LA FOTOGRAFMETRIA
PER IL RESTAUR
E LA STORIA
Tecniche analitiche e digitali

a cura di Nicola Miella

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DIGITAL MODELS PRODUCED WITH PHOTOGRAMMETRY FOR THE STUDY OF MONUMENTS. SOME EXPERIENCES

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This paper presents several examples of the application of photogrammetry for the generation of digital models on CAD. This is a system which solves the problem of the representation of three-dimensional entities, as in fact the architectural models are, so being able to obtain both ground plans and elevations as perspectives. In this way it is possible to work with graphic documents which make it easier to obtain measurements, as with other documents whose way of representing architecture is nearer to the way in which it is seen visually.

Among other examples, we should like to highlight research on the Roman aqueduct at Segovia, from which a three-dimensional digital model has been obtained, connected to a data base by means of the CAD system itself. Each ashlar, formed as a block, is connected to a register of the data base which stores up physical data and that of the state of maintenance, as well as historical and architectural information. Photogrammetry offers the most convenient and accurate system for the creation of these digital models.

Drawing as a means of expression and representation of architecture demands the transformation into bidimensional forms of both architectural space and the volume and elements of which it is composed, and which are always three-dimensional. This need to represent in flat images constantly produces a dilemma in the reproduction of space and forms, in such a way that graphic expression allows them to be known in dimension and extension and allow us to gather a perceptive idea of how the building or its space will be in the eyes of the beholder. There are two processes or bi-dimensional methods of representation which are the most frequent. The dihedral system or orthogonal projection system (plans and elevations) allow us to become familiar with the dimensions at once, although they rarely coincide or approach the real way in which man may know or learn the form and layout of space through vision.

Human eyesight depends on perspective images -conic projection-, generated in the eye, which acts in the guise of a dark camera similar to a photographic or even video camera. Perspective is, therefore, the favourite means of representing architecture, particularly for those people for whom the mere metric questions means an indifferent reaction, and especially for those who have difficulty in interpreting correctly representations in the dihedral system.

However, the use of perspectives as instruments of expression and in representation of architecture, come up against two serious difficulties which are indirectly related. First of all, the greater complexity and therefore difficulty in generating these images, particularly if carried out strictly and exactly. The other difficulty derives from the impossibility of obtaining real dimensions directly from perspective, which relegates it as a valid means of representation for constructive applications or means of analysis which imply dimensional valuations.

Fig. 1 - South elevation of the church of Sta. Lucia del Trampal.
In the history of architecture we can find numerous examples, and on many other occasions too, the way to fit together the dilemma and the difficulties inherent to the two most usual ways of representation has been none other than that of allowing the union of everybody else's advantages, that is, of a three-dimensional model on a reduced scale, i.e. a scale model. As it completely avoids the problem of representing three dimensions within 2 dimensions, this system is resolving the problem categorically, although maybe at the expense of the representa-

The present design systems with the assistance of a computer (CAD), have to a certain extent solved the dilemma with respect to the type of projection, such as the difficulty due to the poor manageability of the model, on allowing the production of real three-dimensional models with which it is possible to find out the dimensional values of what has been represented, as well as obtaining any type of representation, whether it be dihedral, oblique orthogonal (axonometric) or central (conic perspective). The difficulty presented by this type of applications arises precisely from the creation of the digital model which we are given of the image, in greater or smaller detail, of what we are trying to represent. There are two different facets, depending on whether we try to represent imagined or real architecture which already exists. In the first case, the difficulty arising from the creation of the model will depend on the very nature of what has been conceived. However, when we are faced with the problem of representing existing architecture, the subject is considerably more complicated; it often happens that the actual form of the building does not correspond exactly with the idea of its initial conception, and therefore it is not a pure geometric form, since it has received influence from numerous factors, ranging from faultiness in construction to deformation due to structural misconception, or to external factors of any kind. Moreover, in many cases, historical architecture has followed certain patterns of creation and design which
are considerably more complex, or at least from a formal point or view, than the patterns which are usually established by present-day architectural design. In these cases, the formation of the digital model in the CAD turns out to be a considerably more complex task. It is precisely in this respect that photogrammetry has been of incomparable assistance, and has become the ideal tool to create three-dimensional digital models.

