PHOTOGRAMMETRIC INVESTIGATION INTO THE SUITABILITY OF DESKTOP IMAGE MEASUREMENT SOFTWARE FOR ARCHITECTURAL RECORDING

J. P. Mills*, **G. C. Peirson***, **I. Newton*** **and P. G. Bryan****
*University of Newcastle upon Tyne, United Kingdom
Department of Geomatics
j.p.mills@ncl.ac.uk, g.c.peirson@ncl.ac.uk, ian.newton@ncl.ac.uk
**English Heritage Survey Team, York, United Kingdom
UK National Delegate to CIPA
paul.bryan@english-heritage.org.uk

Working Group V/5

KEY WORDS: Accuracy, Architecture, Buildings, Commercial Photogrammetry Software.

ABSTRACT

This paper reports on the rigorous testing of low cost desktop image measurement software that has recently become commercially available to the mass market. These software packages indicate the potential to produce accurate 3-dimensional data from multi-station convergent, and in some cases single, imagery. The investigation, commissioned by English Heritage, has centered on the 3D Builder, Photomodeler and Dimension software packages. The measurements have been carried out on imagery taken to the English Heritage specification on one of their sites. The results indicate that all the packages are capable of returning measurement accuracies to rival analytical photogrammetric methods when examined under ‘real-world’ conditions. Other limitations, such as plotting versatility, however restrict the suitability of the software for architectural applications. These packages have the potential to open up photogrammetry to new users but the dangers of treating them as black box technology are stressed.

1 INTRODUCTION

1.1 Background and rationale

Close range photogrammetry is long established as an essential recording tool for English Heritage sites. As a leading authority on setting standards for architectural survey work, it is imperative that English Heritage investigate new methods and techniques that become available. Several low cost digital photogrammetric software packages have recently been marketed that seem to indicate the potential to produce accurate 3-dimensional data. Importantly, for reverse engineering of sites that no longer exist, many of the packages claim to be capable of achieving this from single images. A recent project in the Department of Geomatics, University of Newcastle examined one of these packages and compared it to conventional analytical photogrammetry with encouraging results (Bottrill *et al*., 1998). This latest project, commissioned by English Heritage, is an extension of the earlier one and it is hoped that the results will benefit not only English Heritage in their evaluation of this technology but also the geomatics community as a whole.

1.2 Project aims and objectives

The aim of the research was to evaluate the new software in a ‘real-world’ environment. Very often such studies are conducted in controlled environments under optimum conditions. By conducting the work on a typical English Heritage survey site it is anticipated that the results will be more meaningful, and thus provide a true indication of the software’s potential. Within this overall aim, the objectives were to:

- Obtain full stereo and multi-station convergent photographic coverage of a test area (at Tynemouth Priory).
- Complete an analytical photogrammetric survey of one façade within the test area (to English Heritage specifications).
- Analyse the potential of three new, low cost photogrammetric software packages (3D Builder, Photomodeler and Dimension) for conducting survey work of this type by comparing the results obtained from these packages with those of the analytical survey.

2 FIELDWORK

2.1 Test site

The study focussed on Tynemouth Priory, an English Heritage site in the North East of England close to Newcastle upon Tyne. The Prior's Hall was chosen as a suitable test area within the site as it was typical of the type of structure recorded by English Heritage and therefore provided an ideal 'real-world' survey. Within this, the west facing façade of the Hall was selected as the test façade. The site is shown in Figure 1.

Figure 1. Prior's Hall, Tynemouth Priory - the test area for the study.

2.2 Control survey

48 butterfly type targets were fixed to the façades and coordinated by theodolite intersection from known traverse stations on the existing site network. The overall mean precision of points coordinated in the control survey was +/- 4 mm which is within the English Heritage specification for a survey of this type.

2.3 Photographic survey

Photography for the project was taken with a Rolleimetric 6006 semi-metric camera fitted with a 50 mm lens.

2.3.1 'Normal' case stereophotography. English Heritage specifications for photogrammetric survey (Bryan, 1998) state that photography should be taken at minimum photo scales of 1: 200 for an output scale of 1: 50; 1: 100 for an output scale of 1: 20, and 1: 50 for an output scale of 1: 10. In order to minimise the time spent in the field, it was decided to use a 1: 50 output scale, meaning that the photo scale should be 1: 200 or larger. A photographic distance to the façade of 7 m provided suitable object coverage with this camera and resulted in an image scale of 1: 140, which is comfortably within the required specification. Other English Heritage specifications, such as amount of tilt on the imagery, were also adhered to.

