THREE-DIMENSIONAL MAPPING AND AS-BUILT COMPUTER MODELLING BY ANALYTICAL PHOTOGRAMMETRY

R.M.Littleworth, D.M.Stirling, J.H.Chandler, Engineering Surveying Research Centre, Department of Civil Engineering, City University, Northampton Square, London EC1V 0HB, UK. ISPRS. Commission V

ABSTRACT:

The paper describes how and why analytical photogrammetry, interfaced with a CAD system, has been used to create 3-dimensional computer models of development sites and engineering structures. Topics covered include: problems in combining data sources of different accuracy (e.g. aerial and close-range photographs and detail ground surveys)compromises necessary to idealise the geometry of the real world so that it can be represented by the CAD elements; and the uses to which these CAD products have been put. Examples include: gantry cranes, chemical plant and industrial and inner-city redevelopment sites.

KEY WORDS: CAD/CAM, Close-range, Industrial, 3-D, Visualization.

INTRODUCTION

Most of the work undertaken in close range industrial photogrammetry is involved with dimensional control. Typical applications include checking the shape of microwave, radar antenna and machine tools (Fraser,1986). These projects have involved the automated measurement of premarked targets utilising specialised photography taken from pre-determined camera stations and have achieved accuracies of up to one part in a million (Fraser,1992). Other examples have provided information for the design of add-on components such as an aircraft hush kit (Fraser,1986) and for computer-aided design in the automotive industry (Wahl,1984). However most of these applications have involved the measurement of objects or components which are comprised of ideal geometric shapes. Until recently very little work has involved the computer representation of irregular 'as-built' features.

With the introduction of industry wide CAD packages (e.g. Microstation, Autocad) the potential for introducing analytical photogrammetric techniques to new users has greatly expanded. This has involved exploiting the CAD potential of modern photogrammetric instrumentation, however, the accuracy achievable creating 3-dimensional computer models is restricted given the geometric restraints imposed by the CAD system. To fully realise the potential of these new areas traditional producers of maps and plans must learn to adapt themselves and their products to exploit the new systems.

The Engineering Photogrammetry Unit (EPU) was launched in 1988 following the purchase of an Intergraph Intermap Analytic Photogrammetric Workstation (IMA) by City University. EPU has the task of exploiting and adapting research undertaken within the university and applying this to industry by way of offering a bureaux service for both commercial and research contracts. Income generated in this way is used to purchase new equipment and fund further research by the university.

In order to provide the potential new photogrammetric users with the 3- dimensional product they require a change in approach and attitude to the traditional photogrammetric product was required. This has involved learning some of the work practices of potential users and using computing techniques that most photogrammetrists would not require. It has also proved necessary to compromise the photogrammetrists' traditional desire for accuracy in order that a geometrically 'imperfect' object can be more easily modelled within a CAD environment. To illustrate the evolution of the 3-dimensional photogrammetric product, examples of some recent projects undertaken by EPU will be given.

Hatfield Aerodrome

This was one of the first projects undertaken by EPU and is closely related to conventional mapping projects. Although a 3-dimensional project it is based upon a traditional large scale 2-dimensional specification. The requirement was for a computer model for use in the

