AN INVESTIGATION OF ARCHITECTURAL AND ARCHAEOLOGICAL TASKS INVOLVING DIGITAL TERRESTRIAL PHOTOGRAMMETRY

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Abstract: Surveying and structural engineers, archaeologists and architects need precise information. Close range digital photogrammetric techniques provide the means to do exactly that, particularly with respect to the spatial information, by allowing 3-D coordinates of photographed features to be accurately gathered, with a precision of about 0.4cm, and archived in an information system. This greatly enhances the flexibility of data usage, allowing it to be translated and interpreted in many different forms, including output as drawings or as 3-D CAD models.
Geographical Information System (GIS) represent a highly relevant branch of information technology. GIS support the import of geospatial data from a variety of sources, including imagery. An appropriate environment for providing the spatial information needed by architects working with historic buildings and archaeologists might be soft-copy photogrammetry coupled with, or linked to, GIS, forming an Archaeological/Architectural Information System (A/AIS).
The practical methodology for using digital terrestrial photogrammetry in sites of archaeological and architectural interest depends on the location, position, shape, size, dimension, accuracy and location of the object. More specifically guidelines have emerged from the author's investigations in the presented project, the Hunter Memorial (located at the University of Glasgow) survey was with a digital camera.

Key Words: AutoCAD-A/AIS-GIS-Digital-Photogrammetry-Imagery-Technology.

1 Introduction

This study is to investigate the feasibility of developing an Archaeology/Architectural Information System (A/AIS) based on a fusion of Digital Photogrammetry, CAD and GIS. Although a great variety of real world objects (e.g. cars, bridges, human heads, etc.) could be described within such a system, the focus of this work is on buildings/structures. A/AIS Procedures, which parallel or mimic those currently, used by experienced practitioners are likely to be most effective. Figure 1 shows the proposed a flowchart of A/AIS.

While the general aim of this task will be met through investigating appropriate projects and relevant full or partial A/AIS implementations, this process can contribute to Geomatics in general if two particular objectives are achieved, namely:

- to create digital models of cultural objects capable of supporting analysis in the chosen environment; and,
- to specify the data content of digital images required for such models.

In this paper there follows an investigation of a survey project in the archaeological and architectural (or cultural) domain that was addressed in recent years. This technological solution involved the use of hardcopy photogrammetry and CAD, as well as terrestrial photography, in projects carried out by historical buildings of Glasgow University. This is in order to ensure, for example, that a system based on digital photogrammetry data capture in a GIS adequately meets the requirements of the 'cultural' domain, at least with respect to the photogrammetry survey of Hunter Memorial successfully completed.

