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METRIC INFORMATION FROM UNCALIBRATED SINGLE IMAGES

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ABSTRACT

In cases of damaged or destroyed buildings, single images can be a basic or the only witness available for documentation, restoration or reconstruction. Such images have mostly not been taken for purpose of geometric documentation. Thus, it is usually not possible to employ standard photogrammetric techniques. This contribution addresses the 'unfavourable' case of single images with no available information on camera/image geometry and without geodetic control. It is merely assumed that directions are identified on the object (defining three vanishing points). Line photogrammetry is used to estimate the main interior orientation parameters and the rotational matrix, which provide basic information for 3D reconstruction. The approach is investigated with test images. A practical example, referring to the Athens Municipal Theater demolished some sixthy years ago, is also included. It is concluded that, in principle, careful treatment of single images allows in such cases to extract their inscribed metric information with 'reasonable' accuracy.

1. INTRODUCTION

Instances where photogrammetry is called upon to solve documentation problems for cultural items partly or totally damaged is not all that rare. In these cases, old ('historic') images may be a basic or the exclusive source of information for documenting, restoring (or reconstructing) the monument. For items of 'minor' importance in particular, the odds are that only single amateur photographs or postcards will be traced - as negatives, paper prints or postcards in public archives, photoalbums, books or private collections. As a rule, one expects that such images have not been taken for photogrammetric purposes. Consequently, neither full ground control information nor camera data will be available. Under such circumstances, photogrammetry ('by-passing' its standard techniques) is expected to make best use of old perspective recordings to extract data of metric quality.

In a sense, every practical application with single images has its uniqueness, as there exist a large variety of conceivable cases resting on available data, object peculiarity and required result. Nevertheless, one needs to group together and document all possible 'monoscopic' techniques, investigate their potential and illustrate them for the users. Recognising the importance of this problem, CIPA has established its Task Group 2 dedicated to single images (the web site cited in the References section includes literature on the use of old images).

Among the 'unfavourable' cases one would count images with no available data on camera/image geometry (inner orientation unknown) and without geodetic control (exterior orientation unknown). Fortunately enough, however, man-made objects as a rule contain straight lines, thus offering themselves to approaches of line photogrammetry. In this context, the authors have employed vanishing points to rectify building facades of a demolished historic centre (Karras et al., 1993). A more general discussion of rectification of planar objects via lines is found in Liebowitz & Zisserman (1998). Regarding 3D structures, Gracie (1968) derived all necessary equations for estimating interior orientation parameters and camera orientation in a three-vanishing-points configuration (see also Williamson & Brill, 1989). More recently, van den Heuvel (1999) has employed constraints among lines for camera calibration, including radial symmetric lens distortion.

Unlike approaches based on vanishing points, here a line algorithm developed by Petsa & Patias (1994) is applied for single image calibration-orientation. Straight object lines in three known (or assumed) directions are required; the parameters of the fitted image lines are directly adjusted to recover the three primary inner orientation elements as well as the rotational matrix which, with a given scale, provide the basic information for 3D reconstruction. Critical geometries and multiplicity of solutions have been extensively studied (Petsa, 1996). The method has been tested with images of existing buildings as well as 'uncalibrated' single images of a demolished theatre.

2. MATHEMATICAL MODEL

The basic mathematical model, as given by Petsa & Patias (1994), may be summarised here as follows. Let G denote an object line and å denote the central projection plane of the corresponding image line g. Furthermore, let **j** denote the normal vector of å. If only the direction vector $\mathbf{d}^T$ = [L M N] of the object line is known, then

$$\mathbf{j}^T\mathbf{Rd} = 0$$

expresses the orthogonality of these two vectors, i.e. the parallelity of the direction of object line G (and hence of all object lines with the same direction) with projection plane å (and hence with all projection planes of object lines having the direction vector **d**). In this condition **R** denotes the matrix of image rotations. Vector **j** is a function of the three main interior orientation elements (camera constant c and principal point coordinates x_o, y_o) and the two image line parameters. If radial symmetric lens distortion is also to be accounted for, its coefficients can be determined during line fitting (Karras et al., 1998).

Every space line of given or assumed direction gives rise to one orthogonality condition. Image lines are first fitted and subsequently carried into the adjustment along with their variance-covariance matrix. As a result, the values of the six desired parameters c, x_o, y_o (interior orientation) and ù, ö, ê (attitude) may be estimated. In case enlarged paper prints, postcards or photographs in books are available and the initial camera format remains unknown, the "photo-constant" c_{IM} rather than the camera constant is found; accordingly, the principal point also refers to the system of the image at hand (x_{oIM}, y_{oIM}) Generally, the ('internal') accuracy of the result depends on the distribution, length as well as sharpness of image lines. Obvious ('external') gross error sources include misinterpreting the continuity of lines, deviations of the lines from their assumed direction or even from linearity etc.

