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BUNDLE ADJUSTMENT IN THE DAILY WORK OF RECORDING CULTURAL HERITAGE

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KEY WORDS: bundle adjustment, monuments recording, reduced control

ABSTRACT

The paper presents different survey works in which the technique of bundle adjustment has ben used for recording monuments as well as for archaeological sites and excavations.
Bundle adjustment is used at the Escuela de Estudios Arabes (C.S.I.C.) for different objectives; in some cases to achieve a homogeneous quality in the survey; in other cases, to reduce the quantity of control points to be measured with topographic methods, especially in big monuments where a lot of stereo-pairs are needed for the survey. The system is also often used for surveying with a reduced and very simple control, recorded with simple instruments (tape, plumb line and water pipe level). This system is adopted in cases in which there is not a previous knowledge of what is going to be recorded, during trips to obtain general information for research or during archaeological campaigns which are far from the institute. In these cases, only a light semi-metric camera, a tape measure and a plastic pipe are included as survey equipment. Finally, bundle adjustment is used for calibration of semi-metric cameras.
Two different programs, ORIENT from the Institute of Photogrammetry and Remote Sensing of the Technical University of Wien and MAAS-CR from LEICA are used.

INTRODUCTION

The day to day work of recording and surveying monuments, whether for their preservation and restoration, to further investigation aimed at a better knowledge of these buildings, or to make them known generally, presents a permanent challenge relating to the parallel problems which have to be confronted. In some cases it is the urgency of the action, in others the difficulties in access due to being at a distance from the normal place of work, or because of the intrinsic difficulties of the building. In some cases it will be the necessity for high precision, in others the lack of economic means - funding, or simply the convenience of the availability of initial surveys carried out by simple procedures and at a low cost for their cataloguing. To summarize, the needs and difficulties are very varied according to the cases, and the solutions must therefore be flexible and adequate accordingly.

Photogrammetry has traditionally had a role reserved in the area of precision surveys for those cases in which an adequate budget was available, and for those which were not given a satisfactory solution using other techniques. Nowadays, photogrammetry has been considerably developed, particularly through the indispensable computing means of calculi. Digital photogrammetry has opened up paths to new possibilities with which we can gradually develop its applications.

Within the possibilities now offered by the techniques of photogrammetry, the so-called systems of bundle adjustment with multiple photos has always seemed to us to be particularly useful. Although initially intended for improving the conditions of precision in photogrammetric measurement, and above all for its application in non-stereoscopic measuring, these systems offer an equal possibility of acting with reduced control information, although in certain cases that might also mean reducing the precision. However, faced by the wide range of problems and cases presented in the recording of cultural heritage, and above all because of the until now unbroachable necessity of having a minimum of information, but with a certain degree of guarantee and trust, it is essential to establish different standards of precision as well as different methodology if we want to be able to give a minimal response to existing necessities (Almagro 1993).

Over the last ten years in the Escuela de Estudios Arabes we have been developing projects of surveys of monuments and archaeological excavations which could be included within two groups, according to the purpose which they are aimed at (Almagro 1994). On the one hand we carry out survey work aimed at research, particularly that which concerns the history of architecture or archaeology. In these cases, the precision requirements, especially at a level of their real position and space, are not over demanding. Formal analysis of the architecture is based more on proportions than the dimensions themselves. The surveys are basically designed for publication where the scales of representation are never going to demand high-scale precision. In these cases it is of greater importance to have flexible system and methods, which allow the plans to be obtained with the minimum of time and equipment, than to be in search of such precision that is not going to be really reflected in the final usage of the survey. There is a similar situation with many of the archaeological surveys, in which we also come across the difficulties intrinsic to this type of recording: extension on the horizontal plane, and the need to coordinate the recording with the excavations so as to avoid unnecessary interruptions, etc.

A different sort of survey we often carry out, usually at the request of other institutes or technicians, is designed for restoration projects. In such cases, the needs and precision requirements vary according to the occasion, although they are usually more frequent in this type of work which demands greater accuracy, in order to be able to use the surveys to control the deformation or damage which the building suffers from. An additional requirement to be taken into account is often the huge size of the buildings and consequently the difficulty in measuring control points with homogeneous precision.

