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New Developments in Architectural Photogrammetry at the Institut Géographique National, France*

The use of the Matra Traster 77 analytical stereoplotter and the Wild OR 1 Orthoprojector and the application of computer derived elevation and perspective drawings are described.

Abstract: *In addition to current surveys of historical monuments, I.G.N.-France is developing its architectural photogrammetry activities in the following three directions: (1) The Matra Traster 77 analytical stereoplotter is very useful in difficult cases, particularly for deep subjects such as the temples at Pagan in Burma; (2) the Wild OR 1 digitally-controlled orthoprojector is being used for surveying curved surfaces covered by paintings; and (3) for general surveys of historical centers, a digital model obtained from aerial stereophotogrammetry makes it possible, after computation, to trace automatically all the elevations and perspectives and to study the insertion of new projects as, for example, in the town of Aurillac, which is discussed here.*

Introduction

In addition to current surveys using normal analog, graphical, and digital stereophotogrammetric methods or sometimes rectifying photographs and mounting them, the Institut Géographique National (I.G.N.) is attempting to extend the scope of its architectural photogrammetry activities in three new ways. The first two ways, still at the experimental stage, concern the use of an analytical stereoplotter and the application of digitally-controlled orthophotographic equipment. The third way, already operational, makes use of digital methods for producing general documents about historical centers.

Use of Analytical Stereoplotters

The I.G.N. makes use of Matra Traster 77 analytical stereoplotters. Compared with other instruments of this type, this apparatus is distinguished by its design as two closely linked units, by its observation system of the negatives, and by its control system. The first unit comprises the electronic devices, the Solar computer (32 K words of 16 bits), and the plotting table. In the second unit are assembled the observation screen on which are projected, in polarized light, the images of the two negatives, a conversational display screen used during the formation and orientation of the model, a third screen showing the position of the zone being observed on one of the negatives, a keyboard grouping all the controls, and, finally, the track ball (x, y) and the thumb-screw (z) for making the general and differential (parallax) displacements of the negative-holders.

The Traster 77 has been used for various non-cartographic purposes, particularly architectural surveys, for which it has proved invaluable for three different reasons:

- It becomes possible to plot photographs with parameters exceeding the limits of usage of analog plotters. This occurs when the environmental conditions of the architectural element to be re-

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corded, or the urgency of certain operations, make it necessary to orient the photographic axes in arbitrary directions, sometimes with strong longitudinal tilt, or even to use negatives obtained with non-photogrammetric cameras.

- One is able to organize more easily, sometimes to simplify, on-site operations, e.g., taking photographs, control measurements, etc.
- In particular, one can form and orient models accurately in those very difficult cases which are sometimes impossible for analog equipment due to the shape of the object.

This latter aspect is very important. All photogrammetrists are aware that, when an object has a large depth compared with the average depth of field, or when its shape and dimensions are such that it only partially covers the surface of the photograph, model formation is long and difficult and there are almost always residual deformations. Errors arising from the centering of the negatives on the negative-holders, even if very small, also have very troublesome consequences and sometimes it becomes impossible to obtain a very satisfactory absolute orientation. These difficulties disappear with the Traster 77 because the centering is done by computation and the model is formed analytically from a large number of points (40 points maximum).

These advantages have been demonstrated during various surveys, particularly those of the temples at Pagan in Burma. Former capital of the kingdom from the 11th to the 13th century, built on the eastern bank of the Irrawaddy River, Pagan once comprised more than 5,000 Buddhist monuments, temples, monasteries, and palaces covering a 40 sq km site. Today, there remain about 1500 of these buildings, a precious heritage of central Burmese architecture, sculpture, and painting of that epoch. In late 1975 an earthquake damaged this group of monuments, and so urgent photogrammetric surveys were carried out in 1976 at the suggestion of the archaeologist Bernard Philippe Groslier. Funded by the French government, these 1:100-scale surveys were entrusted to the I.G.N. A sample of 16 temples was selected according to their architectural and archaeological importance and the earthquake effects. The plotting was carried out in 1978. Many temples were constructed either in the form of step pyramids or as a series of fairly deep elements arranged in terraces rising one above the other and culminating in a high central stupa. In both cases the depths of those parts of the monument covered by each pair of photographs were large compared with the other dimensions and their images only incompletely covered the negatives (Figure 1). The analytical plotter made it possible in this case to easily solve the difficult problem of forming and orienting the stereomodels.

