Association *of* Archaeological Illustrators & Surveyors

Technical Papers

ASSOCIATION *of*
ARCHAEOLOGICAL
ILLUSTRATORS
& SURVEYORS

AAI&S TECHNICAL PAPERS

The Association has had requests from both individuals and organisations for a chance to obtain Technical Papers which have sold out. This folder has been compiled using photocopies of AAI&S Technical Papers 1-7 (edited by Richard Bryant). These papers are now out of print although some are presently under revision.

The reader should be aware that some of the advise is now very dated particularly as work on information technology and computer aided design has advanced at an enormous pace. However even the old information is of considerable interest in the history of archaeological illustration in general and of the Association in particular. Paper 4 was a joint publication with IFA (their Paper 10) and was assigned this number at a later date as Technical Paper 4 was never produced
The papers are as follows:

1. **The Preparation of Archaeological Illustrations for Reproduction**
   by A.S. Maney (1980)

2. **Computers in Archaeological Illustration**
   by J.D. Wilcock (1982)

3. **Drawing Ancient Pottery for Publication**
   by C. Green (1983)

4. **Preparation of Artwork for Publication**
   by C. Philo and A. Swann (IFA Technical Paper 10 1992)

5. **The Archaeological Illustrator and the Law of Copyright**
   by M. Vitoria (1984)

6. **Photogrammetry & Rectified Photography**
   by R.W.A. Dallas (1981)

7. **Drawing for Microfiche Publication**
   by R. Bryant (1984)

Mélanie Steiner (Technical Papers Editor 1999)

added 2006

12. The Survey and Recording of Historic Buildings
by David Andrews, Bill Blake, Mike Clowes and Kate Wilson

THE SURVEY AND RECORDING OF HISTORIC BUILDINGS AND MONUMENTS:

by David Andrews, Bill Blake, Mike Clowes and Kate Wilson

(Technical Paper Editors: Barbara Hurman, Mélanie Steiner)

ASSOCIATION OF ARCHAEOLOGICAL ILLUSTRATORS & SURVEYORS

OXFORD 1995

Cover illustration:
Fountains Abbey, West Guest House,
Photogrammetric base survey.

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The Association of Archaeological Illustrators and Surveyors is a professional body, formed in 1978 to encourage through its activities a high standard of archaeological illustration and surveying, and to establish a code of professional conduct.

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COVER DESIGN and TEXT TYPESET by Mélanie Steiner.

ASSOCIATION OF ARCHAEOLOGICAL ILLUSTRATORS AND SURVEYORS

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Preface

This paper has been written with the purpose of updating the Technical paper on Photogrammetry and Rectified Photography published by the Association in 1980. Additionally we intend to introduce the reader to some of the current building survey techniques and methods of recording standing buildings being used and developed by members of English Heritage staff. It is assumed that the reader has some knowledge of the principles of building survey but would also welcome additional information on the processes, applications and methods discussed here. This is by no means a comprehensive discussion of all the techniques available for the survey and recording of historic buildings and monuments. There already exists a large body of published material on this topic and the reader is referred to the bibliography at the end of this paper for further reading.

The paper consists of four parts, each one written by contributors directly involved in their individual field of expertise.

Part I: Photogrammetry
MIKE CLOWES

Part II: Rectified Photography
DAVID ANDREWS

Part III: The Non-Photographic Survey of Historic Buildings and Monuments using CAD and EDM without Reflectors
BILL BLAKE

Part IV: The use of Digital Data for the Archaeological Recording of Historic Buildings and Monuments
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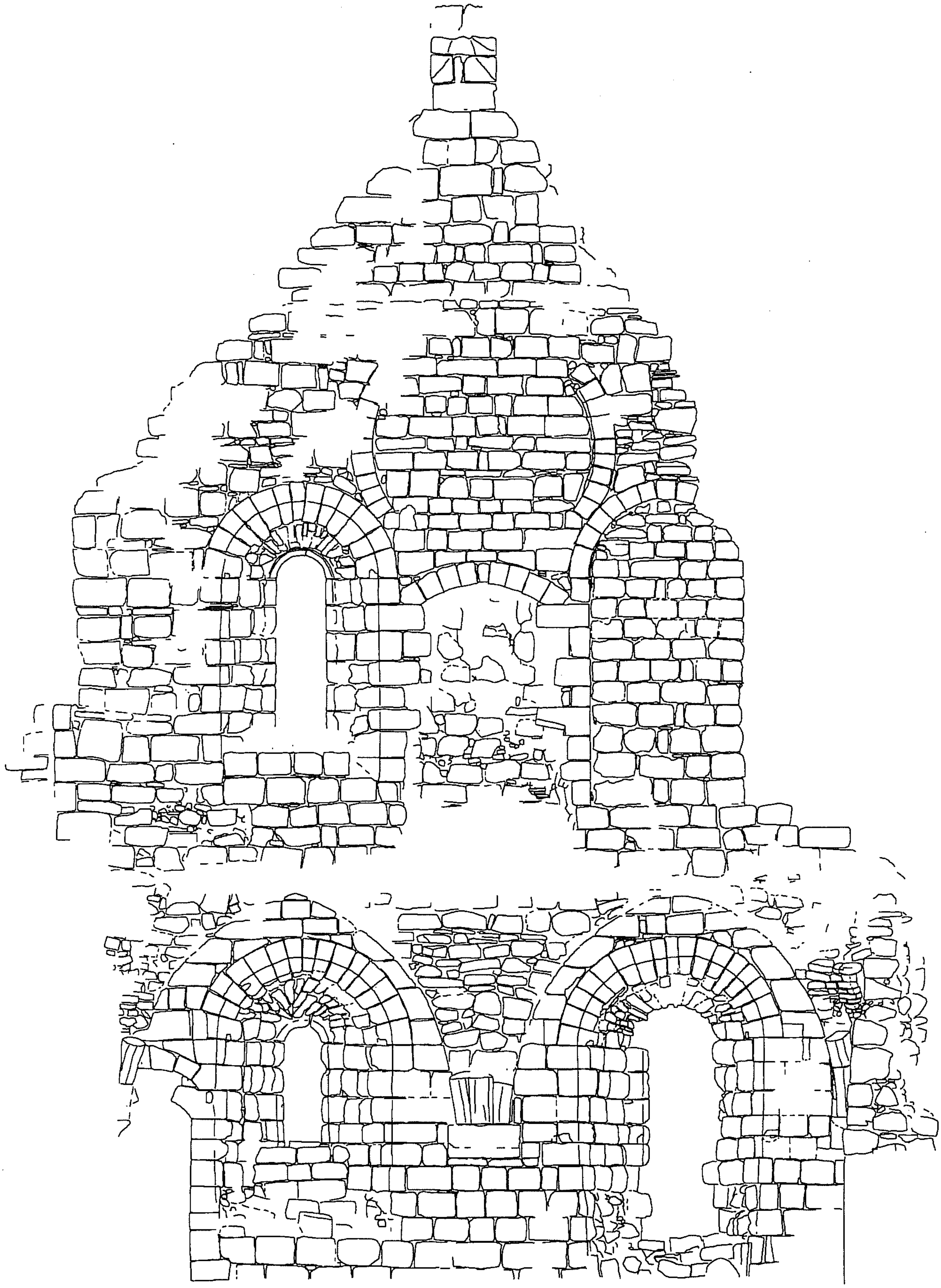

Figure 1. Fountains Abbey, West Guest House, west wall interior. Photogrammetric line drawing. Original scale 1:20

Part 1 : PHOTOGRAMMETRY

Introduction

The recording of historic monuments and building facades with the aid of photographic images is increasingly being utilised by architects and archaeologists. However, because the single photographic image is a perspective view of the subject, accurate measurement of points within that image are not possible because of inherent image displacements and distortions. Image displacements in photographs are due to the tilt of the camera and variations in the depth of the subject being photographed. Distortions are also caused by the camera lens and dimensionally unstable paper or film emulsion.

Photogrammetry is the technique that overcomes these problems by allowing precise measurements to be taken from a three-dimensional image using stereoscopic photography. Once this image has been captured in the field, scaled line drawings of elevations, vertical sections and plans can be easily produced (Figure 1).

The advantage of using photogrammetry over conventional hand survey is its speed and accuracy, especially over large and complex structures. The fieldwork is completed very quickly with a minimum amount of contact with the subject and produces a photographic record which captures the image as three-dimensional data.

Fieldwork

The photograph is normally obtained using a metric camera (Plate 1) as opposed to a conventional or non-metric camera. These are cameras of precise construction with virtually distortion free lens elements. The camera will be calibrated by the manufacturer and the distortion characteristics of the lens and the precise focal length of the camera provided. *Fiducial marks* appearing in the focal plane of the camera and on the image allow the film to be accurately located within the photogrammetric plotter.

The building facade to be recorded is photographed in such a way that the same detail is photographed from each camera station to form the *stereo-model*. The facade may be

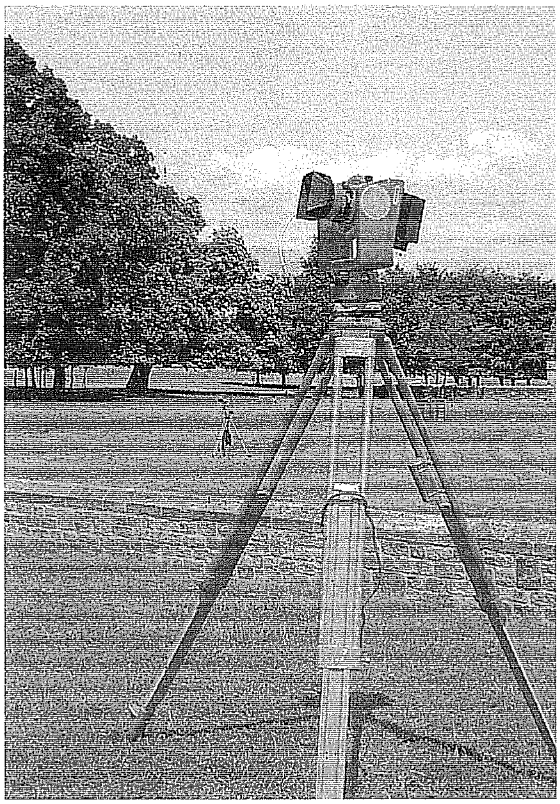

Plate 1. Metric cameras. Wild P31 100mm focal length camera (foreground), Zeiss UMK 300mm focal length camera (background)

photographed to form a single stereo-pair or a series of overlapping stereo-models depending on the size of the elevation or the required scale of the final drawing. In order to stay within the accepted standards of accuracy for a photogrammetric survey, the ratio between the photograph scale and the final drawing scale should not exceed 1:6. Therefore using a camera with a 100 millimetre focal length and a desired final drawing scale of 1:50, it would be possible to set the camera up 30 metres from the facade and achieve a 1:300 photograph scale. Photo scales greater than 1:200 would not normally be used for a 1:50 plot.

Locating the camera positions is most important to provide the appropriate stereo overlap. Whenever possible the photographic base line for the stereo-pair is made parallel to the plane of the facade and with no tilt of the camera. Where the full height of the elevation cannot be covered in a single photograph it is necessary to tilt the camera up or use a scaffold tower to raise the position of the camera.

