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# *TWO EXAMPLES OF NON-CONVENTIONAL PHOTOGRAMMETRIC TECHNIQUES: THE NATIVITY'S INTERIOR FACADE AND THE SPIRE OF S.BARNABA'S BELL TOWER IN THE SAGRADA FAMILIA - BARCELONE*

ABSTRACT -
*An experimental survey of some parts of the Sagrada Familia in Barcelone was carried out: the interior side of the Nativity's Facade and the San Barnaba's Spire. The interior Nativity's facade was surveyed with mono-rail camera making use of the lens off-set; this feature enabling the operator to enlarge the optical stereo-base and to select the most suitable place for the positioning of the camera stations. The photogrammetric measurements were carried out partly in stereoscopy with a stereocomparator and partly in monoscopy in a digitizer table. The final plotting was carried out with AutoCAD 10 (TM). The San Barnaba's bell tower was the only one finished by Gaudi. The spire was surveyed from the road level with 35 mm camera equipped with lenses 300 mm and 1000 mm focal length. The plotting was made in monoscopic mode with a digitizer table, in Autocad 10 (TM).*

## 1. INTRODUCTION

An experimental survey of some parts of the Sagrada Familia in Barcelone was carried out: the interior side of the Nativity's Facade and the San Barnaba's spire. The survey of the whole temple would be too heavy in terms of time and costs. The employed photogrammetric technique was unconventional and the aim of the experiment was to establish whether or not these methods, characterized by low costs and efficiency, are suitable also for rather difficult projects, was to judge whether or not the results are satisfactory in quality.

## 2. NON-METRIC CAMERAS

Paradoxally today in architectural photogrammetry there is a seemingly contradictory trend: the demand for photogrammetric architectural surveys continuously increases just when the traditional manufacturers stop the production of their terrestrial metric cameras, already obsolete and too expensive. In the same time the market and therefore the production of non-metric cameras, i.e.amateur touristic cameras, and large format professional cameras, are quite lively, offering new models, more and more sophisticated, mainly because of the massive employ of the electronics. The many requests of Architectural Photogrammetry could be probably satisfied also by means of these types of cameras.

## 3. THE SELF-CALIBRATION FOR NON-METRIC CAMERAS

With these ideas, a strategy was designed for a quality control of an unconventional, low cost, efficient photogrammetric technique. Metric cameras are supplied with a calibration certificate made by the manufacturer. For non-metric cameras this lack of a-priori information must be replaced by equivalent metric information obtained a-posteriori by extra measurements made directly in the field. Not only that, but also the lens distortion, in practice null for metric cameras, for non-metric cameras is significantly different from zero and it must be estimated and corrected. The required additional information can be supplied by three-dimensional coordinates of the Control Points (Abdel-Aziz, Karara, 1). In the classical photogrammetry the control points are used as well but their quantity can be considerably reduced in comparison with non-metric cameras. Nevertheless in Close-Range Photogrammetry the cost per unit for Control Points is rather low and almost independent from their quantity, the cost for the set-up of the control net being prevailing. A computer program capable of dealing with non-metric cameras was therefore written, based on a self-calibration procedure (Fangi, Presta 2). Its main features are: - suitable for non-metric cameras - employ of graphical tablets as measuring devices of enlarged paper prints of the photos - multi-image restitution - interactive graphical editing with any CAD (Computer Aided Design). The program not only computes some coefficients for lens distortion correction, testing their consistency, but also calibrates the digitizer table taking into account for non-perpendicularity and for scale difference of the X and Y axes.

## 4. THE PHOTOGRAMMETRIC PROGRAM AS RESIDENT PROGRAM INSIDE INDEPENDENT CAD PROGRAMS

After the orientation of the photograms, (the computation of those parameters for the transformation from the photo-coordinates to the ground coordinates), the operator can switch to the plotting phase. The plotting can be carried out directly inside an external CAD. That means that the photogrammetric program is quitted, and the CAD is activated. For the plotting of primitives the 3-D coordinates of the points are furnished by the photogrammetric program, recalled just by pressing a key, in the same way as they would be typed in the keyboard (Fangi, Presta 2). The advantages are as follows:

- interactive graphical editing,
- little training period, because the operator usually knows already the CAD, employed also for different purposes
- high quality CAD, continuously up-dated
- modularity of the system

- large transportability of the plotting files.

