DIGITAL PHOTOGRAMMETRY: 3D REPRESENTATION OF ARCHAEOLOGICAL SITES

Mercedes Farjas

ABSTRACT

The aim of this document is to show the results of the digital photogrammetry methodology and its potential for application in Archaeology. The photogrammetry technology was carried out in order to study the possibilities for using photogrammetry methods and digital modelling techniques in archaeological sites and findings, giving them a precision appropriate to these techniques.

The specific aims of this project are to obtain a three-dimensional digital model, applying photogrammetric methods for near-by objects, with a final precision of coordinates of the object of $\pm$2,5 mm, securing a methodology that was precise and practical for filed use, and easy to transport and apply. This digital model could be incorporated in the reconstruction of the archaeological environment, in the reconstruction of the site in the event that it was in bad condition, in the acquisition of profile and transverse sections, and could be integrated in multimedia applications with different finishing and visualisation sequences.

In this document we will show the general possibilities of the digital photogrammetry methodology and the application of the 3D representation of three different sites in Jebel Buhais Archaeological Area, in the United Arab Emirates. It will show the data collection works of archaeological data in BHS 66, BH67 and the 5 Burial artefacts, in an attempt to create and define a general methodology with non metric camera images to serve to archaeology, transferring the updated potential of photogrammetry into Archaeology.

In order to conduct the observations, a T2 Wild theodolithe and a TC 705 total stations by Leica were used, with stationing equipment and rigid stars. The observations were simultaneously carried out, thereby, reducing the observation times and the problems derived from them.

Two sorts of data were observed: support points and auxiliary points. In the case of the support points, spherical signals of 3 mm diameter were used, which permitted precise aiming from any incidence angle of the line of vision. The auxiliary points were made using adhesive targets, being very careful with the angles which could affect the lines of vision.

The support points were located on a metallic support stakes, and they were distributed by placing five of them at five different heights. These points of support were used for the calibration of the photograms and throughout their orientation process.

The observation method was used to carry out the multiple resections and to applied least square adjustments by the calculation. In the calculation process, first of all, the analytical relative orientation of the theodolite stations was carried out in order to obtain the coordinates of the common points observed from the stations, but with an arbitrary scale and orientation. The clouds of independent points with different scales and orientations are going to be distributed in only one system of reference through spatial similarity transformations.

For the photogrammetric process of the project, without knowing the internal parameters, a nonmetric digital camera was used. This sort of camera has the advantage of being cheaper and easier to use, besides using cheaper film, which is easier to process. Since they are not calibrated, the determination of the parameters must be carried out for each take, which implies an increase in workload during the process.

The photogrammetric process of calibration and orientation of two sets will include the following phases:

- Previous measurement to determine the parameters of internal orientation of each photogram.
- Determination of the parameters of the internal orientation of the camera.
- Internal orientation of each camera.
- Relative orientation of each pair of photograms.
- Absolute orientation of each pair of photograms.
- Verification of the adjustment.

The restitution of the sites is going to be undertaken using the *Microstation* environment, which supports the digital restitutor. The digital model is going to be transformed with points and lines obtained through the stereoscopic display of the epipolar images obtained. In each model, as many points as required to obtain a good distribution for the triangulation of the digital model, will be obtained. The edges and well defined details will be restituted through lines, and the uniform areas or areas with a lower level of detail are going to be restituted by points. The cloud of points obtained are going to be triangulated using the Intergraph modelling programme.

Photogrammetry nowadays has been developed as technology using remote sensing images treatment software, to automise the processes. Image processing allows 2D features but photogrammetry provides the third dimension instantaneously making it possible to introduce high accuracy analysis in the archaeological data collection process.

As photogrammetry specialists our goals are not only to provide 3D data registers, but also to get sufficient accuracy at any scale to avoid the necessity for sketches during the excavation process.

1. INTRODUCTION

This report forms part of the *Sharjah Project: Geodesy, Surveying, Cartography and Landscape applied to Archaeology,* currently being developed by the research group CARPA of the Polytechnic University of Madrid within the framework of the agreement between the University and the Ministry and Culture of the Emirate of Sharjah in The United Arab Emirates. As specialists in cartography, the work has given us the opportunity to make a global analysis of archaeological processes and to consider which of our available tools could improve archaeological methods. There is frequent cooperation between specialists in cartography and archaeology and in the many joint projects carried out the aim has been to apply the latest topographical methods and technology to the diverse fields in archaeology. Our project does not aim to produce classical maps that geometrically indicate archaelogical sites and points of interest. Our interest lies in the applications of digital models, teledetection, GIS, photogrammetry and in generating interest in archaelogy through museums, schools and universities.