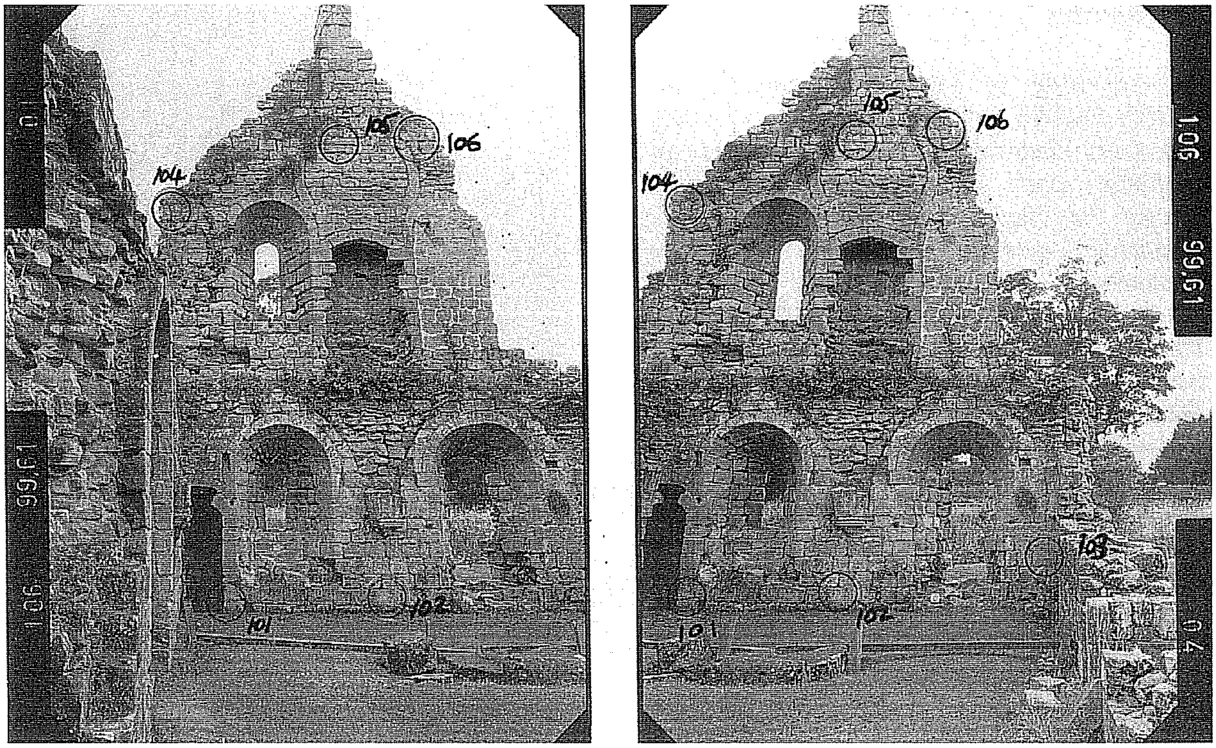

Plate 2. Stereo-pair. Fountains Abbey, West Guest House, west wall interior. A pair of overlapping photographs forming the stereo-model showing the positions of the survey control points on the elevation.

A framework of control points is essential on the building facade to which the stereo-model will be fitted. These are normally targets stuck on the face of the wall or points of detail which are accurately surveyed to provide a three-dimensional co-ordinate value for each point. Each stereo-model will normally have three or four control points to provide an accurate fit for the model. These control points are also used to accurately reference individual stereo-models to one another, over the same building facade where necessary. (Plate 2)

Stereoplotting

A number of different photogrammetric instruments are available for the plotting of detail from the stereo-model. The aim of the plotting machinery is to set up the pair of photographs to replicate the exact positions they were taken from in the field. These instruments fall into one of two categories: analogue or analytical plotters.

Analogue plotters are the older traditional instruments which form the stereo-model by optical and mechanical means. The setting up of the stereo-model is generally carried out empirically by the operator. These instruments are normally constrained by the degree of freedom allowed restricting the amount of acceptable tilt in the photograph.

Analytical plotters are the latest generation of instrument and form the stereo-model under computer software control. They are more versatile, more accurate, have a wider range of functions, and there is less restriction to the amount of camera tilt allowed.

The photogrammetric operator forms the stereo-view using film diapositives positioned on the instrument's plate carriers. These are observed through the eye-piece of the instrument (Plate 3). The photographs are accurately aligned relative to each other to produce the three-dimensional view and the positions of the control points established, so that the stereo-model is at the correct scale. In the centre of the field of view is a small measuring mark called a "floating mark" which can be manipulated by means of the handwheels and footdisc or a free-hand cursor. When looked at in the stereo-image this mark appears to float on the image and the operator traces

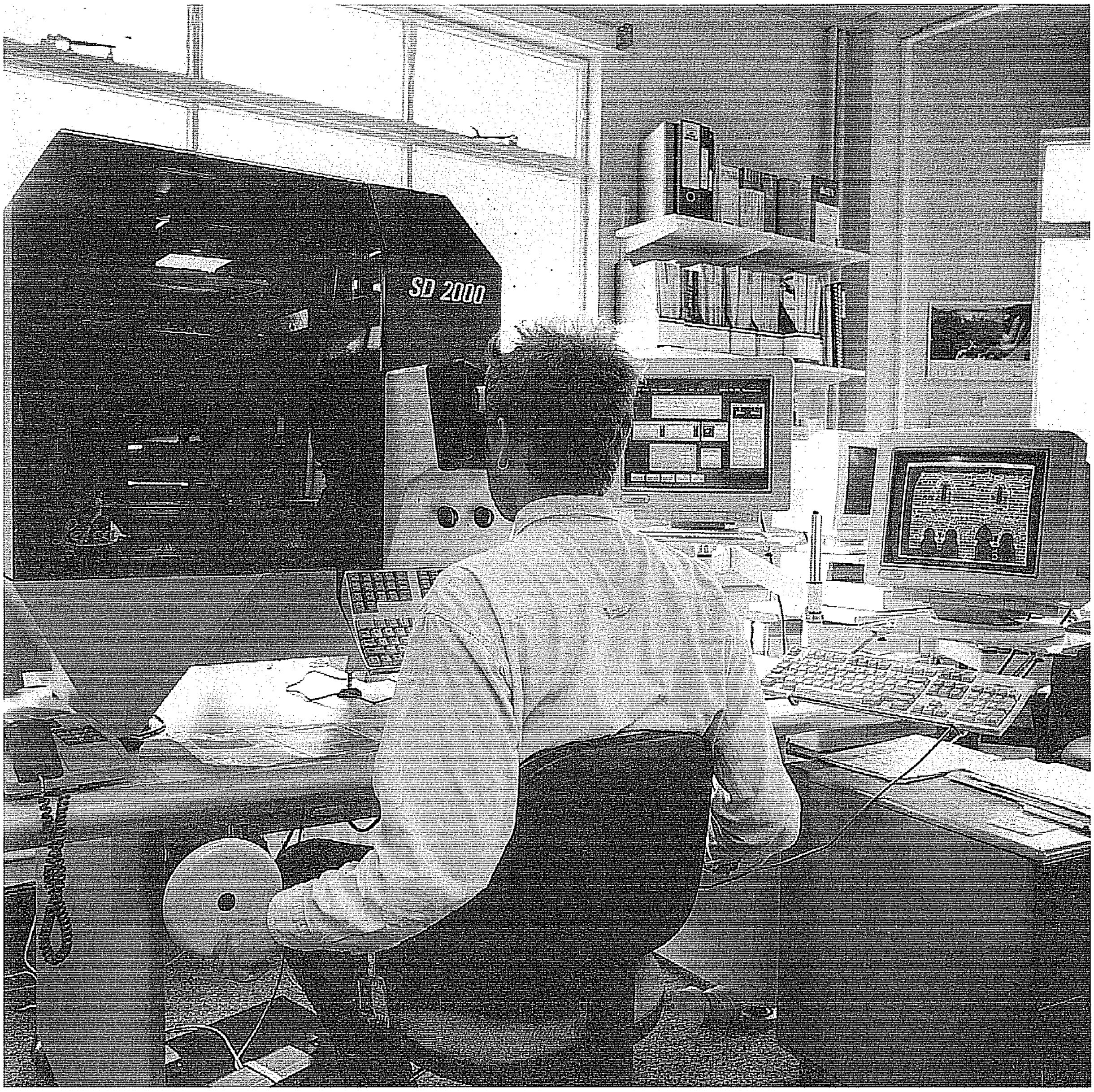

Plate 3. Leica SD2000 analytical stereo-plotter.

around any feature that is to be recorded adjusting the floating mark so that it is always sitting on the surface of the feature. Photogrammetric data is captured three-dimensionally so care should be taken to ensure that features are faithfully recorded. Failure to keep the floating mark on the surface of the feature will result in positional errors of detail. The operator then works systematically across the stereo-model, recording all the information that is required. This data is normally recorded digitally, directly into a computer aided drafting *(CAD)* software program such as AutoCAD and Microstation, or a photogrammetric mapping package such as Kork and CADMAP.

Although the majority of architectural plotting is fairly straightforward, the accuracy is dependent on the skill and experience of the operator. In particular sufficient points should be taken during plotting to accurately define the various features being recorded on the building facade. Plotting parameters and recording modes should be appropriate for the type of detail being recorded. Where straight lines or smooth regular curves are encountered then point by point recording modes should be used. Where the feature is irregular, then a *stream digitise mode* should be used. Architectural features should whenever possible be recorded as *polylines* and closed polylines.

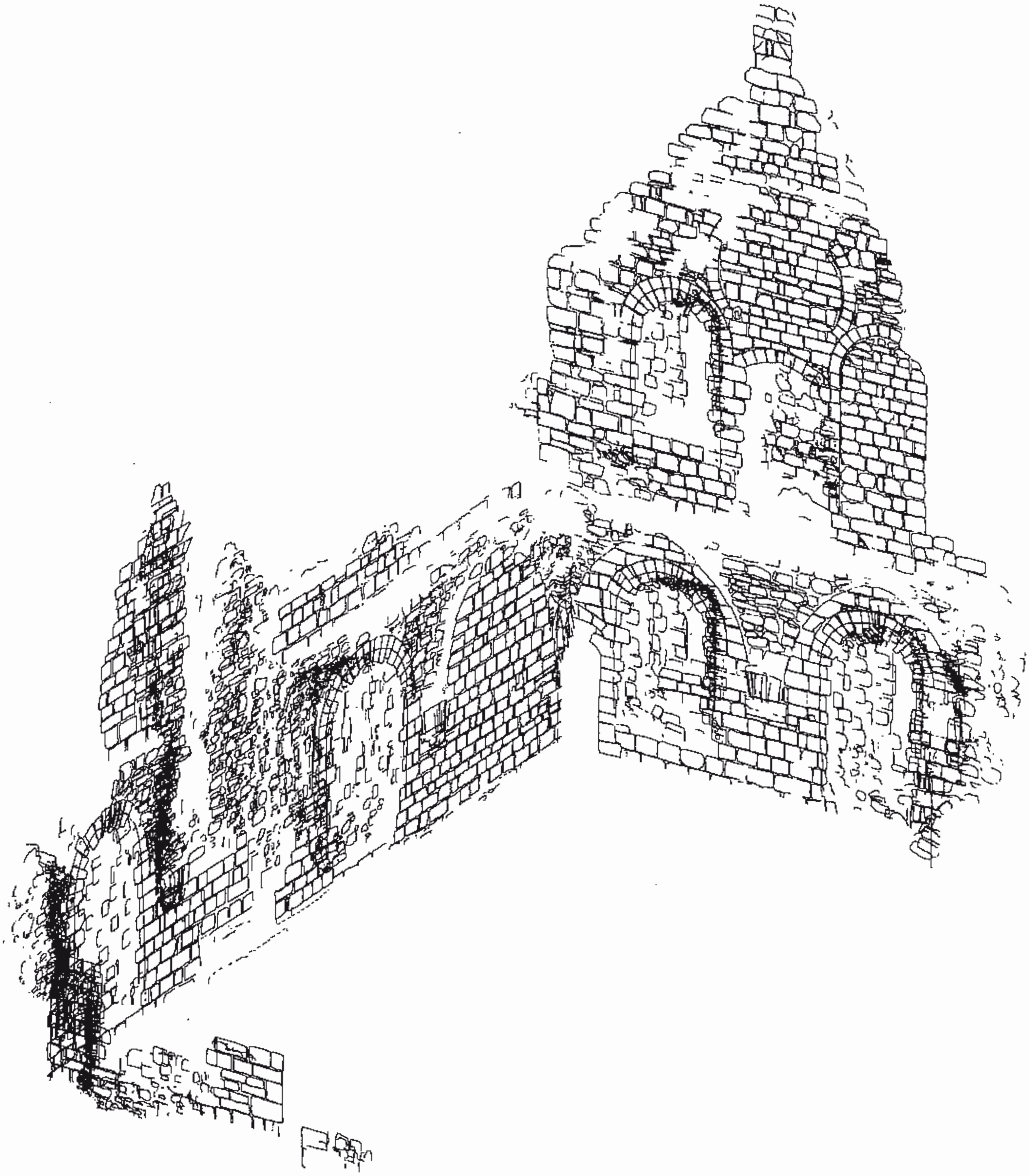

Figure 2. Fountains Abbey, West Guest House.
Isometric projection derived from 3D photogrammetric data.

