COMPARATIVE ANALYSES BETWEEN ANALYTICAL AND DIGITAL SYSTEMS: SAN PRIMO TOWER NEAR ROME

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Abstract

Comparative tests of analytical and digital analysis systems were conducted. The experiment took the form of a photogrammetrical survey of a tower from the Roman period near Rome.

To measure the x, y and z coordinates on an identical regular grid both a DIGICART analytical stereoplotter and the STEREOVIEW 300 digital system were used. The STEREOVIEW 300 was produced by Nikon S.p.A. in collaboration with Dr L. Menci.

The analytical system was used to semi-automatically plot a DTM with a regular 30 by 30 cm grid on each facade. The same operation was then repeated for each facade using the digital system in the two prescribed modes: semi-automatic (manual) and automatic.

The data obtained in this way were used to compare a series of points. Their quality was also analysed on the basis of their position on the general architectonic structure (points that could be clearly identified, gaps, areas whose architectural features could not be clearly identified, etc.).

Vertical and horizontal profiles of the tower were also plotted in a single reference system in order to establish the spatial dimensions of the 3D model.

1 - Introduction

The tower of San Primo at Gabii in the vicinity of Rome is one of the buildings dating back to the Roman period that can still be found in the countryside at the feet of the Frascati hills.

It is an approximately 9-metre high square construction that is in a poor state of repair at the top so that it is difficult to interpret the battlements.

The main structure consists of stone blocks with some brickwork in the upper section that was used for decorative purposes and for the string-courses that can be made out on the facades.

The aim of the study was to analyse a stereoscopic digital system to identify its scope and compare results with those obtained using traditional analytical plotters.

The tower of San Primo seemed to be an ideal test-piece for the experiment, both because it was easy to access throughout the survey stages but above all because of its unusual nature: a simple architectonic structure consisting of masonry fabric whose graphic features could not always be clearly identified.

The work was divided into different phases:

- acquiring stereoscopic photogrammes using a UMK Zeiss metric camera;
- survey of control points placed at different points on the facades;
- stereoscopic restitution, using both the analytical and digital methods;
- comparison of the two systems consisting of a comparison between the DTMs plotted both analytically and digitally in a single reference system, (digital plotting was both semi-automatic and automatic);
- selected digital processing to test the different potential provided by this technique compared with other forms of restitution.

2 - The topographical survey

To measure the coordinates of the points on the tower facades in a single reference system a 4-point control network was defined.

The space resection method was used, starting from a control point indicated as S1, which is assumed to be the origin of the reference system.

Vertices S1, S2, S3, and S4 were selected at a distance of about 30 metres from the tower in order to be able to measure the points on the two facades from the same station.

The survey from the ground used a WILD TC2000 total station and measured the angles and distances from the 4 vertices of the control network.

On each of the 4 facades of the monument 6 natural points were measured. They were selected on photogrammes and were monographed. They were distributed in the traditional manner in order to have a good support during the restitution phase.

The 3D network adjustment of the measurements showed that standard deviation of the three coordinates for the total number of points was not greater than 3 mm and the greater semi-axes of the error ellipses had a 95% confidence level of between 4 and 8 mm, as shown in fig. 1.

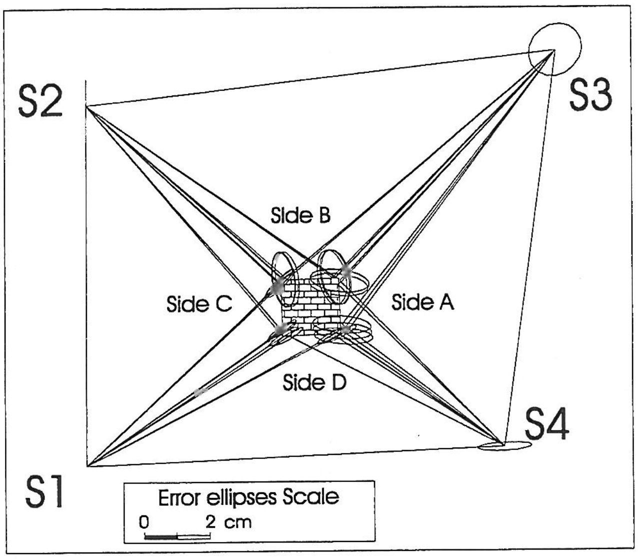

Fig. 1. – Planimetric diagram of the topographical surveys of the tower. The error ellipses obtained from least squares adjustment had a 95% confidence level.