With knwown interior and (rotational) exterior orientation, and an indispensable known length for scaling, 3D reconstruction may then succeed at extents determined by object morphology. It is convenient to select the axes directions with XY defining a basic vertical plane of the object, with Z running in the direction of depth. The collinearity equations available for each object point require that one of its three space coordinates is known (points on the same vertical planes parallel to the XY plane have identical Z, points on horizontal lines identical Y, on vertical lines equal X and Z). Thus, the reconstruction process rests on points found previously. Often two coordinates of a point are known (e.g. points on a previously found vertical line or lying on the intersection of a known horizontal plane with a known vertical plane parallel to the XY plane); this evidently helps to check the accuracy of reconstruction.

3. EXAMPLES WITH KNOWN OBJECTS

The approach has been tested with several images taken for this specific purpose. However, to assess its performance in a more realistic way it was decided to avoid 'convenient' photographs. Thus, images of two building were selected which had been taken in the context of students' projects regarding planar facades. In these photographs a few short lines (balconies) in depth also 'happened' to be present, providing a third vanishing point.

Table 1. Results for test images a

Images	a1	a2	a3
Format (mm^2) Number of Lines	147×97 20	152×101 18	152×101 18
c_{IM} (mm) x_{oIM} (mm) y_{oIM} (mm)	161.55 0.35 -5.50	158.70 -1.95 -1.89	158.50 2.00 -0.39
ù (°) ö (°) ê (°)	14.58 -33.39 5.30	10.36 -12.22 3.38	12.70 -36.76 8.73
Affinity in Y (%) Difference in Z (cm)	-0.1 5	-1.4 -4	0.2 6

Table 2. Results for test images b

Images	b1	b2	b3
Format (mm^2) Number of Lines	176×125 17	152×101 18	152×101 17
c_{IM} (mm) x_{oIM} (mm) y_{oIM} (mm)	195.97 -3.39 4.48	163.54 -8.14 4.58	158.90 -0.56 -1.20
ù (°) ö (°) ê (°)	34.31 41.04 -6.52	22.26 58.14 -26.31	35.19 -48.06 25.86
Affinity in Y (%) Difference in Z (cm)	-0.3 -2	0.8 1	0.9 2

All six images, shown in Fig. 1, had been taken on three different occasions with small format camera and 35 mm lenses. Certain object dimensions were known to allow for checks. The resuts seen in Tables 1 and 2 refer to enlarged paper prints not including the full negative format. The metric information derived from these uncalibrated photographs is regarded as indeed satisfactory, with differences of just a few cm in depth and differential scales in height maximally reaching 1.4% (10 cm in 7 m). Furthermore, the presented results might well be considered as somehow representative since they include cases with relatively small and very large rotations (images a and b, respectively), as well as differences regarding lines: clear but badly distributed in depth (images b); well distributed though short and unclear (images a).

4. EXAMPLE WITH AN UNKNOWN OBJECT

In this case the Athens Municipal Theatre was considered, an imposing building designed by the prominent Bavarian architect E. Ziller. The theatre was built in the city centre in 1888 and, regretfully, torn down in 1939. Some images of the building are to be found in public archives or photoalbums. The three images and the one postcard used here were direct scans from books and were mostly of very poor quality. In order to have some kind of check, initial designs of the architect were traced at the Municipal Museum. Yet these differed strikingly both from each other and from the building finally realised as seen on the photographs; only an approximate scale could be extracted. Hence, the possible check was to compare the data derived independently from single images to each other.

The four images used have been taken at different time periods (c3 just before demolition) and are seen in Fig. 2. Three of these show the front and include extremely perspective views of the side; the fourth photograph shows the side and allows to 'guess', rather than establish, just a few short lines in the third dimension. The results from this data are found in followingTable 3. For scaling, a horizontal dimension of 30 m has been given to the central front part of the building, to which all measures refer.