## 5. MONO-RAIL CAMERAS AND LENS OFF-SET

They are large-format professional cameras, where the lens plane and the negative plane can be moved and rotated with respect to each other in any direction (see fig. 1). They are obviously non-metric cameras.

The above mentioned capabilities can be useful in architectural photogrammetry:

1) rectified images are taken directly from the field,

2) it is possible to increase the base/distance ratio of a stereo-pair getting a better accuracy in direction of the depth and mainly improving the flexibility and the efficiency of the survey. They enable for large taking bases, keeping the parallel lines in the main object plane (i.e a facade) again parallel in the image plane. In practice the operator can choose in a easier way and with less limits the positions of the shooting stations. Mono-rail cameras add the advantages in flexibility of monoscopic takings to the advantages of the stereoscopy (Fangi, 4).

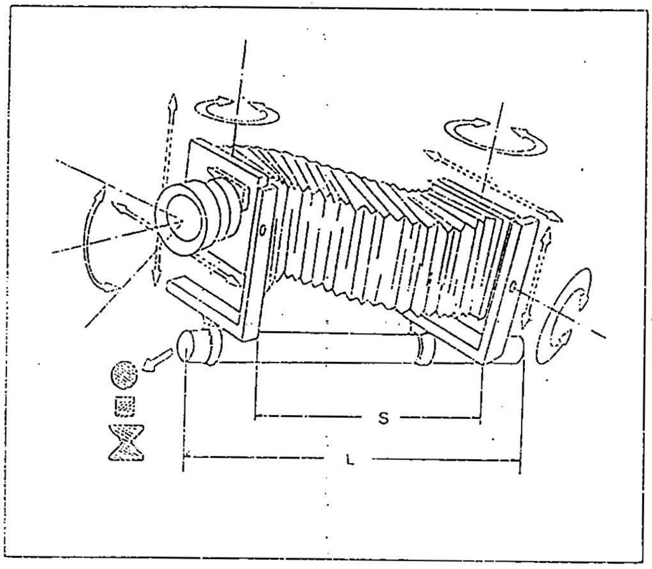


*Fig. 1 - Scheme of mono-rail camera*

## 6. THE PHOTOGRAMMETRIC SURVEY OF THE INTERIOR SIDE OF THE NATIVITY'S FACADE

Making use of this type of camera the photogrammetric survey of the interior Nativity's facade was carried out. Three stereo couples were shot, one for the upper part, with horizontal axes, and two couples from the ground, one with horizontal axes for the lower part, and one with inclined axes for the middle part (see fig.2). The camera was a Fatif 9x12 cm with 150 mm lens. Let's take into consideration

