APPLICATIONS OF NON-METRIC PHOTOGRAMMETRY IN ARCHAEOMETRY

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ABSTRACT

Advances made in the last decade or so into the restitution of non-metric photogrammetry have lead to the application of this technique to a variety of new measurement tasks. One area of interest that has seen an increase in the use of photogrammetric measurement techniques is archaeological mensuration. This paper illustrates applications of non-metric photogrammetry to the mapping of archaeological sites from kite-borne 35mm photography, stone tool analysis, craniology, analysis of chance photography and several other mapping projects. Camera calibration techniques are compared, and the manipulation of digital data is illustrated by an example of the reconstruction of a Bronze Age city using an Intergraph CAD-CAM instrument.

1. INTRODUCTION

Non-metric photogrammetry now needs little introduction to photogrammetrists, the principles and techniques have been in use for some time and are well established and documented. This paper presents nothing new on the calibration of conventional cameras, but merely illustrates the application of existing techniques in a specialised field of varied measurement tasks.

Archaeology has been defined as the study of 'mans' past by means of the material relics left behind (Bray and Trump 1982). As more and more importance is being placed on the history of the peoples and societies that comprise the world, the demands on these remains and their interpretation have increased dramatically. The increased demand, and even expectations, of the preservation and study of the cultural heritage of the world has led researchers in these fields to turn to other scientific disciplines for assistance. The metric analysis of these material remains has become known as 'archaeometry', and it is in this field that photogrammetry is finding increased application.

2. CAMERA CALIBRATION

There are two procedures for camera calibration in use at the University of Melbourne, a multi-station convergent bundle adjustment based on the collinearity principle (Earls 1981) and a self calibration program using a vector solution (Shortis 1980).

The bundle adjustment process is used mainly for the calibration of both metric and non-metric cameras using test range photography, and for high accuracy engineering measurement and monitoring. The program suite offers routines to optimise networks, a choice of error models to compensate for unknown orientation parameters and comprehensive statistical testing of results. In the context of this paper, it has been used to post calibrate cameras that have been used in situations where there has been insufficient or poorly distributed control to enable the self calibration of the camera.

The self calibration program offers a solution designed for stereo pairs, and is most useful for applications where medium order accuracies are required and the photogrammetric record is in the form of the familiar, easily interpreted stereo model. As the solution is capable of providing the internal and external orientation parameters as well as terrain coordinates of an object, sufficient dimensioned control must be provided and visible in the stereo model. This procedure is sometimes known as on-the-job calibration, although in this paper no distinction is made between this and self calibration.

3. APPLICATIONS

A selection of projects undertaken by the Department of Surveying, University of Melbourne will be used to illustrate some of the applications of non-metric photogrammetry in archaeometry. These are by no means exhaustive, but are presented to show that in many cases conventional cameras can provide results that would otherwise not be possible by using the available metric survey cameras.

3.1 El Qitar

El Qitar is the modern name for what appears to be a Middle to Late Bronze-Age fortified city on the west bank of the Euphrates River, about 130 road kilometres north east of Aleppo in Syria (Cullican and McClellan 1983). This site has been the subject of three seasons of excavations by the University of Melbourne, led by Dr. T. McClellan (Department of Middle Eastern Studies, now with the Oriental Institute, University of Chicago) and the late Mr. W. Cullican (Department of History).

The site itself is a natural rock outcrop about 700 metres long, 400 metres wide and 100 metres high, however there are two specific areas of interest, known as Area X and Area Y, and it is here that the excavation has been concentrated. These two areas show substantial surface architectural remains, and as part of the detailed archaeological investigation of the site it was necessary to prepare plans of these features. The conventional approach to this task offers two options, both based on substantial field survey. As it was desirous to map as many constructional elements within each wall as possible, in a limited field season a third option was sought, based on a combination of photogrammetry and field survey.