3 - The photogrammetrical survey and restitution

As mentioned previously, a UMK Zeiss metric camera with a 90 mm lens was used for the architectonic survey. 13 cm x 18 cm stereoscopic shots on glass plates were used: two for each side of the tower (one model).

A distance from the tower of about 15 metres was maintained with a horizontal stereoscopic base of about 5 metres in order to ensure full stereoscopic coverage.

The stereo-pair was then scanned with a 1000 dpi resolution for the comparisons that were to be made and was then calibrated with the Scanview software.

Masonry fabric restitution was in this case very onerous and not always reliable because the line of the perimeter of a block of stone had a very irregular geometry because the stone was worn. It was a very subjective operations and therefore depended on the operator's experience. The operator had in any case to simplify plotting to adapt the restitution to the physical state of the surveyed object.

For this reason, for restitution it was decided to plot simple vertical and horizontal profiles for the four sides and to use a diagram to represent certain architectonic features of facades A and D.

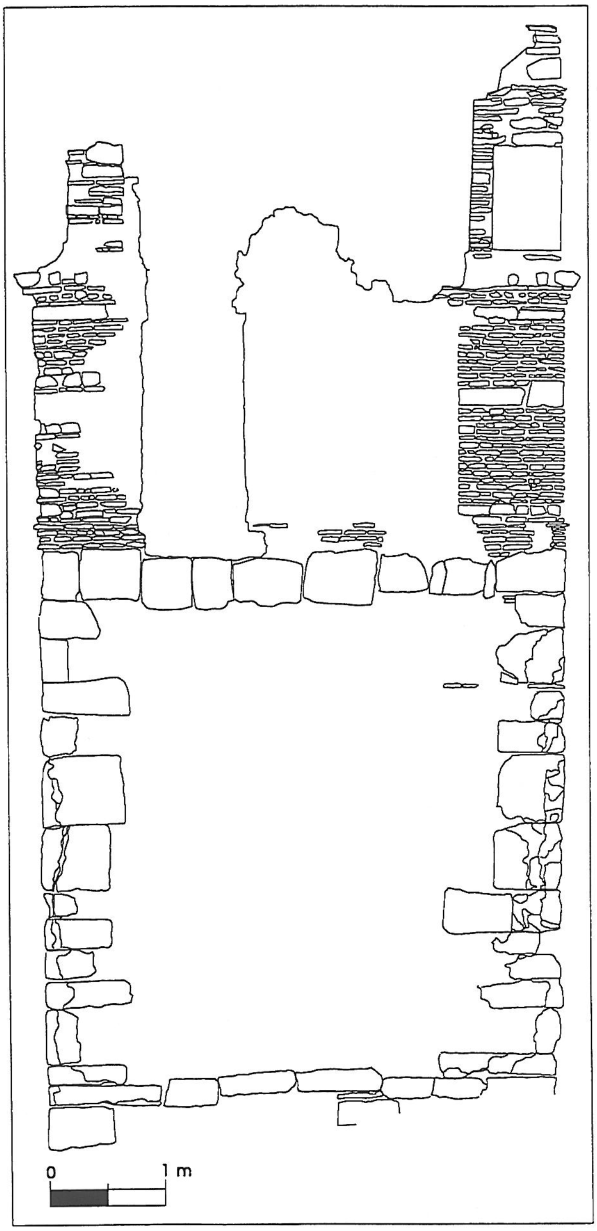

Fig. 2 - Analytical photogrammetrical restitution of side A.

The Digicart 40 analytical stereoplotter from *officine Galileo* was used for restitution. The reference points were those described in the account of the previous phase. First, 4 reference systems were used, one for each side, starting from the single reference defined with the control network.