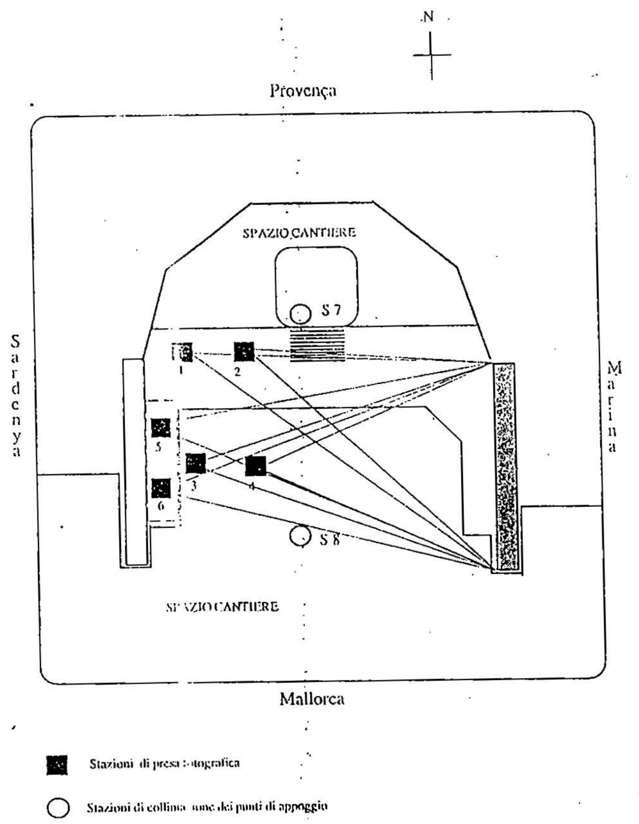


*Fig. 2 - Interior Nativity's Facade. Lay-out of the photographic stereo-pairs*

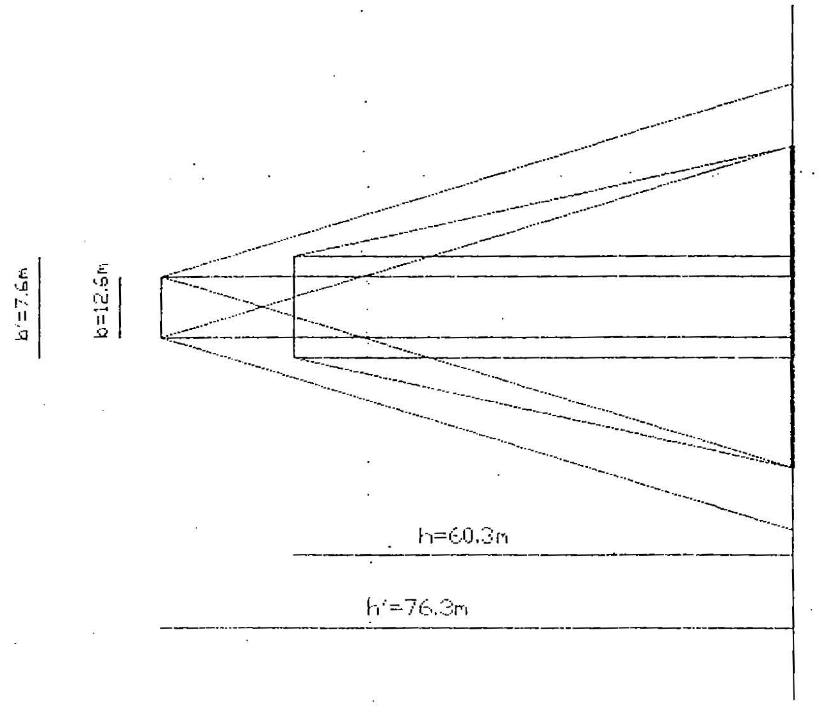


*Fig. 3 - Stereo pair made with off-set lens camera versus the equivalent stereo-pair made with centered otpical axis*

for instance the stereo-pair 5-6 in fig. 2. With a centered axis camera equipped with the same lens, the negative side should be increased from 9 to 11 cm for the same overlap; alternatively with the same format, the same lens and the same overlap, the distance from the base to the object should be increased from 60 to 76 m, while the base should be reduced in the same time from 12.5 to 7.6 m (the base/distance ratio would change from 1/5 to 1/10). That would be just not possible. 19 control points were surveyed by intersection from a two theodolites base. The duration of the geodetic works was about two hours. With the classical photogrammetry for the three stereo models, partly overlapping, a least of 9 points would be needed. The saving in time would be around half an hour only.

## 7. LONG FOCAL LENSES

Lenses with large coverage angles are generally used in photogrammetry, (wide-angle). In the case that a suitable photo-scale is needed for objects hardly reachable or very far from the accessible places, long focal lenses are used (narrow-angle). The coverage angle is narrow and the focal lens is large in comparison with the negative format. Even in this case the equipment of metric cameras is rather limited, while the normal photo-market offers a wide choice of any focal lenses at rather low prices. It was demonstrated (Fangi, 3) that in order to use long focal lenses and non-metric cameras, the camera station positions must be known.

## 8. THE PHOTOGRAMMETRIC SURVEY OF THE SAN BARNABA'S SPIRE

The San Barnaba's spire is located about 100 m above the ground level. The survey was carried out for economy reasons from the ground and therefore long focal lenses were required. The photos were shot from the four directions corresponding to the four vertices of the polygon surrounding the temple (fig.4). A 35 mm reflex camera, Olympus OM4, equipped with a 300 mm and a 1000mm lenses was used. Eleven photos were shot with 300 mm lens. The taking distances from the spire were ranging from a minimum of 150 m to a maximum of 180 m about.

## 9. THE CONTROL NETWORK

For the survey of the control points a traverse was established all around the temple. The traverse was composed by five stations. An open arm connected in the same reference system the interior side of the church (fig. 5). From the traverse by intersection 31 control points for the spire were determinate. From the interior side 19 control points were surveyed. From the traverse vertices, the photogrammetric stations were surveyed also. Their coordinates were needed because of the long focal lenses used. The adjustment for the control points was carried out in a least squares procedure. All the control points were coinciding with natural details in the object (fig. 7).