Applications of Digitally Controlled Orthophotography

The shape of curved architectural surfaces can be surveyed in a satisfactory manner either by vertical sections or by contours. However, this does not apply to the paintings or mosaics which sometimes cover these surfaces. The subjects represented are often placed side by side and are destined to be viewed from the front, and it is practically impossible to photograph them under good conditions. Digitally controlled orthoprojectors can provide elegant scientific solutions to this problem.

Interesting research on this subject has already been carried out, in the first place when the surfaces to be surveyed are developable, e.g., barrel vaults, in particular, the reports published by Prof. K. Kraus of the Technical University of Vienna and the trials conducted by Prof. H. Kasper. For irregular surfaces, such as those of domes and half domes, also studied by Prof. Kraus, another method must be adopted. At the I.G.N. we decided to apply to architectural surfaces the systems of projection conceived for representing the Earth's surface on a plane.

As a sphere cannot be represented correctly in its entirety, one must use projections adapted to each special subject. For example, one uses the polar stereographic projection for the summit of a dome, the Mercator projection for a frieze of persons placed along the equator of a dome, and a transverse Mercator projection for a meridional subject, such as the "Christ in glory" subjects in medieval iconography. This last projection was chosen for the trials presented here (Figure 2). They concern a half dome in the Church of Saint Aignan-sur-Cher, photographed from the copy at the Musée des Monuments Français, in Paris. The photographs were taken with a Wild P.31 camera (f = 100mm), the digital plotting was carried out with the Traster 77 analytical stereoplotter, and the orthophotography was produced with the Wild Avioplan OR 1 both in black and white and in color.

In order to obtain the magnetic tape which controls the OR 1, one begins from the principle that the data which the latter must receive are the coordinates of a photographic image of a regular grid drawn on the required orthophotograph. The computation consequently comprises the following phases:

- determination of the photographic perspective of the photography: it is a resection in space;
- determination of the best sphere representing the half dome, which is not exactly spherical;
- computation on that sphere, of the image of a regular grid traced on the orthophotograph: the formulae are the inverse of those for the projec-