These systems were obtained by rotating the coordinates of the reference points in such a way that the reference system was always parallel to the side of the tower being analysed.

The methods adopted for this phase were those used for each orientation made with analytical plotters. However, it must be stressed that the residues after absolute orientation were less than 8 mm in the three coordinates, although they were natural points.

To accurately plot the tower dimensions and any projection three horizontal profiles at different heights were used as shown in fig. 3, with a 1 cm sampling space; these sections were then inserted into the single reference system.

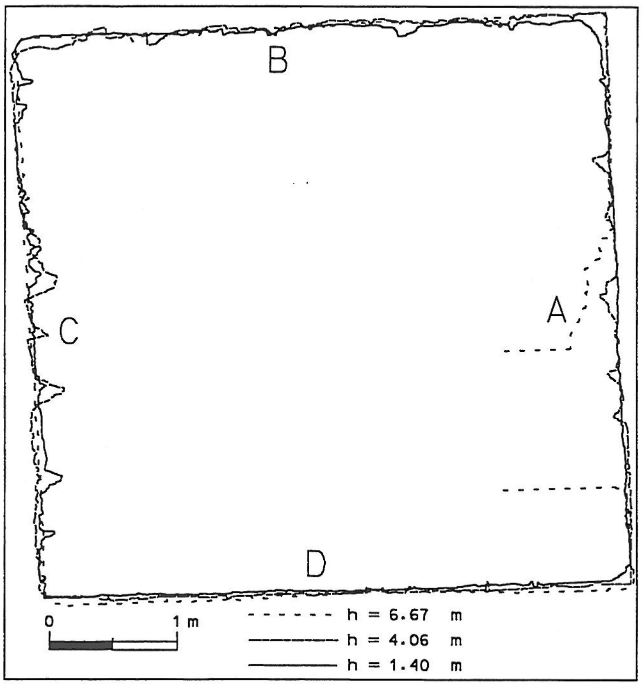

Fig. 3 – Horizontal profiles of the tower carried out with the Digicart 40 analytical stereoplotter

To describe the vertical sweep, on the other hand, three vertical profiles were made for each model, again with a 1 cm sampling space. These profiles were then entered into the single reference system and were found to be parallel to one another, thus confirming that the tower was completely vertical. Fig. 4 is a 3D representation of all the profiles and traces the tower perimeter.

4 - Processing and comparisons

First, after orientation, the effect of digitalisation error on the two systems used to acquire the ground coordinates was measured. For this purpose, for each system and for each facade 4 control points were selected on each of which 30 measurements were carried out.

Although these were natural points that made it rather difficult to repeat the measurement, the results obtained showed that within each system the values could be considered to be comparable and it is therefore reasonable to affirm that the measurements were equally accurate, regardless of the measured point.

For the comparisons the x, y and z coordinates were measured on an identical regular grid using the DIGICART Galileo 40 analytical stereoplotter and the STEREOVIEW 300 digital system.

For each facade the analytic system was used in the semi-automatic mode to plot DTMs on an identical regular 30 by 30 cm grid; the same operation was repeated using the digital system in the semi-automatic (manual) and automatic modes.

The values obtained from the DTMs without any further processing in the manual and automatic digital environment were compared with those obtained using the analytical system and then these values were compared with those obtained using the digital system in the manual and automatic modes.