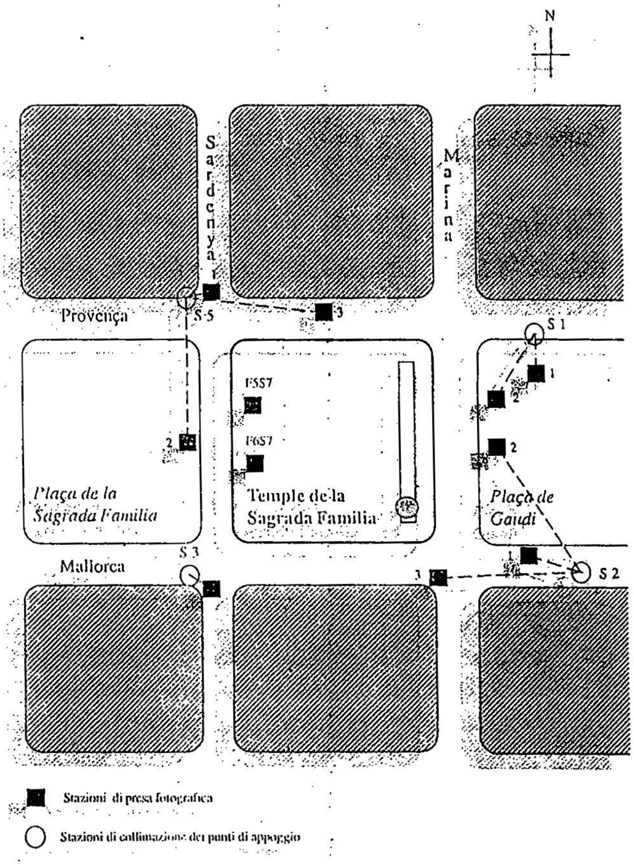


*Fig. 4 - Plan of the photographic takings of the s.Barnaba's spire*

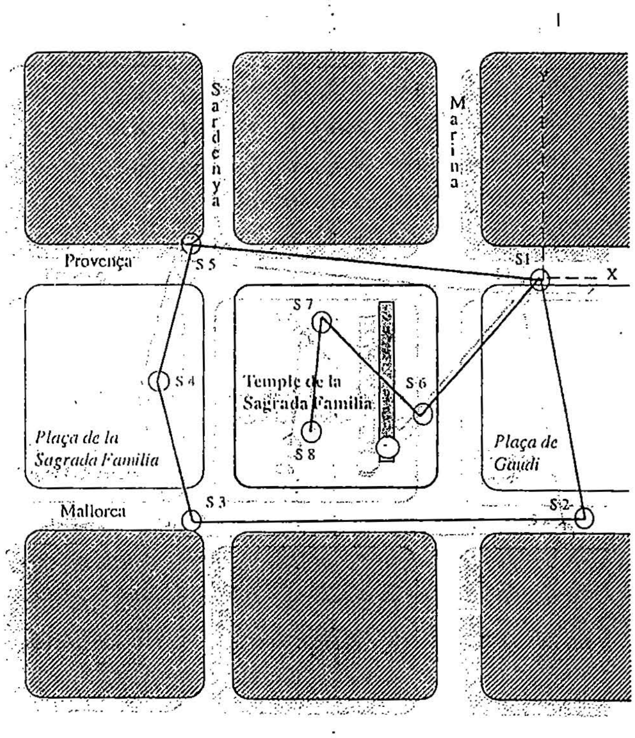


*Fig. 5 - The Control Network*

## 10. THE COMPUTER AIDED DESIGN AND THE GRAPHICAL ELABORATION

The plotting was carried-out on-line in Autocad (wire-frame and spatial model) and in Autoshade for the final elaboration (solid model, color treatment and shading). The plotting was carried out partly in a stereocomparator and partly in a graphic tablet with 2.5x enlarged paper prints (20x30 cm). The reason for that, was the limited training of the operators. It should be noted that for the facade the restitution was edited, correcting and rectifing non-aligned lines, when it was evident that they were not corresponding to an ideal architectural geometry. This is mainly due to a point-by-point restitution. The plotted points were the ending points of straigth lines or better lines supposed to be straigth lines. This procedure made difficult to point-out geometrical "anomalies", such as curved lines, off-set of planes, etc. Therefore the graphical editing was more demanding in comparison with traditional continous plotting. From one side the operator could be rather inexpert in photogrammetry but from the other side he should have a deeper knowledge in architecture. The average of the absolute values for the residuals in the three dimensions of the control points was 1.3 cm. The plotting accuracy is expected to be around 2-4 cm. The plotting was carried out inside AutoCAD 10 as CAD program, with the 3-D coordinates passed directly by the photogrammetric program working as resident program in the RAM memory of the Personal Computer. The operator was fully inexpert in photogrammetry, but already trained in CAD. The final drawings were two-dimensional (see fig.6).

## 11. THE S.BARNABA'S SPIRE

Because of its complexity, it could not be fully represented and understood by the traditional representation (front and side views, cross-sections, plan). The only exhaustive approach seemed to be the fully three-dimensional representation and therefore the Computed Aided Design was probably the most suitable mean to define, represent, understand the spire in all its shapes, patterns and geometry. This plotting was carried out therefore in four different phases:

1) build-up of the wire-frame by photogrammetric measurements (fig.8). The plotting was carried out in monoscopy in a graphic table A2 format with 10x enlarged paper prints. Three phogrammetric models, each made by four photos, were formed. Two other models were set-up for minor parts. 31 control points were used. The upper part only of the spire, 15 m long, was plotted. In these photogrammetric models the orientation of the photograms were particularly difficult because of
- the great distance,
- the prevailing linear shape of the object,
- the little depth of field
- and the incompleteness of the models (the bigger part of the photograms being occupied by the sky). The average of the absolute values for the residuals on the