Civilian aerial photography is difficult to obtain in Syria, and would most likely have been of too small a scale to see the wall remains in detail. There are also prohibitions on the use of tethered balloons and remote controlled model aircraft, so it was decided to acquire large scale aerial photographs using a kite to elevate the camera. The kite used was a 'Jalbert Parafoil' self inflating sled, which has a high lift capability in moderate winds and is relatively stable once launched. The camera was a standard Olympus OM10 auto exposure, auto wind 35mm SLR fitted with a Tokina 28mm lens, without additional fiducial marks or a film flattening device (Figure 1). This camera was flown over both the main areas of interest and a variety of scales of overlapping photography were eventually obtained, along with experience in the unpredictable handling characteristics of a kite/camera system. (In fact the kite flights were an endless source of amusement for both the local workmen and Australians alike). The resulting photographic overlaps were considerably different from those usually encountered in aerial photogrammetry, but as the negatives were to be observed on a stereocomparator the geometry of the 'pairs' was not a major consideration. The picture quality varied greatly, mainly as a result of the movement of the camera caused by the turbulent air over the site, but by taking multiple exposures over the areas of interest fairly good photographs were available for most of the site (Figure 2).

3.1.1 Area X

The rock by rock plan of Area X was prepared from three aerial pairs of 35mm photographs. Ground control was provided by the three-hair stadia surveying technique, and based on the 1982 El Qitar Plan Grid (arbitrary datum, magnetic orientation). Stecometer observations were made to all significant rocks in each wall. Single point observations were made to the centres of small rocks, and connected strings were observed around the edge (at ground level) of large rocks. The resulting plan (Figure 3) was then infilled by the Archaeologist using enlarged photographic prints and the Aerotopo Sketchmaster, resulting in Figure 4, the published plan of Area X (Cullican and McClellan 1983).

Two data reduction programs were used to process the stecometer observations to ground coordinates. Initially the camera was unavailable for post calibration, so the self calibration vector solution was used. This resulted in a coordinate accuracy of approximately 0.13m in plan and 0.08m in height, quite adequate for the preparation of the maps. Later, when the camera had been returned to Melbourne, a test range calibration was undertaken more to verify the results than to improve on them. The data were reprocessed using the new calibration parameters, and the results compared. The accuracies of the final coordinates from the post calibration were virtually identical to those obtained from the self calibration solution, and comparable to that possible with three-hair stadia. These accuracies were quite acceptable to the archaeologist, which after all was the overall aim of the exercise.

3.1.2 Area Y

The major part of the Area Y plan was produced on site using optically rectified photo-enlargements. This process was similar in concept to the final drafting of the Area X plan, but generally there were substantially less known ground points. Enlargements of many of the photographs taken over the seasons were taken into the field, and prominent features, rocks or targets were identified on the photographs and coordinates using E.D.M. radiation tacheometry. The 'photo-idents' were then computed and manually plotted at a scale of 1:100 onto graph paper covered in 'mylar' film. A crude camera lucida was built from a pottery drawing cradle, timber, and the prism arm and lenses from a Sketchmaster (which in the complete form was too heavy and bulky to transport to Syria). The photo-enlargements with the control identification marked were then mounted on the Sketchmaster, and each strip of wall was rectified onto the appropriate control points and traced onto the drawing film. If difficulty was encountered when comparing detail plotted from different photographs, or when joining mapsheets, extra control was provided where necessary and/or other photographs chosen for rectification.

The resultant plan of Area Y along with that of Area X, has been found to be most satisfactory. In the case of the Area X plan the final level of detail was decided by the archaeologist, who was responsible for the infil detail and the selection of which rocks to include or ignore. In the case of the Area Y plan, the level of detail was decided by the surveyor, after on site evaluation and consultation with the archaeologist.