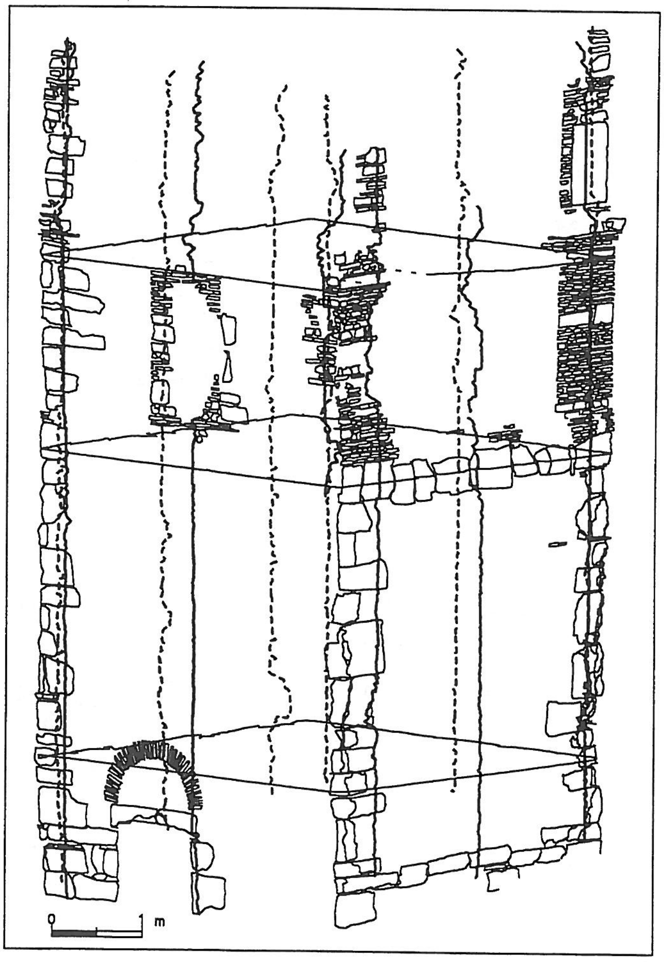

Fig. 4 – 3D view of tower. The Digicart 40 analytical stereoplotter was used for tower vectorisation.

It was found that the average measurements made using the systems were equivalent. The greatest differences in measurements of sampled zones were found in comparisons between the analytical system and the digital system in the manual mode, where it was more difficult to carry out stereoscopy.

The results of the differences between the coordinates surveyed analytically and those surveyed digitally have been summarised by plotting frequency histograms with the Δz differences being shown at 10 mm intervals on the x-coordinate and frequencies being expressed as percentages on the y-coordinate. For each side, Column a shows the comparison between Digicart – Steroview in the manual mode, and Column b shows the comparison between Digicart – Stereoview in the automatic mode. Column c shows the difference between the two Steroview modes.

The comparisons were made on a set of points that varied for each side and for each mode as indicated in Table 1. In the manual modes, the points of parts that could not be identified were not plotted. In automatic mode, the points were selected by giving an appropriate correlation coefficient, which was 1. This enabled all the points to be used.

A further refinement was to define an a priori depth outside which the points were eliminated that exceed it because they fell below the automatic correlation.

The auto-correlation technique (Kraus K., 1993) used in the StereoView was found to be fast and accurate in this test. It took 5 minutes to automatically acquire 200 points using a PC of the latest generation (Pentium Intel 200 processor, MHz MMX PCI, 128 Mb of RAM).

The stereo matching algorithm (recently devised by Dr L. Menci was applied at three pyramid levels (Ackermann F., Hahn M., 1991). On the basis of a certain number of points acquired manually from the model by the operator, a rough starting surface was obtained. On the first level (1/4 of the image) the 'feature based' correlation was applied. On the second level (1/2 of the image) the 'area based' correlation was applied and at the same time congruency with the model of the previous level and coplanarity on the same points were sought. The third level used 1/1 images and refined the surface by applying an 'area based' correlation. Finally, on all the measured points the range rating was applied: this consisted of the correlation coefficient used for data screening and eliminated data that had a higher value than that defined a priori by the user.

The DTM was in this case an indispensable document for careful description of the stone elements used for automatic plotting of contour lines and orthophotos.

Over a significant area of side A, 80 mm x 70 mm DTMs were carried out with regular 10 cm grids and with 1 cm grids. The automatically obtained DTM with a 1-cm grid provided 5967 points. As can be seen, this latter grid enabled the analysed elements to be better represented but it was too difficult for normal PCs to manage, especially when it covered wider areas.

The data of these DTMs were in this case interpolated to enable the orthophotos to be constructed. The Kringing interpolation method was used. This is based on the concept of the regionalised variable and subdivides the height variations into a component that is correlated with adjacent ones and with a casual error component. This method adopts an interactive approach. Without examining the specific algorithm, we can say that it produces a surface that passes through the measured points and makes it possible for the variation of each interpolated point to be estimated.