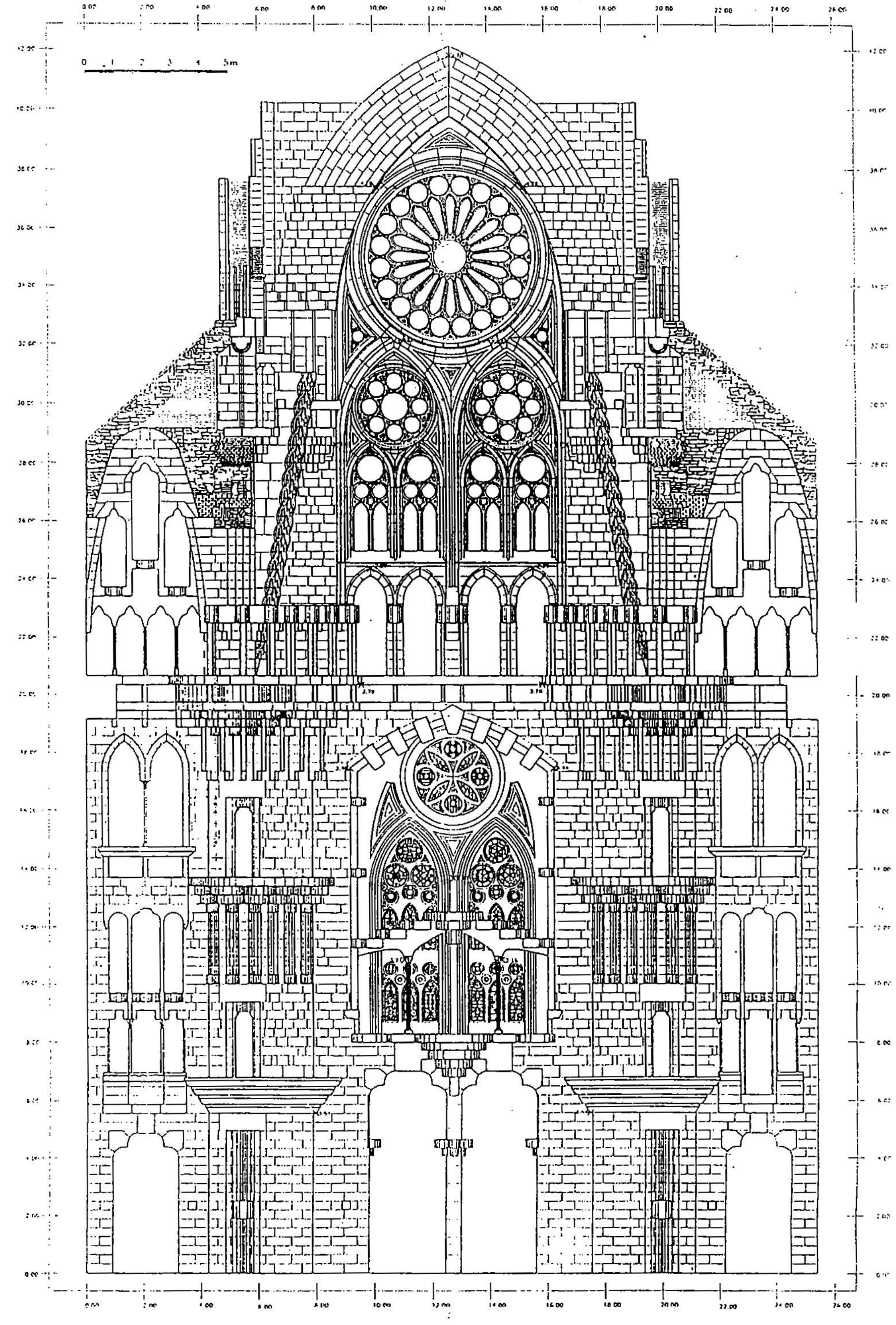

Fig. 6 - The interior side of the Nativity's Facade

control points was 2.7 cm, while the plotting accuracy is supposed to be around 3-5 cm.

2) Off-line build-up of some particular parts The point capture was monoscopic: therefore some continuous parts could not be plotted directly by photogrammetry. Based on the dimensions taken from the wire-frame, working as skeleton, four parts were selected; the upper part, formed by two opposite plates holding on their perimeter 8 spheres each, a central part with shield shape, the base and the connection between the upper part and the central one. The probable law of their generation in space was established, with the help of pictures made with 1000 mm lens.

3) Composition in space of the isolated parts and their jonction with the wire-frame; the wire-frame was then transformed in a solid model, by the identification of the planes and the surfaces passing through the lines. (fig. 9).

4) Removing of hidden lines, shading and color painting.

## 12. CHARACTERISTICS OF THE PHOTOGRAMMETRIC SURVEYS

Nativity's Façade, interior side

- Photogrammetric System PhOX
- Graphical editing: AutoCAD 10
- Mono-rail camera Fatif 4"x5", lens 150 mm/5.6, color reversal film Ektachrome 64 asa Kodak, B.W Ilford 125 ASA
- average taking distance 60 m
- average photo scale 1:400
- plotting accuracy 2-4 cm
- duration of the geodetic and photogrammetric works: one working day for a three men crew
- n. of photograms : 6 in three stereo-couples

San Barnaba's spire

- Photogrammetric System PhOX
- Graphical editing: AutoCAD 10
- Camera reflex 35 mm Olympus OM4, 300mm lens, 1000 mm
- color reversal film Fujicrome 100 ASA
- taking distances 150/180 m
- average photo-scale 1:500/ 1:650
- plotting accuracy 3/5 cm
- duration of the geodetic and photogrammetric works: three working day for a three men crew
- n. of photograms: 11

## 13. CONCLUSIONS

The point-by-point plotting of lines doesn't express the full potentiality of the photogrammetry because of non continuity; in addition the monoscopic data capturing