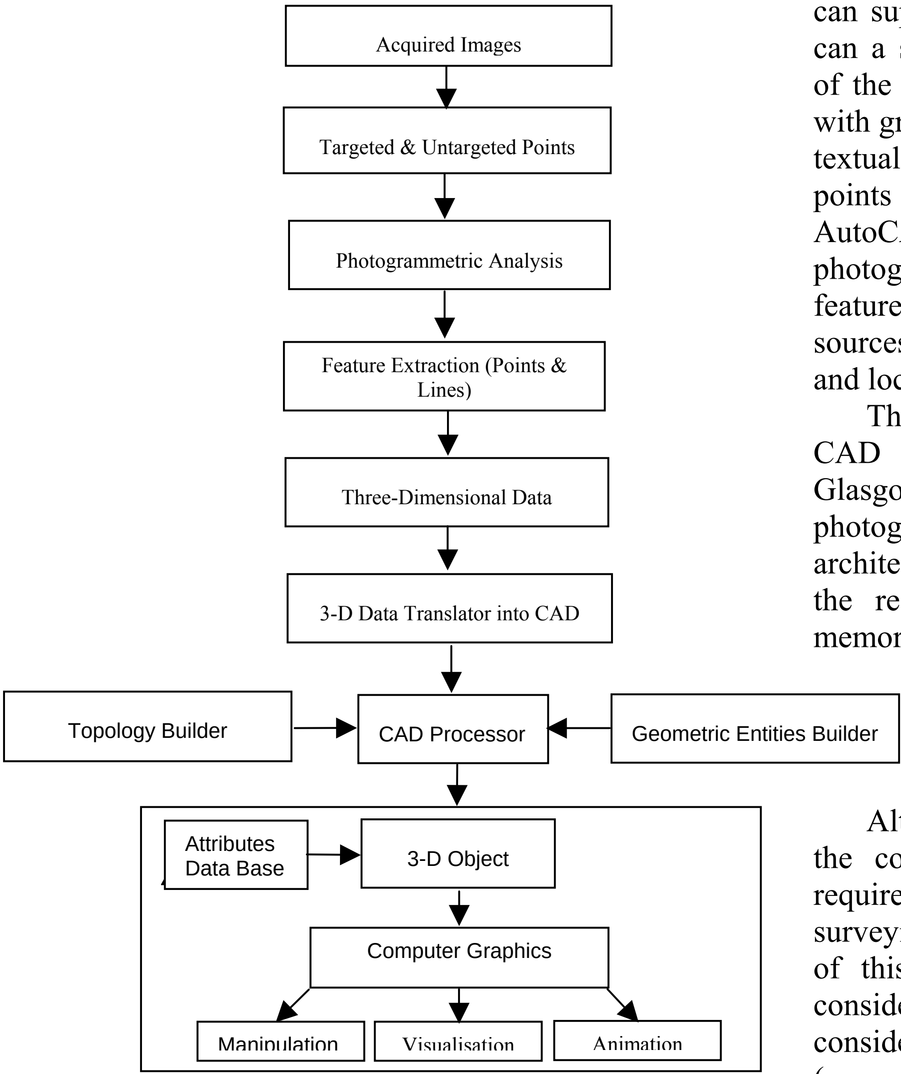

Fig. 1. An Overview of Archaeological and Architectural Information System

2 The Photogrammetric Survey

The successful modelling of a cultural object implies that reconstructing the whole object becomes achievable. Digital photogrammetry techniques and digital facet modelling (involving representation of the object by facets instead of lines) combine the integration of the geometric and the pictorial characteristics of a building. Additional information is accessible through the "hot-linking" or equivalent facilities.

Unlike standard GIS with its restriction to 2-D, CAD systems offer 3-D modelling capabilities [7]. [7] have advocated that a CAD system like AutoCAD is simpler than using a GIS environment in the architectural context. AutoCAD employed for architectural and archaeological purposes can supports direct database access, just as can a standard GIS package. The elements of the relational database can be integrated with graphical entities like raster images and textual information. The output of digitised points can be supplied directly into AutoCAD. By using digital terrestrial photogrammetry the existing architectural features can be modelled, whereas other data sources are required to model the size, shape and location of missing features.

This investigation involved creating a CAD model the Hunter Memorial, Glasgow University, using digital photogrammetry, the reconstruction of architectural elements in the computer and the recording of other attributes of the memorial.

Although some tape measurements of the components of this monument were required to make an accurate model (land surveying is an important part of any project of this type), the accuracy obtained, by considering other check distances, was considerably in excess of requirements (suggested RMSE 0.40 cm; obtained RMSE 0.28 cm). Figure 2 shows the North Front view of Hunter Memorial. A few dimensions (tape measurements) are added to this figure.