The two images in fig. 6 show the level of different detail required to obtain a significant representation of the morphology of the surface that enables a DTM with a 1 cm grid to interpret the masonry fabric.

SIDE	A			B			C			D		
Strategy	*a*	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*
Control Points	*164*	*143*	*138*	*151*	*152*	*151*	*177*	*175*	*173*	*168*	*168*	*168*
Average (mm)	*17*	*17*	*-2*	*12*	*15*	*2*	*3*	*-1*	*-4*	*-4*	*-7*	*-3*
Minimum (mm)	*-20*	*-37*	*-60*	*-45*	*-50*	*-51*	*-89*	*-110*	*-106*	*-52*	*-99*	*-92*
Maximum (mm)	*59*	*49*	*19*	*70*	*70*	*85*	*82*	*121*	*99*	*44*	*18*	*23*
Standard Deviation (mm)	*13*	*13*	*12*	*13*	*19*	*20*	*17*	*30*	*28*	*12*	*13*	*12*

Table 1 – Results of comparisons between DTMs made of 4 sides of the tower (**A, B, C, D**) at regular 30 cm intervals. **a** = Digicart – StereoView semi-automatic procedure; **b**= Digicart – StereoView automatic procedure; **c**= StereoView semi-automatic – StereoView automatic procedures.