3.2 Anthropometry

The application of photogrammetry to the measurement of the human form is well documented and established, and has been responsible for the development of some of the non-metric techniques generally in use today (Coblenz and Herron 1978, Herron and Karara 1974). The measurement of the human form is an important research tool in anthropology, and the measurement of crania provides valuable information for the study of evolutionary pattern and development. Is it possible to obtain some of the craniometric data from the measurement of photographs when the skull itself is not available?

A problem arose recently where is become necessary to record a large collection of skeletal remains in a very short time. Given the rigid time constraint it appeared that a stereo photogrammetric record could provide an adequate dimensional record of the crania. The most suitable metric camera available was a Zeiss Obercochen SMK-40, however it was not possible to acquire the extra four to five hundred glass plates needed if this camera was to be used. This seemed to leave only one choice of photogrammetric technique, that of a non-metric camera solution.

Two 500ELM model Hasselblad cameras with 120mm T* series macro-lenses were mounted on a rigid base bar and located so that the cranium and control occupied the entire field of view. Both 80mm and 50mm focal length lenses were tried initially, and were found suitable for the photogrammetry, but these lenses were rejected by the Anatomist because of the resultant picture scale. It was necessary to have one camera directly in front of the cranium so that the photograph would resemble a familiar view for anatomical interpretation, not quite the ideal location for the photogrammetry but unavoidable. Four 800 watt portable floodlights were arranged to give even shadowless lighting, but two of the lamps needed to be raised and lowered between views to avoid