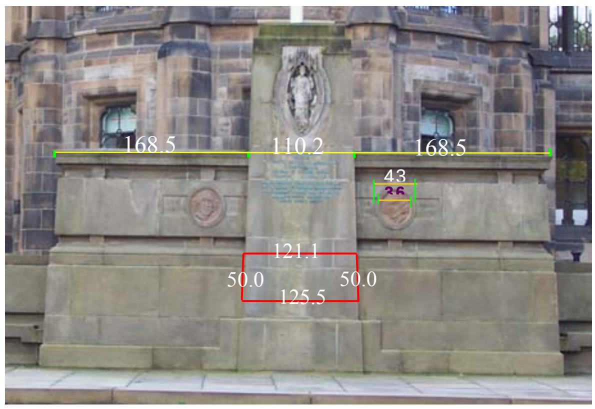

Fig. 2 The North Front View of Hunter Memorial (Scale 1:50)

The Hunter Memorial designed in 1925 by J. J. Burnet (Architect) with the collaboration of G. H. Paulin, (Sculptor). Portrait Medallions of the Hunter brothers can be found on the North Front view of the monument. William and John Hunter made names for themselves as anatomists [6].

2.1 Data Acquisition

For the 3-D model of the Hunter Memorial, the most significant features were acquired from terrestrial photographs using a digital camera. It is important to carefully select the images to be used, because, in the approach chosen here only a small number of images can be processed. Furthermore, the usefulness for reconstruction of some objects depends on the orientation of the image relative to that object.

The camera used to obtain digital images was a Kodak DC4800 digital camera. The DC4800 is not an expensive camera, but the use of this camera offered a variety of resolutions for digital images. The specifications of this camera are:

1. 3.3 megapixels resolution CCD delivering up to 2160 x 1440 pixel images.
2. 1.8-inch LCD monitor and real image optical viewfinder.
3. 3x zoom, 6.8 to 18.0 mm lens (equivalent to a 28 to 84 mm on a 35 mm camera).
4. 2x digital zoom, power zoom with two driving speeds from 16 to 1/1000 seconds.
5. Aperture options of f/2.8, f/5.6 and f/8.
6. Image capture with JPEG and uncompressed TIFF file formats.

The photogrammetric system used was designed for the purpose of creating the basic 3-D models needed for monument documentation and computer reconstruction, within a potential A/AIS. Also the photography was used for the documentation of the façades, to direct the architects to adequately identify the conservation needs of the monument. This was done using approximately 1:50 scale photography for all the architectural features. This integrated all stonework, Portrait Medallions, columns, inscriptions, epigraphs, etc. including visible damage, e.g. cracked stones and mortar leaching. The survey was executed using digital photography taken around the object.

In multiple photo projects, each point or feature that is to be modelled should be visible on two or more photos. For this reason, the positions of the photographs need to be thought out. Thus, it is necessary to plan the photography and measurements of an object before data capture.

Nineteen digital photographs supported the Hunter Memorial project. This rather low number arises became nearly all of the architectural features are symmetrical. All photographs were hand held (no tripod was used), but the camera axes were almost horizontal and nearly perpendicular to the monument at all exposures, unless they were oblique when the photographs were taken of the top view of the monument, from a nearby window.

2.2 Data Input

Probably this was the first time that Hunter Memorial provided data via the PhotoModeler Program (PMP). The data were extracted from PMP and used in AutoCAD for the further processes towards creating the A/AIS. The PMP procedures interactively construct the geometric base for the A/AIS. Figure 3 shows the procedures in PMP and AutoCAD. It should be noted that many cultural objects are symmetrical and the same procedure can be used to reconstruct, e.g. the west part from the east one, by lateral inversion. Using systems such as those supporting CAD tools allows architects to model missing parts e.g. of one end the building and copy the appropriate part to the other end.

2.3 Processing

In moving from traditional surface reconstruction to automated systems, in which the human operator is the quality controller and editing manager, requires efficient interaction with 3-D data close to the specific application situation. The requirements of modelling terrestrial objects all point towards an increased use of automated processes to model the surface geometry and tools to determine nongeometric properties. For example, computer graphics and computer vision processes.

