

# PHOTOGRAMMETRIC SURVEY OF ARCHAEOLOGICAL CERAMICS

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## ABSTRACT

This paper presents the study to carry out the reconstruction of fragments of three ceramic vessels found in the location of Zonzamas. Along this manuscript the whole necessary procedure will be explained to get the three-dimensional reconstruction of the vessels, where it figures the design from a system of control points appropriate to the dimension of the fragments, the study of illumination and required precisions.

This project arose to enlarge the perspectives of the Photogrammetry and to demonstrate the viability of the works with not very sophisticated tools, besides offering new possibilities to the World of the Archaeology considering this form of analysis the archaeological remains.

## INTRODUCTION

This project consists on the reconstruction of three vessels of mud, starting from the photogrammetric survey of fragments belonging to this vessels.

This work arises like project pilot for the Faculty of Geography and History of the University of Las Palmas de Gran Canaria, in its section of Prehistory, of face to the possible execution of a G.I.S. applied to the archaeology. The Archaeological Location where the ceramic ones were located it is the one denominated as Location of Zonzamas. Also popularly known as Palace of Zonzamas, it is erected on a basaltic hill of the central area of the island from Lanzarote to 29°00'25" of North latitude and 90°52'00" of longitude West, starting from the meridian of Madrid, in the municipal term of Teguisse.

The occupation of this establishment took place in a continuous way until the XVIII century, so that its abandonment it must correlate with the volcanic eruptions of 1730-1736. Starting from those moments and until half-filled of the XX century, it was only occupied in a sporadic way and always linked to the cattle activities.

The recovered archaeological material is very important, and it reflects the characteristics of an aboriginal establishment of great perceptible socio-economic entity in the simplest handmade works, in the personal ornament or in the ideological manifestations, as well as the transformations that were happening in the place for effects of the extensive and systematic occupation that took place until the XVIII century. At the moment a guided architectural project is elaborated as much to its conservation as to the adaptation of the necessary infrastructure for its exhibition as a Museum, in continuous improvement and amplification for the continuity of the works and, to the same time, like space for complementary public use.

## DESCRIPTION OF THE CARRIED OUT WORKS

In the first place it was carried out a study to obtain the necessary parameters for the realisation of the photographic takings as they were: distance camera-object, opening of the diaphragm, separation among the takings, etc.

Subsequently it was carried out the calibration of the camera and a badge of control points was designed on which the pieces were placed in the moment to carry out the photos. Once obtained this badge the co-ordinates of the control points were calculated as well as the errors associated to this co-ordinates. Once the photos were had it spent to the photogrammetric procedure.

## ELECTION OF THE CAMERA

The used camera was a Pentax 645 belonging to the group of the semimetric cameras. It has a glass badge in the focal plane containing a reticule (badge Reseau) that serves to control the film deformation. Their format is 6 cm (horizontal) x 4.5 cm (vertical), ideal for the realisation of works of closed range Photogrammetry. Due to the size of the format, this camera is classified in the group of cameras of medium format.

## ELECTION OF THE FILM.

A film was used for special slides for light of Tungsten EPY 120 Ektacrome of 45 handle. This movie was employed so much for the calibration of the camera as for the realisation of the photographic couples used in the rising of the pieces.

- EMULSION: It was used slides in colour. So that the image was realer and more intuitive it was chosen the slide and the colour for a bigger definition of the tonalities of the piece.

- SENSIBILITY: Not very sensitive film of 45 asa, of smaller grain for a better definition of the contrast, to weigh that this required a bigger time of exhibition, although the lingering time of exposition was not a problem because the camera was placed on top of a tripod.

- FILTERS: As it was used sources of artificial light that emit yellow light it was convenient the employment of a blue filter or a film for tungsten light. As filters were not available, it was chosen to use a special film for light of Tungsten EPY 120 Ektacrome of 45 asa.

- ELECTION OF THE CONTROL POINTS: To be able to carry out the external orientation of the photos it should be known data of the space object photographed to be able to locate each picture in the terrestrial system. These data are the terrestrial co-ordinates of the control points.