At present, practically all the photogrammetry systems are interconnected through the CAD systems, in such a way as to convert the plotter into a 3D digitalizer, which transmits to the CAD programme the three Cartesian coordinates of all the points being marked. In this way the three-dimensional digital model is being created in real time, and the CAD programme will later allow it to be represented in the desired projection and on the required scale. In this way, photogrammetry can facilitate easily and precisely the creation of a digital model of any object, building or site which may be photographed from different positions, thus allowing it to be represented in any possible system. The programme itself facilitates the obtaining of metric information, either by means of the tools provided or by means of the lists of the data from the different entities integrating the model, which are always expressed in digital format of coordinates. Generally speaking, programmes like AutoCad offer, together with the coordinates of the defining points of the entity, other data, such as the difference in coordinates, actual length, projection length, enclosed area, etc.

The possibilities which these new systems of measurement offer in the field of restoration and in general, in the recording and studying of monuments are vast. In the first place, as information systems, which allow us to have access to metric data together with images of the building in a unique information base which can offer different representations of the object or building. On the other hand, as a base for analysis, including within this everything related to the three dimensions. Within these analyses should be included both those of a physical or structural type and those of a more immaterial nature, such as the study of proportion, metrology, space values, etc. Lastly, the system can also be used as a basis for studying reconstruction, whether for carrying out in situ, or for theoretical studies and hypothetical solutions which will never in fact be carried out, but which are of great importance in the field of investigation in the history of architecture.

We would not like to overlook the difficulties arising from the creation of these models and their management in CAD. Firstly, all surveys requiring the use of several stereo-pairs will need to have available an adequate network of control points related to a sole system of coordinates. In the plotting, the operator should continuously bear in mind the three-dimensional representation, also registering those lines or elements which may remain hidden in any one specific projection but which should appear in others. In order to facilitate the representation of the different projections, the elements should be adequately codified, since nowadays the creation of surfaces capable of producing an automatic concealment of lines turns out to be too complicated.
Fig. 6 - Vertical perspective view of the interior of the Temple of Debod.

for all plotting which contains sufficient detail.

As an illustration of what has been set out until now we would like to present several studies carried out by the School of Arabic Studies of the C.S.I.C. (Higher Council for Scientific Research) and by the office of Latore & Camara in collaboration with the same Council. As a first example, we have the documentation on the 7th - 8th century Visigoth church in Caceres, Santa Lucia del Trampal. The preparation of the elevation of the church on the basis of control points in a sole system of coordinates for the whole building gave as a result the obtaining of three-dimensional digital models for each façade. The overall information obtained in this way was excessively dense to be handled all together (each elevation required about 4Mb), and for this reason only the outlines were used. The joining point of all the outlines of the façades provided a wire model of the whole building. By means of codification in various layers and freezing those which were not visible from any determined direction, it was possible to obtain different axonometric views which could be used for studying a solution to the roofing and for the analysis of the volume of the building. (Figs. 1-2)

A similar study has been carried out on the underground station in the Karlsplatz in Vienna, a building designed by Otto Wagner. This study was part of a joint project developed by various photogrammetry centres under the auspices of the CIPA. In this case, the information contained in each elevation was less and it was possible to work on all the plotting details. Isometric and conical perspectives were obtained. (Figs. 3-4)

As regards representing internal space, we carried out an experiment with the room decorated with reliefs in the Egyptian temple of Debod, now to be found in Madrid. The initial plotting of the decoration of the hall made it possible to create a three-dimensional model which could be observed from different vantage points and directions, while maintaining all the information of the elevations. No greater effort was required to obtain the conic perspectives than conceiving the recording as a whole instead of as a series of independent drawings, i.e. as a three-dimensional model of the interior hall of the temple.

Data-taking of this room was accomplished after about three hours work inside. A pair of stereoscopes were used for each of the short sides of the hall, and two pairs for the long sides. A total of 12 photographs taken with a semimetric ROLLEI 6006 Metric camera, with a 40mm focal length lens and negative format of 6 x 6 cms. To determine the orientation of the photographs they were measured with a WILD T1000 electronic theodolite with a recorder of coordinates WILD GRE4, giving a total of 26 points pre-marked with autoadhesive labels. The average errors obtained for the coordinates of the control points were 1 mm. As is to be expected, all the coordinates of the control points have been obtained referring to a sole system of coordinates with the Y axis in the direction of the axis of the room.