By using the system of simultaneous adjustment of the bundles of numerous photos we have provided the solution to many of these requirements. I shall shortly present some cases which may be considered as more representative of the different problems and the ways of solving them. I would like to make it quite clear that as users of photogrammetry, we have been more interested in solving the problems of obtaining the records we needed than those of a purely photogrammetrical type. With these cases we have tried to give an overall idea of the advantages and possibilities of this method; we do not, therefore, provide exact details of the measurements obtained. Those who are interested in this can refer to the ample bibliography offered by many specialists, particularly from the centers specialized in photogrammetry (Eder & Stephani

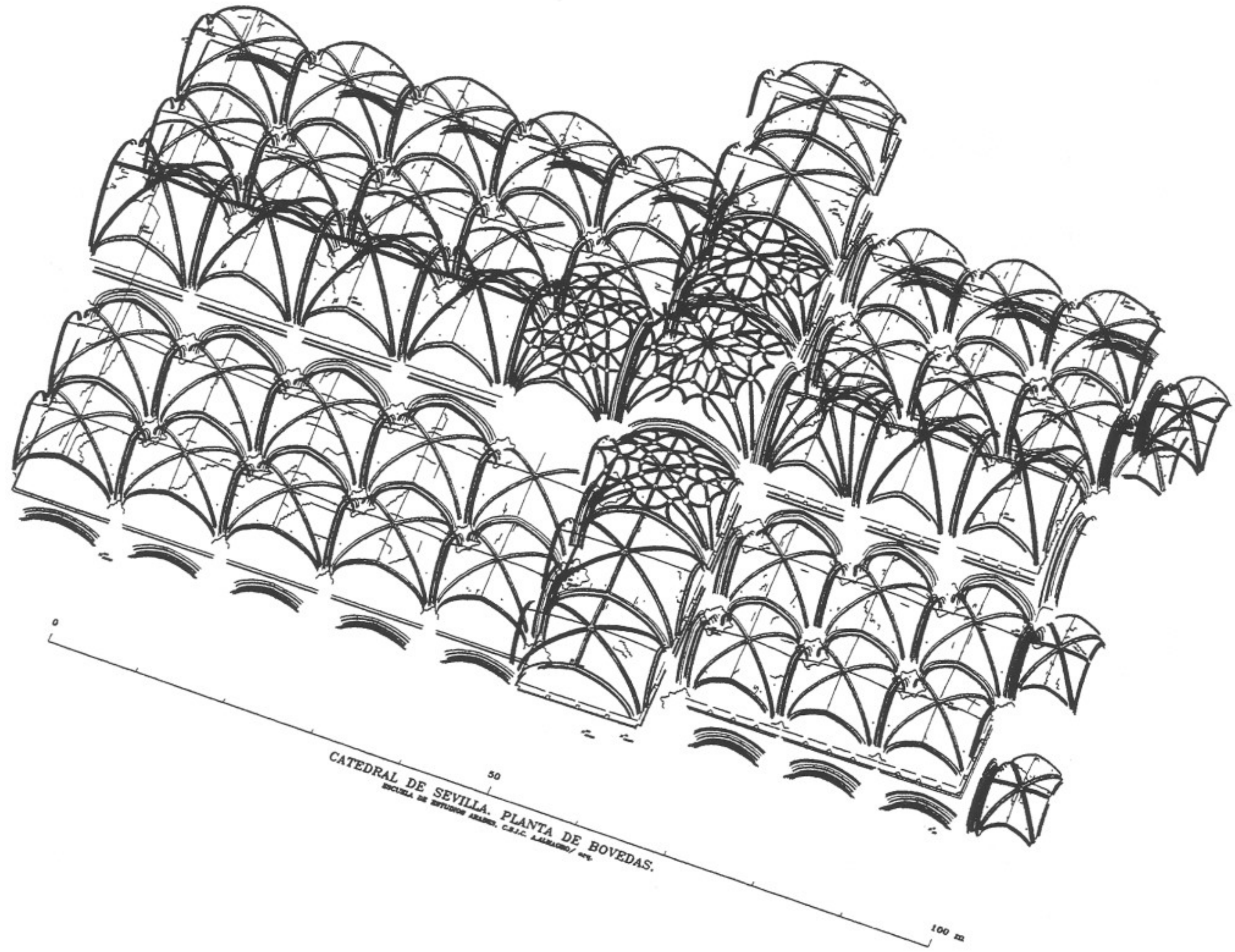

Fig. 1 3D model of the vaults of the cathedral of Seville

1988). What we would like to demonstrate here is that what specialists have carried out with the rigor of their professional training and knowledge, can be fulfilled by those of us who, in fact, have a more reduced knowledge, but who work daily on tasks of recording our heritage. We would like to show that what works in theory is equally efficient in daily practice.