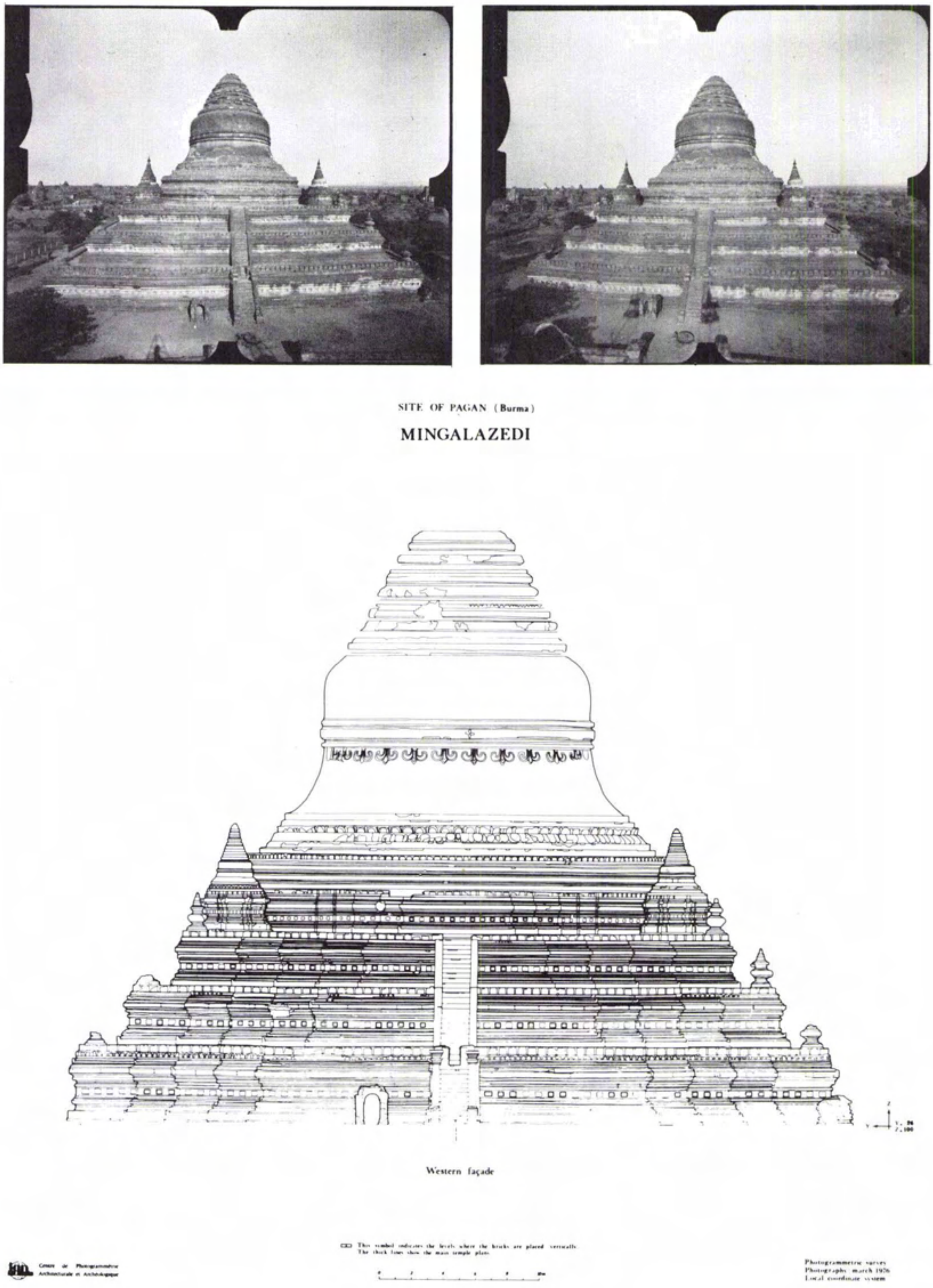
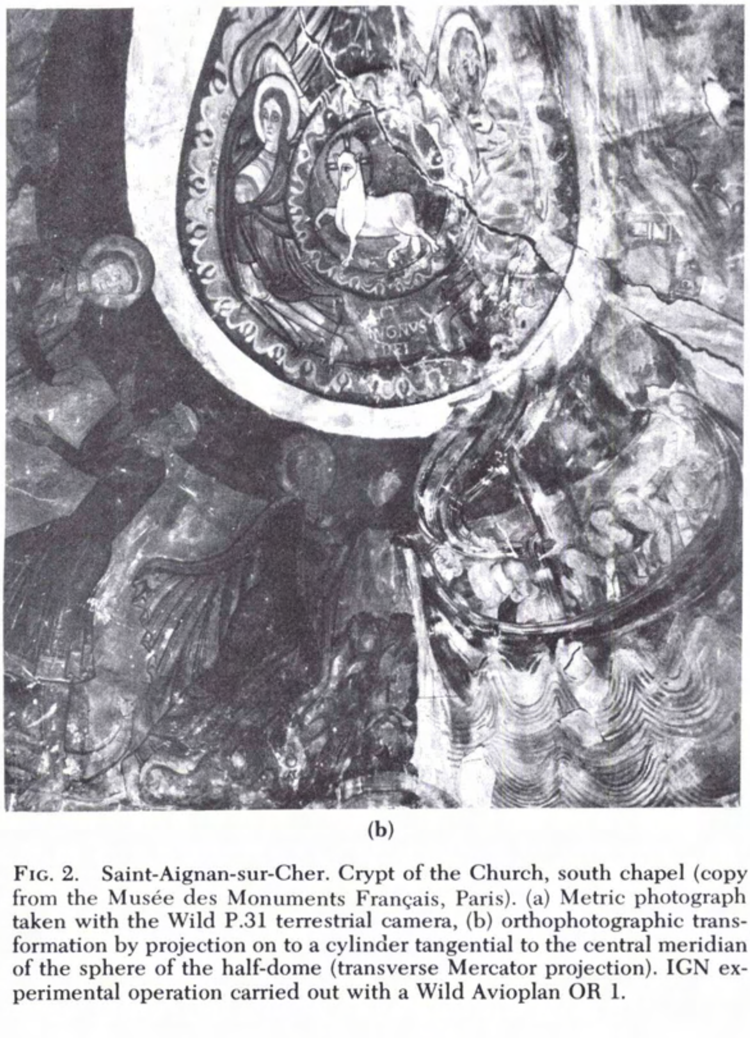