2.3.2 Multi-station convergent photography. In addition to the 'normal' case stereophotography, convergent photography was taken. Three images of the west facing façade (one normal to it, and two at convergent angles) were scanned onto Kodak Pro Photo CD, a proven media for digital photogrammetric work (Thomas *et al.* 1995, Mills *et al.* 1997). A typical image of the façade taken with the camera can be seen in Figure 2.

3 ANALYTICAL SURVEY

3.1 Plotting of the façade

The photography was measured in a Zeiss P3 analytical plotter. An English Heritage photogrammetrist assisted with the measurements to ensure that the work was carried out to the correct specification. The resulting plot can be seen in Figure 3. The survey required two 'normal' case stereopairs and took approximately 11 hours to complete.

Figure 2. Photograph of the test façade.

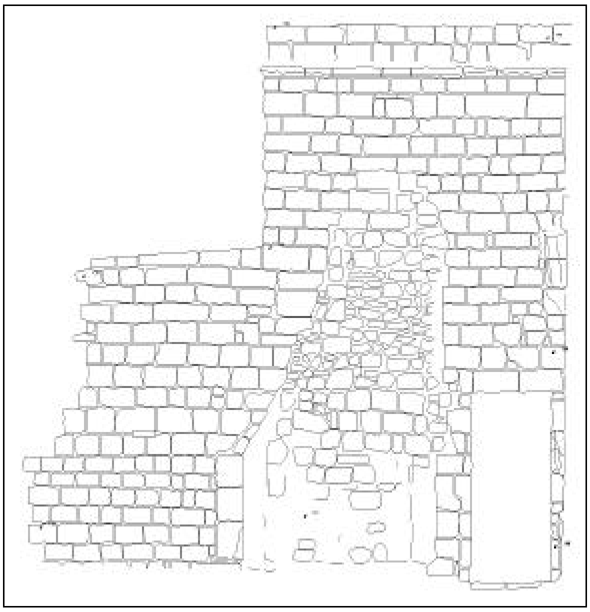


Figure 3. Analytical plot of the test façade.

3.2 Assessment of precision and accuracy

The internal precision of the Zeiss P3 measurements was assessed from 10 repetitive measurements made to the 11 targeted control points used to control the two stereomodels. Standard errors in measurement of 1.2 mm, 0.5 mm and 1.2 mm in X, Y and Z respectively resulted. It should be noted that, since the measurements are based on the English Heritage ground co-ordinate system for Tynemouth Priory, the X axis is essentially the depth measurement and is therefore expected to produce the largest standard error.

To assess the external accuracy of the measurements, the same data from the Zeiss P3 were compared to the co-ordinates produced by theodolite intersection and RMS error values computed. RMS error values of 7.2 mm, 3.6 mm and 3.9 mm in X, Y and Z respectively resulted. This dataset is rather limited in size however and, as the points were also used in the orientation process, cannot be trusted implicitly to provide a meaningful statistical analysis. What can be stated is that the external accuracy is worse than the internal precision, a reflection on the limited accuracy of the theodolite intersection method used to derive the control point co-ordinates (+/- 4 mm).

In order to provide a true measure of the precision of analytical measurement, and to evaluate the software under test on the basis of accuracy, the co-ordinates of an independent set of natural detail points that were not used in controlling measurements or orientations were required. A set of 38 such points was measured across the two models, 15 points on Model One and 23 points on Model Two. Each point was measured 10 times and the mean coordinates used in later analyses. The precision statistics for analytical measurement of these 38 points can be seen in Table 1.

	X (mm)	Y (mm)	Z (mm)
Maximum standard error	13.0	8.0	6.7
Minimum standard error	2.6	0.6	0.8
Mean standard error	5.4	2.2	2.6

Table 1. Precision statistics for the Zeiss P3 determined from 10 sets of measurements to 38 natural detail points.