Regarding general classification, we can establish two general applications of bundle adjustment. In both cases the aim is to simplify the work of measurement-taking and particularly that of obtaining control information. In the first case, the idea is to simplify the methods of obtaining this control, particularly by substituting topographical measurements, based on the use of a theodolite, by other instruments which are more easily used and transported. Normally, these instruments are limited to a tape measure, a plumb line and a water level (a transparent, flexible plastic tube filled with water allowing the marking of points at the same level, based on the principle of communicating vessels). These are very low-priced instruments, easy to use and easily purchased, therefore avoiding transport of the same. This can, therefore, limit the equipment to be transported to a semi-metric camera (Waldhausl & Brunner 1989).

In other cases, the reduction in the work of obtaining control measurements refers to their quantity, maintaining the characteristics of precision common to topographic methods. These cases are usually large buildings, the measurement of which requires a large number of photographs or stereoscopic pairs and therefore control points. Such cases still require the use of topographic instruments (theodolite and distance-meter), although their use is considerably reduced, and so is the length of time working on the building.

EXAMPLES

One example of a case where we have used this technique has been for surveying the vaults of Seville cathedral. This cathedral, which has the largest surface area of any in Europe, nearly 2.5 ha., has five naves, transept and straight ambulatory. In all, without taking into account the chapels, it has 49 sections with the corresponding number of vaults (Jimenez 1997). For the survey of these vaults, registered within the general program of cathedral survey, 48 stereoscopic pairs were taken. These pairs had sufficient overlap (about 50%) with the adjacent vaults to guarantee a good intersection between the consecutive pairs. In support of this, a theodolite by intersection of the lines of sight was used to measure as many as 28 points of control distributed through the end vaults, the central nave and the transept, using 9 established and marked stations

Since none of the bundle adjustment programs which we had available were able to calculate using all of the photographs, it had to be done in two blocks, one from the apse to the transept, and the

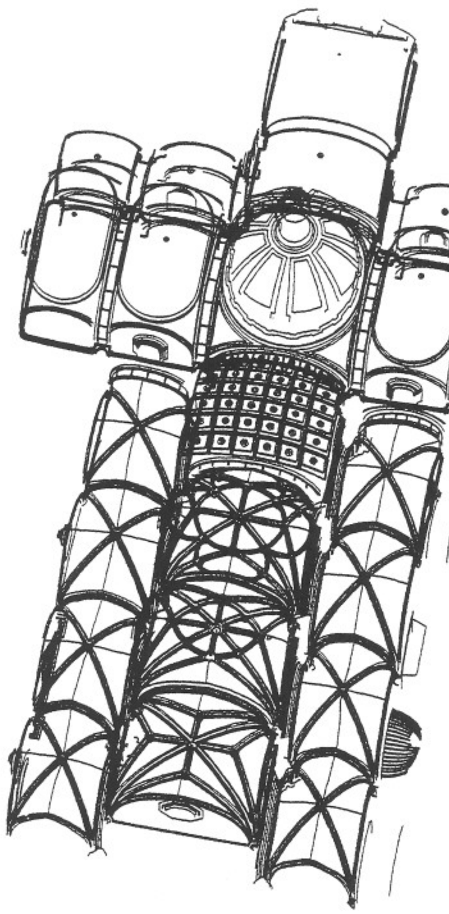

Fig. 2 3D restitution of the vaults of the church of St. Michael in Morón de la Frontera.

other with the rest of the photographs. In this case we used the ORIENT program (Waldhausl & Kager 1990), as it offered us the greatest amount of data to operate with. Even so, prior calculation was necessary, and rejection of some photographs which could later be incorporated into the calculation in the place of others previously selected and oriented. In this way it was possible to calculate the orientations of all the photographs and the coordinates of some 150 pass points evenly distributed throughout all the vaults.