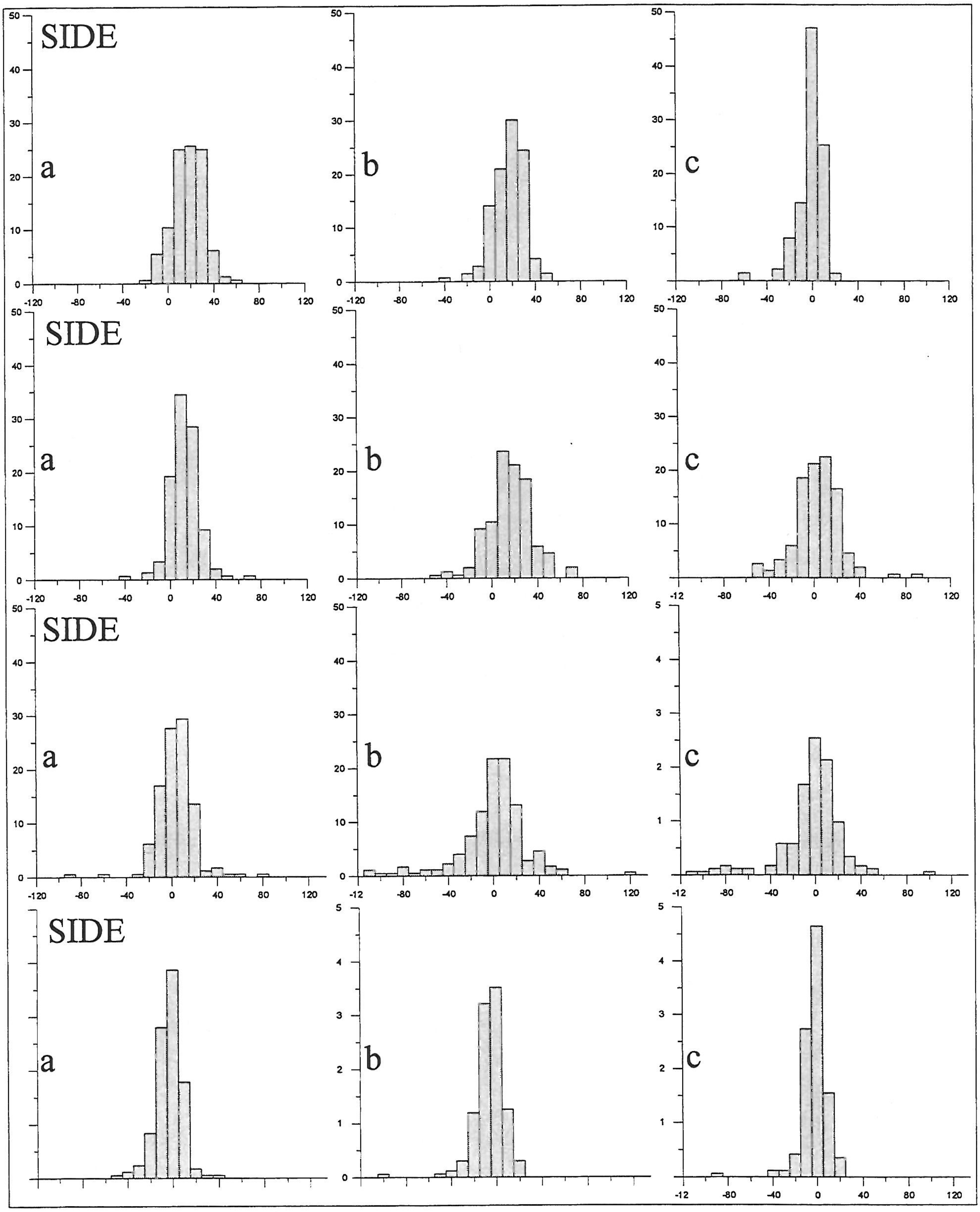

Fig. 5 – Distribution of residues deriving from the DTMs comparison, plotted at 30 cm intervals. Along the x-coordinate the categories are expressed in mm; on the y-coordinate the frequencies are expressed in percentages. **a** = Digicart – StereoView semi-automatic procedure; **b** = Digicart – StereoView automatic procedure; **c** = StereoView semi-automatic – StereoView automatic procedures.

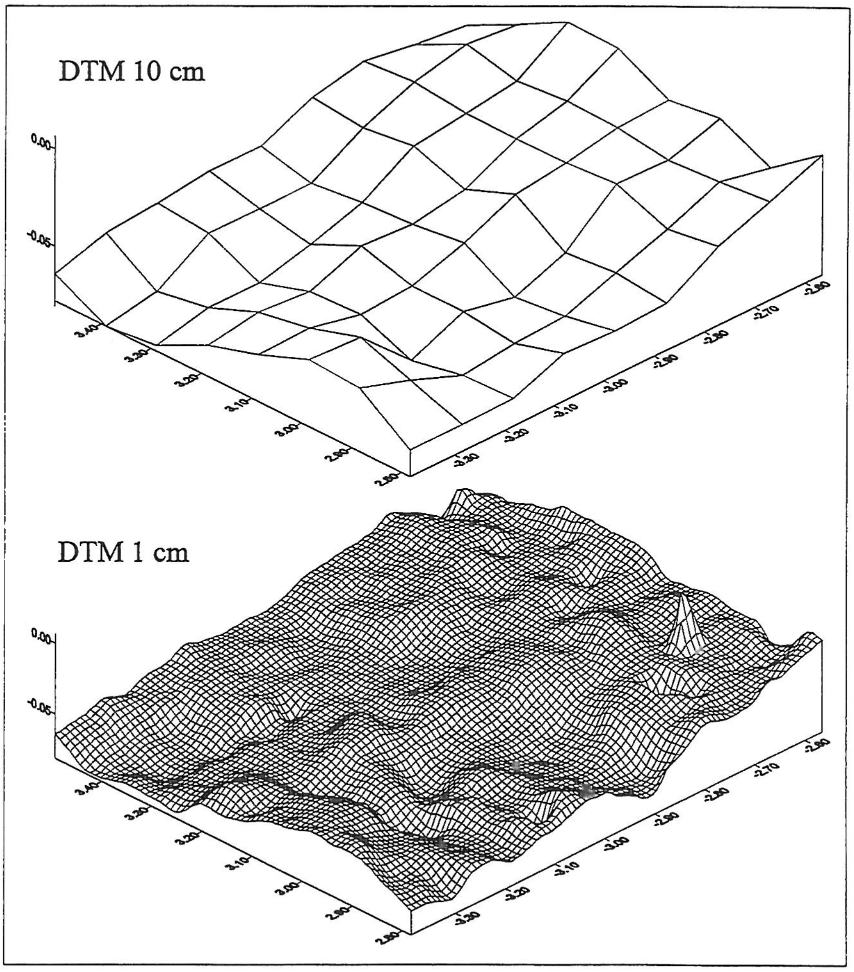

Fig. 6 – DTM made of a sample area a the base of side A of the tower using the Sterioview in the automatic mode.