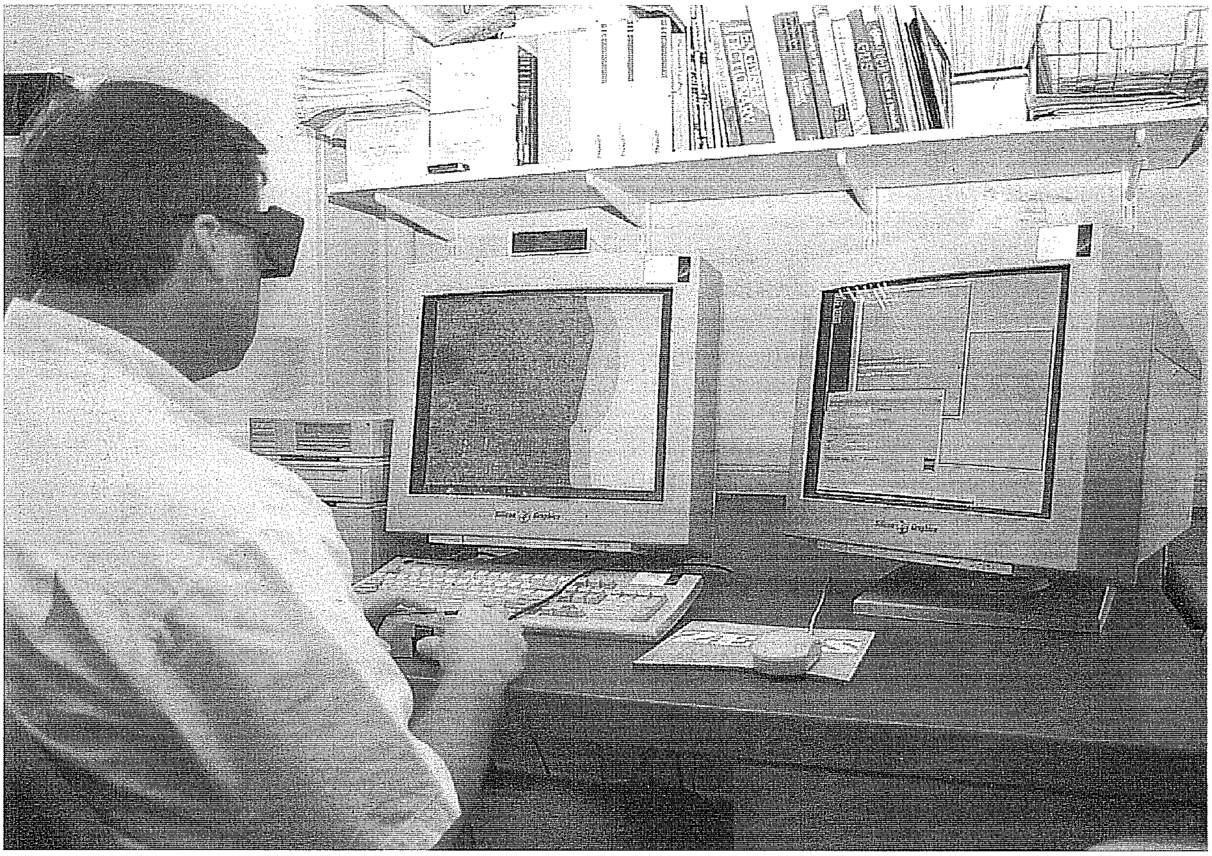

Plate 4. Zeiss Phodis ST 30 Digital Image Workstation.

Current projects within English Heritage, where photogrammetry is being used as part of the building survey include work at St Mary's Church, Studley Royal; Whitby Abbey within the Whitby Headland Project and at Windsor Castle to record the pre and post fire damage.

The capture of photogrammetric drawings as three dimensional *digital data* has enabled CAD manipulation of the data. Views of the structure from various angles can be created with ease, and a series of isometric or perspective drawings created from the one data set (Figure 2).

Conventions also exist for the *layering* of digital photogrammetric data when recording historic buildings allowing for further manipulation by the end user (Appendix A).

Recent developments

The introduction and development of digital imagery to photogrammetric technology has produced a number of new and exciting developments. Such techniques are currently being applied to Stonehenge, a World Heritage Site, to produce a complete three dimensional record of all of the stones. The digital images making up the stereo-models are acquired by *scanning* the original photographic negatives at resolutions of between 7-25 microns. These images are then transferred to a digital photogrammetric workstation where the stereo image is formed and viewed in 3D on a high resolution monitor using *polarising or liquid crystal glasses* (Plate 4). Once established, data captured from the stereo-model can be performed manually or by means of an automatic point extraction mode which works on the principle of matching corresponding *pixels* from the left and right images. In this mode three dimensional co-ordinates of points forming a closely knit mesh are determined automatically. The digital workstation is capable of measuring at an average rate of approximately 100 points per second. For Stonehenge, points are being measured at a 20 millimetre spacing to accurately model the irregular surface of each stone. Data output can be in the form of points to which a surface model can be fitted or contours which are created automatically by the workstation. This information could then provide the framework for the production of a *virtual reality* model or the creation of a replica solid model of the monument.

Digital orthophotographs (an image that has had scale and tilt errors removed) can also be derived from the original digital images. Surface point information is computed to generate the orthophotograph. This can be output as a raster file for monitor display, or for the production of paper or film *hard copy*. Research into the application of this technology is currently being undertaken for the recording of medieval floor tiles and Roman mosaic floors. The surface information generated should also prove useful for monitoring damage and weathering patterns over time.

High resolution digital cameras are currently being developed which will negate the need for any photographic processing. A digital image data file is captured by the camera and stored on disc or tape. The file can be downloaded into the image workstation for data extraction.

The potential and benefit of working with digital imagery has yet to be fully exploited, but the variety of possible applications can only enhance the recording process.

Part II: RECTIFIED PHOTOGRAPHY

Introduction

The term rectified photography is usually applied to aerial photographs which have had any errors, due to camera tilts, removed using a rectifying enlarger. In the world of architectural and archaeological recording we use this term to describe photographs which have been taken with the negative plane as near parallel to the facade as possible. This single photograph method is often used as a cheaper, but less accurate alternative to photogrammetry and although subject to a number of limitations, the end product does have some advantages over a photogrammetric plot (Plate 5).

Theory

A photograph of a completely flat facade, taken with the negative plane exactly parallel to it, using a distortion free lens, could be used as an accurate image of the facade. Most photographs, however, do not comply to the above criteria and therefore contain errors due to one or all of the following:

1. Displacement of the image as a result of a change in the depth of the facade (Figure 3a).
2. Changes in scale due to changes in the depth of the facade. Objects or features further away from the camera will appear smaller.
3. Changes in scale because the negative plane is not parallel to the facade (Figure 3b).
4. Distortion of the image due to imperfections in camera or enlarger lenses.

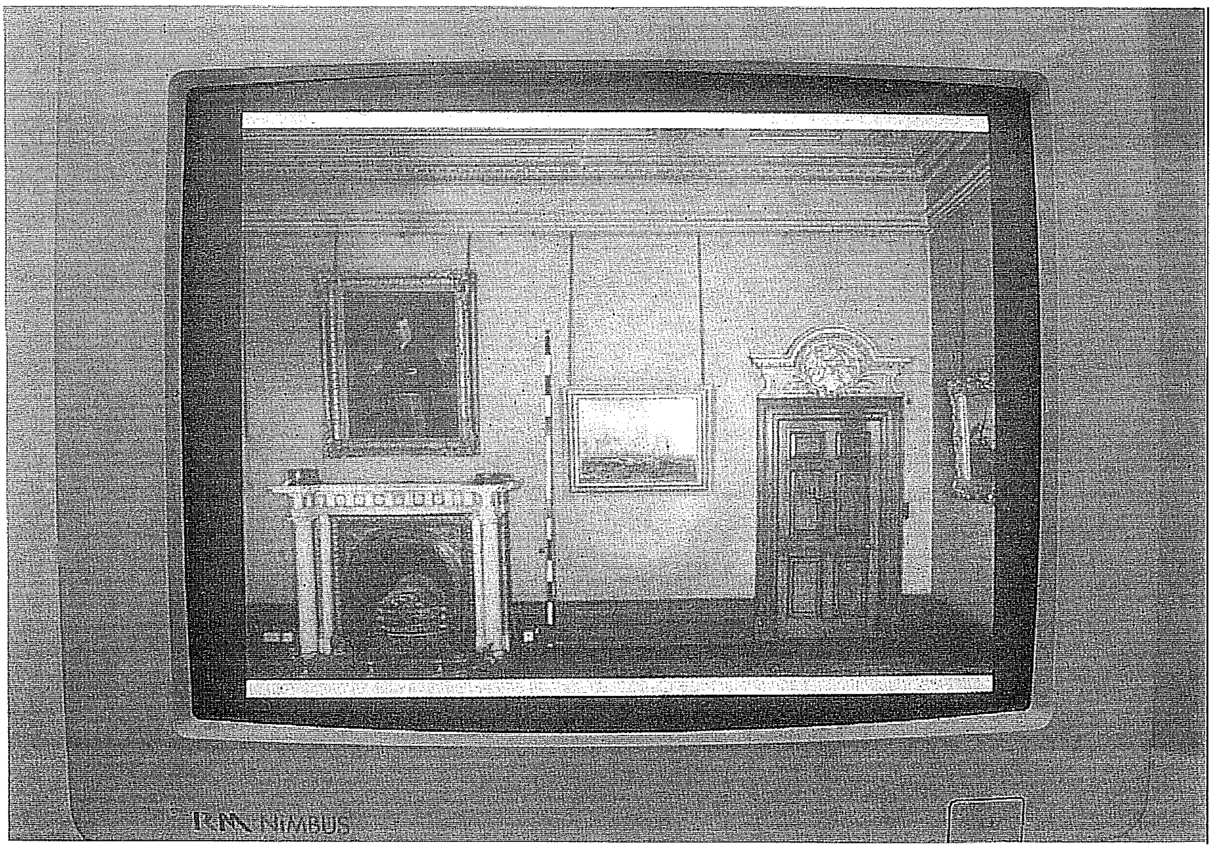

Plate 5. Rectified Photograph.
This typical rectified photograph has been scanned and is displayed on a computer screen.