Fig. 1. The Mingalazedi Pagoda, Pagan, Burma. Pair of metric photographs, taken with a Wild P.31 terrestrial camera, and the elevation survey, plotted with a Matra Traster 77 analytical stereoplotter (original scale 1:100).

(a)



(b)

FIG. 2. Saint-Aignan-sur-Cher. Crypt of the Church, south chapel (copy from the Musée des Monuments Français, Paris). (a) Metric photograph taken with the Wild P.31 terrestrial camera, (b) orthophotographic transformation by projection on to a cylinder tangential to the central meridian of the sphere of the half-dome (transverse Mercator projection). IGN experimental operation carried out with a Wild Avioplan OR 1.

tion being used, in this case a transverse Mercator projection, and they are very simple:

$$x = R\,\frac{\cos Y/R}{\mathrm{ch}\, X/R} \qquad y = \mathrm{Rth}\,\frac{X}{R} \qquad z = R\,\frac{\sin Y/R}{\mathrm{ch}\, X/R}$$

- computation of the image of that grid on the original photograph using the usual projection formulae:

$$x' = \frac{a_1x + a_2y + a_3z + a_4}{a_9x + a_{10}y + a_{11}z + 1}$$

$$y' = \frac{a_5x + a_6y + a_7z + a_8}{a_9x + a_{10}y + a_{11}z + 1}$$

The same procedures can be applied to the plane representation of painted surfaces on any kind of object, so long as they are surfaces of revolution, e.g., ancient vases. A trial is currently being carried out at the I.G.N. As the painted surface forms a strip situated on the most convex part of the vase, below the neck, a Lambert conical projection will be used.

Development of Digital Methods for Surveying Entire Old Urban Centers

We have already announced in various publications the photogrammetric methods developed at the I.G.N. in order to meet the needs of architect-town planners responsible for developing and conserving old town centers. These methods are based primarily on aerial photogrammetric methods and, in addition to the normal plane representations, result in the volumetric representation of urban centers by the graphical plotting of elevations and sections as well as axonometric and perspective views.

Analog graphical plotting instruments give excellent results for these kinds of operations so long as one slightly modifies the instruments or adds complementary devices, in particular for plotting the axonometric views. They give an excellent product. However, they have at least one drawback: for each new plot the operator must explore the entire stereomodel and follow once again all the lines to be plotted. For obvious economic reasons this constraint often makes it necessary to restrict the number of representations of the urban center being studied. However, in order to have a better understanding of the morphology of a given town center or have a better appreciation of the impact of proposed new construction, it is often important to have several elevations, several axonometric views obtained along different axes, and several complete or partial perspectives. Digital methods can be very useful here because, starting from the same digital model of an urban center, one can obtain rapidly and at low cost, using computer calculations and automatic plotting, all the required documents. In addition, starting from the position and height data of the new projects, which provide another digital model in the same reference system, it is easy to insert the latter into the plots of the undisturbed urban center.

Technically, the methods designed and used at present at the I.G.N. in this field form the TRAPU (TRacé Automatique de Perspectives Urbaines) program and comprise several phases.