Using this data, all of the vaults of the naves were plotted as digital models in 3D (Fig 1), including cross sections through the center of each one of them in both main directions which are used for drawing the general sections of the cathedral. Together with the general lines of the arches and ribs, it was also possible to plot the visible cracks which have been used to analyze the performance of the structure of the cathedral.

We worked on a similar case, although of less magnitude, in the church of St. Michael in Morón de la Frontera (Fig. 2). In this case 23 vaults were plotted with 20 stereoscopic pairs, 24 control points and 71 pass points.

Among the cases in which we have used the bundle adjustment for orientating the photos with very reduced control obtained using simple instruments, we should make special mention of the survey of the weather vane statue known as the **Giraldillo**, crowning the great tower, once a almohade minaret, converted into the bell tower of Seville cathedral. As we are dealing with a revolving statue, there was no point in referring the plotting to any predetermined system of coordinates. Anyway, due to its position, we had to carry out the obtention of data from an scaffolding

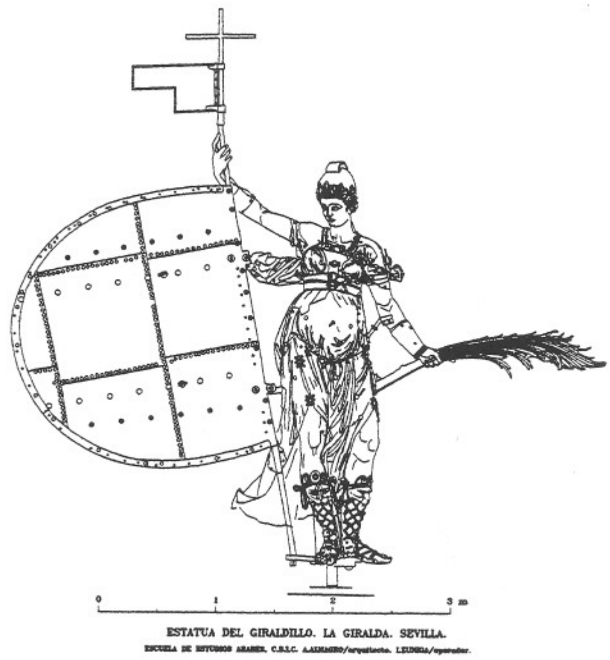

Fig. 3 Restitution of the front view of the statue of the **Giraldillo** (Seville)

where it was impossible to place a theodolite in a stable position. So the only information we had to start off was a series of stereoscopic pairs taken around the statue and some of the distances between different points of it. The simultaneous orientation of the eight photographs used allowed us to plot on the same system of coordinates both the front (Fig. 3) and the back (Fig. 4) views, as well as different profiles of the statue. Later on, once the plotting was completed, we continued, using AutoCad, to rotate the drawing in the space until it reached the appropriate verticality, based on levelling data which we took from the object. In this case, the program used was MAAS-CR from the firm WILD.

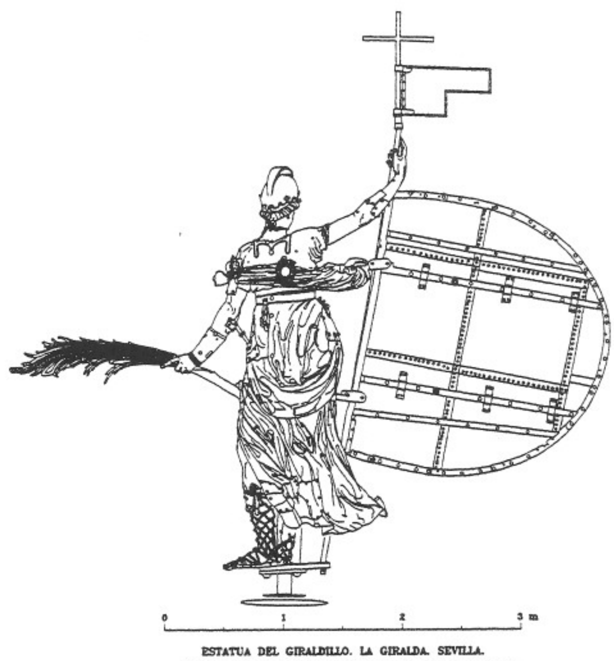

Fig. 4 Restitution of the back view of the statue of the **Giraldillo** (Seville)