The system of support points is made up of:

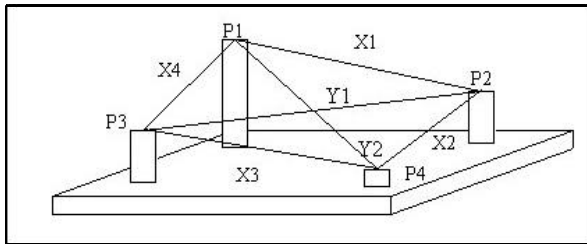


Figure 1

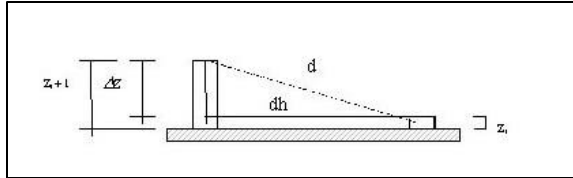


Figure 2

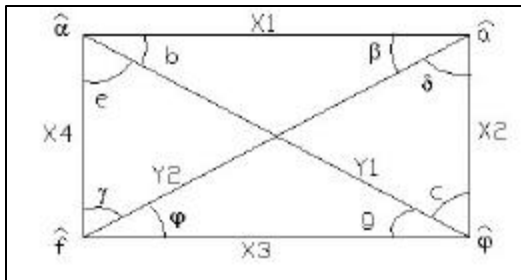


Figure 3

- Badge of 15x15 cm of refined steel so that doesn't reflect the light.
- Four fixed cylinders of variable heights that oscillate between 0.5 and 3.5 cm, located near the corners of the badge.

### CALCULATION OF THE CONTROL POINTS COORDINATES.

The Centre of Metrology and Calibration, belonging to the Department of Mechanical Engineering of the University of Las Palmas de Gran Canaria, provided the measures of the system of control points. Those measures were taken 10 times each one.

For the distances X1, X2, X3, X4, Y1, Y2, (Figure 1) an external micrometer with division of scale of 0.01 millimetre was used, and the measure of the "z" was carried out with a digital caliper with division of scale of 0.01 millimetre. Being P1, P2, P3 and P4 the positions of the bars on which are marked the crosses whose intersection defines the support points.

The following result was obtained after carrying out the calibration:

DISTANCES		ALTITUDES	
X1	140.388	Z1	33.36
X2	111.977	Z2	18.84
X3	140.807	Z3	14.69
X4	113.450	Z4	5.02
Y1	180.36		
Y2	179.68		

So provided distances were slope ones, among the crosses that are in the highest part in the cylinders, the horizontal distances had to be obtained so that co-ordinates were able to be calculated. The reduced ones were obtained starting from graph (Figure 2). In the figure it is observed that:

$$d^2 = D_z^2 + dh^2$$

where the horizontal distance is:

$$dh = \sqrt{d^2 - \Delta Z^2}$$

Being,

$$\begin{aligned} D_{z,x1} &= z_1 - z_2 & D_{z,x2} &= z_2 - z_4 & D_{z,x3} &= z_3 - z_4 \\ D_{z,x4} &= z_1 - z_3 & D_{z,y1} &= z_1 - z_4 & D_{z,y2} &= z_2 - z_3 \end{aligned}$$

Once calculated all the horizontal distances, the angles of the parallelogram that form the Control Points were calculated, leaving of the figure 3.

It is a simple operation consistent in clearing the angles starting from the Theorem of the Cosine:

$$\begin{aligned} x_i^2 &= y_i^2 + y_j^2 - 2 \cdot y_i \cdot y_j \cdot \cos \alpha \\ \cos \alpha &= \frac{y_i^2 + y_j^2 - x_i^2}{2 \cdot y_i \cdot y_j} \end{aligned}$$

Then the compensation of the angles of the parallelogram was carried out in two parts: 1.° sum of angles in opposed triangles, and 2.° Total sum of angles.

1.° compensation. It adds of angles in opposed triangles. To be supplementary angles of those that are formed in the intersection of the diagonals, it will have to be verified that:

$$e + g = d + c$$

$$b + b = y + g$$

but because these angles are calculated starting from distances that contain small errors, this won't happen but rather it will be:

$$e + g = d + c + e_1$$

$$b + b = y + g + e_2$$

2.° compensation. Total sum of angles.

As the group of the eight angles they are the interiors of the quadrilateral, their sum should be 400g, but because they are not rigorously exact:

$$b' + b' + d' + c' + g' + y' + g' + e' = 400^s + e_s$$

The error is compensated to same parts in the bought stages. The second compensation doesn't modify the effects of the first one, because each one of the angles suffer the same correction. If one observes thoroughly it will be proven that for the fact of being completed the sum of angles of opposed triangles and the total sum of angles, the closings of the four triangles 124, 243, 432, 312. are also correct.