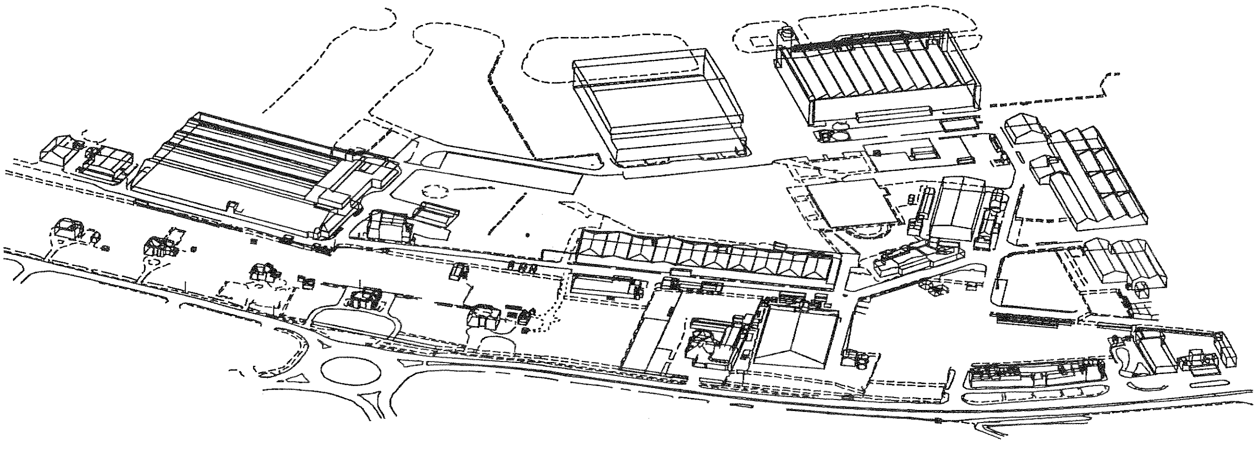


Fig.1 3-d model representing Hatfield Aerodrome.

planning and design of a new office complex. In the United Kingdom there are several aerial photographic libraries and archives held by various organisations. EPU make full use of these services for two main reasons, firstly it is considerably cheaper than commissioning new photography and secondly the material is readily available and this reduces project take up time. Suitable vertical aerial photography at a scale of 1:5000 was located for this particular site.

In conventional mapping photogrammetrists normally digitise detail that is traditionally shown on maps and plans by its outline or silhouette. For this project it was necessary to adapt the approach so that the detail digitised not only represented ground features accurately but gave a good visual impression of how these features actually appear (Fig. 1). Roof detail was digitised indicating their pitch, major details on the roofs themselves, tree canopies indicating height and spread, fences and walls showing width and height. The ground surface was represented by 0.25 metre contours (Fig. 2) which were derived from pertinent ground detail (kerb lines, boundaries etc.), a grid of spot heights and supplementary height points on important natural changes of slope processed using a digital terrain model package.

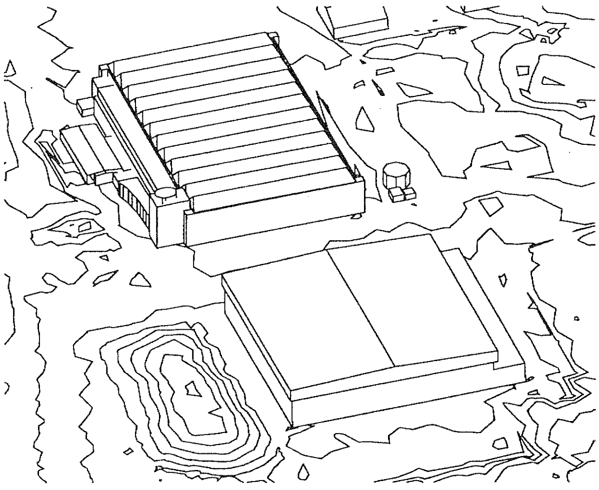


Fig. 2 3-d detail with DTM derived contours

The coordinate system for the model was the project coordinate system and would be used to generate all setting-out data for the construction of the new complex. Therefore permanent coordinated groundmarks were distributed around the site and their positions included in the CAD model. A field completion exercise was undertaken in order to include obscured and missing features. This included building groundlines if there were large overhangs or if they had sloping walls, tree boles and the identification and coding of hundreds of utility inspection covers. This exercise involved the use of electronic tacheometers and also simple 'tape and offset' measurements for some features. This additional detail had to be added to the original dataset using Microstation on an Interpro 125 workstation. This editing was not as straightforward as was initially thought. The 3-dimensional nature of this project meant that it was no longer acceptable to simply extend lines to intersect in plan but variations in elevation also had to be considered. Also included in the field completion exercise was the checking by ground survey of the position of certain critical structures on the site. It then proved necessary to move the photogrammetrically derived models of these buildings, by less than 50mm, to produce a consistent model.

Inner-city redevelopment areas

Architects have for some time been aware of the advantages of 3-dimensional computer graphics, for the planning of new projects through to the production of near photographic quality visualisations. Until recently photogrammetry has been used for the production of conventional site plans and more detailed facade details. These are normally supplied in a 2- dimensional form on paper or film and, more recently, in digital form on a floppy disk, However whatever format is delivered the amount of additional information that can be obtained from this 'flat' product is limited. Architects have had to create 3-dimensional models from this 2-dimensional data source. This has involved them approximating building heights by counting brick courses and estimating window sizes and has led to unsatisfactory and inaccurate results.