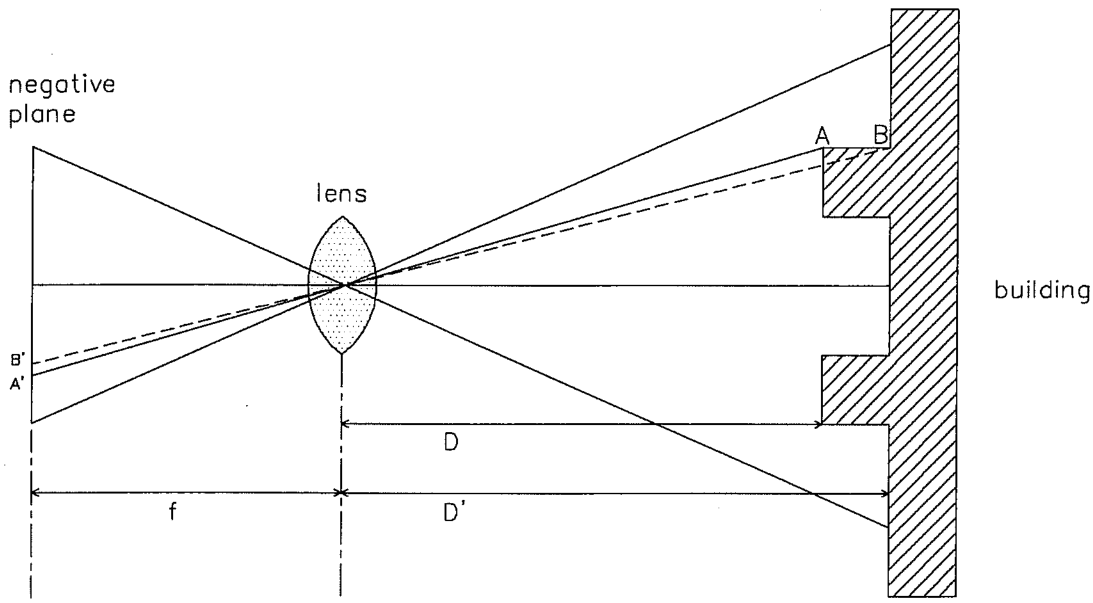

Figure 3a. Perspective Projection. Due to the perspective projection, points A and B which have the same two dimensional position on the facade are imaged at different positions on the negative ie. A' and B'. The scale of the negative is the focal length (f) divided by the facade distance (D). The front face of the buttress is therefore at a larger scale than the main facade, since D is less than D'.

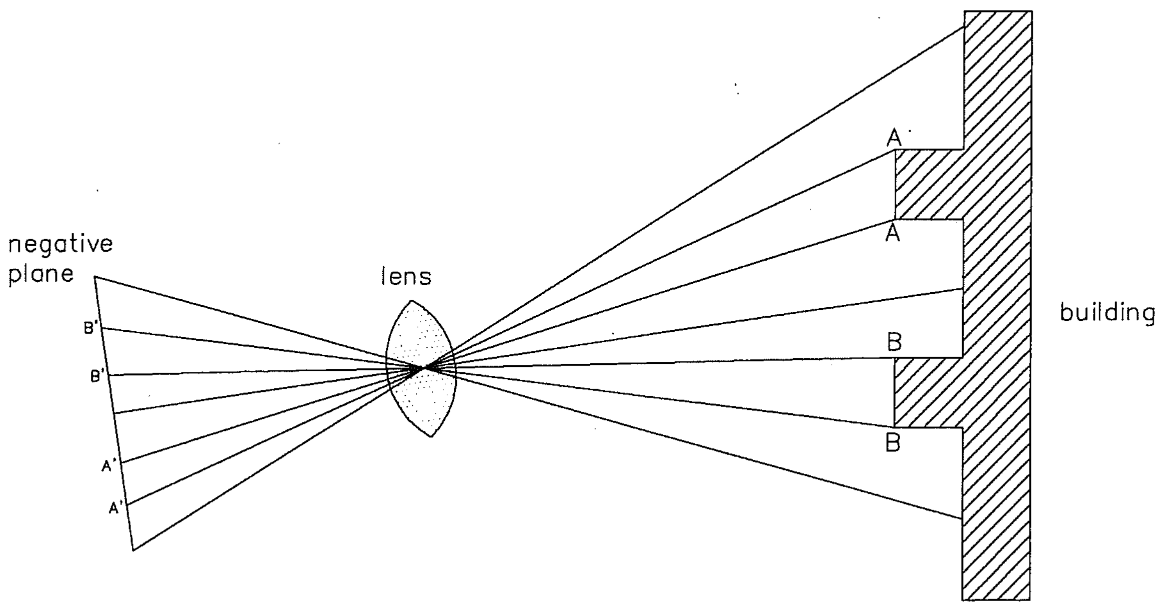

Figure 3b. Lack of Parallelism. Where the camera is not parallel to the facade there is a scale change across the negative plane. The distances AA and BB on the facade are the same, whilst on the film, A'A' is less than B'B'.

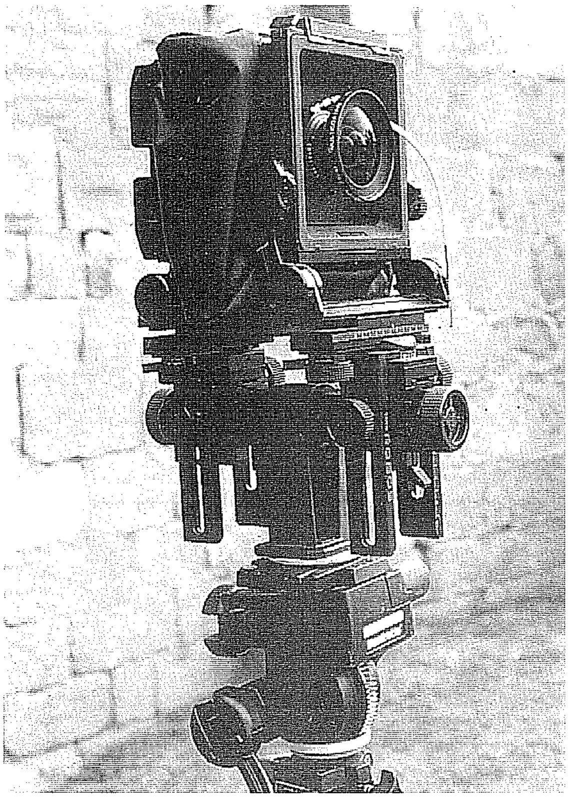

Plate 6. Monorail Camera. The rising front and other movements make this type of camera very useful for rectified photography.

To minimise these problems care must be taken with both the application and practice of rectified photography. The subject matter must be a relatively flat facade or one that can be easily broken down into a number of flat facades. For instance a facade that contains projecting buttresses should be broken down into the wall and the buttresses to produce photography of each element of the facade that appears on a different plane. Good procedure and high quality equipment will lessen the likelihood of errors in scale and distortion.

Fieldwork

The English Heritage Photogrammetric Unit usually uses a 5" x 4" format monorail camera with a choice of 150mm or 90mm focal lengths (Plate 6). The rising front and other movements of this camera are used to avoid tilts.

Occasionally photogrammetric cameras are used where a combination of products is required. These cameras have high quality lenses with minimal distortion. A scale must be provided within the image using either a scale bar placed against the wall or targets stuck to the wall. The positions of the targets are usually co-ordinated using *theodolite* intersection. To save time and money, but at the expense of accuracy, it is possible to simply measure the various distances between the targets using a tape.

To achieve parallelism in the vertical plane a bubble is used to level the camera. The bubbles found on many photographic tripods are not sufficiently accurate for the process so a small spirit level is usually employed. Achieving parallelism in the horizontal plane is more complicated. An *optical square* can be used or a system of triangulation with tape measures. English Heritage use a method which requires the camera to have a ground glass back with engraved grid lines. A metre long spirit level is placed horizontally against the facade and levelled up. The photographer then looks through the camera and rotates it from side to side (Plate 7). In this way he is able to judge when the spirit level is parallel to the horizontal grid lines and thus the negative plane parallel to the facade. For this method to work, the spirit level must be well above or below the camera axis.

In order to produce prints with a high level of detail a great deal of care must be taken over the exposure of each photograph. For best results a *spot metre* and professional flash system are required. Indeed for most interiors this sort of equipment is essential if anything is to be achieved. Some subjects such as floor tiles and wall paintings necessitate the use of colour film. Here exposure is even more critical as colour balance must be maintained. The use of a colour chart can be beneficial to aid the printing process and ensure that an accurate colour representation is produced.

Printing

For printing an enlarger fitted with a Multigrade filtration head is used. This system will correct the grade and exposure for Ilford Multigrade III paper. Where a scale bar or taped distance between two targets have been employed, a scale ruler is placed on the base board of the enlarger to scale the print by reading off from the required scale. When the

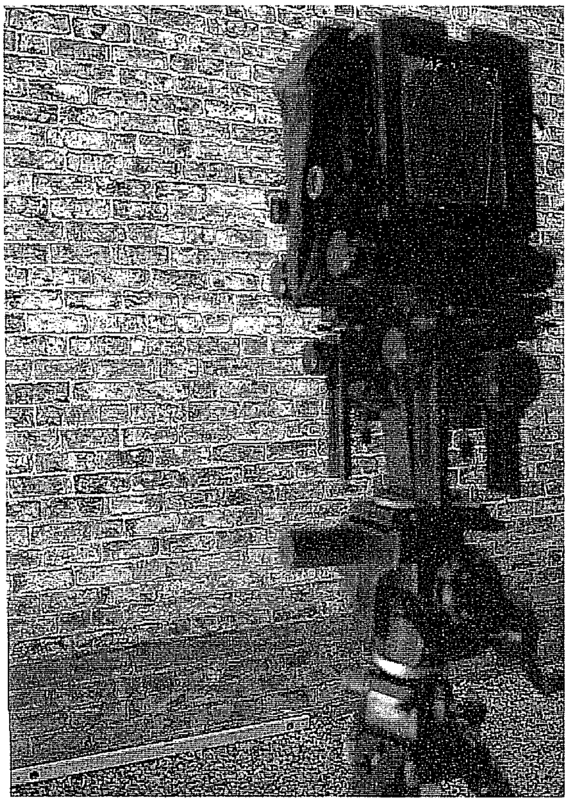

Plate 7. Camera Setup. The spirit level is used to help achieve parallelism between the camera and the facade.

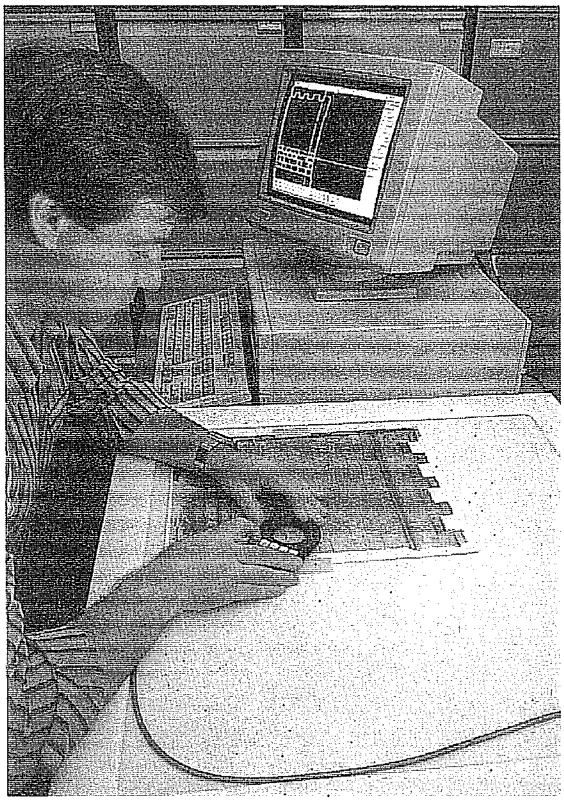

Plate 9. Digitising. Line drawings can be produced from rectified photographs by digitising into a CAD system.

targets have been co-ordinated by theodolite, a plot of the targets at the correct scale is produced on film. This is placed on the base board of the enlarger and the photographic image fitted to the plot. Small distortions caused by camera tilt are removed by tilting the base board. If a number of different planes appear in one photograph the negative can be printed several times with each print fitted to the control specific to that particular plane. The resulting prints can then be fitted together to form a complete mosaic. Similarly a large facade can be covered by a number of photographs and a *mosaic* constructed (Plate 8).

Black and white prints are processed using an automatic print processor in order to ensure the required archival standard is met. When hand printing it is very important to use the correct "fix" and "stop" times. Colour printing will often require the services of a professional processing company. The scaling process is exactly as for black and white work.