The planimetric co-ordinates of the control points were obtained starting from the definitive angles. Leaving of the control point PA 1 with co-ordinates would arbitrate X = 500 (mm), AND = 500 (mm), the co-ordinates of the other points were obtained. As for the altimetric ones these were not necessary to calculate them since, like it has been commented, they were obtained directly of the calibration of the badge. Obtaining this way the definitive co-ordinates:

CONTROL POINT	X (mm.)	Y (mm.)	Z(mm.)
PA 1	500	500	33.36
PA 2	639.635	500	18.840
PA 3	498.048	388.114	14.69
PA 4	638.426	389.005	5.02

#### CALCULATION OF THE ERROR ASSOCIATED TO THE CO-ORDINATES OF THE POINTS OF CONTROL.

To carry out this study the Theory of Errors' Propagation it was applied to the different stages for the obtaining of the co-ordinates of the control points.

They are distinguished two sections, on one hand the error associated to the Planimetry, and for other the associated to the altimetría.

- Planimetry: For the determination of the error associated to the planimetric co-ordinates of the control points it should be kept in mind the followed steps for the obtaining of the same ones. These steps are the following ones:

1. Conversion of the obtained slope distances of the calibration.
2. Obtaining of interior angles using the horizontal distances.
3. Obtaining of planimetrics co-ordinated using horizontal distances and interior angles.

Next the errors are calculated made in each one of the steps.

#### 1. Conversion of slope distances obtained in the calibration.

Observing the Figure 2, it is obtained that for the conversion of each one of the distances, two altitudes and a distance were used:

By means of the Theorem of Pitágoras the expression was obtained for the calculation of the reduced distances:

$$dh = \sqrt{d^2 - \Delta z^2}$$

for the Theory of Errors' Propagation, the error associated to an operation comes expressed for:

$$m^2(x, y) = \left(\frac{\partial F}{\partial x}\right)^2 d_x^2 + \left(\frac{\partial F}{\partial y}\right)^2 d_y^2$$

being

$$m^2(\Delta z, d) = \left(\frac{\partial F}{\partial \Delta z}\right)^2 d_{\Delta z}^2 + \left(\frac{\partial F}{\partial d}\right)^2 d_d^2$$

$$m^2(\Delta z, d) = \left(\frac{-2\Delta z}{2\sqrt{d^2 - \Delta z^2}}\right)^2 d_{\Delta z}^2 + \left(\frac{2d}{2\sqrt{d^2 - \Delta z^2}}\right)^2 d_d^2$$

where:

d = distance (obtained of the calibration).

d<sub>d</sub> = uncertainty of the distance in the measure process.

Δz = difference of z between two bars.

d<sub>Δz</sub> = error associated to the obtaining of ΔZ .

The error in the measurement of "d" was obtained by the Laboratory, but the error in the obtaining of Δz, it is obtained in the following way:

$$Dz = Z_n - Z_{n+1}$$

$$d_{\Delta z} = \sqrt{dz_n^2 + dz_{n+1}^2}$$

being the differences of z the following ones:

$$\Delta z_{x1} = z_1 - z_2 = 14.668 \text{ mm.} \quad \Delta z_{y1} = z_2 - z_3 = 3.9370 \text{ mm.}$$

$$\Delta z_{x4} = z_1 - z_3 = 18.605 \text{ mm.} \quad \Delta z_{x3} = z_3 - z_4 = 9.824 \text{ mm.}$$

$$\Delta z_{x2} = z_2 - z_4 = 13.761 \text{ mm.} \quad \Delta z_{y2} = z_1 - z_4 = 28.4290 \text{ mm.}$$

That is to say, examined that heights (z) they intervene in the calculation of the different Δz, one can know which they are the errors associated to the measures of z that we should take of the chart in each case; we have this way the errors associated to the obtaining of the Δz. Substituting these values in the expression of m<sup>2</sup>(Δz, d), and with those that have of the calibration, they are the following errors in the reduction of d:

#### Errors of the horizontal distances

$$F_{x1} = 0.0514 \text{ mm} \quad F_{x4} = 0.0270 \text{ mm}$$

$$F_{x2} = 0.0289 \text{ mm} \quad F_{y1} = 0.0477 \text{ mm}$$

$$F_{x3} = 0.0480 \text{ mm} \quad F_{y2} = 0.0368 \text{ mm}$$

## 2. Obtaining of interior angles using the horizontal distances.

In the Figure 3 it is observed that to obtain the co-ordinates of the control points PA2, PA3 and PA4, it was needed to calculate the angles b and e.

