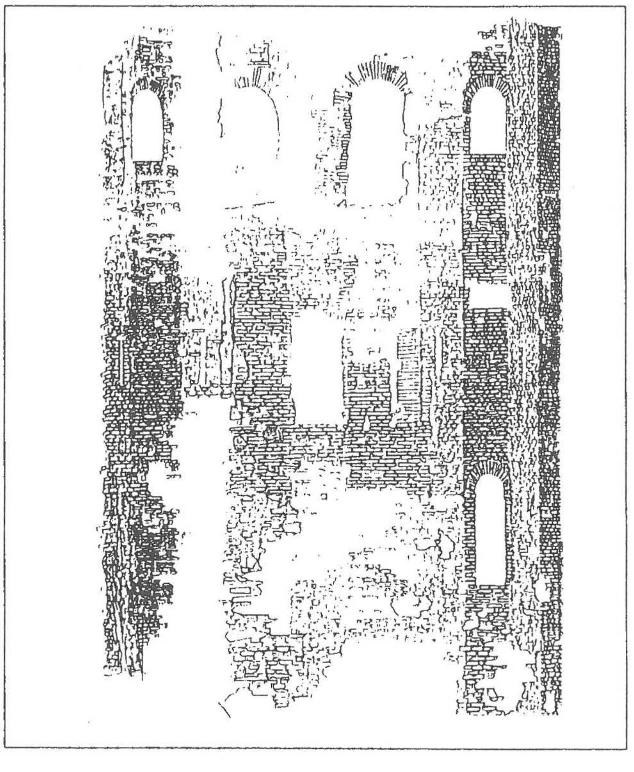
Dr. Roberto Bugini and of Dr.Arch. Gianfranco Pertot.

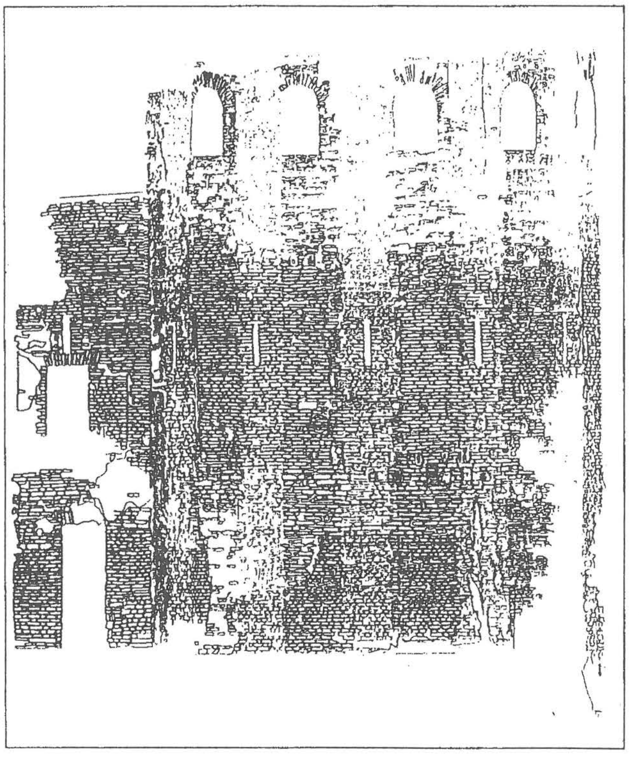
4. INSTRUMENTS

For the Topographic phase a Theomat Wild T1000 was, joined to a Distomat Wild with reflecting prism. In the taking phase a Rollei 6006 semimetric camera with 40mm focal length was used.
The photograms were phogrammetrically plotted by the Elcovision 10 system (version 4.0); Thus they were printed partially in b/w and partially in color with a magnification factor of 3.9.
The photogrammetric measures were obtained by a Calcomp 2500 UNIA3 format digitizer ($s = \pm 0.1$ mm on the tablet, $s = \pm 0.025$ mm on the photogram). The plotting editing phase was made by Autocad rel.13.
A sequence of drawings was realised at 1:50 scale; the accuracy to pursuit was therefore around 2 cm in all the three coordinates of each surveyed point.