The product and recent developments

Rectified photography provides a scaled image of a building's elevations. The accuracy of the scaling will depend on the flatness of the facade as well as the competence of the photographer. Although the image may not be as easy to read as a line drawing, a great deal of valuable textural information is contained in the photograph, for example, the condition of the stone or surface textures such as tooling or weathering.

Where a facade is generally flat, but contains a number of three-dimensional features, such as windows and doorways, a composite product can be useful. This involves plotting a line drawing of the features photogrammetrically then printing the rectified photography to fit the line drawing. Reprographic techniques can then be used to print the photographs and line work onto draughting film. During this process a

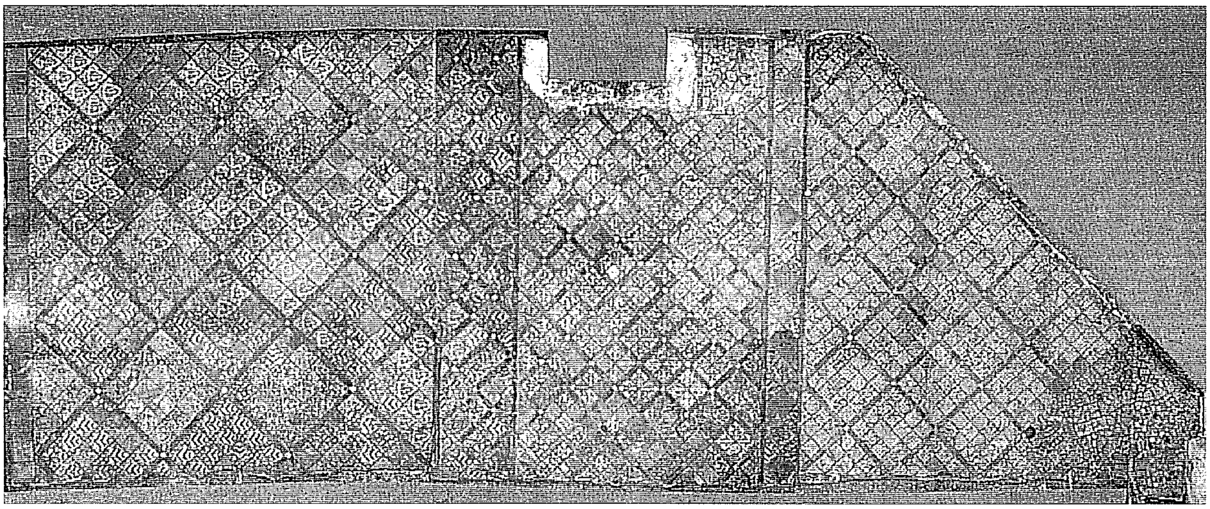

Plate 8. Mosaic. This image of the tiled floor at Cleeve Abbey, Somerset was produced by fitting together several photographs to form a mosaic.

"screen" of about 130 dots per inch is usually introduced, so that the final image on film can be copied satisfactorily using *dyeline techniques*.

If a line drawing is required this can be traced, using ink on film, from the photographic prints. A computer aided drafting (CAD) file can also be produced by digitising detail from the photograph (Plate 9). In this case it may not even be necessary to print the photographs to scale, as most CAD packages have a *transformation facility*. This is normally used when digitising conventional drawings from distorted paper plots but can equally well be applied to rectified photographs. When producing a line drawing it is advisable to make clear to the end user that the image was obtained from rectified photography so that they know any potential sources of error.

Developments in this field have produced a number of computer programs for creating line drawings from single photographs, including for example FOTOMASS. These programs allow the use of photographs with quite considerable tilts. They rely on the availability of sufficient control points to define the working plane. In addition, if the depth of a plane parallel to the main plane is known, scale and displacement errors can be corrected. The increasing use of digital workstations means that photographs of building elevations can be scanned and manipulated to produce accurate scaled images. It must be stressed however, that these software programs will not produce the quality and accuracy offered by conventional rectified photography without the input of a thorough survey coverage of control points for the building facade.

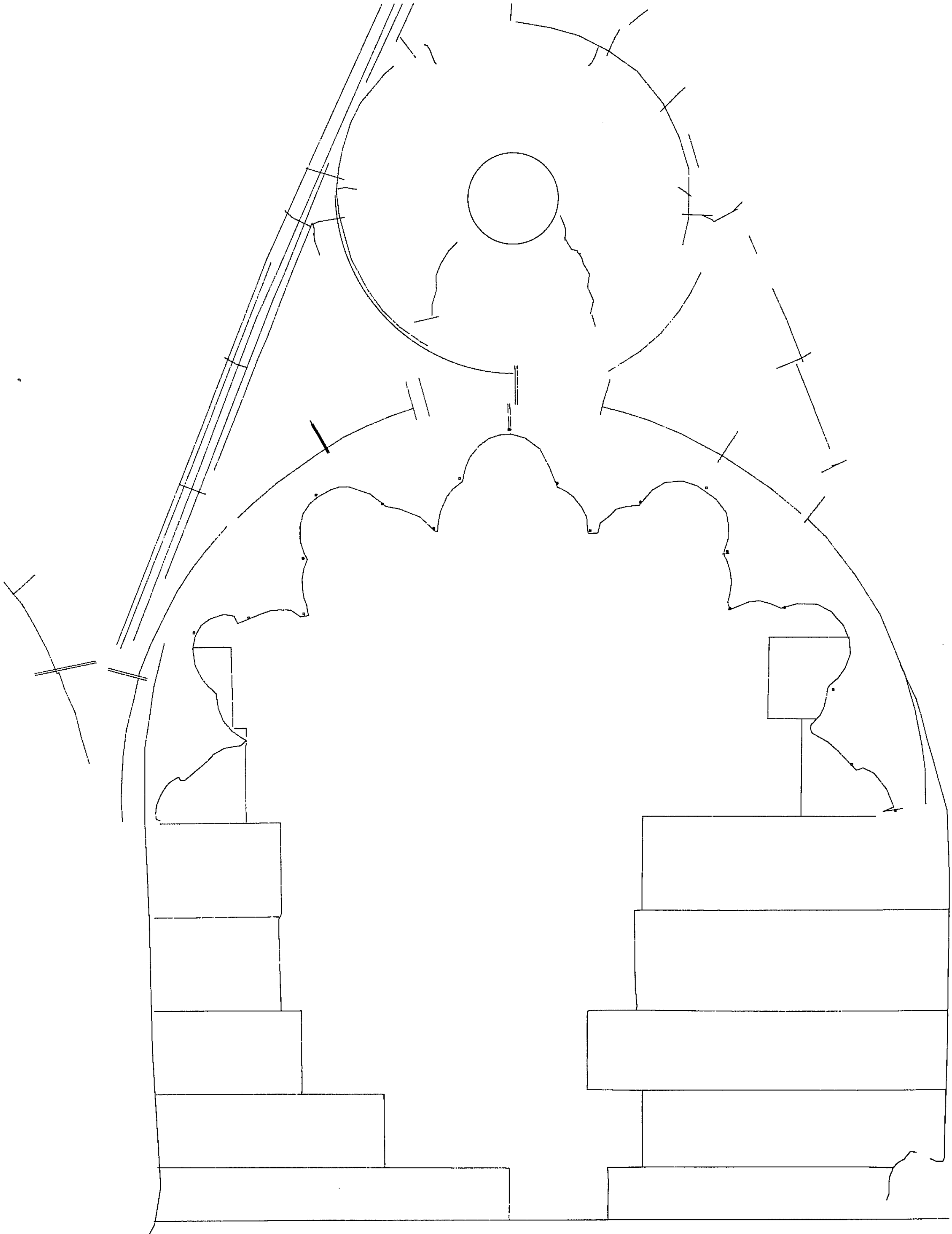

Figure 4. Wire frame of tracery at Greyfriars Church, Great Yarmouth. The restricted range of 1.2 metres limited the use of photographic techniques; REDM was used to form an armature for subsequent measured drawing.

Part III : THE NON-PHOTOGRAPHIC SURVEY OF HISTORIC BUILDINGS AND MONUMENTS USING CAD AND EDM WITHOUT REFLECTORS

Traditional, non-digital methods of building recording.

Architectural survey of building plans, elevations, sections and sectional elevations has been traditionally carried out by measured drawing techniques. The control of measured drawing surveys at 1:50 and 1:20 is usually achieved by taped diagonals across individual rooms or areas of a building (known as cells). These are linked together by a traverse with key radial observations (usually to corners) running through the building. Heights are controlled by the use of a levelled datum which is transferred onto the elevation or section to be recorded. Plans of vaults, roofs and other overhead features require the use of a plumb line to project the information onto the plane of the plan.

Measured drawing in practice

1. Data collection

The field work is prepared as a set of annotated sketches or drawings giving dimensions of building components, their positions are tied to the control traverse or datum by taped measurement and booked onto the sketch as dimension lines. 35mm photography is often taken to support these notes and drawings.

2. Data presentation

These site notes are plotted to scale by repeating the measurement process (at the plot scale in miniature) on the drawing board in pencil, on a dimensionally stable material (usually cartridge paper) and then traced off as an ink on plastic film plot. The final drawing and the site notes form the data set.

3. Data format

The method generates a one-off scale drawing. This is not a problem if drawings are produced on a one drawing, one function basis but the ability to fit disparate data sets together and compare them is limited by the high cost of reprographic methods.

Digital methods as a new platform for architectural survey

CAD offers more to the user than looking at a drawing on a computer: the view can be rotated, dimensions can be taken to a high order of precision, analytical information can be overlaid and tested, and new views can be projected to reveal new aspects without redrawing. The drawing can be constructed in 3D or 2D and can be matched with positional data from a total station instrument, digital photogrammetry, digitised or scanned drawings.

Digital data collection

It is now possible to collect the framework or control of the survey of a building using surveying instruments such as a total station. This is a theodolite and distance measurer combined co-axially with a data recording device so that vertical and horizontal angles as well as a distance are recorded. The data can be stored as co-ordinates (easting, northing and height or x, y and z) or as polar co-ordinates (angle and distances) or sent to a data logger or computer for processing.

Digital survey in practice

Using a total station the data is logged as the surveyor points the telescope at a reflector placed on or above the target on the building face. The co-ordinates can be used to plot lines into CAD layers to describe the subject being recorded. This information can be inserted into a CAD drawing and fitted to data plotted into CAD from hand drawn notes. The precision of the fit can be taken to a far higher order in CAD than drawing board practice allows as there is no practical limit to the enlargement of drawings so positions can be fixed to a high order of precision.

Use of Electronic Distance Measurement (EDM) and total station instruments

The use of EDM in building survey is now a common method of preparing building survey drawing. The method requires the positioning of a correctly aligned *reflector* on or over the point to be recorded (eg. the edge or corner of the building) siting from a known station position and recording the reflector position on the data logger connected or built into the instrument. Usually the points recorded by the instrument are marked onto a field sketch which would be used much like a measured drawing tied to a control system by the recorded points. These points can be plotted by computor as a hard copy and the drawing completed on the drawing board. Alternatively, the field notes can be plotted into CAD creating a drawing file in which the data from the instrument is directly fitted to the results from the field notes.

The sequence of activity for survey is as follows:

1. Control is established after reconnaissance so that a traverse station is established in each room or cell of the building. This is usually linked to a traverse or control outside the building (often established for photogrammetric purposes).

2. Field drawings. The surveyor will prepare such drawings as are needed to show the position of details, and the control points marked as a cross (in red). The sketch will show the traverse station in the room and the ties used to position the walls of the room.

3. The principal dimensions of the room are measured by tape and instrument with the point numbers marked onto the field drawing as they are observed. The surveyor will use an assistant to hold the reflector in position over the points recorded. The offset distance (the distance between the point of measurement on the reflector and the subject being fixed) is recorded.

4. The survey progresses radially from the traverse station and any detail such as door and window plans are surveyed by annotated sketch.