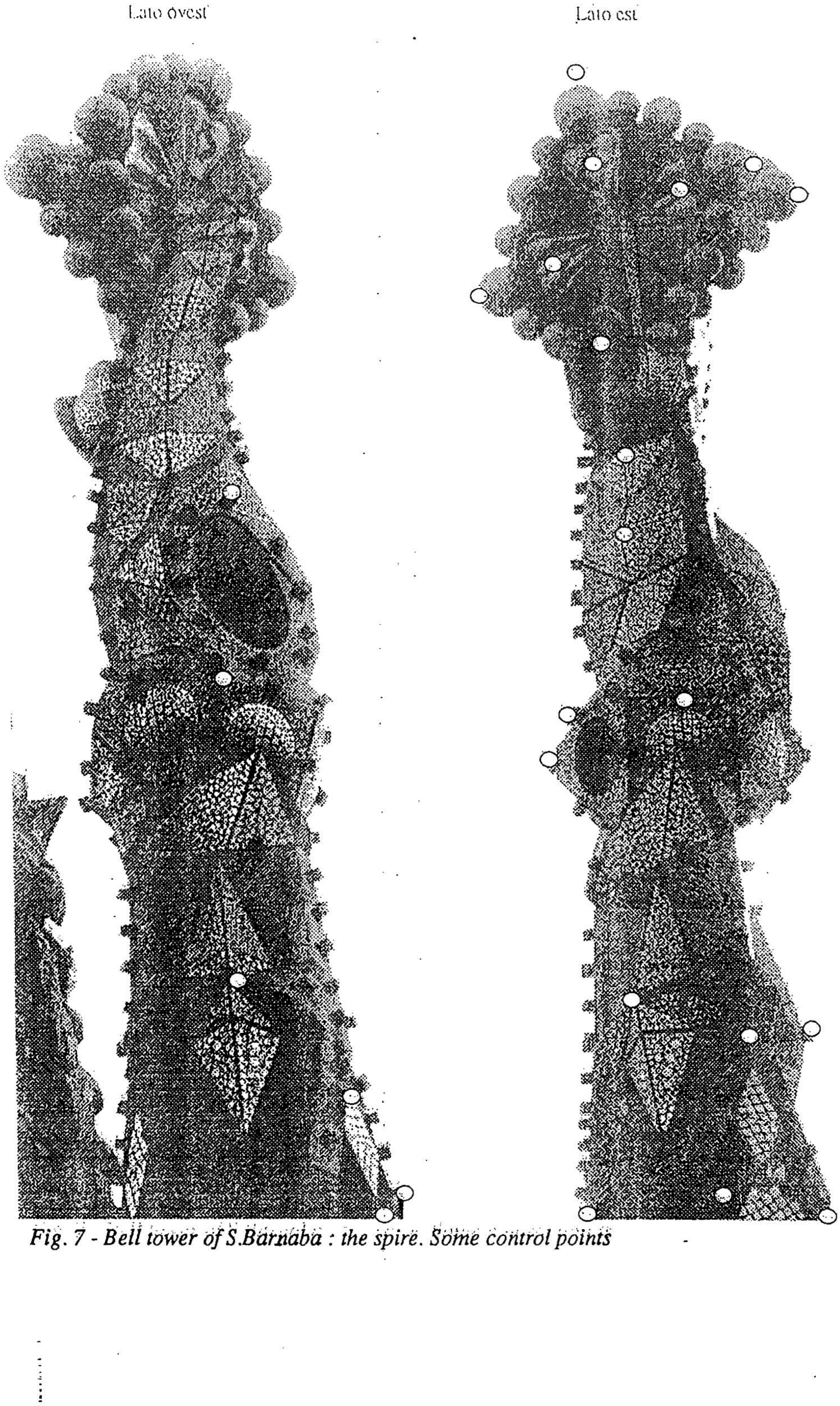


*Fig. 7 - Bell tower of S.Barnaba : the spire. Some control points*

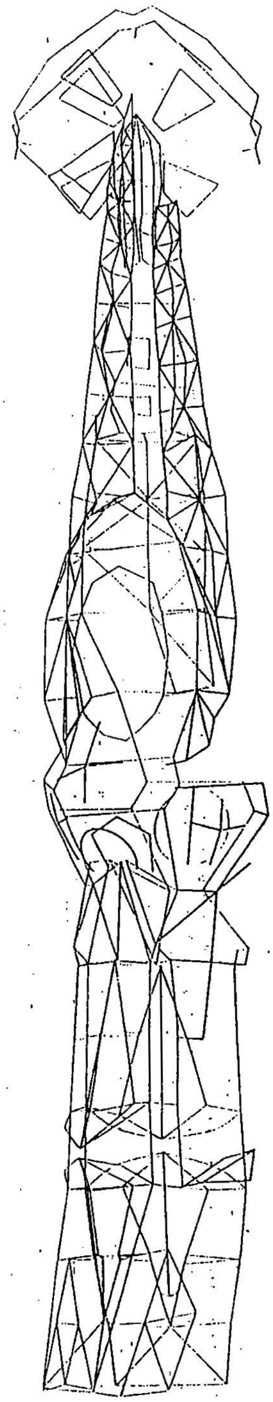

*Fig. 8 - S.Barnaba's Spire : the wire frame*

reduces even more the information contents of the photogrammetric surveys. The emploied P.C. CAD program, not expressely designed for photogrammetry, had limitations in memory and speed. Nevertheless the efficiency and low cost of this photogrammetric techiques were assessed positively with a satisfactory degree of accuracy. The same surveys would be certainly possible by means of the classical photogrammetry as well (metric camera and stereoplotter). Their results would be certainly better, but their employ would be much more difficult, mainly for the spire, and after all at a much higher cost.