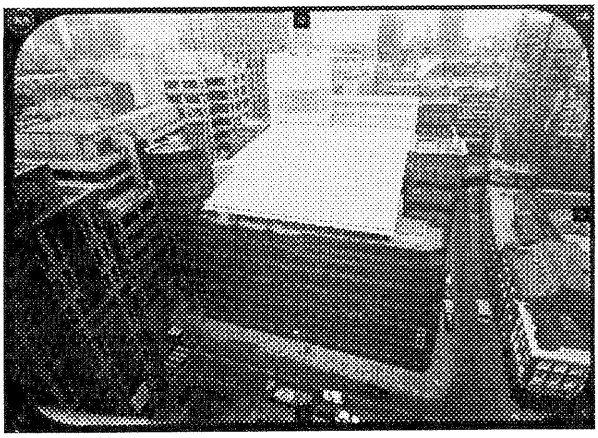


Fig. 3 Oblique photograph taken with UMK 10/13181

Fig. 4 3-d Line string representation of facade detail

EPU were asked to produce a 3-dimensional model of a redevelopment area of London. The specification required a simplified block model of all structures with selected facade information, road edges and some detailed facades

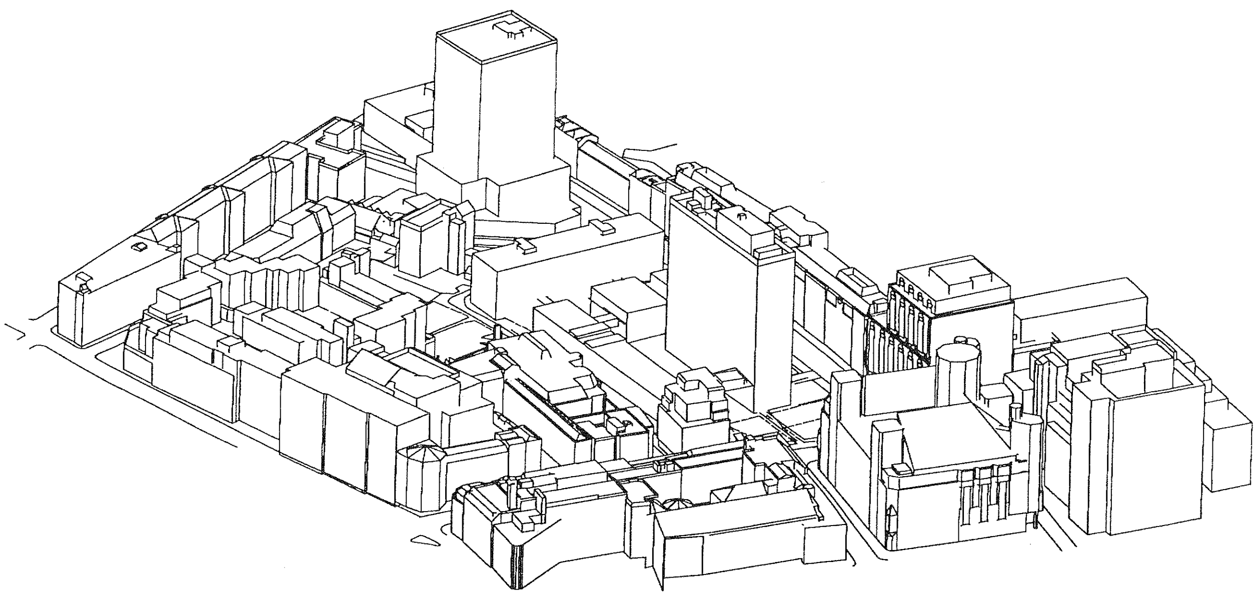


Fig. 5 The completed 3-d model of a redevelopment site

of certain buildings. Enquiries as to the availability of suitable vertical aerial photography were made but unfortunately the only suitable photography was 3 years old. However because it was at a scale of 1:5000 it was felt that it would be useable. In many other parts of the UK the age of the photography would have been inconsequential, but as London is still undergoing major redevelopment it was important that recent photography be used to get the most from the photogrammetric work and reduce the amount of field completion required. It was decided to supplement the vertical photography with oblique photography (Fig. 3) taken from the roof of a conveniently situated building on the site. This together with the terrestrial photography that was required for the detail facade work was taken with a Zeiss Jena UMK 10/1318.

All sets of photography were studied and suitable control points selected which were coordinated by field survey to give 3-dimensional coordinates based upon the Ordnance Survey National Grid so that any subsequent site survey or additions could be more easily linked with the model. The accuracy requirement for this project varied according to the subject, detailed facades +/-30mm, building lines +/-150mm. This meant that the control survey was potentially a two phase operation, but it was decided to coordinate all control points to the higher precision and allow the photographic scale to determine the final accuracy.