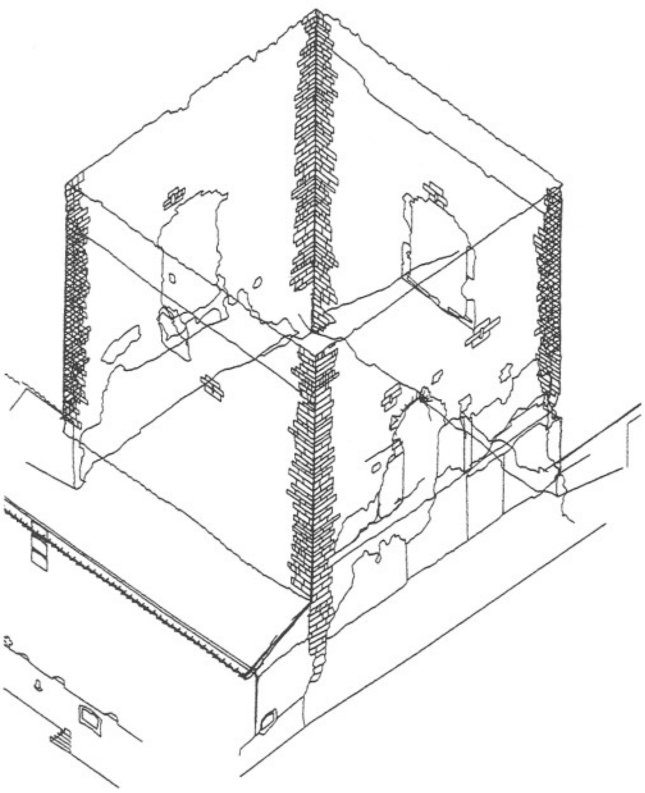

Fig. 5 3D model of the tower of Doña Blanca in Albarracín (Teruel)

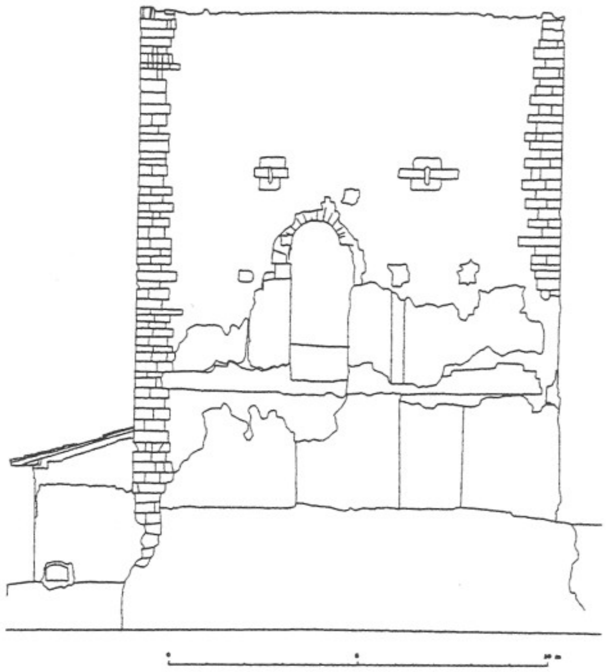

Fig. 6 Elevation of the nord front of the tower of Doña Blanca in Albarracín (Teruel).

Another two cases of the use of reduced control measured with the simplest of means are: the Tower of Doña Blanca in Albarracín, Teruel)(Fig. 5-6), a military tower of the thirteenth century, and an old almohade minaret in "Cuatrohabitas" (Bollulos de la Mitación, Seville)(Fig. 7), from the beginning of the thirteenth century. In these cases we took measurements of the length between visible points, and the verticality of the edges of both towers was controlled. In both examples this information and the photographs taken (14 of the Tower of Doña Blanca and 18 of the minaret of the Cuatrohabitas) were sufficient to determine the pass points and the orientation of the photogrammes.