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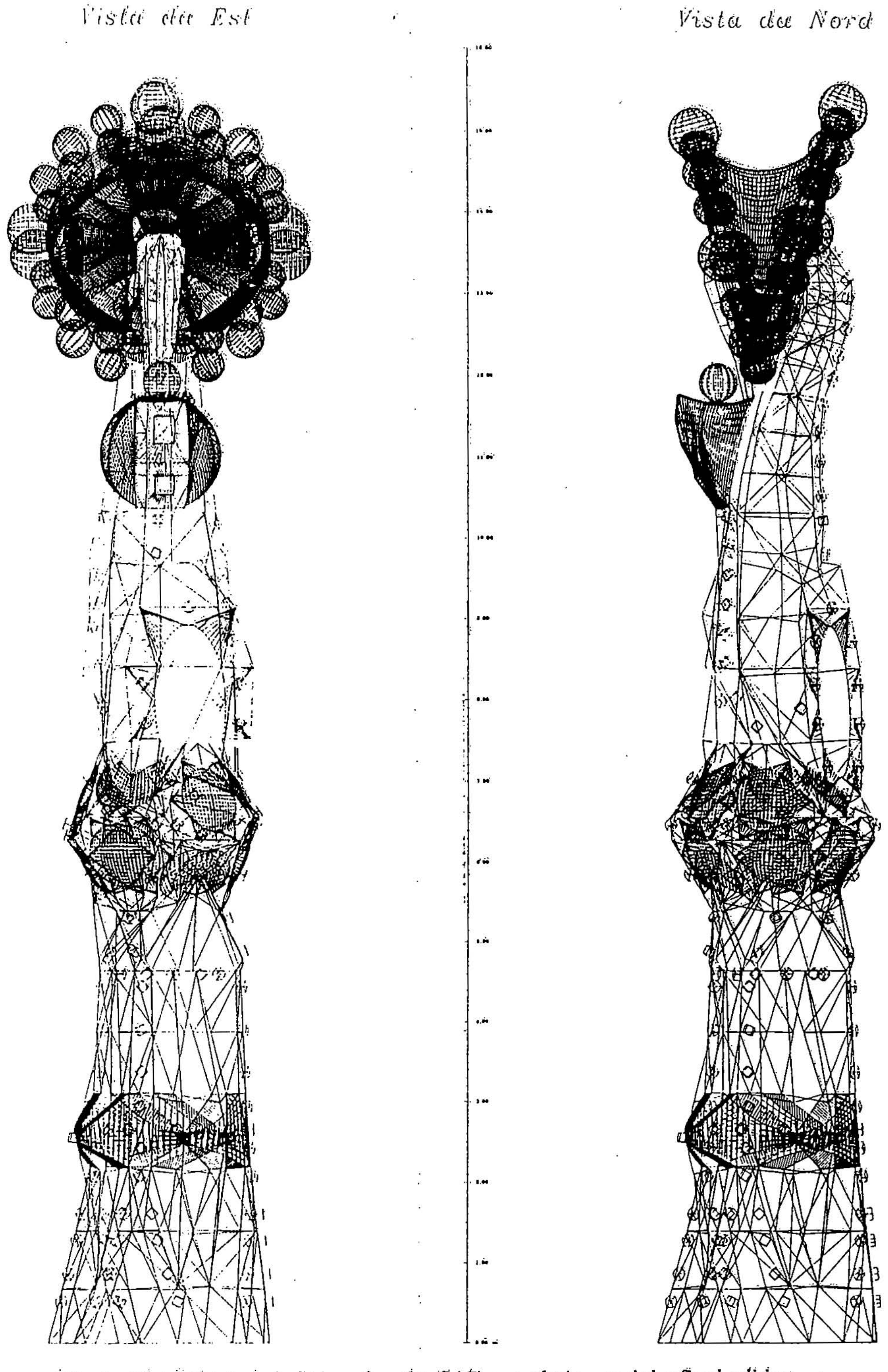


*Fig. 9 - The S.Barnaba's Spire after the CAD completion and the final editing*