The first phase is the recording of the data, which can now be carried out by two different methods. For the volumes of a new project, one uses either digitization with a coordinatometer or directly the dimensioned architectural plans; a catalog of shapes and an automatic sectioning process speed up the process for the operator. For existing buildings the digitization unit is the convex polyhedron, which has very useful mathematical properties for plotting perspectives. Vertical aerial photography, often at the 1:8 000-scale, is plotted digitally in an analog instrument linked with a coordinate recorder by successively pointing at all the apexes of all the sides of each convex polyhedron forming the urban center. The digitization so obtained is sufficiently redundant for the majority of the plotting errors to be automatically corrected by the program; a few faults for which there may still be some doubt must be corrected by the operator, but that never requires new measurements in the plotting instrument. For a dense town center this digitization requires about 8 to 10 hours for each hectare.

These operations are followed by computer processing, which is divided into the following two stages:

> The first, independent of the output required, is done once and for all after the digitization. The aim is to obtain, starting with the plotting data, a computer file from which all the errors have been eliminated. The principle is shown in Figure 3. The necessary computing time is very short: about one minute for 1000 polyhedra on an IBM 370/138 computer.
>
> The second stage depends on the graphical output required and must, therefore, be carried out for each perspective. It comprises the perspective computation, the determination of the visible and hidden parts and the control of the off-line automatic plotting table in accordance with Figure 4. The computations are much more complex than the previous ones and so require more computer time which however remains very reasonable thanks to a thorough optimization of the algorithms and the programming. For example, one needs about 10 minutes of IBM 370/138 central processing unit time for a complete aerial perspective of a 10 hectare zone in a town center (1000 polyhedra).

At the end the program produces graphical output. At present the possible outputs are of three kinds:

- Pedestrian (ground observation) or aerial (observer at any altitude) conic perspectives;
- Cylindrical perspectives: plans, flat perspectives

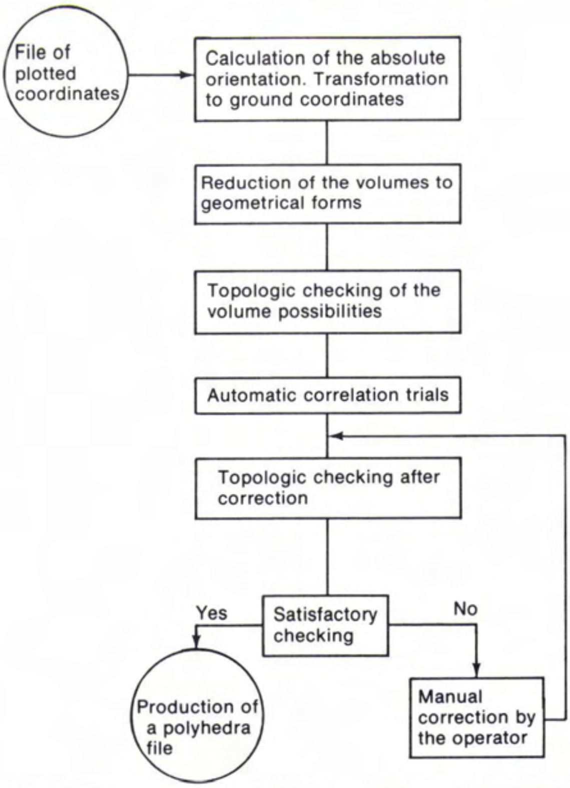


FIG. 3. TRAPU program. Production of the polyhedra file starting with a photogrammetric coordinate file.