Figure 1: The kite and camera used to photograph El Qitar

Figure 2: An example of the kite Photography of Area X

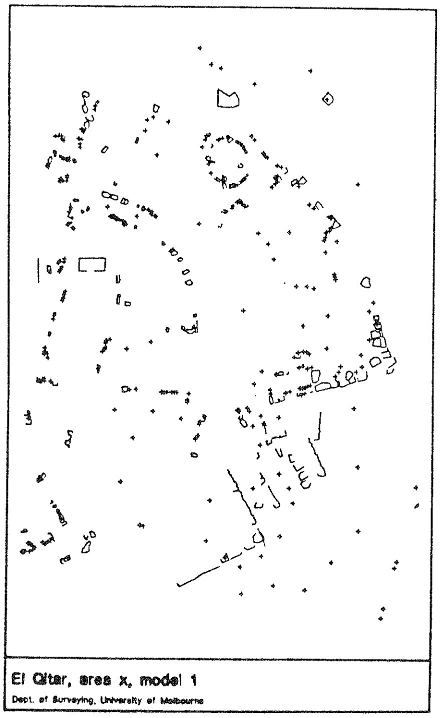

Figure 3: The HP7580 plot of Area X at El Qitar

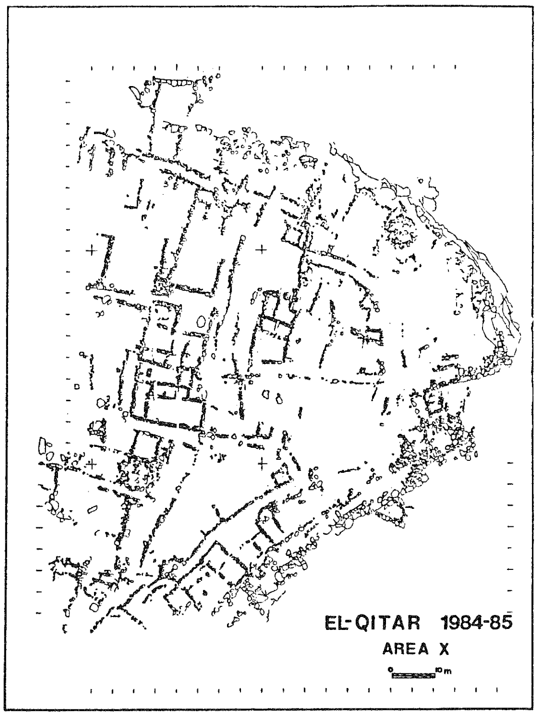

Figure 4: The final plan, Area X

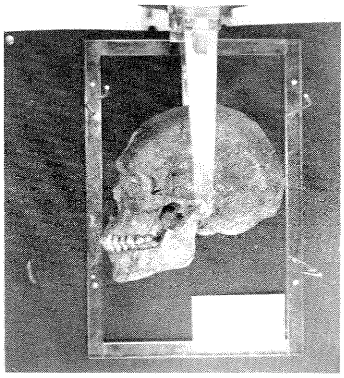

Figure 5: An example of the cranium photography

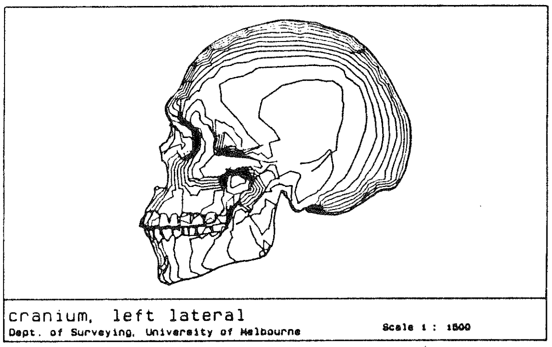

Figure 6: The digital surface of the left lateral

reflection from the perspex cephalastat used to support the specimens. A 35mm camera was also used to acquire colour transparencies of each cranium view as well. Each cranium was suspended by the auditory meatii in a cephalastat mounted above a safety net. Six standard views of each skull were taken sequentially, consisting of the frontal, left lateral, right lateral, basal and superior views along with the mandible. Figure 5 gives an example of the photography.

Control for the pairs of photographs consisted of four protruding rods located as close as possible to the cranium, but so as to not interfere with the lighting or rotation of the specimen between views. The rods were mounted on a perspex frame, affixed to the wall behind the cephalast. The frame, mounting screws and rods were given coordinates derived from a least squares adjustment of all the distances measured between all points, the accuracies between around 0.5mm in X, Y and Z.

3.2.1 Craniometry

Having acquired the photography of the crania it was then necessary to determine whether the conventional cranial measurements could be derived from stereoscopic measurement of the images.

One series of negatives was selected to be measured on the Stecometer and computed through the self calibration, vector solution to obtain distances between some of the cranial landmarks. The points chosen were by no means exhaustive (Ashley Montague 1960, Brothwell 1963, Brown 1973), but are typical of the datum points referred to in craniometry. Observations were also made to enable the production of a digital surface model for display purposes (Figure 6). Only one skull has been measured photogrammetrically at this stage, more to prove that the technique is viable than to supply dimensions to an anthropologist.

Some of the distances calculated between the points of reference were then compared with those kindly supplied and measured by an anthropologist from another University. These measurements were obtained some time before the photogrammetric project, and are shown along with their computed differences and percentage errors for several runs of the program in Table 1.

The differences between the photogrammetric distances and those measured directly on the skull are explained not only by possible variations in the self calibration of the cameras, but also other factors that influence the selection of the points in the photogrammetric model. Observations were made by the Stecometer operator to the standard points as suggested by the diagram shown in Brown 1973, but the operator had not had any other experience working with skeletal material. Ideally an anthropologist should work in conjunction with the operator during the observation of the photographs to assist in the location of the reference points. Unfortunately, this was not possible during the observation of the skull. Recognition of the reference point is half of the problem, locating this in the photograph is another. Points like the Zygion (the extremes of the cheek bones) are easily identified and measured between using the calipers, but not quite so on the photographs. These points are untargetted, and in the frontal view are not really imaged on the negative; they are located where the depth viewing direction is tangential to a curved bone surface. Measurements can be made with some accuracy in the terrain X and Y dimension, but the Z dimension is subject to some uncertainty. With photographs of this large scale, this pointing error can reduce the coordinate accuracy. Although the photogrammetrically determined distances can vary by several millimetres from the 'true' distances, even these estimates would not have been available for many of the crania if the project had not been undertaken.