Not surprisingly these statistics are worse than those obtained for the targeted control points. However, the English Heritage specification states that the accuracy of coordinates produced for 1: 50 output scale plotting should be better than 9 mm (standard error). The mean standard error values in Table 1 are clearly within this specification. In spite of this, an analytical plotter such as the Zeiss P3 should be capable of measurements of a higher quality, and examination of the parallax equation reveals that in this instance X-parallax is being eliminated to only 18 µm.

A good operator using the Zeiss P3 should be capable of eliminating parallax to a factor of anything up to eight times better than this, so clearly there is another cause for the degradation in the measurement precision. This is almost certainly due to the use of natural detail points and the difficulty of re-measuring exactly the same point. Consequently using an analytical plotter that provides a higher order of accuracy is actually unnecessary in this case and this is an important factor to bear in mind when examining the low cost software packages. A Rolleimetric 6006 negative / diapositive scanned onto Kodak Pro Photo CD provides an image pixel size of 14 µm (Base 64 resolution). Further, the software packages being evaluated use multi-station convergent imagery and should be capable of producing homogeneous precision in all axes. Hence if measurements can be made consistently to the pixel level, a similar level of measurement precision to that produced on natural detail points by analytical measurement should be possible.

4 EVALUATION OF 3D BUILDER

4.1 Background

3D Builder is produced in the USA by the 3D Construction Company. The UK retail price of the software is £430. Further information about 3D Builder can be found on the 3D Construction Company URL www.3dconstruction.com.

4.2 Precision tests

Internal precision was tested by 10 repetitive sets of measurements to each of the 38 natural detail points measured in the analytical plotter. The two convergent images were first measured and processed. The third image was then added to the project and the measurements re-processed. By the 10th measurement set, the observations were taking approximately 45 minutes per set (approximately one minute per point and 10 minutes to orientate the imagery). Up to 30 minutes could be added for adding the third image. Table 2 shows the statistics for measurements made on two and three images respectively. By comparing the statistics with those in Table 1, it can be seen that 3D Builder performs very well in comparison to the analytical survey, even to the point of outperforming the analytical plotter in the depth dimension. This is due to the superior network geometry, the software providing more homogeneous measurements than the 'normal' case photography in the analytical plotter, and the precisions in X, Y and Z being very similar.

	Two image network			Three image network		
	X (mm)	Y (mm)	Z (mm)	X (mm)	Y (mm)	Z (mm)
Maximum standard error	7.9	7.1	9.1	8.4	6.9	5.2
Minimum standard error	2.9	1.7	1.3	2.0	1.3	1.8
Mean standard error	5.1	3.5	4.0	4.9	3.8	3.3

Table 2. Precision statistics for 3D Builder determined from 10 sets of measurements to 38 natural detail points.

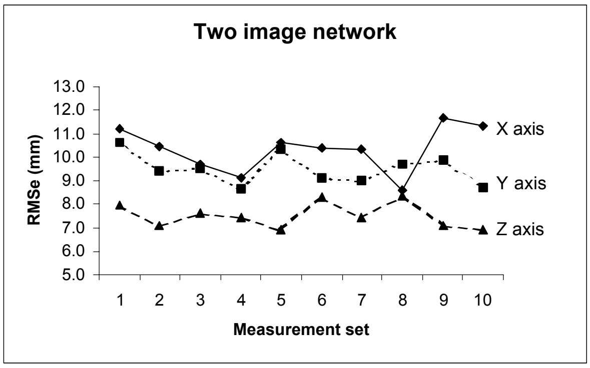
There is a slight improvement in the statistics for the three-image network, but it is not significant enough to warrant the extra time involved to make the additional measurements. In this case, the third image was located between the other two and taken from the same height. As such, it did not really improve the geometry of the network and simply provided an additional set of measurements. The spatial restraints (such as the location of other Priory walls; not being able to take photographs from different heights etc.) on taking photography in this kind of environment mean that the multi-station convergent methodology is not fully exploited.

4.3 Accuracy tests

The co-ordinates for the 38 natural detail points for each set of measurements were entered into Excel and the Zeiss P3 derived co-ordinates (the mean of 10 measurement sets) subtracted from them. Mean error values for the 10 sets of measurements can be seen in Table 3. Figure 4 shows the RMS error values for each set of measurements. A slight improvement is observed when the third image is added to the network.