We therefore consider that the study of an archaelogical site of whatever type (on land or under water) is a complex process that should only be undertaken after meticulously planning the methodology of the excavation and the supporting processes of documenting finds and collecting data. From the analysis and evaluation of the possible excavation methodologies, one will be chosen which best fits the requirements and will be followed in the detailed studies to be carried out in the course of the excavation. From our point of view, the excavation *project* involves the choice of scales, types of sketches and their indications on maps, etc. As in an engineering scheme, two different stages must be identified together with the scope of each: the pre-project and the project itself.

It has been said that the starting point of all investigations is when we come up against a question or uncertainty that forces us to wonder about a situation and to start searching for an answer. It was during a visit to an excavation site at *Jebel Buhais,* in the in the Emirate of Sharjah (UAE), as part of the research group of the Polytechnic University of Madrid, when in the course of our map-making work, we found ourselves involved with the clover-shaped tomb BHS 66. In our case, the question occurred to us spontaneously and had us thinking about it for a whole year, until the following campaign.

How could we accurately reproduce and transmit the beauty and curious geometry of that tomb without forgetting the technical and metric features which interested us so much?

We belong to an engineering environment which has taught us how to use photogrammetry as a tool for generating cartographical databases. From our first impressions in contacts with the archaeological teams, we learned that photogrammetry was being applied to isolated cases with methodologies that were not applicable to general cases. It was therefore not considered a valid alternative for recording information at archaeological sites.

Aerial mapping provide the most effective means of making or updating maps. At the present moment, aerial photogrammetry combined with computer and digital systems is the most advanced technique available to engineers to make studies and projects for roads and other civil engineering work. Also, the evolution of this technique offers by-products of great interest for the diffusion of archaeological information. We therefore decided to apply the methodology used in aerial photogrammetry for our project to terrestrial photogrammetry and to try to define methodologies that could be used by archaeological teams.

In this report we deal with the challenge of designing all the processes necessary to obtain cartographic databases for numerical exploitation in archaeological sites, using all the automatic techniques offered by digital photogrammetry.

We took the experimental design to the United Arab Emirates, not only because of the interesting archaeological remains to be found there, but also to be able to consider the variable of the widely dispersed geographical location, as is often the case in Archaeology. We began our research, the subject of which is included in the heading to this document, with the following objectives:

- ✓ To obtain a cartographic base of sufficient precision to meet the needs of the excavating team.
- ✓ To cover the information needs for evaluating archaeological information.
- ✓ To permit the integration of digital information in the database in the formats suggested by the excavation director.
- ✓ To achieve, through the use of new, verified and approved technologies, working methodologies for the optimum use of human, material and financial resources.

We planned to carry out all the work within the theoretical framework of close-range aerial photogrammetry. Our aim was to apply the methods of close-range photogrammetry to an archaeological discovery by aerial photography with a non-metric digital camera, comparing the results with the same methodology used with a semi-metric camera, with vertical and horizontal photos to form the photogrammetric model. The results would be subsequently restituted to obtain a 3D representation of the archaeological object. The method of calculation would be Direct Linear Transformation, a reliable method to use with non-metric cameras, programmed by Professor Francisco García Lázaro.

The selected objects were the tombs BHS 66 and BHS 67 and the gravesite known as “Five Skeletons” at the BHS 18 site. All these sites are in the archaeological zone of Jebel Buhais in the Al-Madam region of the Sharjah Emirate in the United Arab Emirates.

2. DIGITAL PHOTOGRAMMETRY IN ARCHAELOGY

Photogrammetry, like the other aspects of topography, has been changed by the technological advances of recent years. In the photogrammetric process, analogue restitutors, and analytic restitutors have been replaced by digital photogrammetric stations, due to the huge advances in computer software in recent years. These advances have included improvements in sensors, data collection, use of information and time saving. These new systems allow the use of digital images, which means that digital aerial cameras can be used, thus permitting the use of photograms that do not need to be previously scanned.