3.3 Microlith Analysis

In an environment where organic materials decay rapidly, or when dealing with a site of an age such that organic materials have long since decayed, stone artefacts are often the only remains left to the archaeologist to discover. This is a common situation in Australia where prehistoric sites of habitation or occupation can go back as far as 40,000 years. Stone tool analysis has become an important research discipline in the study of Aboriginal prehistory. The measured features of stone tools vary with the archaeologist and the theory under validation, but generally consist of the shape, butt cross-section, maximum length, maximum width, maximum thickness, weight, facet angles, and butt thickness. Qualitative analysis of lithics also includes a material description, break type, striking platform description, edge wear analysis and often a standard typological classification. Conventionally this data is acquired by laborious manual measurement, often in a laboratory environment, using excavated material.

Prompted by a presentation at a conference on the problems of the measurement and classification of stone artefacts and debitage on a site where there was a strict field time limit, and prohibitions on the removal of material, it was decided to attempt to derive some of the metric features from stereo-macro photography.

A stone tool of unknown origin was photographed using a Minolta XD7 camera coupled to a set of extension bellow and 50mm lens, resulting in an image scale close to 1:1. Once again, this photography was observed in stereo on the Stecometer and processed through the self calibration program to obtain 'terrain coordinates'. Control was provided by a specially constructed aluminium tool carrier, with distances between marked points being measured by a dial caliper and computer through a three dimensional variation of coordinates least squares adjustment.

The resultant coordinates were processed through a digital terrain modelling program suite to compute a volume and to derive a contour plot for display purposes. Significant stone tools are usually fair drawn for publication so it seems logical to compare the contour plots with this method on the grounds of shape depiction only. (Fair drawing can better represent the surface texture and features, although this data can be observed easily on a photograph). A contour/string plot (Figure 7) shows the form of the tool clearly, especially the retouch and wear along the edge. However at this stage, there has been no indication from an archaeologist as to whether this is acceptable or otherwise.

It is not being suggested here that photogrammetric measurement of stone tools be used on a routine basis, but in specific cases where the artefact is complex or unique, or where the field environment demands expediency, the photogrammetric record can supply much of the metric data required, as well as an indication of edge wear, typology and fabrication techniques.

3.4 Chance Photography

At El Qitar a lucky coincidence of correct timing, a light snow fall and sunlight combined to reveal the outline of a structure that previously had been almost completely invisible. Apart from being an excellent illustration of the principles of remote sensing, this offered an opportunity to record some previously undisclosed architecture without excavation. A 'snapshot' of the scene was taken with a hand held camera while the wall lines were visible (Figure 8) and within five minutes of the photograph being taken the snow had completely melted and the building outline had faded into obscurity. On observation it was found that four control points placed in anticipation of continual kite wind (which did not eventuate) were just visible in the colour transparency, so a digital rectification was performed onto these points. The slide was projected onto a graphics digitizing tablet, the control was recorded and strings along the building outline were observed. The data file was then processed through a bilinear rectification program and plotted on the HP7580 plotter. After slight cartographic enhancement, mainly as a result of the difficulty in actually intersecting walls and identifying features on the oblique image, the plan shown in Figure 9 was produced.

This plan is of limited accuracy, but nevertheless impressed the archaeologist who immediately recognized architectural parallels with several other buildings on the site. The acceptance of accuracies by other researchers that would normally be avoided by photogrammetrists means that a lot of metric data can be extracted from single non-metric photographs, opening up possibilities for the perspective analysis of historical photography of monuments and artefacts that no longer exist.

3.5 Building 10, El Qitar

A wooden bipod, built to a design similar to that used by Flemming (1976), was used to acquire near vertical photography of the excavated areas at El Qitar. Selected pairs of Building 10 were mounted in a Zeiss Jena Topocart stereoplotter, and treated as if the photography was from a metric survey camera. The models were oriented to within about 0.75 dot of residual parallax, and then scaled and levelled onto the trench corner pegs. Six pairs of photographs were plotted to a scale of 1:25, and generally the models joined to within cartographic tolerances. The plan has been verified in the field during subsequent visits to El Qitar and found to be most satisfactory (Figure 10).