	Two image network			Three image network		
	X (mm)	Y (mm)	Z (mm)	X (mm)	Y (mm)	Z (mm)
Maximum error	14.6	20.2	17.6	16.3	19.7	18.8
Minimum error	-25.6	-12.7	-12.2	-24.8	-10.6	-10.2
Mean error	-4.5	5.8	3.3	-4.0	5.1	3.4
Standard error	9.3	7.5	6.7	9.0	7.4	6.3
RMS error	10.3	9.5	7.5	9.8	9.0	7.3

Table 3. Accuracy statistics for 3D Builder determined from 10 sets of measurements to 38 natural detail points.



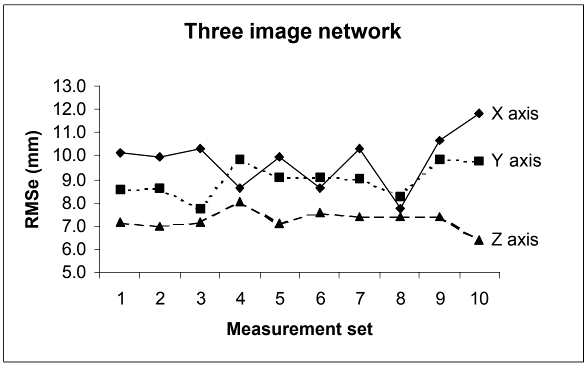


Figure 4. RMS error values for coordinates determined by 3D Builder.

The graphs in Figure 4 display consistency, indicating that the software is rigorous in its measurement process. If the Zeiss P3 co-ordinates are assumed perfect (which they are not), the software is yielding coordinates only slightly outside the maximum tolerance set by English Heritage specification (9.0 mm standard error). Errors in the 3D Builder coordinates arise from: overall accuracy limitations of the software; not being able to measure fiducial marks with the software; not being able to view the points in stereo; scanning distortions introduced into the imagery by the Photo CD process, and subsequent resolution loss in the analogue to digital conversion.

4.4 Suitability tests

In order to assess the suitability of 3D Builder for survey work of this type, a plot of a small area of the west façade was made using the software. The two convergent images of the façade were used and a test area, consisting of 14 stones in a relatively flat area of wall was chosen. The plotted detail was to be compared with that produced using the Zeiss P3.

Several different methods of plotting were investigated. At first sight, the most efficient method of plotting vector detail would appear to be the 'free form curve' option. This allows the user to plot detail (for example a stone) on two or more images and then match the defined curve on the images assuming that the first and last points are the same. Unfortunately there are two problems with this option. Firstly, unless the curve is restrained to a particular plane, significant errors can occur in the depth direction. Constraining the curve to a single plane obviously degrades the accuracy, but does provide a suitable method of deriving 2-dimensional data quickly and efficiently. It is unfortunate that a plane cannot be 'hinted at', as is the case when setting up regular shapes, since this could potentially provide the optimum solution to plotting in software packages of this type. A second problem with this option, however, is that the curves are not driven perfectly through the points on an irregular shaped stone. The derived point co-ordinates are given as the nearest point on the curve, not the actual point location that was marked.