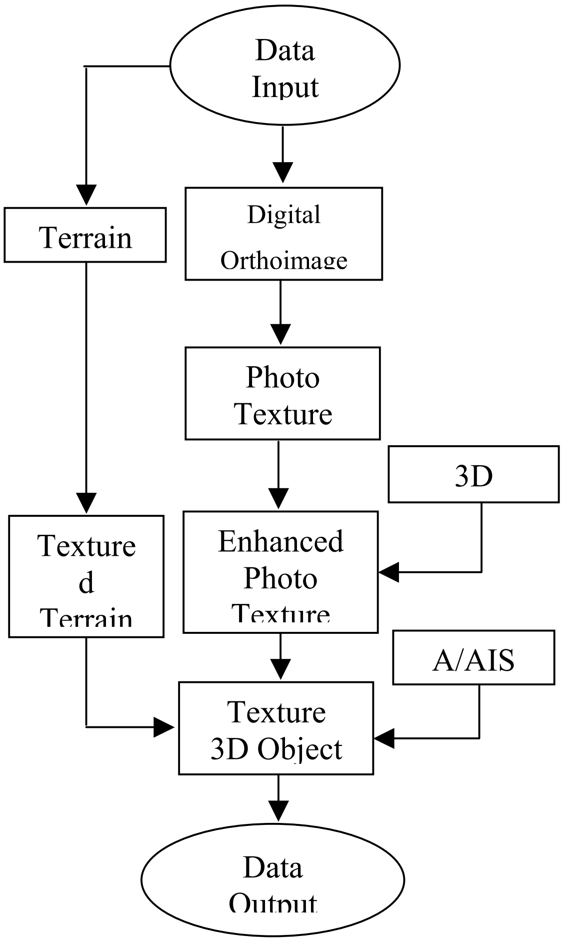

Fig. 3. A Scheme of Procedures for Developing A/AIS

Computer graphics calculates images from model descriptions, computer vision deals with the inverse process: the modelling of the object from images (for example, when presenting the results of a photogrammetric process or when rendering DTM data). If these processes are available close to the application site a computer model can be quickly generated to ensure adequate data capture.

Processing the photographs was achieved with PMP and the creation of 3-D models starts with the connection of 3-D points, edges, curves and cylinders. There are eight steps in creating a 3-D model with PMP:

1. Create a calibrated camera report;
2. Plan the measurement of the object;
3. Capture photographs of the object;
4. Import the captured photographs into the PMP;
5. "Mark" features on the photographs, which will be 3-D points (control points, tie points and feature points);
6. Match 3-D points on the various photographs;
7. Data processing; and
8. Export the result of 3-D data to a CAD program.

As explained, any processing starts with camera calibration. In the Hunter Memorial project an approximate calibration for the DC4800 camera was used. After the camera calibration, the locations of features on each photograph were prepared.

To "*mark*" a point in multiple photographs indicates that a point can be determined in 3-D. When a point or a line is marked in several photographs, it is essential to insure (for PMP) that these are exactly the same points and lines. In the PMP documentation, a process called "*referencing*" identifies the points on one photograph of a feature as being conjugate to the points on the other photograph of the same feature. The PMP uses the "*marked*" photographs to create 3-D models through an interactive iterative process determining the location of points, and edges, in 3-D space.

After identifying and marking at least 3 points manually with the cursor (three points gives six equations, enough to solve for the camera orientation), the rest of the point identification is done automatically. Then a transformation of each point back into the image space is done, and the closest target in the image is chosen as the corresponding point.

The amount of processing time depends on the number of photographs and the number of marked points. The four best photographs were correlated to create 3-D objects in this project. More than four photographs in an adjustment are prohibited in the interests of getting a good result in a reasonable time [4]. Figure 4 illustrates four chosen photographs applied in this project in one adjustment.

A method to ascertain the accuracy of a project is to use "*checking distances*" (i.e.

check distances). Checking distances are compared with measurements for several items in a scene, obtained from the PMP. In this project, tape measured checking distances of several features were used. The results from the “checking distances” are given in Table 1.