Table 3. Results for the Municipal Theatre (images c)

Images	c1	c2	c3	c4
Format (mm^2) Number of Lines	157×92 19	179×122 18	140×120 13	107×78 13
c_{IM} (mm) x_{oIM} (mm) y_{oIM} (mm)	179.62 -7.71 -11.18	240.67 -22.53 6.86	198.51 5.32 -12.72	93.26 12.12 -10.49
ù (°) ö (°) ê (°)	2.96 29.06 -0.92	3.88 32.73 -3.44	5.40 -27.69 1.75	3.69 34.01 -3.07
Height (m) Width - Left (m) Width - Right (m) Depth (m) Total Depth (m)	12.75 9.80 9.56 1.16 65.90	12.68 9.91 9.47 1.19 67.00	12.75 9.79 - 1.16 65.20	- - - - 67.20

As seen in the above Table, no scale differences are detected in height. The widths of the two smaller blocks are also consistent (maximal difference 1.2%). The difference between the left and right widths, however, remains unclear since this dimension could not be measured on the third image due to the palm tree. Regarding depth estimation, the small relief on either side of the central block also appears as consistent. Finally, the total depth of the building is estimated with a maximal difference of 3%. E

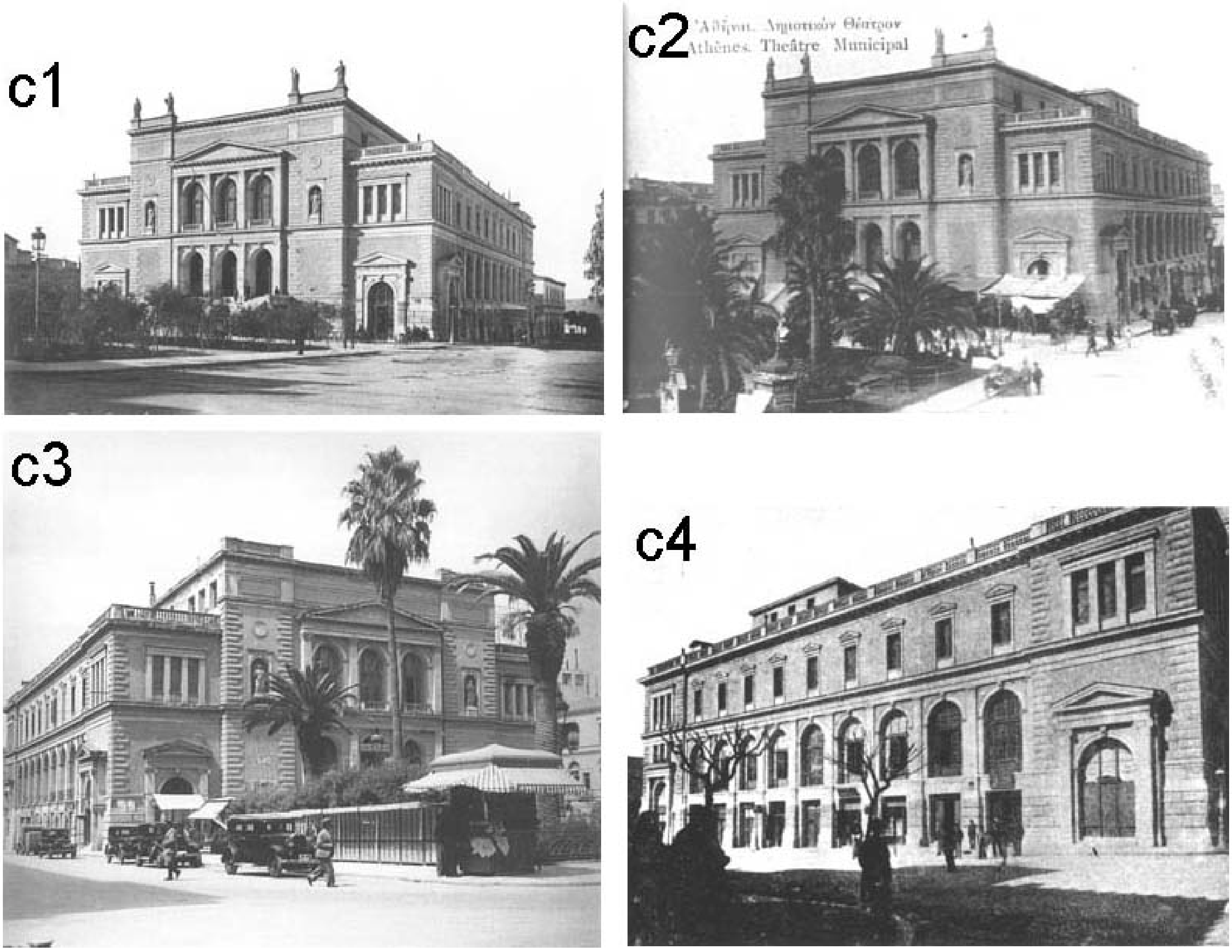

Figure 2. The four old images of the Athens Municipal Theatre.

ven the view c4 from the side (the results of which were simply scaled through a height transferred from the other images) gives a close estimation.