Finally, the orthophoto was produced and this made it possible to obtain a 3D view of the Steroview digital system (fig. 7-A).

The DTM raster command of the Stereoview was used to project the image tilted to the left onto the 1-cm grid facades created automatically by the DTM grid as shown in fig. 6. With this projection, each pixel was projected onto the 3D surface, which was made up of as many facades as there are DTM start points. The pixel then followed the projection line that originated in the main point, went through the plate and joined the 3D point identified on the model.

The orthophoto of fig. 7-A is a flat view of the raster model thus generated. Figures 7-B, C and D show different views of this model that have been respectively rotated at 50, 70 and 80 degrees around the axis of the x-coordinates. Note that the contour lines were superimposed on these figures at intervals of 1 cm. Rotating the raster model thus highlighting surface irregularity.

Conclusions

In our concluding remarks we should point out that the tests conducted and the results obtained refer to a well-defined architectural object that is virtually flat and the surveying method was not designed for comparisons.

It is also clear that it was particularly difficult to set up a test that could compare all aspects of systems as the parameters that influence digital restitution are very numerous.

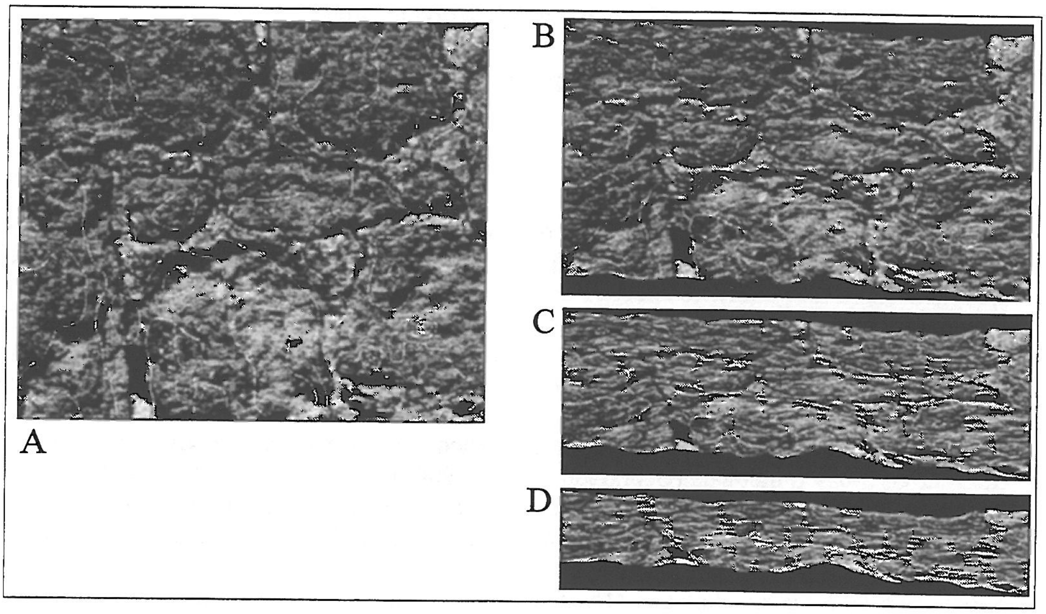

Fig. 7 – DTM Raster made on 1 cm side grid by StereoView 300. A = right-angled view; B, C, D = views tilted 50, 70 and 80 degree respectively around the x-coordinate.

The tests carried out have, however, shown that the digital system provides impressive results both in terms of accuracy and in terms of flexibility especially for orthophoto production.

The graphic and representational aspects must nevertheless still be examined although it has been seen that the digital environment offers wide restitution scope that could be very significant for building surveying.

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