At first, these workstations had a low capacity and calculation processes were slow due to lack of processing power in the computers. Research into automatic orientation processes, aerial triangulation, automatic generation of digital terrain models by correlation of images, have drastically reduced the time required for map-making and consequently the costs involved.

The desire to obtain photographic images of uniform scale throughout is almost as old as photogrammetry itself. This objective, as well as the new techniques in geometric and radiometric image treatment by digital systems, have resulted in the successful use of orthophotos that combine the information of an aerial photograph with the geometric characteristics of a map.

This methodological alternative is the one we proposed to apply to archaeology, simplifying it as far as possible and designing an easily applied procedure. We attempted to include the use of non-metric digital cameras in the photography. We applied this mapping procedure to the 3D modelling of an archaeological site in order to demonstrate the possibilities offered by the automation of the sequence of these different techniques.

Our project contains the set of operations necessary for the generation of a cartographic database to be used as a reference in the drawing up of a pre-project excavation plan and also as cartographic support in the cataloguing of objects.

When we had got the answer to our initial question, we considered the use of terrestrial Photogrammetry in archaeological sites. The objective was to obtain a 3D metric document as scientific support and also to obtain other derived photogrammetric products to help museums with their archaeological exhibits.

Aerial surveys are not only useful in map-making but are particularly so in the initial reconnaissance, since aerial photograms provide much additional information such as the shape of the site and the various types of material of which the ground is composed, thus helping in the preliminary selection of excavation methodologies.

This project could also solve another problem existing in archaeology, which is the cataloguing of finds at the site and the evolution of the dig, since the methodology employed in photogrammetry offers an alternative to registering the sequence and cataloguing of the field work. This work can be reduced at the same time as it increases the capacity for metric and graphic analysis of the entire archaeological process.

To achieve these results, the project also includes the innovation of the possible application of data capture with pre-targeting of control points, in order to obtain the final Digital Terrain Model (DTM) and orthophotos of the site. These metric documents, in 3D and 2D, will allow us to solve the problem of cataloguing finds and the evolution of the dig.

Our sites are located in the United Arab Emirates (Figure 1), an independent sovereign Moslem state in the Arabian Peninsula. Its geographical boundaries are between Latitude 22º30’ and 26º North, and Longitude 51º and 56º30’ East.

The country is composed of seven emirates: Abbu Dhabi, Dubai, Sharjah, Fujairah, Ra's Al'Khaimah, Ajman y Umm Al'Qaiwain.

Figure 1: Location of the UAE.

As we mentioned previously, the Research Group is working in the Emirate of Sharjah on large-scale maps of the excavation areas and the archaeological background. It is also developing a project for integral data management.

3. THE ARCHAELOGICAL AREA OF JEBEL BUHAIS

The sites selected for the photogrammetric test are in the archaeological zone of Jebel Buhais (Figure 2). The present archaeological importance of this part of the country is due to its geomorphology.

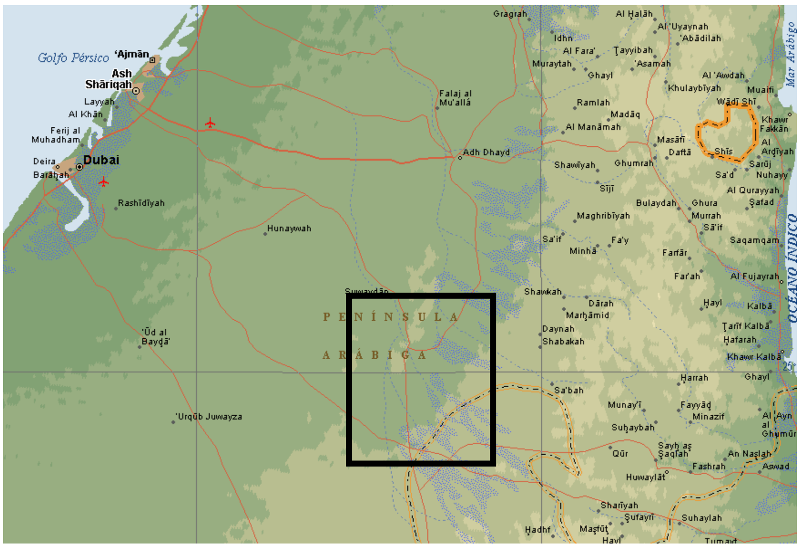

Fig 2: The Archaelogical Area of Jebel Buhais (Al-Madam)