5. The total station data is transferred from the data logger to the computer and into CAD. The plan of the recorded points, sometimes known as "join up the dots plot" is prepared and can be plotted onto plastic film for hand finishing or used in CAD as the basis for plotting the field notes to scale.

6. Hand drawn notes of the detail, such as full size profiles can be plotted at actual size and scaled to fit the survey in CAD either by digitising or by construction. This means that the survey can often be used at a larger scale than the plot scale and redrawing of details for different sets is not needed.

Why Reflectorless Electronic Distance Measurement (REDM)?

The problem with the survey of buildings by EDM is twofold. Firstly the position of the prism or reflector requires adjustment to record the true face of a wall, internal corners are particularly awkward. The distance from the measuring centre of the reflector to the wall face has to be taped and applied as a correction to the logged data, an unhappy solution as the instrument controlled points will form the framework for the survey. Secondly, many historic buildings do not fit well into the practice of a "join up the dots" method where the controlled points are not enough to fix curved or twisted shapes like roof timbers or the plans of a castle tower; positioning the reflector precisely over enough points proves difficult, costly and slow, the plots often looking spiky and in need of much editing.

The production of sectional drawings (ie. in a vertical plane) using a reflector has proved to be difficult especially when a pole is used to position it at high level, often two point intersection methods are used for high level points but this is a painstaking process needing two instrument observations for each point.

A solution to this is the use of the recently developed (1987) reflectorless EDM (REDM) which uses the building surface as a target. The REDM works in a similar way to the estate agents sonic tape but to millimetre tolerances by using a pulsed infra red laser beam to measure distances. The device is able to measure distances to most surfaces provided

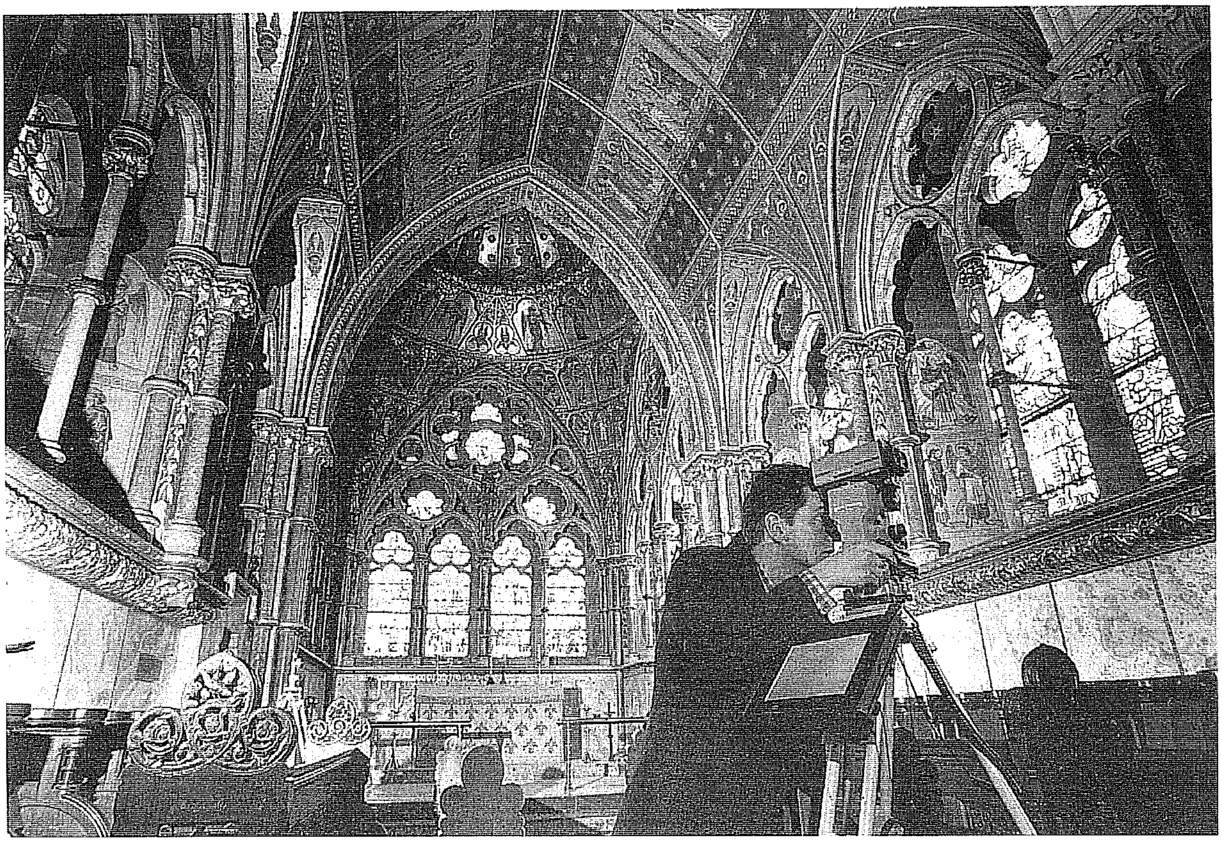

Plate 10. T1000 electronic theodolite with Leica 3002S REDM with realtime data logging to PenMap (Reproduced by kind permission of the Guardian. Photograph: Don McPhee)

there is adequate surface area to reflect the beam. When mounted to an electronic theodolite the combined devices (provided target conditions are met) can record the position of a point on a surface to plus or minus 3 millimetres in x, y and z.

Benefits of non contact measurement.

1. It provides outlines of difficult subjects.
The absence of reflectors means that the position of remote objects can be measured such as the surfaces of roof timbers, the soffits of tie beams, the ribs of vaults and even the centre lines of window tracery.

2. It is ideal for curved surfaces.
The measurement of curved surfaces in plan or section is simple, by using the surface of the building as a target the number of instrument recorded points can increase so that the surface profile can be mapped very precisely often to the point where no further editing is needed.

3. It is complementary to other digital methods.
The REDM is a high accuracy close range instrument allowing the survey of internal spaces to be recorded digitally; this allows the data to be produced in a CAD compatible form of areas too awkward for other digital methods such as photogrammetry.

4. It reduces access needs.
As the building surface is the target there is no need to use scaffolding or ladders to the degree needed by pure manual methods or by methods using reflectors.

5. It produces *3D wire frame modelling.*
Due to the fine beam width and precise pointing it is possible to trace the edges of a room as lines in 3D space to form a complete cell bounded by a line where the walls meet the floor, a line tracing around the openings, and a line where the ceiling meets the walls. Once the data is loaded into CAD it can be rotated to the desired view and used as a framework for fitting detail from field notes,

digitised rectified photography and photogrammetric data, typically of the outside envelope of the building.

6. It improves precision of building plans and sections. Using the outlines provided from the REDM the reliability and repeatability of the survey is improved over *taped triangulation* methods as the ambiguity of taped intersects is solved by the precision of data linked to the traverse.

Fieldwork: the reflectorless EDM (REDM) in practice

The instrument used by the survey team of English Heritage Survey Branch is the Wild Leica 3002s mounted onto a T1000 electronic theodolite (Plate 10).

The principal characteristics are:

* Beam width of 20mm at 30m
* Angular accuracy of 3" of arc
* Visible laser pointer 1mA, rated eye space at 0.25s
* Mean distance function from multiple targeting
* Communication to external data logger
* Batteries: 12v 7 Ah external
* Measurement time 0.3s
* Maximum obliqueness to target at c5-15m range 70deg

The data logger used is a Compaq Concerto 486 pc running PenMap software supplied by Strata Software in association with Leica UK.

The data logger used is of import because of the return signal characteristics of REDM devices. The return signal from the target is a mean distance between the surfaces of the target within the contact area of the beam. This means that as the beam is fired into a corner, the return beam is bounced off the two wall surfaces, thus generating two distances; the instrument records the mean of the two. As the angular information is all correct, the result is a small error in the recorded position inside the true corner. As the REDM traces across the surface of a wall the position of the wall is plotted onto the screen of the data logger as a line, at the point at which the signal is interrupted by poor targeting the error is plotted on the screen and is immediately visible.

As the plan or section progresses the surveyor can correct errors or omit misleading results as they occur whilst on site with the evidence present. The recording of edges is carried out using a simple card target if necessary or by using PenMap to converge lines surveyed. The survey is plotted to the screen as the points are collected. The surveyor can control the density of points needed by checking the plotted shape as it is recorded by increasing the number of points for curves and decreasing them for straights.

Real time display data logging using the REDM with PenMap software

The sequence of activity for survey is as follows:

1. The first task is to establish points of known value to form the control network of stations from which detailed recording will take place. The simplest form of control is the baseline orientated along the axis of the building using arbitrary co-ordinates, the instrument is set up over the station at one end of the line and sighted onto the station at the other end (the co-ordinates can be calculated by adding the horizontal distance along the line to the easting of the start point). The orientation information is fed into the data logger.

2. The layers for the drawing are set up in PenMap so that the views of the survey will be logical in CAD and a graphics type is selected such as line, point or arc.

3. The laser pointer is used to mark the points as they are measured, the surveyor will trace around the subject using the laser spot: at each change of direction of the line the instrument records the position by plotting it automatically onto the PenMap screen; this can be described as "drawing with a laser".

4. The view of the file can be switched to a vertical plane to show the section on the PenMap screen allowing the surveyor to select the edges and faces of the subject needed to produce both plan and section in the same exercise. To produce *sectional elevations* of a

vault the laser can be traced around the ribs of the vault and place each rib in its own layer so that they can be separated for each elevational view.

5. The survey drawing is saved as a PenMap file and written to CAD as a *DXF* to form a framework for the fitting of plots from hand drawn notes and digitised photography.

6. The framework can be plotted at 1:20 or larger and used to prepare site notes at scale. This allows for controlled drawing for detail to be drawn up and digitised.

7. The final drawings, after editing to correct layer and view errors, adding detail and text etc, are plotted in ink on plastic film from CAD as plans, sections or elevations (Figures 4-8).

Conclusion

The use of REDM has allowed the non photographic survey of buildings to advance from processes of difficult and slow data collection to an immediate and precise method. The value of the new REDM is only fully realised when monitored using a real time mapping system such as PenMap to produce CAD ready frameworks which form a control for detail from manual or photographic methods.

In the same way that CAD has provided us with an assembly platform for drawing components, the framework from REDM is a further tool in the array of techniques for problem solving in survey.