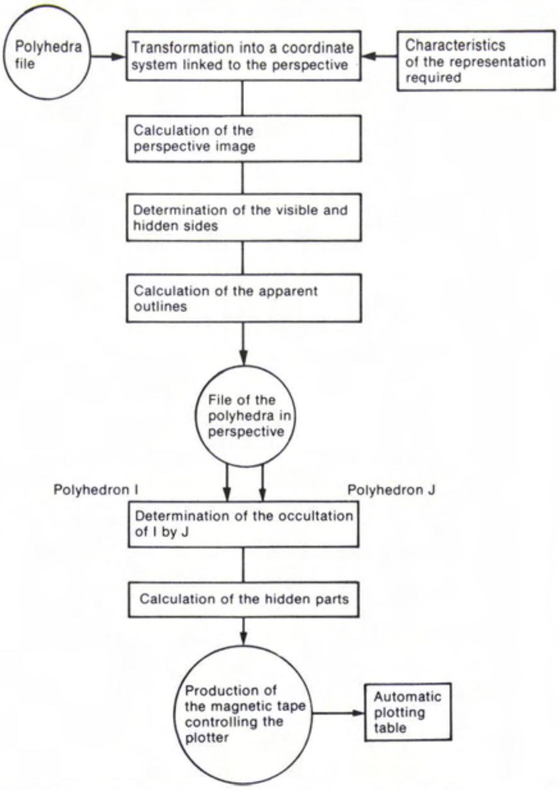


FIG. 4. TRAPU program. Production of the plotter control tape starting with the polyhedra file.

FIG. 5. Aurillac, town center, plan survey. (N.B. Figures 5-8. The original plots at a scale of 1:1000, obtained by digital plotting of 1:8000 scale aerial photographs, computation with the TRAPU program, and automatic drawing, were carried out by the I.G.N. for Mr. Jean-Pierre Duthoit, architect.)

FIG. 6. Aurillac, town center, eastern axonometric view, rough plotting.

FIG. 7. Aurillac, town center, eastern axonometric view. Accentuation of the urban zone and plotting of the development project.