On the hillside at Jebel Buhais we can find more than eighty tombs and other archaeological remains in a distance of only two kilometres. Ancient fire sites have also been found. Of special importance is a rectangular stone building (44 x 19 metres) located on the top of a hill, the subject of various theories as to its origin. Utensils found at these sites could be dated and were found to have had their origin in the Stone, Bronze and Iron Ages. Remains from all these ages have been found at Jebel Buhais. In those times, people were buried with their personal property, and diverse types of artefacts have been found such as necklaces, carved stones, metal and pottery objects, as well as many skeletons, since in many cases the graves were communal. At nearby excavation sites animals were found buried next to their owners, providing the first indications of animal husbandry in the area.

4. FIELD DATA COLLECTION

PROJECT Nº 1: *Photogrammetric mapping of Tomb Nº 66 at the excavation site at Jebel Buhais in the region of Al-Madam (UAE)*[1] *in October 2003.*

The methodology employed in the research project of data collection at the clover-shaped tomb BHS 66 proved to be highly complex due to a series of premises that had to be complied with:

- Control of the line of flight of the photographic aircraft had to be precise regarding both height above the ground and the planimetric situation. It therefore had to be constantly monitored.
- The fieldwork of the archaeologist at the excavations must not be interrupted under any circumstances.
- The equipment had to be transported from Spain to the Emirates. This meant there could not be any last-minute improvisation, but a certain flexibility had to be maintained to deal with unforeseen circumstances and necessities arising during the establishment of the station at the site and during the data collection period.

Before undertaking the journey, the photogrammetric flight programme was designed to define the photographic shots and the basic support network to be employed in the project. For this, we used data and sketches made on previous visits to Jebel Buhais, with special emphasis on this excavation site. Analysing the size of the target object, the altitude of the camera and the photographic coverage, the distance between the photographic flight lines were planned to pass over the petals of the clover-shape of the tomb, approximately 100cm apart. It was decided that a photograph would be taken every 40cm along the line of flight. In this way we were assured of good coverage in the photos, both transversally and longitudinally. A detailed flight map was then drawn up.

The survey of the tomb site was carried out by close-range aerial photogrammetry, with classic topographic support. The fieldwork consisted of the targeting and surveying of support points in sufficient numbers to permit application of DTM, by means of classical topography. We expected to achiever a precision greater than $\pm$ 5 mm.

Using GPS, a basic grid was drawn out covering the entire Jebel Buhais zone (2km x 500m), with 17 vertices 200m apart, which permitted work to be carried out at any point with the same reference system. For the basic photogrammetric support network, a micronetwork containing five high-precision points was planned, in the same reference system as the principal network. The survey was performed by the topographic methods of triangulation and trilateration.

After studying the previously mentioned premises, a support point pre-targeting system and data capture methodology were devised. For this project all the methodology was designed. A distinction must be made between two fundamental elements; the support and transport structure for the digital camera, and the structure for pre-targeting support points and sighting points.

Support and transport structure for the digital camera

This structure consisted of some light aluminium tripods (Figure 7) with a telescopic pole inserted through a metal plate. The pole had a ferrule at the end, supporting a guide on which the camera travelled.

The telescopic pole had a support with a spherical level to ensure the orthogonality of the photos. The pole also permitted the camera to be raised to the necessary height to achieve the coverage required for photogrammetric treatment. The movement of the camera to simulate aerial photography was achieved by positioning the digital camera on an aluminium plate supported by a trolley. The camera was held in place by a screw (Figure 3). The centre of gravity of the camera was also calculated to ensure that it was perfectly vertical after being fixed in place on the transport system.

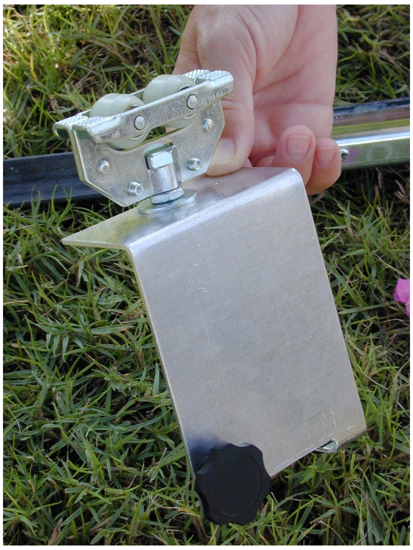

Figure 3: The camera support

This consisted of a set of seven poles. Each pole holds two different symbols.