Experience has shown that it is necessary to work closely with clients to obtain a good understanding of what further use will be made of the finished product. In this way the most suitable methods of 3-d digitising can be employed on the IMA in order that further workstation editing time can be reduced.

Initially features are digitised as line string elements and where possible higher order elements such as shapes. These data act as a background template from which shapes representing roofs and walls are interpolated. This process inevitably leads to the degradation of the accuracy of the original line strings but this compromise situation is presently unchangeable due to the geometric restrictions imposed by most CAD systems.

This particular project did not require surface modelling to be carried out on all features. Detailed facades (Fig. 4) were required to be represented by 3-dimensional line strings, which retain the original photogrammetric accuracy. Surfacing of these facades would have compromised the accuracy and would not have been cost effective. The main blocks or masses of buildings were surfaced by the placement of shapes and projected elements but ensuring a homogeneous fit between the idealised blocks and the facades caused some problems mainly due to the overhanging eaves of the buildings. This problem was overcome by the client who simply moved the facade detail forward so that it fitted just over the surface! This obviously compromised the absolute accuracy required by the specification, but the relative accuracy of each facade was maintained.

The representation of the ground surface was derived from a triangulated digital terrain model with the kerb edges being projected down to the road surface for a more realistic effect. The triangles were colour coded according to whether they represented roads,pavements or grass areas. The advantage of having a ground surface for the buildings to sit on not only gives a better visual effect, but also makes the creation of the building surfaces simpler as the building walls can be projected through the ground surface. This can produce a dramatic time saving in the editing process, especially on sloping sites.

Gantry Crane

EPU were commissioned to carry out surveys on three gantry cranes used in separate hydroelectric power stations in northern Italy. The power stations were constructed during the 1930s' and over the ensuing period the original engineering drawings have been lost. The generators within each plant needed to be replaced by more efficient modern ones. To achieve this the gantry