Various other monuments have been plotted by assuming the Hasselblad photography to be metric, including a carved Roman tomb and examples of Australian colonial architecture. In most of the projects undertaken, a measured drawing was the desired product. Although the precision of the data obtained by the metric treatment of this non-metric photography is not as high as that possible with an analytical solution, in all cases here the plan was readily accepted. In the case of the Roman tomb, limitations in the surface modelling routine meant that the plan produced from the digital data was in fact not a true representation of the surface, the Topocart plot was much closer to the truth.

3.6 The Manipulation of Digital Data

The preparation of plans for publication is one of the main requirements of most archaeological investigations, the supply of data in digital form (apart from statistical information) is uncommon. In the case of some of these investigations the existence of digital data allowed the use of rather advanced methods of display and manipulation.

3.6.1 El Qitar

After substantial data editing, both graphical and computer assisted, a three dimensional model of El Qitar and the surface architecture was created on an Intergraph CAD-CAM system. The Intergraph enables the model of El Qitar to be viewed from a multitude of view points, enables different elements to be displayed at will, and facilitates the reconstruction of the architectural features. The wall rocks were generalized into block features, and then later generalized again into building complexes. Software was developed to generate surfaces automatically from the blocked wall data to a given height above the highest point on the wall, thus creating solid walls to a horizontal plane. The line images created could then be surfaced to give a 'roof off' view of all the rooms in any given location. The software-generated walls could also be edited and enhanced to give an image more typical of a Bronze Age city. Building 10, the presumed temple, has been 'reconstructed' in a style typical of similar buildings from the same era, wholly within the computer. Figure 11 shows some perspective views of the temple, and Figure 12 illustrates how the Intergraph can provide base drawings for an artistic interpretation more suitable for publication.

3.6.2 Projective Transformation

The existence of graphical data in digital form also facilitates the transformation of these data from one reference system to another. The recording of rock paintings and engravings by photogrammetry often involves the projection of the rock surface onto the plane of the photograph, which can introduce distortions into the shape of motifs. If the photogrammetric record is digitised, the resultant coordinate strings can be transformed onto a surface that more closely represents the shape of the original. A pair of Hasselblad photographs taken on a field expedition to the Cape York Region of Australia was observed on the Stecometer, reduced to terrain coordinates and then projected onto a cylindrical surface with approximately the same dimensions as the original rock face. The initial photogrammetric plot (Figure 13) shows the figure distorted as a result of

Skull Measurement	Landmark Abbrev.	Frontal	Left Lateral	Right Lateral	Brown (UNE, 1984)	% Error
Bizygomatic Breadth	Zg-Zg	119.8			123	-2.6
Morphological Facial H.	n-Gn	118.3	117.0	115.0		
Bigonal Breadth	Go-Go	93.5			92	+1.6
Mandibular Body Length	Gn-Go	L 87.6 R 93.7				
Anterior Nasal Height	n-Sp	50.2				
Orbital Height, Right		33.8				
Orbital Height, Left		32.1			31	+3.5
Orbital Breadth, Right		40.1				
Orbital Breadth, Left		42.5			42	+1.0
Nasal Breadth		27.0			28	-3.6
Upper Facial Height		74.9				
Symphyseal Height		33.3			36	-7.5
Total Mandibular Body L	Gn-Cd		114.8		112	
Maximum Cranial Length	g-Op		183.4	182.2	187	L-1.9 R-2.6