5. THE PHOTOGRAMS RESECTION PHASE

The peculiarity of this survey stands in the criteria that were used in the plotting phase, especially in the photograms orientations.
Relating to the plotting scale (1:50) 16 models were made, with a total amount of 32 photograms. The photograms mean scale varies from 1:100 to 1:400. As mentioned, the magnification factor from the film to the printouts was 3.9
The two photograms for each model have been taken with a considerable convergence (φ angle between the two images), as preferable when one is intentioned to use non-stereoscopic plotting systems, such as Elcovision.
Furthermore, as a consequence of the existing geometry around the tower, the highest part of it was pictured from the ground, with the consequence of a sensible tilt angle. (ω angle of the two pictures with the standard direction, almost perpendicular to a vertical plane).
An open polygonal, developing only around the eastern part of the building, was made to determine the geocoding, as the whole western side courtyard wasn't accessible.
The control points were individuated by positioning some markers over the wall and the tower's surface (eastern side). The inaccessible points, at superior heights, have been selected by considering the easiness of recognition (corners, edges, peculiarly coloured bricks, etc.). In total, thirteen marked points (seven on the tower, six on the wall) and eleven natural points (three on the highest part of the wall and eight on the highest part of the tower) were surveyed, by using the simple forward intersection method.
To be noticed that it hasn't been possible to insert any control point on the West, Northwest and Southwest façades; in those parts it has been necessary to use an exclusively photogrammetric tie, by using the bundle adjustment logic.
To warrant a good quality to the photogrammetric observations, in such a way to give a satisfying precision level to the final result, at least forty collimations on the same number of crosses in the réseau, were made in every photogram internal orientation phase.
Thus, it was possible to estimate in quite a correct way the internal orientation parameters and to highlight some area in the photograms where the distortions were particularly high, to avoid to put any tie points into those areas. The use of magnified printouts often introduces quite serious, for goals like ours, deformations in the border areas.
The internal orientation was kept when the residuals RMS on the measured crosses was under 0.012 mm on the original photogram; this value showed to be in other applications a prudential limit.
To execute in a correct way the photogrammetric block we started with the relative and absolute orientation of those models referring to parts that were rich in control points.





Figures 4,5: *Examples of the plotting editing phase.*

Once we obtained some acceptable result we operated the first global adjustment of the block that was built until that moment: actually it's very important that the approximate values used into the photogrammetric block and that are estimated by the space resection, are good.
Before beginning the orientation procedures of the non-resected photograms it has been necessary a careful project of the photogrammetric tie: the tie points must be selected in order to allow the space resection too, in other words they have to be determinable in the previous model to guarantee an external orientation (even if approximate) of the following model.
During the measure phase it was necessary to proceed very gradually in the calculation, executing the global adjustment of the photogrammetric block for every new model to orient.
Only when closing the photogrammetric block, with the last model that goes to pinch the other area of the tower where control points were present, the result of the adjustment has a definitive value; in the previous phases the numeric model corresponds to a projecting structure, with a longer and longer projecting.

6. RESULTS

The thirty-two photograms we used, defined 192 unknowns, regarding the orientation parameters.
The photogrammetric block results to be laying on the ground with 24 control points, which mean 72 constraints in the solving numeric system. To execute in a correct and robust way the photogrammetric tie, 115 tie points were selected on the 16 photograms that were without control points; that means 345 unknowns more.
By the other side 618 photogrammetric observation were made (collimated points on several photograms) generating 1236 equations. The system globally has 537 unknowns, with 699 redundant observations (equations). The RMS in the photographic co-ordinates after the global adjustment resulted to be 0.027 mm, evaluated onto the original 6x6-format picture.
In the following table the residuals on the control points are given.

	x	y	z
Passino residual	0.013 m	0.017 m	0.015 m
Control points RMS	0.008 m	0.010 m	0.007 m

7. CONCLUSIONS

As one can see the obtained precision is coherent with the job's aim.
To orient a sequence of photograms that encompass an architectural object, by using the bundle adjustment characteristics, so that one can survey few control points on the ground, is a pursuable method, in some applications, if supported by rigorous but flexible calculation software dedicated to architectural photogrammetry typical orientations.
The result has been obtained without any preventive off-line estimation of the approximate photogram orientation parameters.
The operative research in this sector must be prosecuted with other examples, by introducing some test points to be photogrammetrically measured so that one can verify the results with the topographic determination.

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