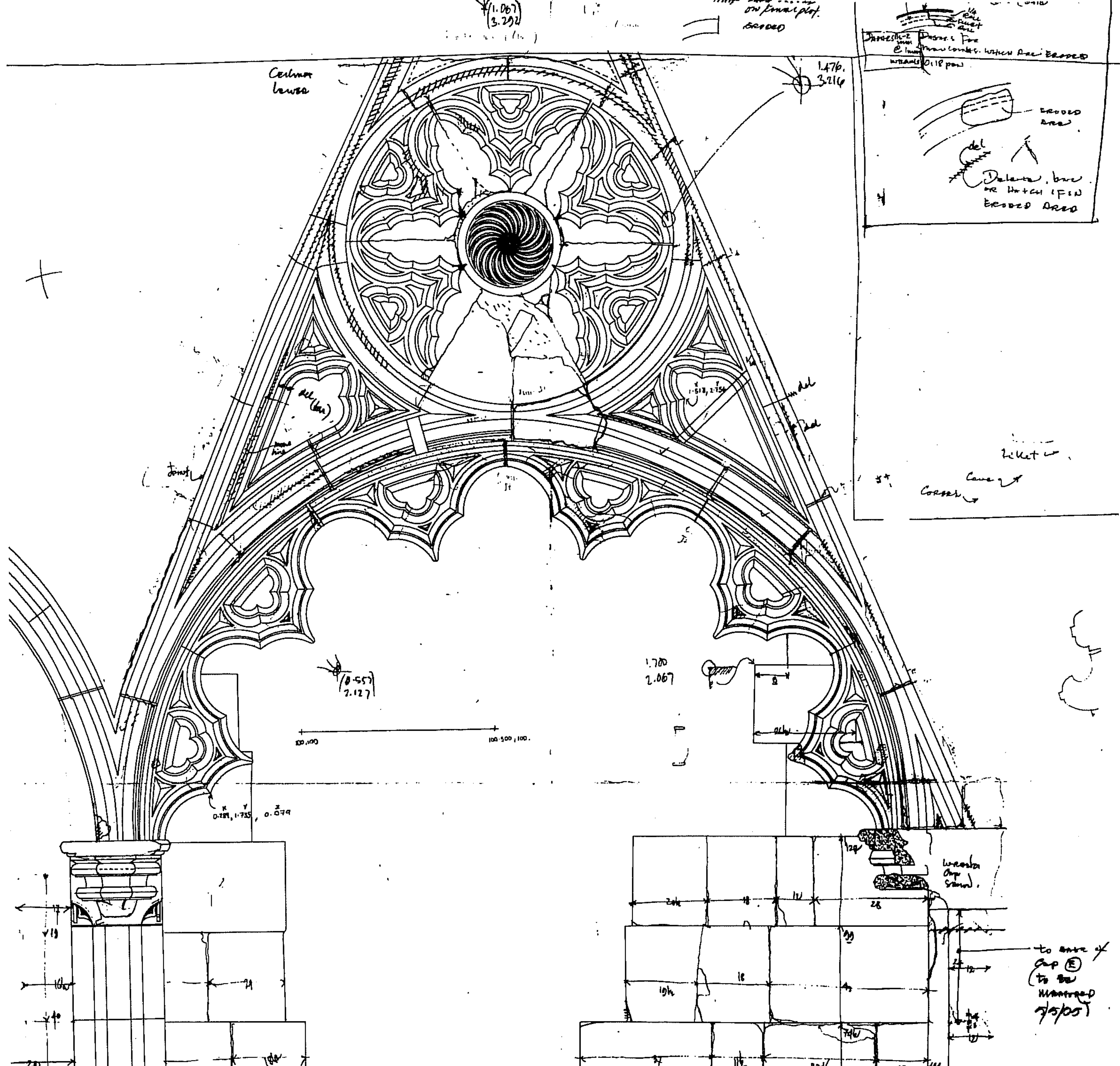

Figure 5. Site notes used at Greyfriars, Great Yarmouth. This is an "over scale plot" of the CAD file with annotation of detail to be fitted to the REDM trace.

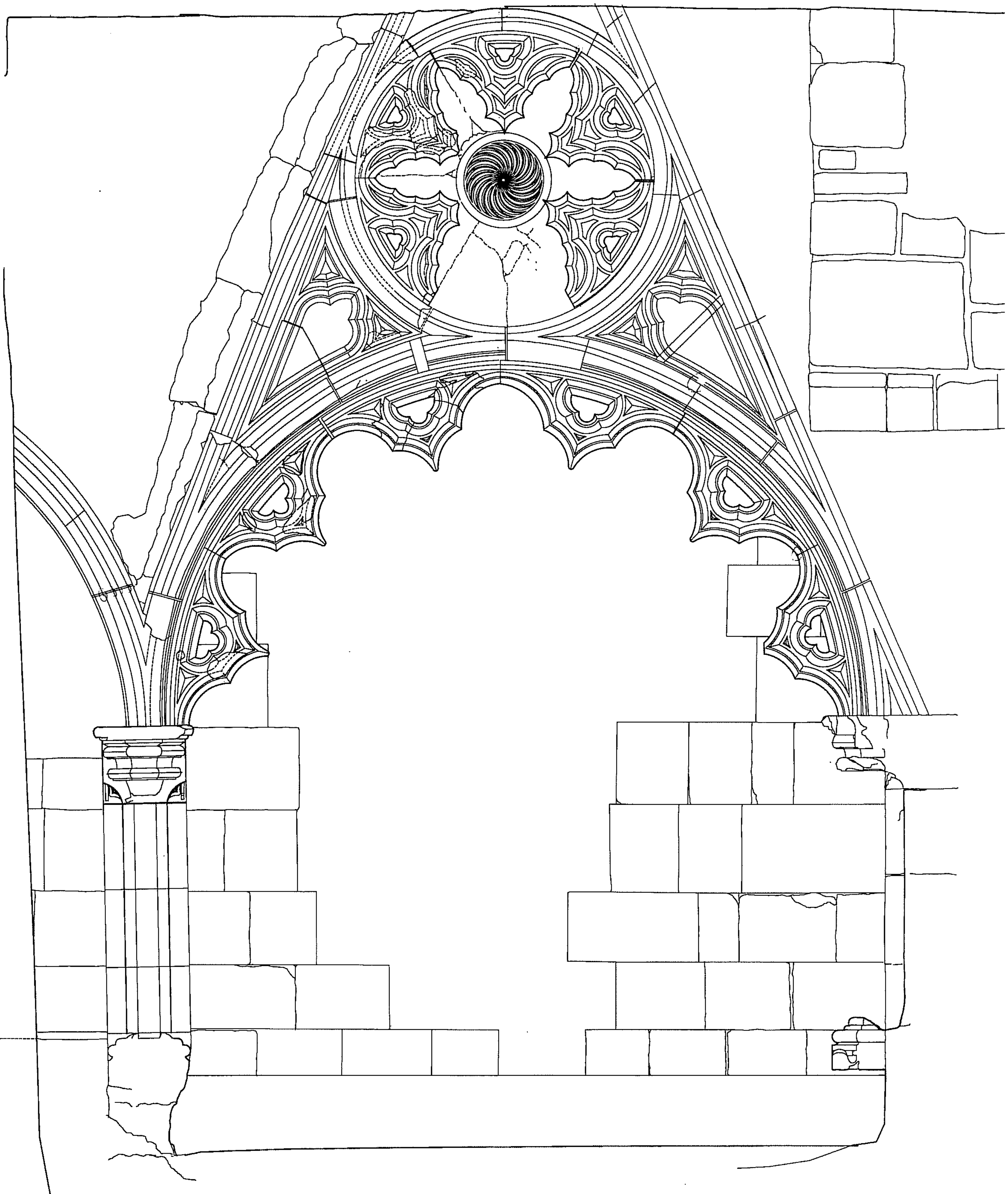

Figure 6. Final plot, seen here at approximately 1:12 scale showing the integration of hand measured detail, REDM trace and CAD digitising of drawn detail.

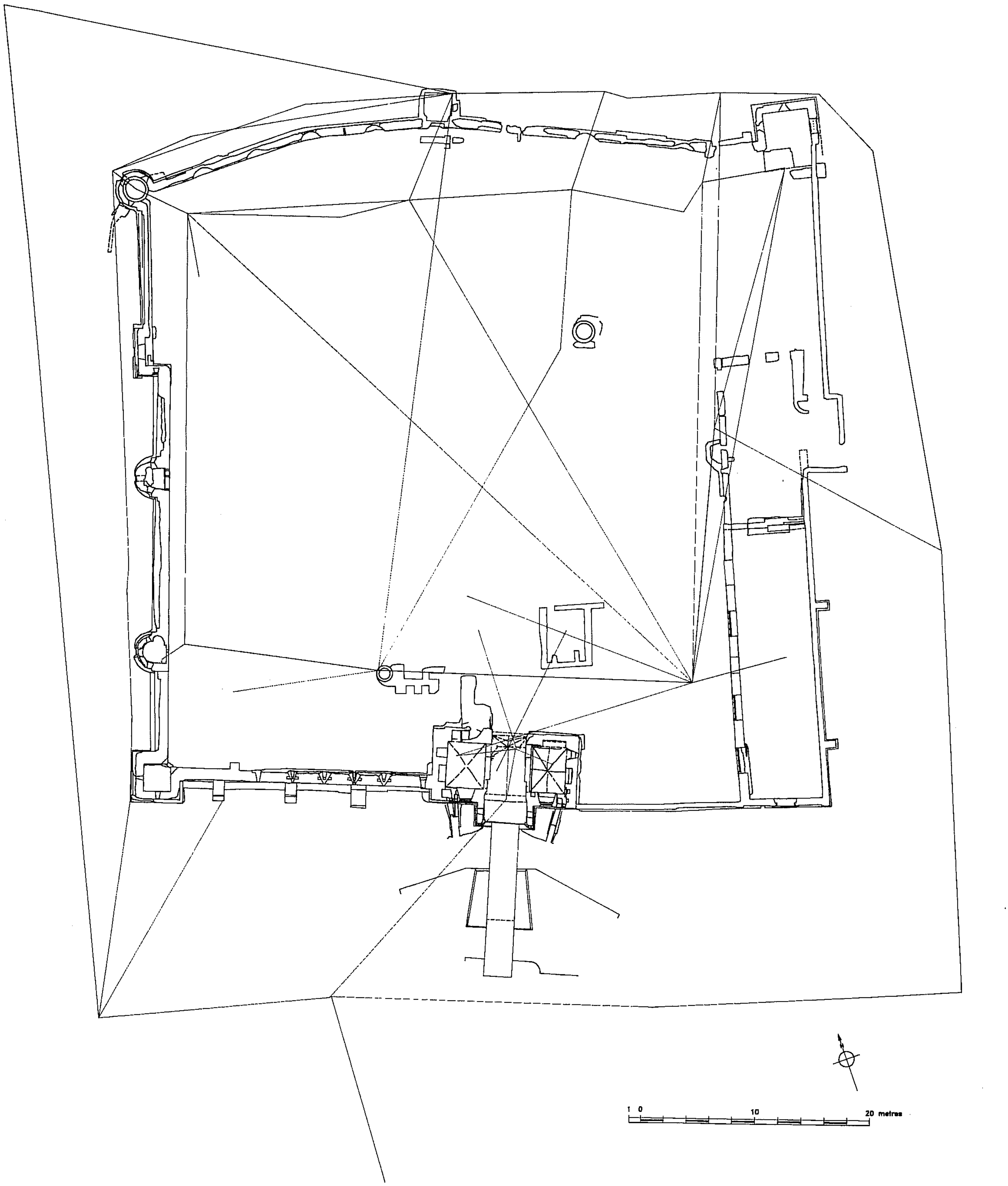

Figure 7. Baconsthorpe Castle, Norfolk. Plan of inner court ruined walls at best surviving height, showing control network to position REDM for tracing the plan.