Table 1: Craniometric Dimensions

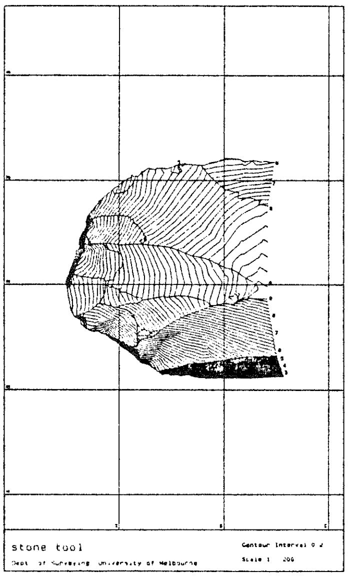

Figure 7: Stone tool

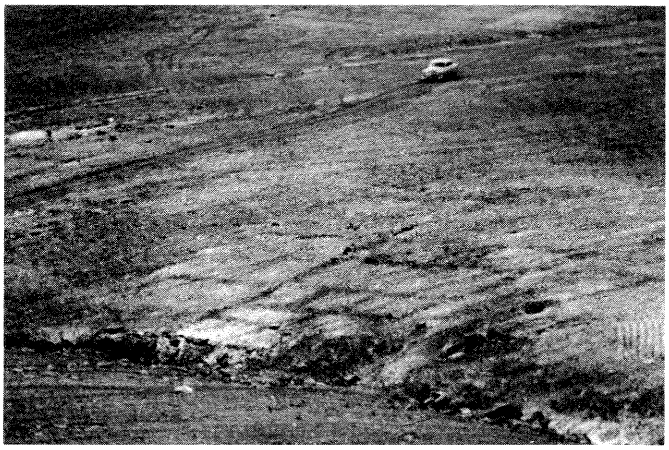

Figure 8: Building made visible by melting snow

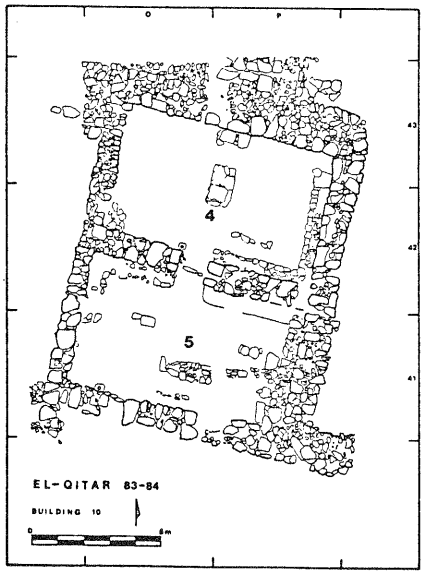

Figure 10: Building 10

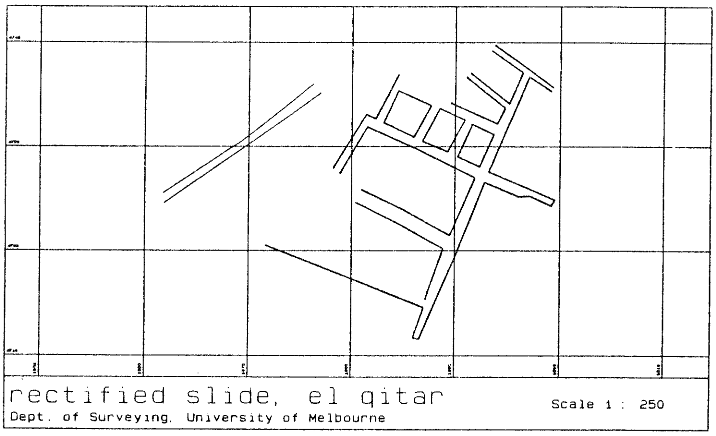

Figure 9: Plan of underground building

it being on a curved surface at an angle to the plane of the photograph. The transformed motif (Figure 14) more closely represents the motif as if it was viewed on the rock surface. Although the projection of a plane onto a cylinder is a relatively simple transformation, it illustrates another advantage of digital data, often the result of the reduction of observations to non-metric photographs.