Of course, with the quality of x, y or z coordinates as much as distances will be concerned. Given a distance is obtained from two sets of triplets (x, y, z coordinates), then, assuming that RMSE of 0.7cm (see Table 1) has the same numerical value as standard deviation and that the error in x, y and z is the same, then error theory (propagation of variance) presents us with estimated coordinates standard deviation of $\sigma x = \sigma y = \sigma z = 0.28$ cm. This meets the accuracy requirements being sought of 0.41cm.

Table 1. Checking Distances

Ground (mm)	Model (mm)	Discrepancy (mm)
3715	3708	7
1415	1421	6
835	831	4
935	941	6
859	865	6
5185	5198	13
RMSE		**7**
Maximum Discrepancy		**13**

2.4 Product Accuracy

For a scale of 1:50, RMSE is less than10mm using some points in Table 1 as checkpoints.

2.5 Mathematical Considerations

Some surface interpolating techniques do not fix the values of control points. Consequently, local characteristics may strongly influence the entire surface. Bézier and B-Spline mathematics use control points to define the shape of the surface, but only the B-Spline approach has the power of local shape control.

The B-Spline approach is used in PMP. An advantage of using the B-Spline approach is the possibility of controlling the polynomial degree of the blending functions, independently of the number of control points.

Fig. 4. Four Photographs Used for Processing in Hunter Memorial Project

2.6 CAD Layers

The CAD software of Intergarph Microstation (Bentley) was used in this investigation, where the detailed 3-D surface model of a part of the Gilbert Scott Building was constructed within Intergraph Microstation’s CAD software, using 3-D coordinates derived from digital photogrammetry (Socet Set). The following tasks have been investigated:

- A computer graphics 3-D representation of a window bay has been created.
- Texture from images acquired on the site has been acquired.
- Ray traced and rendered images have been created.
- The information has been managed in a GIS environment.
- The derived data points have been checked within the 3-D visualisation environment provided by AutoCAD and PhotoModeler.
- A textured surface model of a window bay has been fitted to the data.
- All photographs were imported into a directory (Windows folder) and then examined to eliminate the poor photographs and also checked to ensure the required coverage of all sides of the object was achieved.

2.7 Visualisation

The rendered images were generated using the appropriate functions in the AutoCAD package and PhotoModeler software. The visualisation process undertaken in this investigation consisted of producing orthoimage rendered façades of the Hunter Memorial.

2.8 Linking of Hunter Memorial Project

Common formats (e.g. DXF and Text files) are used to connect and integrate different programs; thereby Object Linking and Embedding (OLE) can be achieved. DXF and Text file formats support Running External Program (REP) for an embedded link between different programs, for example between AutoCAD and ArcView, SOCET SET, PhotoModeler and Excel.

Thus an object created by AutoCAD can be used as an OLE object. A destination application creates the compound document that accepts OLE objects created with the program. The OLE links to one or more complex documents and exports the information to other applications. The AutoCAD REP facility can also be used to access more complex/specialised information, such as documents, texts, diagrams, photos, etc. Many other CAD and rendering packages can import text, diagrams, digital photos and DXF data files for more detailed measurements in A/AIS applications.

Figure 5 shows a result of the A/AIS, a digital facet model of a component of the Hunter Memorial. The OLE capability can export the created surface model from AutoCAD for further processing. For example, the orthoimage and digital facet model can be used for more detailed measurements in the SOCET SET and PhotoModeler programs.

The author has determined export files in the formats DWF, JPEG and 3DS can also be exported to the Web (in HTML file format) for downloading and regenerating images by others for future purposes. Figure 6 gives a result of integration between digital terrestrial photogrammetry (extracted PMP from PhotoModeler program) and AutoCAD software in the form of wire-frame model.