Pre-targeting of the aiming point

This is placed on the upper section of the pole and consists of a 25mm square aluminium plate fixed to the pole with a clasp. On both sides of the aluminium square stickers with small crosses were fixed to provide precise sighting points (Figure 4).

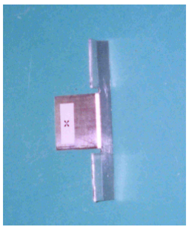

Figure 4:
Topographic aiming point

Pre-targeting of support points

These were placed at three different positions on the lower part of the pole. As in the case of the aiming points, they were formed by 25mm square aluminium plates attached to the pole by a clasp. A sticker was attached to only one side of the aluminium plate with a cross symbol somewhat larger than those used for the sighting points, so that they would be clearly visible in the photograms (Figure 5).

Figure 5: Support point

The poles supporting the pretargeting of sighting points and support points consisted of two sections with a total length of 2m, along which the symbols necessary for data collection were placed, as can be seen in the figure. As has been mentioned above, the sighting points were placed on the upper section of the pole, one above the other at a distance of 40cm, to ensure high precision.

Figure 6: Support point on a pole

On the lower part of the pole were placed the support point symbols (Figure 6). These consist of three symbols in a horizontal position, so that they appear in the orthogonal photos. They are clearly visible among the tombs. They occupy three different horizontal planes at 40cm from each other and at 30cm from the sighting-point symbols. The constant height difference between the support points allows direct linear transformation (DLT) to be carried out. This is a necessary operation since the digital camera used is not a metric camera of known parameters.

The positioning and alignment of the symbols for the aiming points and support points on the poles is a fundamental part of data collection, on which the success of the whole project largely depends. They must therefore be checked periodically for the correct distance and alignment. They should trace a vertical straight line parallel to the vertical axis of the pole on which they are placed in order to facilitate the mathematical calculation of the coordinates of all the symbols.

Photographs are then taken with a non-metric digital camera (Figure 7), after which the camera is calibrated by DLT. The relative and absolute orientation are then performed, followed by restitution by a digital restitutor.

Figure 7: Data collection at BHS 66

The aim of the project is to demonstrate the great advantages of photogrammetry as an archaeological mapping system. It is precise to within less than 1cm in the internal metric of the model represented. Thus, depending on the optimum parameters obtained, attempts will be made to demonstrate its usefulness in archaeology in the two proposed aspects: as high-precision metric documents and as a support for the publication of archaeological information.

PROJECT Nº 2: *Photogrammetric mapping of tomb nº 67 at the Jebel Buhais excavation site in the Al-Madam region (UAE), November 2004.*

The first results obtained from the methodology applied to BHS 66 involved a great deal of topographical work. The topographical sighting points were not clearly visible from the precision micro-grid stations and we had to be especially careful to check all the references from at least two stations before dismantling the pretargeting pole grid in order to carry out the subsequent photography.

The data collection at BHS 67 took place in the campaign of 2004. The objective was to create a generally applicable methodology, introducing changes in the design of the pretargeting of the support points and aiming points for the survey of the supporting topographical grid. The plates and crosses were replaced by 3mm diameter spheres (Figure 8), which were surveyed by tangential angular observation. The points composing the topographical grid could be seen and identified from the photogrammetric stations and could therefore be used as support points of known coordinates.

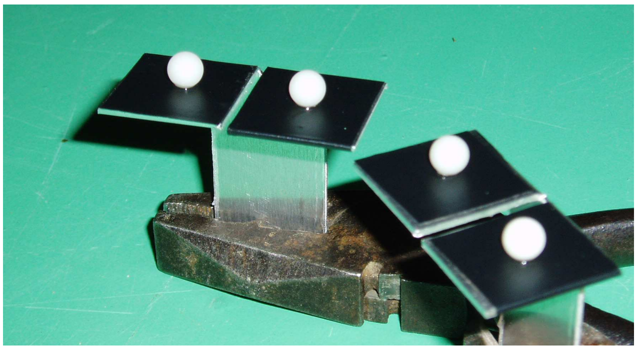

Figure 8: Sighting points for the topographical grid and pretargeting

The visibility of the pretargeting and topographical support points was considerably improved, which meant that a greater number of topographical observations from points within the principal grid became possible. All the spheres were identifiable by the number of the pole to which they were attached (1,2,3,4,5,.6,7 and 8) and by the height at which they were placed on the poles (A,B,C,D and E).