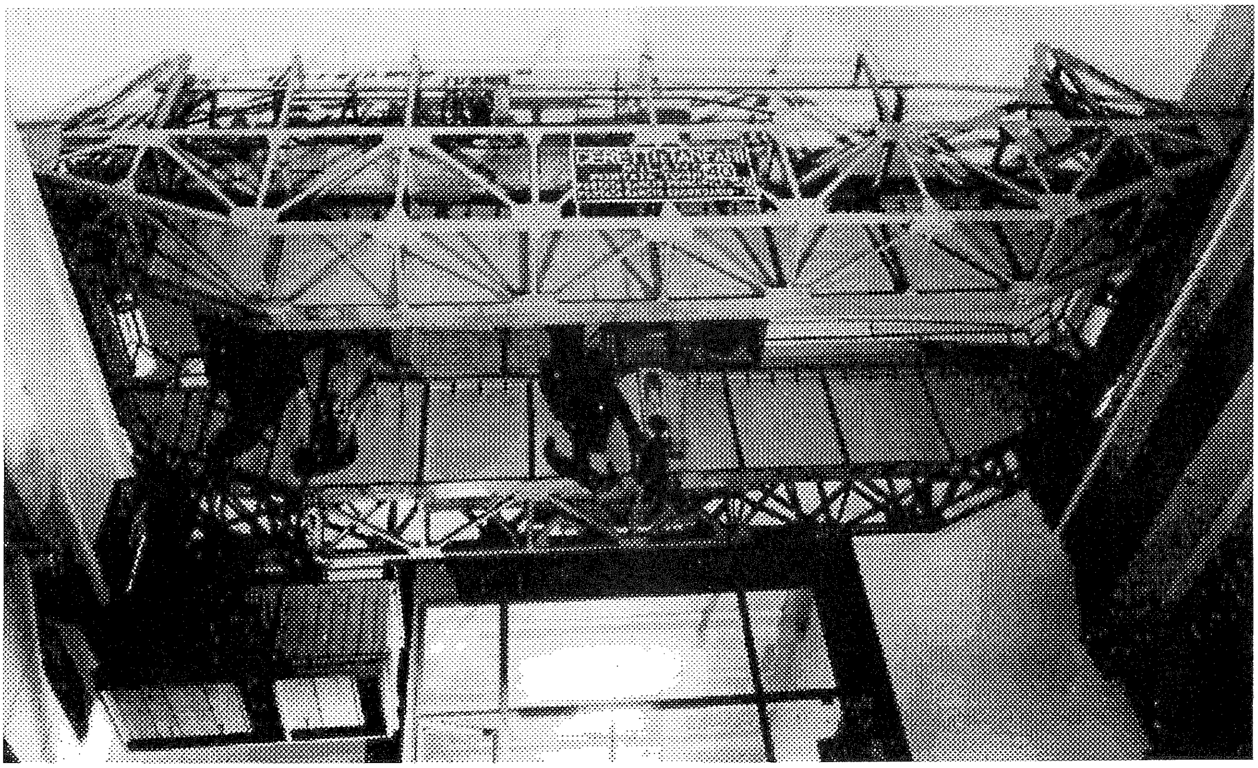


Fig. 6 Semi-metric photograph of gantry crane

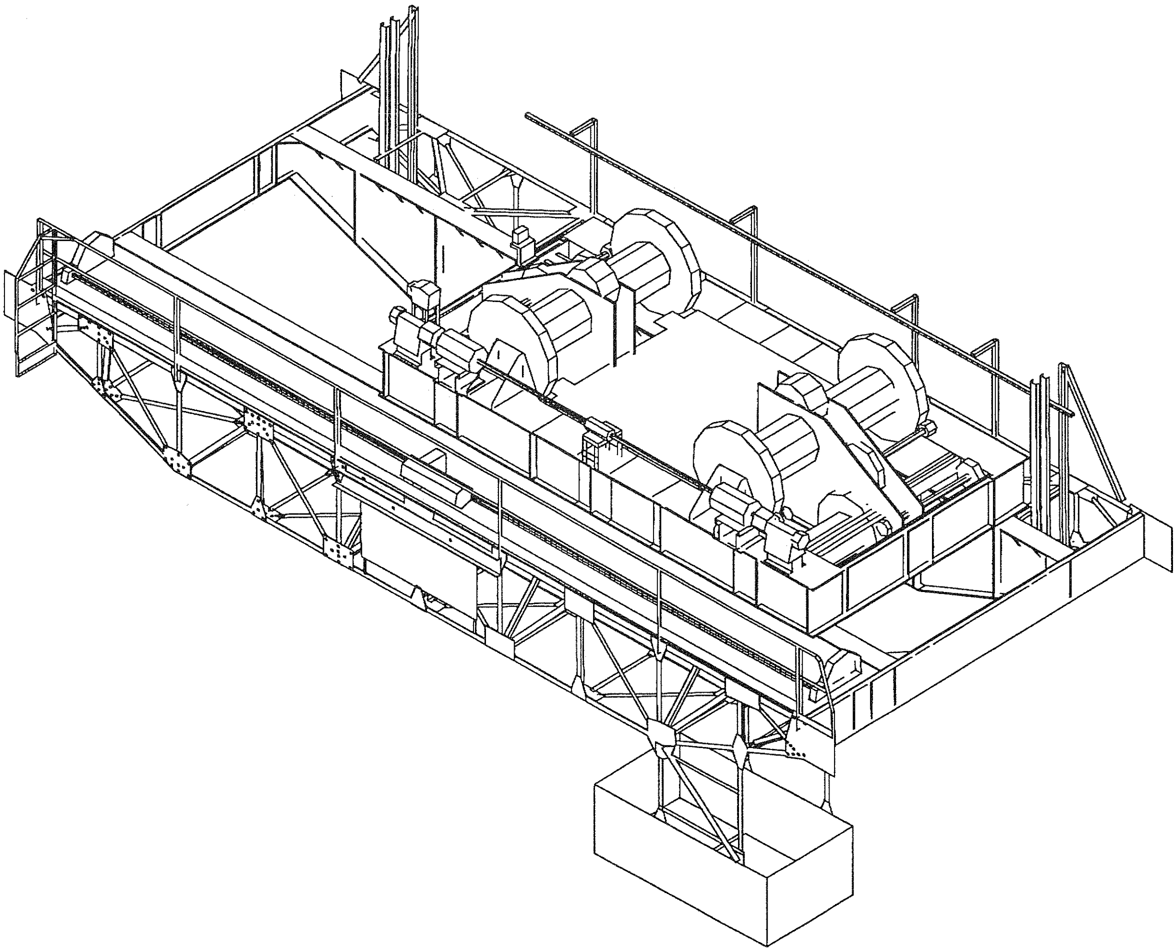


Fig. 7 3-d model of gantry crane with hidden line removal cranes had to be analyzed structurally to ensure that they had adequate lifting capacity. 3-dimensional CAD models were required which would be suitable for further manipulation and interrogation by the clients CAD system.