In this development, 3-D polylines are created and a part of this (as a sample) is presented in Table 2. All vertices can be examined as a script file, available in AutoCAD for further processing. The file may also be stored as documentation of this cultural object.

Fig. 5. A Digital Facet Model of Hunter Memorial Exported into AutoCAD

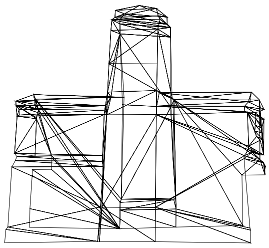

Fig. 6. A Wire-frame Model of the Hunter Memorial, from PMP

2.9 Digital Facet Modelling

To visualize an architectural object, a geometrically correct description of the object's surface is needed. In this Hunter Memorial case a TIN was preferred because no more interpolation was required for further processing. A TIN representing the object's surface was created from registered data points fitting the original data exactly. Figure 7 shows the TIN for the cap of the middle column of the Hunter Memorial façade.

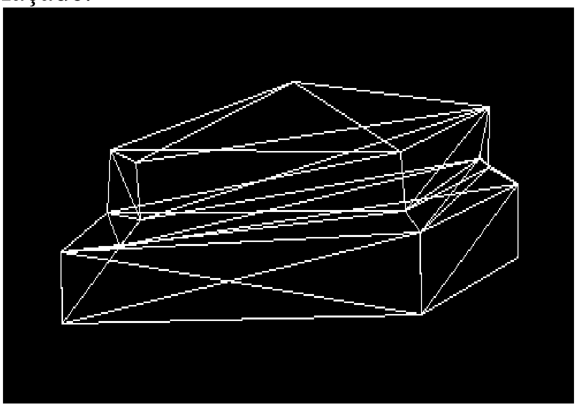

Fig. 7. A TIN of the Cap of the Hunter Memorial

Table 2. Reported File of the 3-D Polyline for Facet Modelling

Polyline Layer:"0"
Space: Model space
Handle = 437
Closed space
First 3 points did not define a plane.
No area calculated.

VERTEX Layer: "0"
Space: Model space
Handle = 438
Space at point, X= 10.18 Y= 12.08 Z= -459.62

VERTEX Layer: "0"
Space: Model space
Handle = 439
Space at point, X= 10.18 Y= 12.08 Z= -459.62

VERTEX Layer: "0"
Space: Model space
Press ENTER to continue:
Handle = 43a
Space at point, X= 10.18 Y= 12.08 Z= -459.62

END SEQUENCE Layer: "0"
Space: Model space
Handle=43b

POLYLINE Layer: "DEFAULT"
Space: Model space
Colour: 7 (white) Linetype: "BYLAYER"
Handle = 2a2
Polyface mesh

VERTEX Layer: "DEFAULT"
Space: Model space
Color: 7 (white) Linetype: "BYLAYER"
Handle = 2a3
Polyface vertex at point, X= 31.56 Y= -25.88 Z= -391.73

2.10 Rendering

Computer Graphics deals with the pictorial synthesis of real or imaginary objects from their computer based models [5] and ranges from rendering and image generation through scientific visualization to graphic illustrations for documents. Modern graphics hardware supports many techniques and algorithms for realistic image synthesis and opens the way to a wide range of applications.

Rendering offers a technique for the visualization of digital facet models. To improve the impression of the surface model one can change the direction of illumination. Figure 8 shows the rendering of the cap of the middle column of the memorial. PMP can also export the camera station for those programs that support rendering. This is to identify where the camera is placed. Thus, the user can also view a rendered model from that camera position.