Plotting has been accomplished with an ADAM MPS2 analytical plotter. This instrument has an interface of connection on line with AutoCad. The average values of the residual errors of the control points after orientating the stereoscopic pairs of photographs have been of 2 mm. for the coordinates in the plane parallel to the base and 4 mm. for the perpendicular coordinate. Evidently, the errors in drawing will sometimes be greater due to the lack of definition of the relief outlines caused by serious erosion. However, in any case it would be perfectly admissible to accept an error for a plotting scale of 1/10, and it would be completely impossible to appreciate for the scales of reproduction under publication, being at maximum 1/20 or 1/25. The total time spent in plotting this chapel of Azakheramon was 170 hours.

With the plotting of the four paraments carried out as three-dimensional AutoCad files, it was sufficient to coordinate them all by means of inserting all four in a new drawing, to which the floor and roof were added, thus completing the 3D model. Each plotting of a parament was
inserted at a different layer, the same with the floor and roof. This model contains all the information, and it is enough to choose the direction and plane of the projection to obtain the ground plan, elevations, axonometric or conic perspectives. To obtain the conic perspective, this is done automatically, is enough to follow the instructions which may consist in fixing the observation point, the direction for observation and the angle of opening equivalent to the angle of a photographic lens. (Fig. 5-6)

Another interesting case has been the surveying of the Comares tower and its internal hall in the Alhambra in Granada. The complete survey of both the exterior and interior of the tower has not only given us the elevation and sections, but also a three-dimensional model of the ceiling, which has allowed us to analyze its space deformities and to compare the theoretical design of the decoration with reality. (Fig. 7-8)

Finally, we would like to submit the most important study carried out until now, consisting of an ambitious plan to record and analyze an exceptional building. We are referring to the research into the aqueduct of Segovia, which is a Roman construction listed in the World Heritage. The visible part of the construction measures 915 metres in length, with two short stretches of blank wall of rubblework and 120 pillars supporting one or two rows of arches, all of them of granite masonry without mortar. The highest part measures as much as 29 metres. There was a dual aim to this survey. On one hand we were trying to achieve three-dimensional information, which meant gathering evidence on all the visible surfaces of the aqueduct and achieving a three-dimensional model of it. On the other hand, the intention was to create a database whose register unit is the ashlars related to the digital model which may contain information ranging from straightforward physical type data (size of the stone, weight, centre of gravity, etc... obtained automatically from the model) to other types of data on its state of conservation, damage, different restoration work, chronology, etc. Naturally, this second type of information has been collected quite independently from the creation of the model. As the register in the database is the ashlars, each ashlars has the nature of a block within the CAD system used (AutoCad), although within the block, the different lines which characterize it are coded in different layers according to whether they are groins, cracks, profile lines, etc, and according to the orientation of the face of the ashlars.

To carry out the digital model 1260 stere-pairs obtained from the ground and with special systems of elevation by means of semi-metric Rollei 6006 cameras with 40 and 80 mm focal length lenses and Hasselblad SWC with 38 mm focal. For the orientation of the models we marked and measured 2900 control points by means of a theodolite. The average errors of this measuring were less than 10 mm. Plotting was done with ADAM MPS2 and Leica SD2000 analytical stereoplotters working directly on AutoCad.

Using AutoLisp routines, the different polylines in 3D are codified
in the corresponding layer and connected with the data base. Since the ashlar is on the whole in a state of erosion, it has been decided not to plot the angled groins, taking in their place two vertical profiles, one on each face, and which define the visible outline in an elevation view. Using Lisp routines the lines of an ashlar are assembled to form a block. Other Lisp commands allow us to visualize the different elevations by automatically freezing the layers which are not visible. (Fig. 9) Each pillar forms an independent drawing with two half arches, making the information easier to handle. Several drawings may be grouped together to analyze larger elements (Fig. 10). Each block corresponding to an ashlar may be manipulated as an individual object, thus achieving a physical similarity between the digital model and the building itself.

The end result of this survey is not so much a precision drawing, but rather a powerful tool for information management, with all the “intelligence” conditions of the management systems of computer data bases. The drawing will work as a graphic index of access and reference to the data base, which will be able to answer queries on the physical condition of any stone in the aqueduct. Moreover, the data base is an open document which can be brought up to date at any moment. On the other hand, the digital model can be simplified in such a way that each block becomes converted into a prism of flat sides. This more simple model may be used to simulate static behaviour in the structure of the aqueduct, and this simulation will be remarkably close to reality.

The opening up of these possibilities of manipulation, study and maintenance of a historic building constitutes one of the main interests in the formation of digital models, for the creation of which photogrammetry offers the quickest and most efficient means.