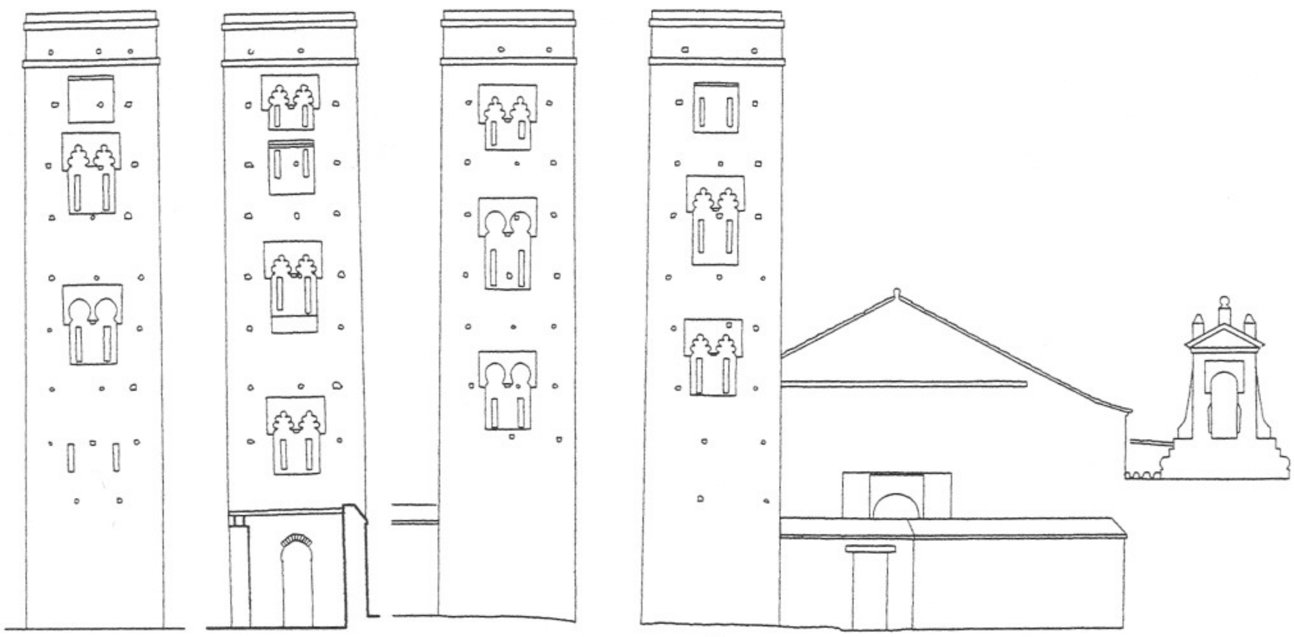

Fig. 7 Facades of the minaret of Cuatrohabitas (Bollullos de la Mitación. Sevilla)

The last case I would like to present is that of the survey of the great cistern of the Umayyad Palace of Amman (Jordan) (Almagro 1983:110). This is a circular cistern measuring 17.65m. in diameter and 6.50 in depth, with the perimeter wall almost in a state of ruin. Prior to its restoration it was decided to make a recording of the initial state of conservation with a photogrammetry survey. Only a semi-metric camera was available, a tape measure and a water level made of a piece of plastic tubing. Twelve photographs were taken, six from above and six from the interior. As control measurements, four points were marked on the inner face of the wall, three of them at the same level, and the distance between all of them was measured. With this information the points were drawn in AutoCad and the coordinates x and y were determined. The coordinate z was the same for three points, and that of the fourth was deduced from the difference of level with respect to the others. Using this data 35 pass points were measured with the bundle adjustment. The plotting gave a three-dimensional model of the cistern (Fig. 8), from which it was possible to obtain the ground plan and two sections with the projection of the interior paraments. By means of a simple computer program, the three-dimensional plotting of the cylindrical perimeter was transformed into a flat development of the same cylinder to obtain the measurements in their true size more easily. In order to do this, the three-dimensional drawing was transform into a DXF file, and this in turn was converted by means of a program written in Basic into another file, also DXF, containing the flat drawing. This file read from AutoCad was converted into the drawing of the development of the cylinder (Fig. 9). Barely half an hour of field work and just one semimetric camera taken to the site were sufficient to obtain the recording necessary for this construction.