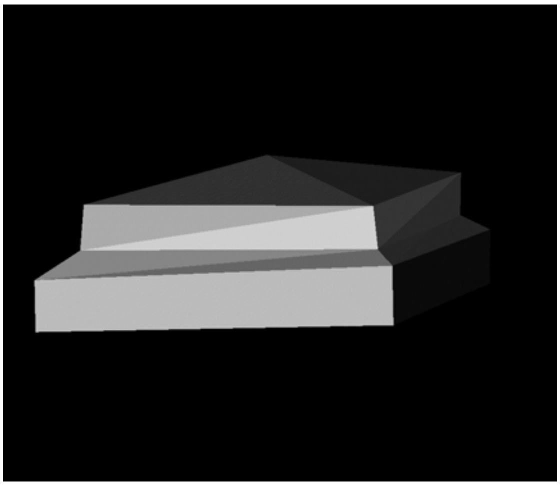

Fig. 8. A Rendered Display of a Digital Facet Model of Hunter Memorial Cap

6.11 Data Extraction

PMP was able to supply the data for different layers in AutoCAD to illustrate the architectural elements, damaged surfaces, etc. The content of layers and their representation (e.g. colours, line types, etc.) and the operations between layers depend on the proposed applications. The different façades of the Hunter Memorial were processed individually for further development.

More information such as height layers and slopes can be extracted directly from the specified surface model and displayed as colour coded images. This can be used for monitoring different façades of the object.

6.11 Products

Texture maps are very important in (human) facial representation; poor texture seriously detracts from the realism of the image. It can be assumed that this is true for some other objects, too. A recently developed procedure, not investigated practically in the work reported here, involves texture laser-scanners. Texture laser-scanners are capable of collecting information on intensity as well as distance, resulting in a high-resolution surface with a matching high-resolution texture. Images scanned using a laser-scanner at a very high resolution can be rectified using photogrammetrically derived points' data [3]. The DXF files, created by importing the photogrammetrically derived points data to AutoCAD can be used to generate the 3-D wire frame model and the laser imagery can also then add texture rendering to a 3-D digital facet model.

The data, which can be exported from PMP, are raster, vector or text data. Facet texture and orthophoto raster file export is proposed using the uncompressed *tiff* files, because of its widespread acceptability (e.g. it is the only format which can be 'hotlinked' to ArcView).

Vector data extraction employed DXF, in this project. In PMP, there are seven other vector output file formats available. The 3-D digital facet models created by PMP can be exported to another program, e.g. a CAD program. PMP generates its 3-D models in an arbitrary coordinate system. When a 3-D model is exported it will need transforming. The created models can be used in other programs with the following 3-D formats: *dxf, 3ds*, *obj*, *vrml*, *x*, *iges* or *raw* file. The AutoCAD program uses the DXF file format exported by PMP. The exported file can be manipulated and rendered using AutoCAD's tools.

PMP can export the 3-D data in a model projected onto a 2-D plane readable by a 2-D program. This ability can only be useful for planar surfaces, e.g. building elevation drawings. When 3-D surfaces are selected for export, the Face (i.e. facet) Texture Options become available.

An unsatisfactory attempt has been made to create an octree representation of the whole Hunter Memorial using the package 3D Studio (see Figure 9). This arose from an investigation of free space description methods, which can contribute to octree building. The technique has two stages. The first is the decomposition into voxels that can either be 3-D primitives in a CAD system (using solid modelling) or holes in an object (or virtual subspaces resulting from the octree representation of volume spaces).

The second stage is the management of structural or topological links between the voxels. The method involves sorting through a cloud of points and finding their surface topology based on selecting their nearest point. This may find surface holes or surface voxels of the object. It is assumed that improved photography, including camera calibration, of the Hunter Memorial might have improved the outcome of this investigation. But circumstances precluded acquiring new images of the memorial.

For future work, the new results of octree representation can be compared with these so far obtained. A successful outcome would more readily have paved the way for full object modelling, rather than surface facet modelling.

Digital surface modelling (digital terrain modelling) provides input to produce a digital orthophoto of the object's surface. Since the orthorectification process is performed pixel by pixel at the orthophoto scale, a high-resolution digital surface model is required. Figure 10 shows the orthophoto of the middle part of the object from the North Front view of Hunter Memorial Monument. This product can be used in conservation, e.g. to determine of size and location of eroded and water damaged features.