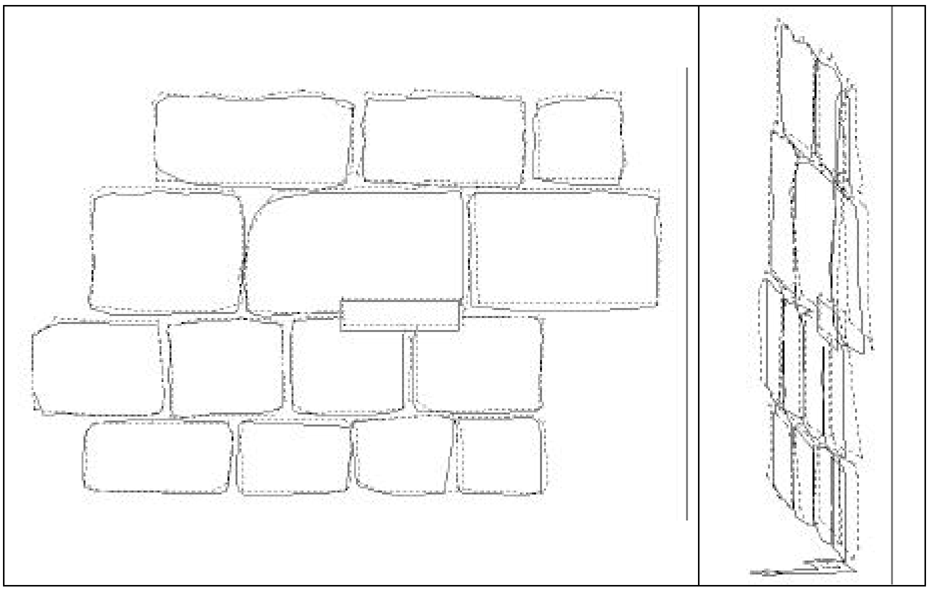


Figure 5. Detail of stonework plotted in 3D Builder (Solid line is from Zeiss P3 plot).

The only method of plotting is therefore to digitise lines or polygons and then match the individual points defining the vectors which is time consuming. It took approximately 60 minutes to plot the section of façade seen in Figure 5 with 3D Builder, compared to 20 minutes in the Zeiss P3. The process would be quicker but for the software's insistence on zooming out during the matching procedure. The 14 stones shown in Figure 5 are comprised of only 154 points (an average of just 14 points per stone). They represent quite reasonably the Zeiss P3 plotted vectors (apart from an evident systematic offset) but a more detailed plot would be required to meet English Heritage specifications. This would be very time consuming to produce as it is extremely difficult to match natural points on stonework in places other than obvious corners.

4.5 Single image capability

3D Builder claims to be able to produce 3-dimensional co-ordinates from single images and initial experiments have indicated that this works quite successfully providing that the plane in which detail is being plotted can be defined. This capability is currently under further investigation.

5 EVALUATION OF PHOTOMODELER

5.1 Background

Photomodeler Pro 3.1 is produced in Canada by Eos Systems Incorporated. The retail price of the software in the UK is £490. Further information about Photomodeler, along with several case studies, and an investigation into its accuracy (Hanke, 1999) can be found on the Photomodeler URL www.eossystems.com.

5.2 Precision tests

Precision was evaluated in the same manner as for 3D Builder resulting in the statistics in Table 4. There was very little improvement when the third image was added to the network.

	Two image network			Three image network		
	X (mm)	Y (mm)	Z (mm)	X (mm)	Y (mm)	Z (mm)
Maximum standard error	6.8	12.0	10.9	7.3	12.2	11.4
Minimum standard error	1.6	1.1	1.0	1.5	1.2	1.1
Mean standard error	3.5	3.2	3.1	3.5	3.1	2.9

Table 4. Precision statistics for Photomodeler determined from 10 sets of measurements to 38 natural detail points.

5.3 Accuracy tests

As with 3D Builder, the resultant natural detail point co-ordinates were compared statistically with those measured in the Zeiss P3. Table 5 and Figure 6 provide a summary of the results obtained. The consistent mean errors that showed up with 3D Builder are not evident in the Photomodeler results, indicating that there is less systematic error present. It is thought that because Photomodeler allows the measurement of fiducial marks it provides a more accurate recovery of the principal point position than 3D Builder. The Photomodeler coordinate errors can be considered to result from the same sources as in 3D Builder except that Photomodeler has the facility to input full camera calibration information (including fiducial marks).

	Two image network			Three image network		
	X (mm)	Y (mm)	Z (mm)	X (mm)	Y (mm)	Z (mm)
Maximum error	20.1	17.6	21.6	20.4	17.2	23.4
Minimum error	-30.5	-15.6	-19.0	-34.1	-14.6	-18.1
Mean error	-0.7	-0.1	2.1	-1.9	-0.4	2.4
Standard error	10.8	7.1	8.3	11.0	6.9	8.4
RMS error	10.8	7.1	8.5	11.1	6.9	8.7

Table 5. Accuracy statistics for Photomodeler determined from 10 sets of measurements to 38 natural detail points.