A topographical survey was also tested with a total station without prism and with topographical equipment accurate to a hundredth of a second (Wild T2). With this equipment experimental application is assured and will allow us to confirm the total suitability of distance measurement with electromagnetic equipment for obtaining metric results of the required precision.

PROJECT Nº 3: *Photogrammetric mapping of a burial site at the archaeological excavations at Al-Buhais 18, in the Al-Madam region (UEA)*[2]*, November 2004.*

With this project the objective was to simulate a photogrammetric mapping process while the excavation was taking place. The methodology proposes the possibility of obtaining 3D images without having to perform more than one photographic sequence and topographic survey, following a previously designed plan. By means of the pretargeting geometry we tried to define the minimum number of points to be surveyed in order to solve the problem of orientation of pairs with sufficient redundancy to ensure the stability of the model.

We wanted the topographic survey and the photographic sequence to be carried out by the members of the excavation team itself, following a small pre-project plan. The survey was carried out on the site known as *The Grave of five Skeletons* belonging to BHS 18 and contained human remains that dated from 5000 to 3000 BC.

5. PROCESSES IN THE DEVELOPMENT PHASE

The methodology chosen was digital photogrammetry. Human intervention occurred in certain processes where precision was not automatically assured.

Bearing in mind that the work sequence of digital photogrammetry. The process to be followed at the excavation sites will be the same as that which we have been utilising in making maps for civilian use. Automatic orientation techniques are employed for photograms (internal orientation), and aerotriangulation is performed by automatic correlation techniques. This aerotriangulation produces the external orientation of all the photograms The DTM is then calculated, using as a base the restitution of the break lines (water runoff channels, walls, roads). The interpolation grid is generated from correlation techniques of identical points.

The second phase is the generation of the orthophotomosaic of the area under study on the chosen scale. In the third phase the complete planimmetry is digitalised from the orthophotography in order to obtain the final topographical map. In the fourth and final phase the specialised map is obtained, for example, a land-use map from the digitalisation of the orthophotography. In our archaeological project we could have obtained maps of materials or other specialised maps of other variables of interest.

In this report we have described what we hoped to obtain from each of the selected archaeological examples, from the special characteristics of each of the projects and with data which could be used in general applications, both in the capture of photographic and topographic information and in its processing.

6. CONCLUSIONS

Our objective is to find the three-dimensional metric in methodologies for representing archaeological sites, either after the excavation (BHS 66 and BHS 67) for the transmission of data to museums and other scientific institutions, or while the excavation is actually taking place (burial site at BHS 18).

The hypothesis of the investigation is that aerial photogrammetry and all its latest technological advances are applicable to the generation of databases for making large-scale maps, especially in the field of 3D representation of archaeological sites.

We obtained the photogrammetric and topographic data necessary to calculate the coordinates of the photogrammetric pretargeting points and the topographic reference points supported by an external high-precision grid. With this data we were able to carry out the external and internal orientation of the pairs and proceed to restitution of the model or obtain other photogrammetric derivatives such as orthoimages.

The data redundancy allows us to select the simplest methodology and an appropriate process to permit the archaeological team itself to obtain the necessary documentation for 3D modelling with the minimum of help from photogrammetric specialists. The use of photogrammetry can thus become a reality in the day-to-day work at excavation sites and will be able to make a considerable contribution to metric representation and to the analysis of materials and outlines.

Our commitment is to reach these objectives from our laboratory in the University School of Technical Topographical Engineering at the Polytechnic University of Madrid, by studying results and standards of precision, applying as far as possible the automation of the various phases of the digital photogrammetric method to obtain 3D databases from the already proven methodology of cartographic data production in civil engineering works.

The information thus obtained will become a cartographic support for the cataloguing of objects and will be available for use by archaeological specialists in scientific archives. Its use will also be possible as a structural element in virtual applications in museum exhibits, as we have already achieved in the Archaeological Museum of Sharjah.

7. REFERENCES

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