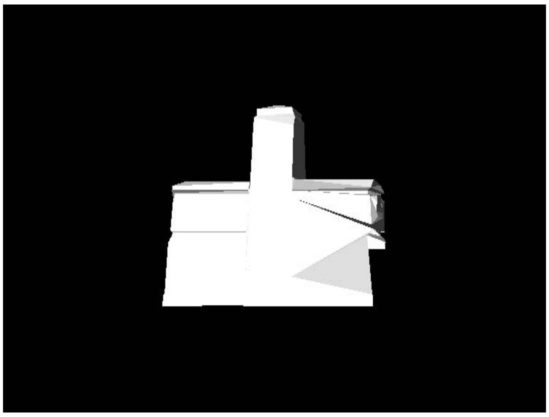

Fig. 9. A Textural Extraction of Hunter Memorial for Octree Representation

Fig. 10. Orthophoto of the Central Part of the Hunter Memorial

This investigation provided 3-D details and orthoimages of the Hunter Memorial. The methodology used has created satisfactory results for recording the façades and for the monument's consequent restoration and digital analysis.

The photogrammetric record using digital facet modelling can create a detailed and complete documentation of all the façade elements. The time spent to provide such documents was kept to minimum for all data gathering, processing and digital facet modelling as data output.

Reliable procedures have emerged in this Hunter Memorial investigation for the photogrammetric survey of architectural monuments that make achievable the architectural drawing and reconstruction of lost details of cultural buildings consistent with existing archived photographs.

3 Conclusions

Photogrammetric techniques bring many benefits to architectural recording. [1] indicate that photogrammetry prompts an excellent stereo photographic record of monuments, and provide a homogeneous level of recording across a whole façade or structure, being largely independent of the level of detail. They suggest results can be provided rapidly and in advance of other site works such as scaffolding. In comparison with traditional surveying and manual methods, a huge volume of primary data is captured and recorded quickly. Likewise, it can be assumed, applications in the archaeological area can benefit similarly.

Archaeologists require the creation of plans and sections. Much of this continues to be carried out by the traditional archaeologist's methods, such as placing a meter square grid over each area of excavation and graphically recording the detail, on taping features. But, rectified photographs are now becoming more commonly used across the archaeological field, and since the mid-nineties archaeologists have taken far more interest digital terrestrial photogrammetry [2].

Although not a common application generally, [2] states that terrestrial photogrammetry has now become one of the best-known applications of photogrammetric science in the specific fields of architecture and archaeology.

References:

[1] Brunet et al., Octree Representation in Solid Modelling: In Progress in Computer Graphics, G. Zobrist (Ed.), *Abblex Publication Company*, 1989, pp. 164-215.

[2] Dallas, Architectural and Archaeological Photogrammetry, Chapter 10 in *Close Range Photogrammetry and Machine Vision*, K. B. Atkinson (Ed.), Whittles Publishing, 1996, pp. 283-302.

[3] D'Apuzzo, Digitization of the Human Body in the Present Day Economy, *Videometrics VIII, proces. of SPIE-IS & T Electronuc Imaging, SPIE Vol 5665, San Jose, USA*, J. A. Beraldin, S. F. El-Hakim, A. Gruen and J. S. Walton (Eds.), 2005, pp252-259.

[4] Eos Systems Inc., *PhotoModeler User Manual*, Version 4.0, Canada:Eos Systems Inc, 2000.

[5] Foley et al., *Introduction to Computer Graphics*, Addison-Wesley Publishing Company, 1990.

[6] Mackie, *The University of Glasgow, 1451-1951*, Jackson, Son & Company, 1954.

[7] Sinning-Meister et al., 3-D City Models for CAAD-Supported Analysis and Design of Urban Areas, *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 51, 1996, pp. 196-208.