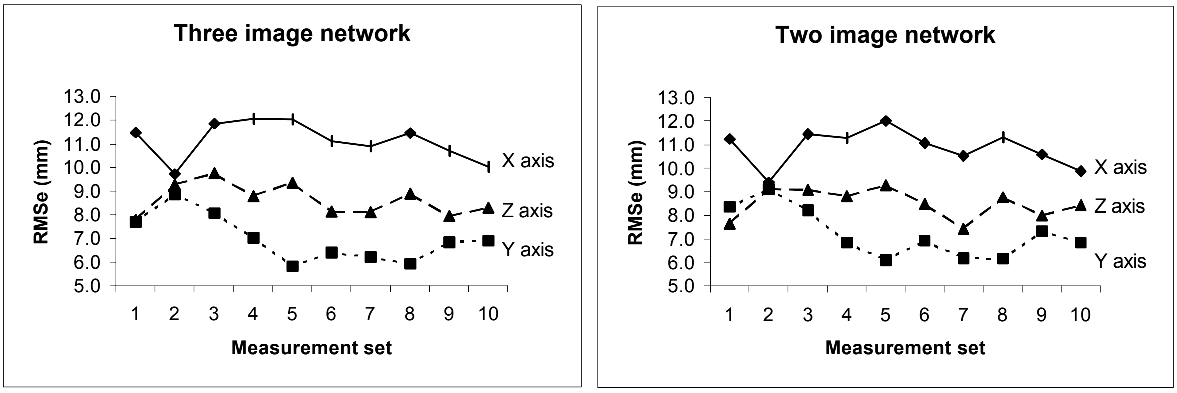


Figure 6. RMS error values for coordinates determined by Photomodeler.

5.4 Suitability tests

The same test area as for 3D Builder was used to assess suitability of the software to purpose. The process of plotting detail is very similar to that used for measuring the detail points. Points around the edges of each stone are marked on both images and referenced together. The edges of the stone are created by linking the consecutive points with lines. Initially, points around the edge of a stone were marked on one image. The 'Reference Helper' facility was then tried out. With this, when a point is highlighted on the first image, Photomodeler draws an epipolar line on the second image – i.e. a line along which Photomodeler believes the point lies. In theory, this should help with marking points on the second image. However, in practice, marking all the points on one image first and then marking them all on the second image was not successful. This was because an obvious point on the edge of the stone on one image is not often obvious on the other image. The optimum method of marking conjugate points was to have both images displayed side by side, and then marking the same point sequentially. In this manner, only points clearly visible on both images were digitised.

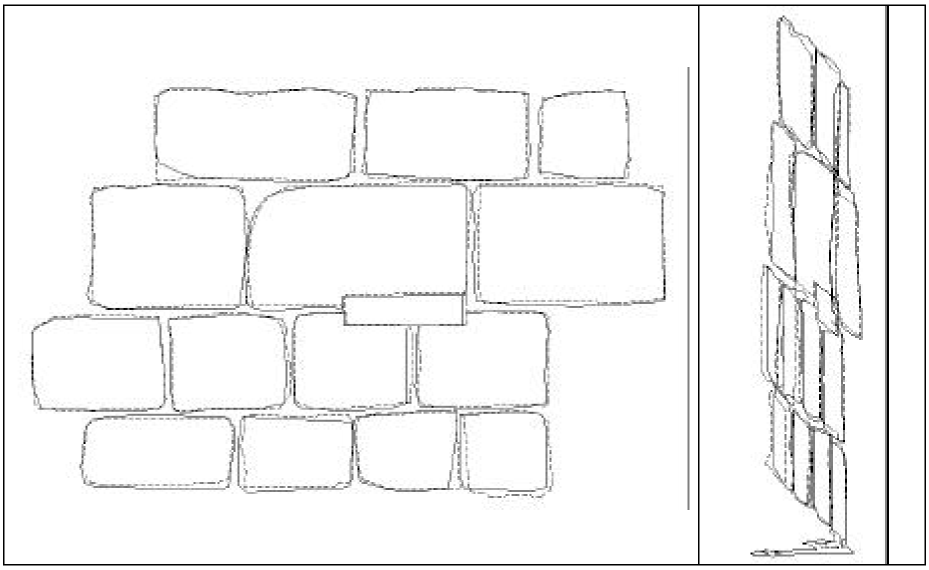


Figure 7. Detail of stonework plotted in Photomodeler (Solid line is from Zeiss P3 plot).