To conclude, it is worth emphasizing the enormous usefulness of the bundle adjustment system, for the saving in work implied when collecting information on site, both regarding the quantity of control points and the measuring of that control by means of simple procedures. Diffusion of this system requires simplification in handling the programs. In this sense, MAAS-CR turns out to be easier to handle thanks to the on-line work with the SD2000 stereo-plotter. Its dependence on this comparator is the only inconvenience. ORIENT is much more versatile and universal, but requires a far greater knowledge of the program and how it works. It would be ideal to have a system available which was better adapted to the work of recording of buildings, and which had a more simplified handling, allowing people with more limited knowledge to use it. At any rate, we would definitely recommend applying bundle adjustment for surveying buildings with photogrammetry.

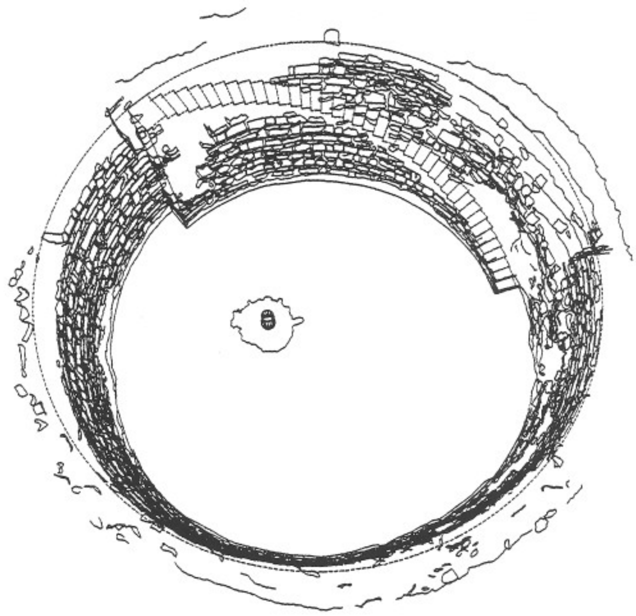

Fig. 8 3D restitution of the cistern of the Umayyad Palace of Amman

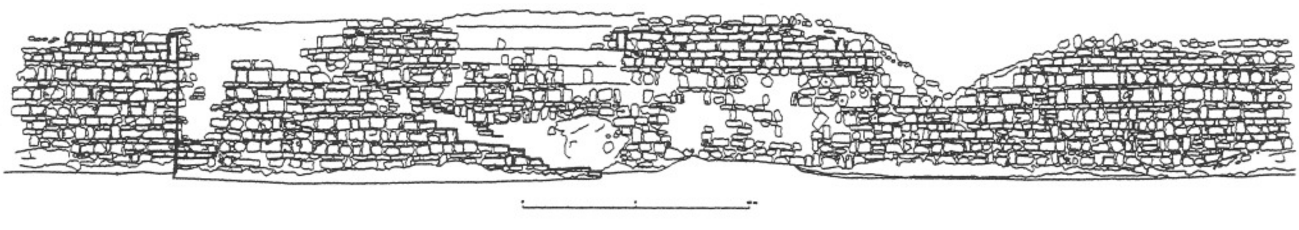

Fig. 9 2D development of the interior parament of the cistern of the Umayyad Palace of Amman.

References

ALMAGRO, A. 1983, **El Palacio Omeya de Amman. I La Arquitectura.** Madrid.

ALMAGRO, A. 1993, Simple methods in architectural photogrammetry, en actas del **XIV International Symposium of Architectural Photogrammetry, Delphi 1991**, Athens. 209-225.

ALMAGRO, A. 1994, Experiences in Rapid, Economical Surveys of Monuments at the Escuela de Estudiuos Arabes, **APT Bulletin**, XXVI, 1, Computers in conservation. 28-30.

EDER, K. STEPHANI, M. 1988, An efficient procedure for recording monuments based on a hand operated camera system. **X Symposium Internacional CIPA, Granada**, 255-268.

JIMENEZ, A. 1997, **Cartografía de la Montaña Hueca.** Sevilla.

KAGER, H. WALDHAUSL, P. 1990, **ORIENT, A Universal Photogrammetric Adjustment System**, Product information. Institute of Photogrammetry and Remote Sensing, Technical University, Vienna.

WALDHAUSL, P. BRUNNER, M. 1989, Architectural Photogrammetry World-wide and by Anybody with Non-metric Cameras? **XI International Symposium of CIPA, Sofia**, 35-49.