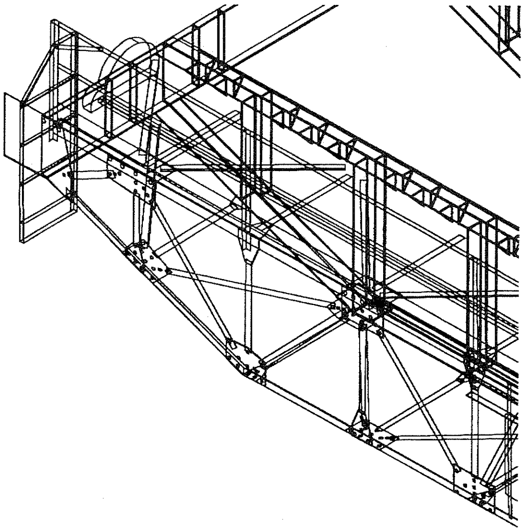
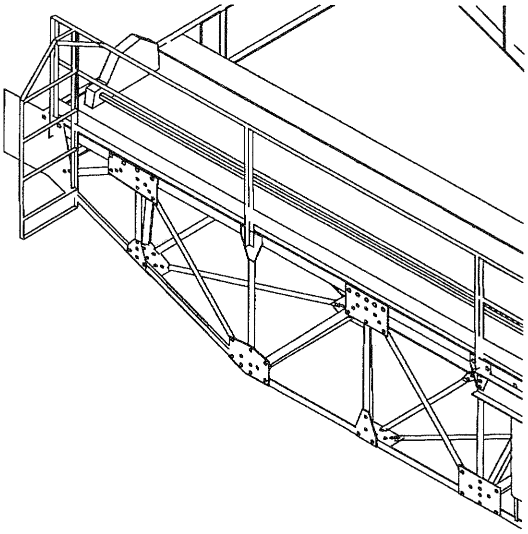


Fig. 8 & 9 Detail of wire frame and hidden line views



The photography required for each gantry crane was taken from a variety of platforms, an elevated hoist, the floor and even on the cranes themselves. The cameras used were a Wild P-32 and a Hasselblad SWC fitted with a reseau plate. The machine halls where the gantry cranes operated provided a challenging environment for analytical photogrammetric methods. They were dimly lit and echoed continuously with the noise and vibration of turbines and generators. Additional illumination from portable spot lamps was essential but even so the recommended exposure times were slow. With the exacerbating effect of reciprocity these were commonly in excess of 45 seconds. The vibration within the halls caused blurring on some images. Particularly affected were those acquired from the elevated hoist when fully extended. The films were processed at the end of each day to ensure coverage and to provide the opportunity of retaking any photography. Fortunately this was not required. The ground control survey was also affected by vibration and many additional survey measurements were taken in order to derive a reliable 'mean' set of measurements. The physical restrictions of the machine halls prevented all survey and photography being obtained with the gantry crane in the same position. One half of the crane was photographed and then the crane had to be moved to enable coverage to be obtained from the other side. This movement also caused a problem in the definition of the survey datum. This was resolved by assigning fixed coordinates to two target points on the gantry crane itself. This resulted in a survey network in which the gantry was static, and the tacheometric stations appeared to have moved relative to each other. There were approximately ten photogrammetric models for each gantry crane. These were established on the IMA. Corrections were applied to the Hasselblad photography to compensate for film unflatness and lens distortion (Robson, 1990).

Initially, the major structural planes were digitised separately. These planes corresponding broadly with the top, bottom and sides of the gantry crane. This division may appear arbitrary but this approach is essential when delineating complex objects into a 3-dimensional CAD system. If every possible feature is digitised using any single photogrammetric model confusion will arise which may introduce errors during subsequent editing and also increase editing time itself. The 3-dimensional model of complex objects such as the gantry crane would be difficult to interrogate and use effectively if represented solely by line strings. By editing these line strings into 3-dimensional geometric shapes to represent beams, metal plates and 'L' shaped supports, individual components which actually comprise the object are identified and reveal details of construction that are essential to the engineer. The finished models were then field completed by the client, to check the accuracy of the model and to add any important detail features. These included the gantry rails, and small mechanical parts of the cranes that were not visible on the photography.