The determination of the angles is carried out using the theorem of the cosine.

- Determination angle b:

$$x_2^2 = x_1^2 + y_2^2 - 2x_1y_2 \cos b$$

$$\cos b = \frac{x_1^2 + y_2^2 - x_2^2}{2x_1y_2}$$

$$b = \arccos \frac{x_1^2 + y_2^2 - x_2^2}{2x_1y_2}$$

And the Theory of Errors' Propagation is applied

- Determination angle e:

$$x_3^2 = x_4^2 + y_2^2 - 2x_4y_2 \cos e$$

$$\cos e = \frac{x_4^2 + y_2^2 - x_3^2}{2x_4y_2}$$

$$e = \arccos \frac{x_4^2 + y_2^2 - x_3^2}{2x_4y_2}$$

Theory of Errors' Propagation is applied too.

The errors in the angles are:

$$m(b) = \sqrt{0.00000007} = 0.000263$$

$$m(e) = \sqrt{0.00000025} = 0.000499$$

## 3. Obtaining of planimetric co-ordinates using horizontal distances and interior angles.

They are distinguished four sections here: A) Error in the obtaining of the co-ordinates of PA1. B) Error in the obtaining of the co-ordinates of PA2. C) Error in the obtaining of the co-ordinates of PA4. D) Error in the obtaining of the co-ordinates of PA3.

3.A. Error in the obtaining of the co-ordinates of PA1. This point doesn't contain error since its arbitrary co-ordinates we give them to him us directly.

3.B. Error in the obtaining of the co-ordinates of PA2. In this case the co-ordinates were calculated using the following expressions:

$$X_{PA2} = X_{PA1} + x_1 \text{SEN } 100^\circ = X_{PA1} + x_1$$

$$Y_{PA2} = Y_{PA1} + x_1 \text{COS } 100^\circ = Y_{PA1}$$

It is observed that in this case the error was the coming from the measure of x1. Being so:

$$e_p \text{ PA2} = 0.0514 \text{ mm}$$

3.C. Error in the obtaining of the co-ordinates of PA4. Now the following expression is presented to obtain the co-ordinates:

$$X_{PA4} = X_{PA1} + y_2 \text{COS } b$$

$$Y_{PA4} = Y_{PA1} + y_2 \text{SEN } b$$

This way the error in the obtaining of the co-ordinates was:

In X:

$$\frac{\partial F}{\partial y_2} = \cos b$$

$$\frac{\partial F}{\partial b} = -\text{sen } b \cdot y_2$$

$$m^2(y_2, b) = \left( \frac{\partial F}{\partial y_2} \right)^2 d_{y_2}^2 + \left( \frac{\partial F}{\partial b} \right)^2 d_b^2 = 0.0410 \text{ mm} = m_X$$

In Y:

$$\frac{\partial F}{\partial y_2} = \text{sen } b$$

$$\frac{\partial F}{\partial b} = \cos b \cdot y_2$$

$$m^2(y_2, b) = \left( \frac{\partial F}{\partial y_2} \right)^2 d_{y_2}^2 + \left( \frac{\partial F}{\partial b} \right)^2 d_b^2 = 0.0431 \text{ mm} = m_Y$$

Both errors spread in perpendicular directions, that is to say if one observes the following graph one can say that the point PA4 will be inside a circle, since the made error can be as much for excess as for defect, of radius the one bigger than both errors, in this case mY.

Therefore the error associated to the obtaining of the planimetric co-ordinates of PA4 was:

$$m_p \text{ PA4} = 0.0431 \text{ mm}$$

3.D. Error in the obtaining of the co-ordinates of PA3.

Finally, for the obtaining of the co-ordinates of PA3 we have the following expressions:

$$X_{PA3} = X_{PA1} + x_4 \cos(e+b)$$

$$Y_{PA3} = Y_{PA1} + x_4 \text{sen } (e+b)$$

This way the error in obtaining of coordinates was:

In X:

$$m(x_4, e, b) = \sqrt{0.00398304} = 0.0631 \text{ mm} = m_X$$

In Y:

$$m(x_4, e, b) = \sqrt{0.00073019} = 0.0270\text{mm} = m_y$$

Both errors spread in perpendicular directions, since the made error can be as much for excess as for defect, of radius the one bigger than both errors, in this case mx.