5. CONCLUDING REMARKS

Obviously the question of the metric exploitation of single images in architectural photogrammetry - and, particularly, of uncalibrated ones - cannot be answered with a unique approach. However, it is a task of CIPA to attempt to 'group' cases together and provide solutions of a more general validity. Thus, a rather wide group of possible cases is the one addressed in this contribution: images totally unknown as regards their 'inner' geometry and geodetically undocumented, showing unknown 3D structures. Yet the recorded objects contain linear features which let one assume that they run in three directions orthogonal to each other (no guarantee that the hypothesis is valid!). There are approaches which can, at least theoretically, cope with such cases. An approach was tested here with 'tough' data, particularly as regards the demolished theatre, the images of which were indeed of poor quality. The results showed an encouraging consistency (though their actual accuracy remains unknown). Other tests also indicated the method's potential. Only more systematic studies, however, will produce tools of practical importance.

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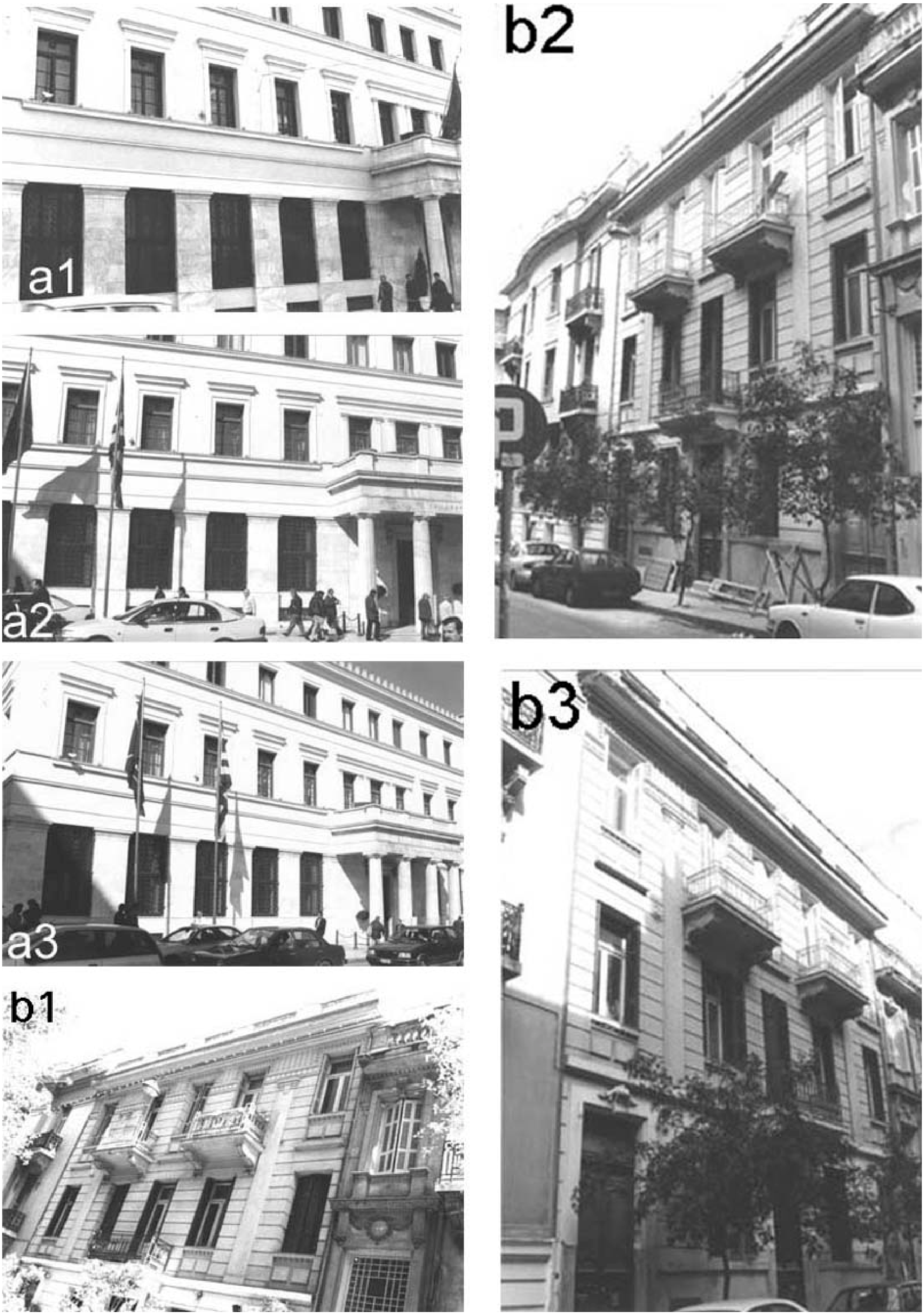

Figure 1. The six small format images used in the test