Chemical Plant

Plant design engineers have had available to them for some time 3-dimensional piping design CAD packages. However, whilst the new areas of plants undergoing refurbishment or expansion have had the advantage of being designed 3-dimensionally within a CAD system, existing plant constructions are traditionally stored in a 2-dimensional form on paper or film drawings and consequently have had a limited use in the new design (Bracewell & Klement, 1983).

EPU were asked to produce a 3-dimensional model of part of a chemical plant for ventilation studies and safety certification. There were existing plans of the area, but because of the time it would have taken to convert these into a 3-dimensional model it was decided to undertake a photogrammetric survey of the site. This had the advantage not only of speed but also it would provide an 'as built' model rather than an 'as designed' one. The area of interest covered approximately 100 metres by 100 metres. This ruled out the use of vertical aerial photography on economic grounds.

The 3-dimensional nature of this site meant that photo control had to be carefully selected so that it was not only visible on one elevation of the area, but also on

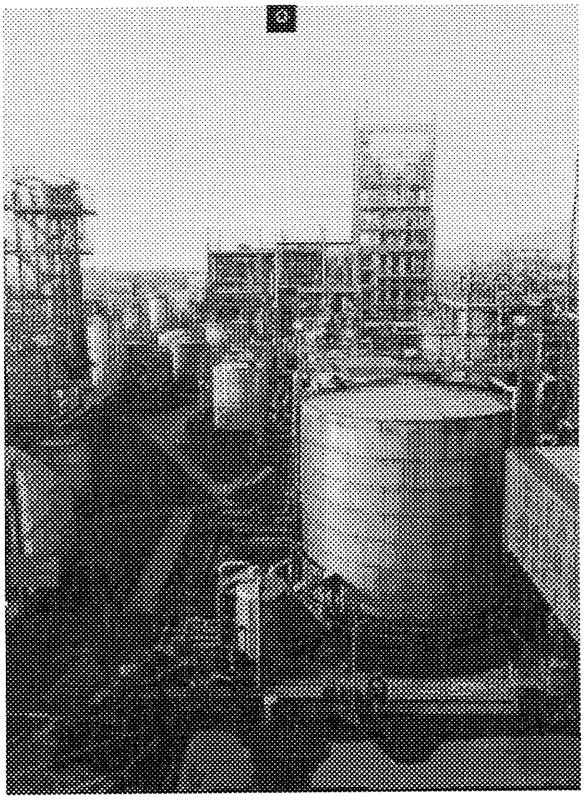


Fig. 10 Photograph showing part of a chemical plant

photography taken from other sides of the site as well. In addition to the photo control, dimensions of certain important features were also taken whilst on the site. Photography was taken from a variety of platforms, an aerial hoist, walkways on and around the site together with ground based stations. The complex nature of the site meant that photography not only had to be taken from around its perimeter, but also from inside the site itself. The amount of stereo pairs taken was restricted to approximately fifty but could quite easily have been double or treble this amount.

The plant was subdivided into logical areas. This enabled the photogrammetric digitising to be phased and enabled the client to receive sections of the site as they were completed. This phased delivery procedure ensured the client received the correct level of detail required as feedback was received on the initial deliveries. Fortunately the section of plant being surveyed was aligned with the overall site coordinates. This simplified the editing process. The editing again consisted of creating 3-dimensional 'surfaced' shapes of the main site structures from line strings digitised on the IMA, storage vessels were represented by cylinders (Chandler & Cooper, 1991). Using the dimensions that were taken on the site it was possible to undertake checks on the accuracy of the model. This was important because of the large variations in object scale on some of the photography.

The complexity of the site inevitably meant that there were some areas where it was uneconomical to use photogrammetry within the clients existing budget. These