4. CONCLUSION

This paper has shown a few of the many potential applications of non-metric photogrammetry in archaeology. The release of photogrammetry from the constraints of a metric camera provides a flexible and accurate method of measuring and delineating cultural monuments and artefacts. The technique is being accepted by many archaeologists as a workable solution to mensuration problems, which can only extend the applications even further.

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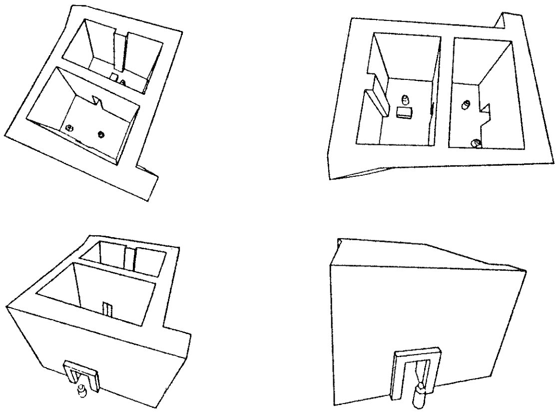

Figure 11: Prespectives of Building 10

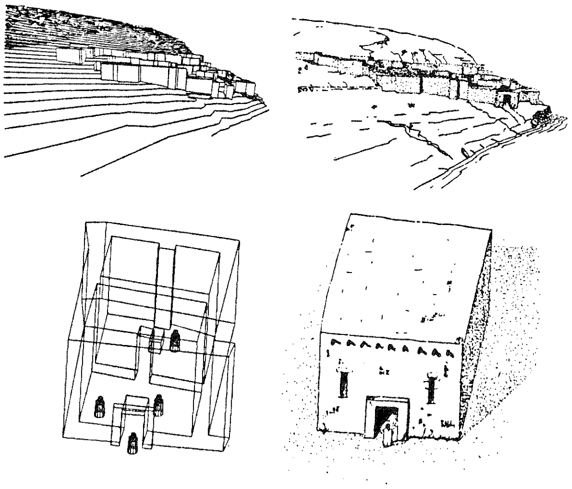

Figure 12: Enhanced views of El Qitar buildings

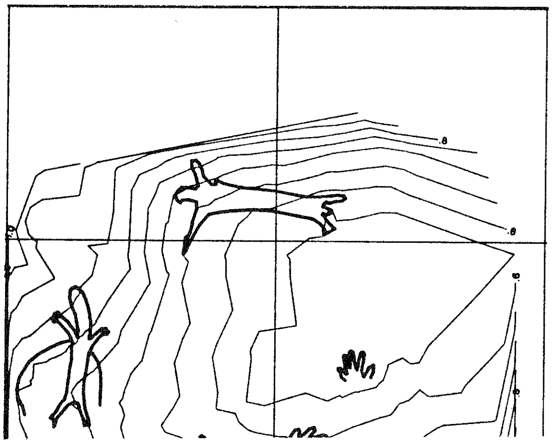

Figure 13: Motif before re-projection

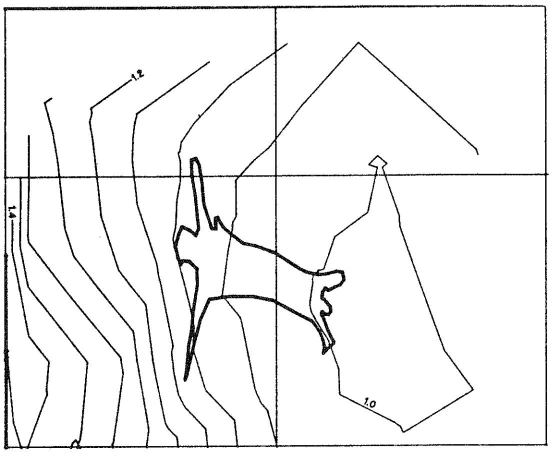

Figure 14: Transformed motif