Therefore the error associated to the obtaining of the co-ordinated planimétricas of PA3 was:

$$m_{pPA3} = 0.0631 \text{ mm}$$

Summarizing:

Control Point	$e_{xy}$ (en mm.)
PA1	0.000
PA2	0.051
PA4	0.043
<b>PA3</b>	<b>0.063</b>

Taking as planimetric error associated to the control points the one bigger than them one has that:

$$e_{ap} = 0.063 \text{ mm}$$

-Altimetry: In this case the errors associated to the co-ordinates those that it facilitated the Laboratory of Metrology were:

Control Point	$e_z$ (en mm.)
PA1	0.012
PA2	0.014
<b>PA4</b>	<b>0.016</b>
PA3	0.015

And the altimetric error associated to the control points will be the one bigger than them:

$$e_{aa} = 0.016 \text{ mm.}$$

### ELECTION OF THE SCENE

**Parameters for the realisation of the photos.** As the minimum focus distance it is of 450mm. this was chosen as the distance object-camera for the following study, considering a focal of 45mm.

- Election of the scale: The scale is directly proportional to the focal and inversely proportional to the distance camera-object that was the minimum distance of focus in this case. Obtaining a photographic scale 1:10.

Substituting in the following formula the scale is obtained,

$$L/D = l/f$$

- Field depth:

In this work, it should be kept in mind the field depth so that as much the pieces as the crosses that determine the support points are focused.

The field depth depends on the focal distance of the lens, of the diameter of the opening of the diaphragm and of the distance of the object. And it comes expressed by means of the following expression,

$$s_2 - s_1 = \frac{4 \cdot s \cdot N \cdot z_0 \cdot f^2 \cdot (s-f)}{f^4 - 4 \cdot N \cdot z_0^2 \cdot (s-f)^2}$$

$s_1-s_2$  is field Depth

$z_0$  tolerated diffusion circle (TO x eg =0.05mm, being TO the diameter of the floating mark).

N is relative Opening

s is Distance camera-object

f is the focal one

The obtained field depth was of 102 mm, value that was obtained when having decided to use a relative opening of 5.6.

- Calculation of tolerances, base and overlay:

For the scale of the rising 1:10, the planimetric tolerance is:

$$eg = 0.2\text{mm} \times 10 = 2\text{mm}$$

To calculate the base the following expression it was used:

$$T_a = \frac{1}{4} \text{ equidistance} = 1\text{mm}$$

$$T_a > (H/B) \times dP$$

(where H is 450mm, dP is sensibility from the Photogrammetric Machine to scale = 0.04 mm)

We have left clearing the base B = 112.5 mm.

Of where a overlay was obtained of:

$$600-112.5 \text{ mm} = 487.5 \text{ that is to say, } 81.25\%$$

**Proves:**

The test takings have been carried out with the following characteristics:

N=5.6

p=450mm. (it distances camera object)

They left placing focuses in different positions observing that the most suitable position in the sources of light was that of two focuses of light of 60 aligned Watios and a normal Halogen to them, like she/he appears in the figure 4:

### ELECTION OF THE PHOTOGRAMMETRIC MACHINE.

The used photogrammetric machine was the MPS-2 (Microphotogrammetric System) of ADAMS TECHNOLOGY. It is an analytic photogrammetric machine

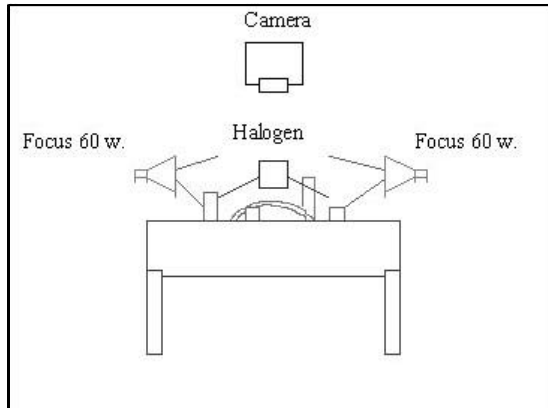


Figure 4

to the small format (6 x 6 cm.), with a software for analytic treatment of the coordinates.