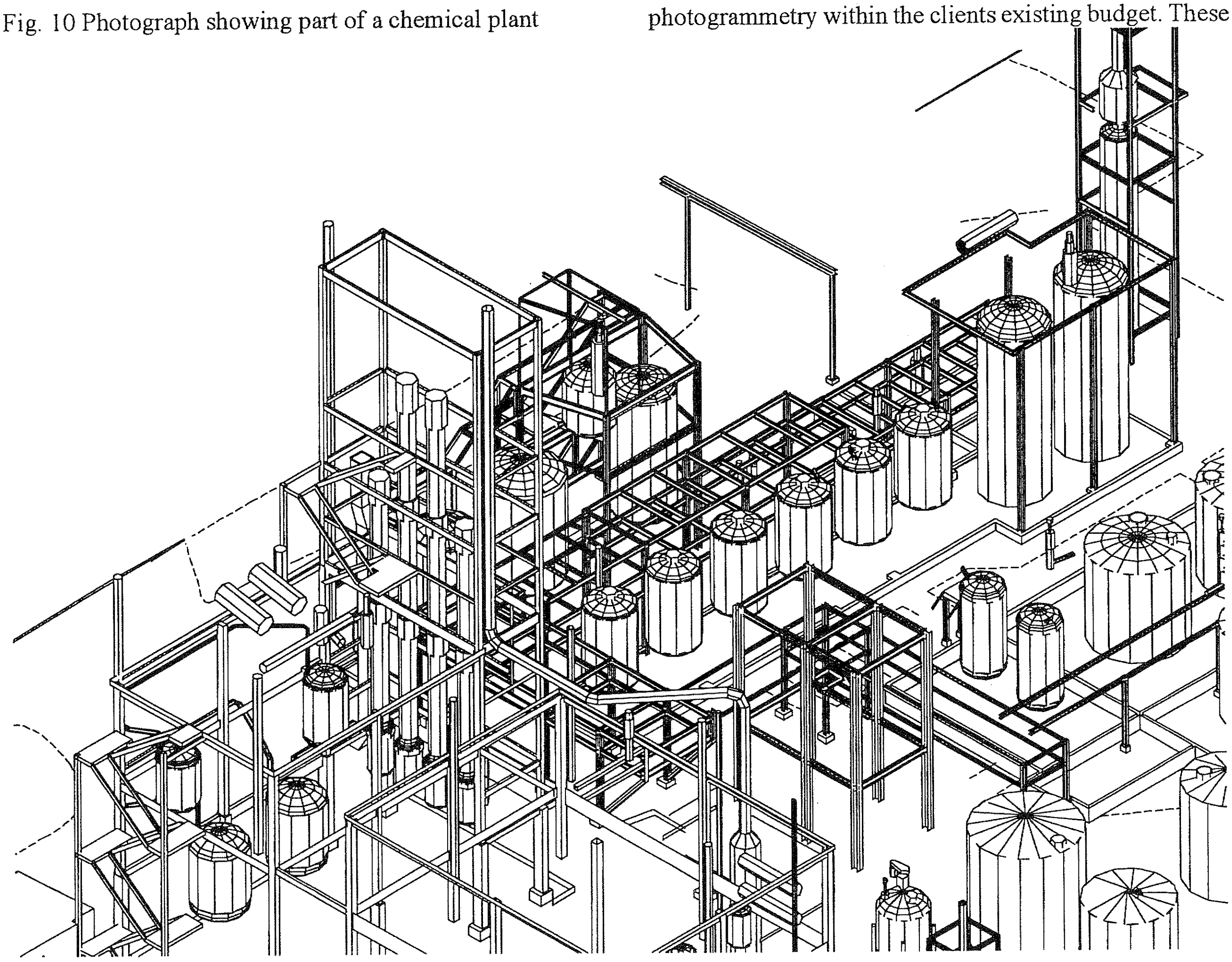


Fig. 11 Detail from chemical plant model

areas could have been completed using traditional field survey methods, but even this would have been a major undertaking. These areas were left incomplete, but sufficient detail has been represented to satisfy the clients needs, and if required this detail can be added at a later stage using the existing controlled photography.

CONCLUSION

Unfortunately most current CAD systems with all the geometric restraints they impose do not allow for the efficient production of these 3-dimensional models. This should not mean that such projects are not undertaken. On the contrary there are many potential new users of photogrammetry who create far more challenges and demand more from photogrammetrists and analytical photogrammetry than the traditional 2-dimensional map product. The answer to this modelling problem will not be easily solved. There are currently some 'solid' modelling CAD packages available but while it is not possible to undertake this modelling directly within the photogrammetric model the advantages are limited.

There is a very real need for the 3-dimensional CAD model with all its inherent advantages over the 2-dimensional product. It offers a potential new range of clients in a diverse range of industries. It also demonstrates that the traditional pigeon-holing of products to specific industries in this computer age is no longer valid. By learning more fully the needs of these industries there is a challenging and diverse future for this 3-dimensional computer modelling by analytical photogrammetry.

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