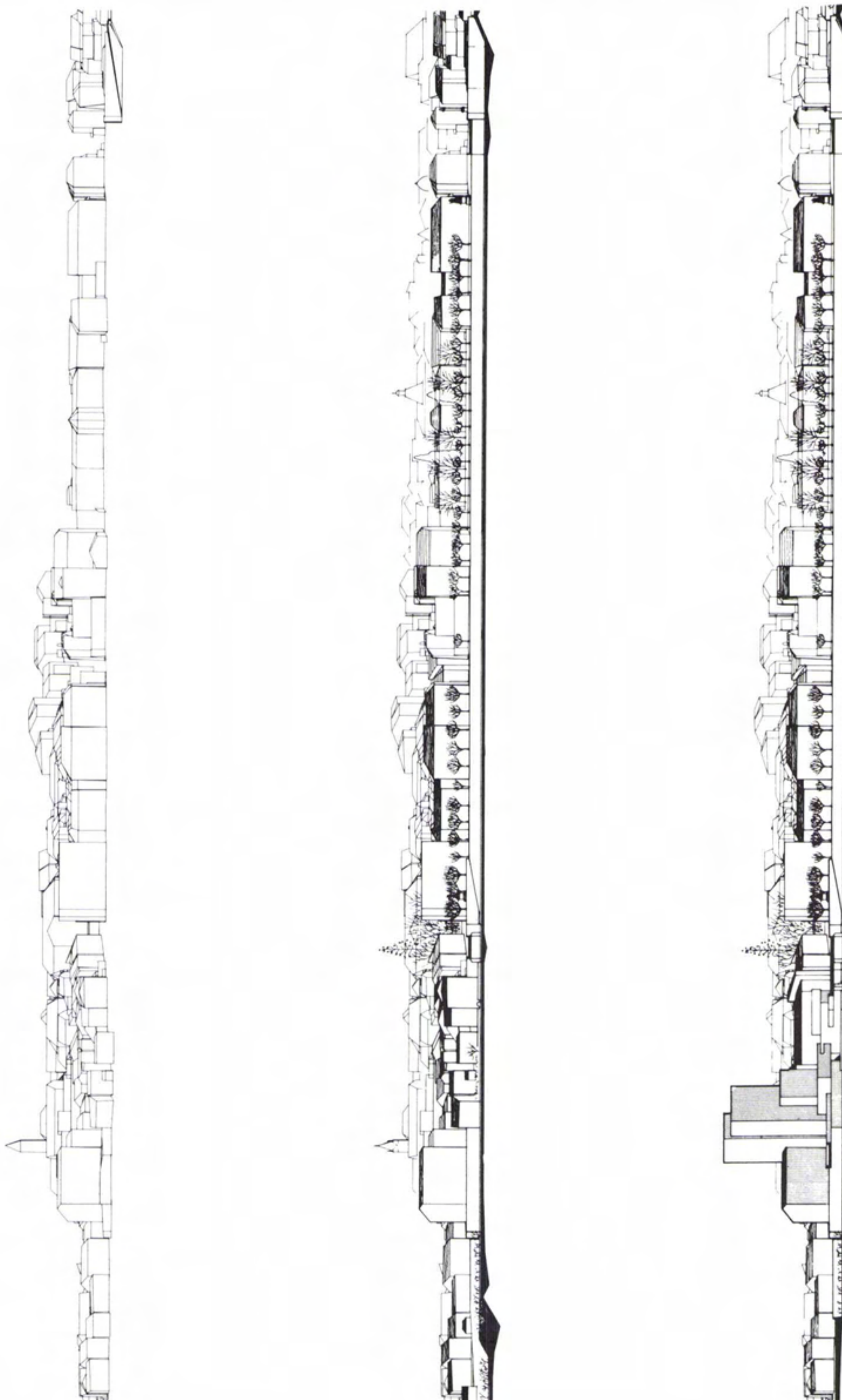


FIG. 8. Aurillac, town center, southeastern elevation. Rough plotting, accentuation of the urban zone, and integration of the development project.

(elevations of an entire center), and axonometric views; and
- Sections (vertical sections across an urban center). One can also automatically produce models at any given scale.

The graphical output can be obtained on three different types of automatic plotter: Contraves, Calcomp, or Benson. Because the program has a modular construction, there is a lot of flexibility both as regards the manner in which one records the original data (other types of plotting equipment, different pointing procedures, etc) and also as regards the use of the different automatic plotters available on the market. The processing capacity is theoretically unlimited, but it is certain that the computing time increases fairly rapidly with the number of polyhedra. However, operations concerning several tens of hectares in town centers can be carried out fairly easily.

The TRAPU program has been fully operational for several years now on the IBM 370. Its rewriting in Fortran IV is just being completed, and it will soon be possible to use it on all the different calculators and probably on most mini-computers now available.

Among the operations carried out by the I.G.N. with the method briefly described above, we will discuss that of the town of Aurillac in the center of France. This example will show the flexibility of the method. It will also demonstrate that, in order not to increase the number of polyhedra to be processed too much, it is necessary to disregard very small details, in particular in the roofing, and to give a somewhat diagrammatic representation of buildings, which, although not very flattering to the eye, is quite satisfactory for the needs of these studies.

In the center of Aurillac an urban group must be replanned. It is constituted mainly by two open spaces with axes almost perpendicular to each other, the one being formed by a very elongated open space along the River Jordanne, the other a rectangular open space extended towards the river by a large avenue (Figure 5). At the intersection of these two axes a new group of buildings must be erected and the street lines must be modified; in addition, certain small adjustments to the houses surrounding these open spaces are also planned. Starting with 1:8000-scale aerial photography, the architect responsible for studying this project, Mr. Jean-Pierre Duthoit, had a plan produced of the zone to be developed (Figure 5), as well as four elevations, NW, NE, SW, and SE, and three axonometric views, south, west and east (Figures 6-8). The rough plots at the 1:1000 scale—obtained by digital photogrammetry, computation, and automatic plotting—were first of all improved by the architect in order to facilitate their reading, i.e., making evident the open spaces as well as the architectural surfaces surrounding them. Then the projects were transferred geometrically to those documents.

A model of this zone of Aurillac was also produced at a scale double that of the surveys, solely on the basis of measurements taken from the plan and the three axonometric views; the development projects were also included in the model. The entire group of documents so produced enabled the architect to advance the studies for which he was responsible with security. Figures 7 and 8, reproducing part of the drawings so obtained, show a phase of that study. An analysis of them, together with an examination of the model, revealed that it has necessary to reduce the size of the large building in the project.

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