Their election was owed because one of the utilities of the team ADAMS is the calibration of the lens of the camera by means of the method of the plumb lines

### LENS CALIBRATION

To carry out the calibration, it was already commented previously, the procedure ADAMS was used that is adjusted to the method of plumb line lines.

The work consisted on determining the Photocoordinates of a series of points in each one of the lines (horizontal and vertical). As the resulting images of the lines they are not right but paraboles due to the distortion, mathematically the equation is equalled before from each straight line to the calibration equations described. For each point one has two equations for what would be enough with the equations generated by four points. For a bigger accuracy of the method numerous points are used distributed on the format, going then to a solution of the system for square minima.

To be able to carry out this method, a board of consistent calibration was designed in a wooden mark of 81 x 65 cm, on which some halfway incisions were marked, with the help of a caliper of foot of king so that the separation among this incisions was always the same one, spaced in such a way that covers the field of vision from the camera to the distance to gauge, being six the minimum number of lines that they should cover the area of the format. Then they were made go by this incisions a thread of nylon of 0.5 mm of thick tightening to the maximum this thread, and to reinforce the position of the thread thumbtacks they were placed in the song of the wood. Finally the threads were coloured of black to get a bigger contrast when placing them on a white bottom.

- Photographic taking. To be able to carry out the calibration according to this method, it was necessary to take two photos rotating in one of them the camera 90°.

The taking was carried out under the same conditions that with the pieces. The focus for a distance of 450 mm. and opening of the diaphragm 5.6.

### MACHINE CALIBRATION

The process of calibration of the machine allows to correct the mechanisms of positioning of the estereocomparador of imperfections due to a lingering use, due to change of the work conditions, etc.

### RECONSTRUCTION

The results of the external orientation were the following ones:

	e.m.c. X	e.m.c. Y	e.m.c. Z
PIEZA 1	0.269 mm.	0.241 mm.	0.604 mm.
PIEZA 2	0.253 mm.	0.250 mm.	0.547 mm.
PIEZA 3	0.237 mm.	0.227 mm.	0.500 mm.

As the planimetric error was very small the final representation scale of the fragments was 1:1.5. When carrying out the curved of the fragments the equidistance among curved of 4 mm. was excessive, for that reason it was decreased to 1 mm.

Tolerance for representation to scale 1:1.5

T= 0.3 mm.

Tolerance for equidistance of 1 mm.

T= 0.25 mm.

The error is passable in planimetry but it is not passable for the altimetry nevertheless, because a rigorous precision is not demanded in the work, this is considered acceptable.

Once obtained the mesh of points, a file of extension " dwg " was made which could be loaded directly in the " Protopo " that it is a AUTOCAD V.12 modulate, being this loaded one as a menu of AUTOCAD. Once loaded the file you proceeded to triangular in the first place the points, and later on it was requested that presents the one curved that it was obtained with those interpolation triangles.

Concluded the curved to carry out some traverse cuts are carried out to the piece. Superimposing these profiles, an ideal profile was traced that it was resulted of the stocking of all saving those particularities of the piece, for example, when the profile crossed an area of fragmentation.

The vessels will be reconstructed with the diameter facilitated by the archaeologist. These values which were proven on the one curved calculating it by means of Autocad. This way the following diameters was settled:

Vessel 1= 220 mm. Vessel 2= 200 mm. Vessel 3= 120 mm.

Drawing a line that materializes the diameter, another perpendicular one to this that symbolizes the height, and placing the border from the perpendicular ideal profile to the diameter, one or several circumference arches were drawn that adapts to such a profile, obtaining the section of the vessel.

Introducing the thick vessels that were measured previously with a caliper, later the profiles was decared like polilines and they was import 3DSTUDIO MAX R.2. There with a modifier was made a revolution figure starting from the section of the same one, so the vessel in 3D was obtained.

## CONCLUSIONS

Has been possible to pass to digital format the pieces with the following advantages:

- Conservation. The bad quality of the materials of the pieces makes that these break up with easiness. To have the digitised pieces supposes to conserve their form for the posterity. Creating this way a product that contains the legacy of the past, conserved in a present format and that it will be able to be used in the future.
- Great storage capacity. Following this process one could have a library of pieces in any PC. A great quantity of them you can store.
- Easy transfer. The archaeologists or any user could exchange a considerable volume pieces by means of e-mail, CD ROM, or to consult a Web page, and the original pieces had not to suffer any displacement, avoiding this way the risk that this supposes.