The test area was plotted in this way in 55 minutes compared to 20 minutes in the Zeiss P3. As with 3D Builder, several problems were encountered during plotting. The shape of a stone can look very different on each image due to the different viewing angle, so it is often difficult to pick out conjugate points. With the oblique images, some detail is also hidden from view. It was often difficult to pick out the edges of the stones from the surrounding mortar due to the poor resolution of the 'zoomed-in' images and the lack of contrast between the two materials. As can be seen in Figure 7, the actual positions of the stones plotted in Photomodeler fit well with those plotted in the Zeiss P3 but the vertices of the edges are quite different. The number of detail points plotted was roughly equivalent to that plotted in 3D Builder.

5.5 Single image capability

Photomodeler allows detail to be plotted from a single image but this can only be done if the image has previously been orientated in a multi-image project. Also, the plotted detail is assumed to lie on previously created triangular surfaces. Two images with marked fiducials and control points were processed to orientate the photographs. As the area of wall appeared fairly flat in the area to be plotted, it was decided to cover the area with just two triangular surfaces (the vertices of each being corners of the stones at the extremities of the test area). The vertices were referenced together on both images. Detail was plotted from the 'normal' case image using the 'Surface Draw' feature and it was relatively quick and easy to plot the perimeter of each stone. However, as before, it was sometimes difficult to pick out the edges of the stones due to the poor resolution and the lack of contrast. The accuracy of the single image detail should be poorer than that from the multiple images, since the detail is assumed to lie on the triangular surfaces. This may, however, be a suitable method of working on flat façades. A way of improving the accuracy would be to use many more triangular planes (e.g. two per stone).

6 EVALUATION OF DIMENSION

6.1 Background

The final software package for evaluation is Dimension produced in the USA by Kodak Limited. At a UK cost of £1 200 this is more expensive than the other software evaluated, but initial investigations have shown its potential for architectural recording. Analysis akin to that carried out on Photomodeler and 3D Builder is underway and will be reported at the ISPRS Congress. Further details on Dimension can be found at Kodak's URL www.kodak.com.

7 DISCUSSION AND CONCLUSIONS

The initial results of this investigation are encouraging. The accuracy and precision attainable with the software packages used clearly rival those of analytical measurement. This is in spite of the fact that site constraints on photography mean that the full benefits of performing a multi-station convergent survey have not been fully exploited.

However, even though the convergent photography has provided better geometry, the use of 'normal' case stereophotography has been found to be a real advantage in architectural recording of this kind. Findings indicate that it is not feasible, on the basis of difficulty and time taken, to record with these packages the same level of detail as the Zeiss P3 operating in stream digitising mode. The time taken to plot the 14 stones with the Zeiss P3 was just 30% of that taken with the packages and a much higher resolution plot resulted.

On the basis of these initial tests (precision, accuracy and suitability to purpose), the favoured package for architectural recording is Photomodeler but all the packages proved to be user friendly and could be used by non-photogrammetrists. Add to this the fact that the packages are relatively inexpensive and the prospect of opening up photogrammetry to new users in many different fields emerges. Such users however should be wary – only by using several 'cheats', for example to input the camera calibration data, did 3D Builder provide a suitable level of accuracy for this work - and treating the packages as black box technology could easily result in erroneous measurements.

Further work is proceeding but these initial findings are presented here in the hope that other users will find them of interest.

REFERENCES

Bottrill, A., Peirson, G., Taylor, G., Parsley, S. and Thomas, P., 1998. 3D modelling of structures - new v traditional methods. *Surveying World,* 6(5), pp. 22-25.

Bryan, P.G., 1998. Standard specification for image based metric survey. *English Heritage* (Unpublished), 41 pages.

Hanke, K., 1999. Accuracy Study Project of Eos Systems' Photomodeler.
http://www.eossystems.com/study/study3.htm (27 March, 2000).

Mills, J.P., Newton, I. and Twiss, S., 1997. Photogrammetry from archived digital imagery for seal monitoring. *Photogrammetric Record,* 15(89), pp. 715-724.

Thomas, P.R., Mills, J.P. and Newton, I., 1995. An investigation into the use of Kodak Photo CD for digital photogrammetry. *Photogrammetric Record,* 15(86), pp. 301-314.