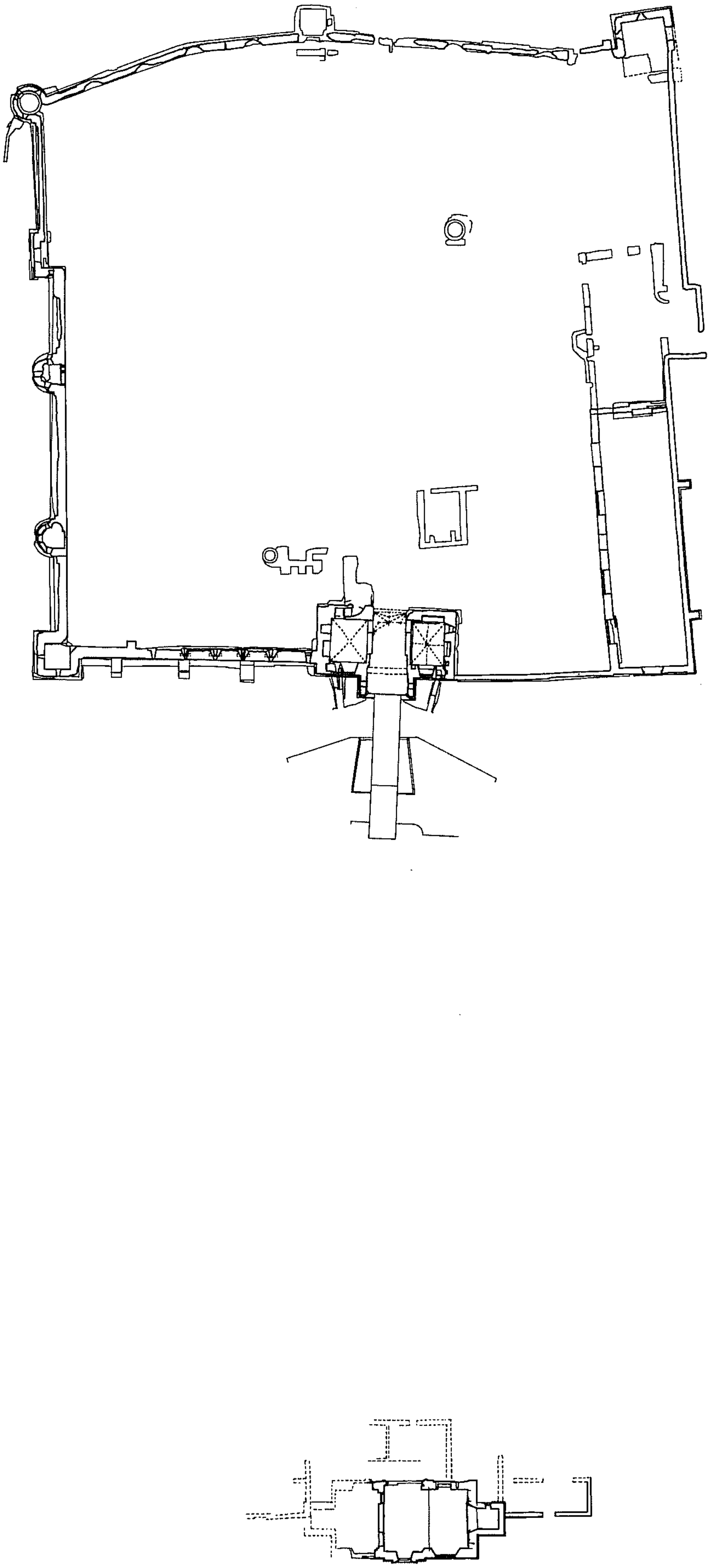

Figure 8. Baconsthorpe Castle, Norfolk. Finished plan from REDM trace.

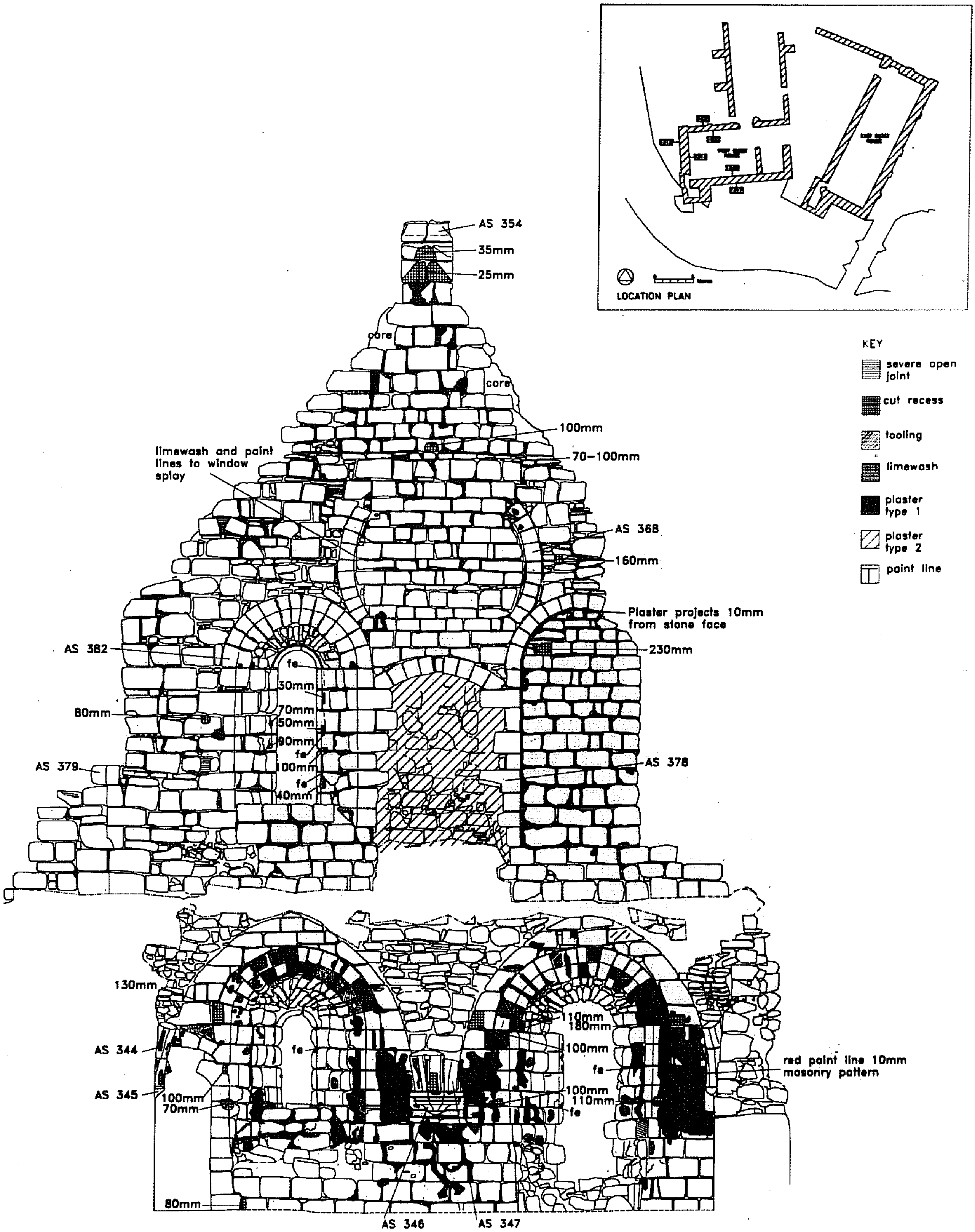

Figure 9. Fountains Abbey. West Guest House. Photogrammetric base survey (see Figure 1) with the addition of some of the archaeological survey recording layers. Not all the layers are switched on in this plot. By producing the survey in CAD, layers can be combined and isolated as wished. Original plot at a scale of 1:20.

Part IV: THE USE OF DIGITAL DATA FOR THE ARCHAEOLOGICAL RECORDING OF HISTORIC BUILDINGS AND MONUMENTS.

Introduction

The use of Computer Aided Drafting (CAD) software within archaeology is not new. A number of archaeological units and consultants in Britain and the rest of Europe are now using a variety of different CAD systems to down-load survey data and to digitise site plans and sections. This has made data visualisation, analysis and interpretation far easier with enormous added flexibility. To accompany this it is now possible to link the visual data with related textual and scanned information, creating "intelligent" drawing files that can be interrogated on all levels. The advantages of these are being explored, from simple graphic and textual links through to the use of highly complex Geographical Information Systems.

As computer hardware and software becomes increasingly cheaper it is now financially viable for most archaeologists handling large quantities of graphical data to plot or digitise survey data onto a CAD system and relate this to other relevant information such as contexts, levels and finds. With this in mind it would seem an ideal medium for recording not only horizontally but also vertically in the survey of historic monuments. This is now being undertaken by archaeologists who have already recognised the advantages but are still formulating the parameters needed for the sensible management and creation of large drawing files on CAD systems.

Existing drawings can be digitised and scanned very accurately and then modified or edited at will. Digitising existing drawings can be very time consuming; the process of creating the digital drawing is made easier if the raw data is collected and provided in a digital format from the start using a variety of data loggers, photogrammetry or rectified photography. However, affordable and accurate scanning systems are now appearing on the market replacing the need to digitise existing drawings. With standing building recording traditional methods of hand survey are still essential, but over large areas errors tend to creep in. A much more efficient and accurate method is to use digital survey techniques as a framework with photogrammetry and rectified photography supplemented by digitised hand survey. All survey can be supplied as a digital drawing file in the appropriate software format for any necessary editing, annotation and detailing of obscured areas.

The majority of the archaeological standing building recording carried out by English Heritage Historic Properties Group is generated from a need to maintain and consolidate the fabric of a building. In this instance detailed historic fabric surveys are essential in order to understand the building before any work can be identified. The archaeological recording is carried out before and during any consolidation work by archaeologists using the digital base survey (as described in Parts I, II, III of this paper) supplied to us by EH Survey branch. The archaeological survey will produce drawings of the building fabric as it stands today, referred to as the "as found" survey. These are then used as the basis for architectural specifications and consolidation and further archaeological analysis, interpretation and management of the structures. The final drawings then form part of the EH archive in London, and ultimately part of the National Monument Record.

The Survey

The detailed recording and collection of archaeological data is clearly the most important aspect of the work. The recording work is greatly helped by the provision of the base survey data as CAD drawing files from which we can plot hard copies of any area of the monument (Figure 1). These files are then modified and annotated by plotting the data captured directly on to the drawing file or by digitising hand survey. At present all building elevations are recorded at 1:20 as this is suitable for architectural specification and archaeological analysis, anything smaller simply limits the level of detailing that can be visualised. The recording work in the field is conducted using a film copy of the base survey on which numerous overlays of information are recorded. At the moment there is no other alternative to this method, but the possibility of using small compact hand held computers in the field with software like AUTOCAD and PenMap is being investigated. The use of hand held computers would obviate the need to transfer the survey data onto the drawing file back in the office. This would save time and remove the possibility of error during transfer with the majority of the recording accomplished as one process on site.

The survey data gathered on site is then transferred to the drawing file (Figure 9). There is not a great deal of time saved with this exercise as opposed to the more traditional pen and ink method, the advantages only become apparent once the data has been entered onto the drawing file. The advantages over traditional drawing methods include the flexibility experienced when viewing, plotting and exchanging information and when updating or adding data to the survey from disparate data sets.

Fieldwork

The archaeological work in the field starts with a thorough analysis of the base survey to ensure overall dimensions are correct as well as individual architectural features. With the photogrammetric base survey, for instance, parts of a building elevation may be obscured from the camera by vegetation or other obstructions, these "blind" areas must be added by hand survey. Once this is complete the fine detail can be added. This includes all the finishes from the stone tooling and masons marks to the plaster, limewash and paint details (Figures 9, 11). Samples are taken of both mortars and plasters to enable easier visual identification from one area of a building to another and to create a type series on each site for future reference. This sampling can be a problematic exercise where consolidation over many years needs to be identified and recorded as well as any remaining original mortar from the original construction. It is hoped that some of these samples will eventually be analyzed so that areas of a monument already securely dated can help in dating others which are not. Stone types and their current state of decay are recorded using simple definitions of weathering and damage, as are all the architectural details and window and door furniture. In addition 1:1 moulding profiles are taken of all architectural features (Figure 12) accompanied by the completion of a detailed architectural stone recording form and a full photographic record of each individual feature. Further comprehensive photography of the whole building and individual features complements the record.

The data collection and analytical aspects of the work are made easier by applying context recording to all aspects of the building, starting with a context number for the building as a whole and breaking this down into context numbers for individual walls, elevations, architectural elements such as windows and doors and building alterations or additions such as window or arcade blockings and so on (Figure 10). The amount of textual information is strictly limited on the drawing so that all information about an elevation or particular feature is held on the context, sample and architectural stone forms. The EH, Central Archaeological Service recording forms are used in the field and this information is transferred on to database software. In this way the detail needed is provided for a thorough architectural analysis and the basis for reconstruction where replacement is necessary.

This kind of detailed building recording can generate numerous numbers of information overlays both graphic and textual, which needs to be managed efficiently and be accessible to a variety of people who will require different aspects of the survey for their work.

The digital drawing file

Once the data has been collected it is brought together to form the completed "as found" survey on the drawing file. The received base surveys tend to be rather large drawing files from anywhere between two and six megabytes. As a result the addition of any further archaeological survey data creates a file that can become slow to generate and manipulate. To overcome this problem the drawing file is broken down into manageable blocks of information dividing the elevations into logical sections by floor or bay before the additional survey data is added. Once all the separate

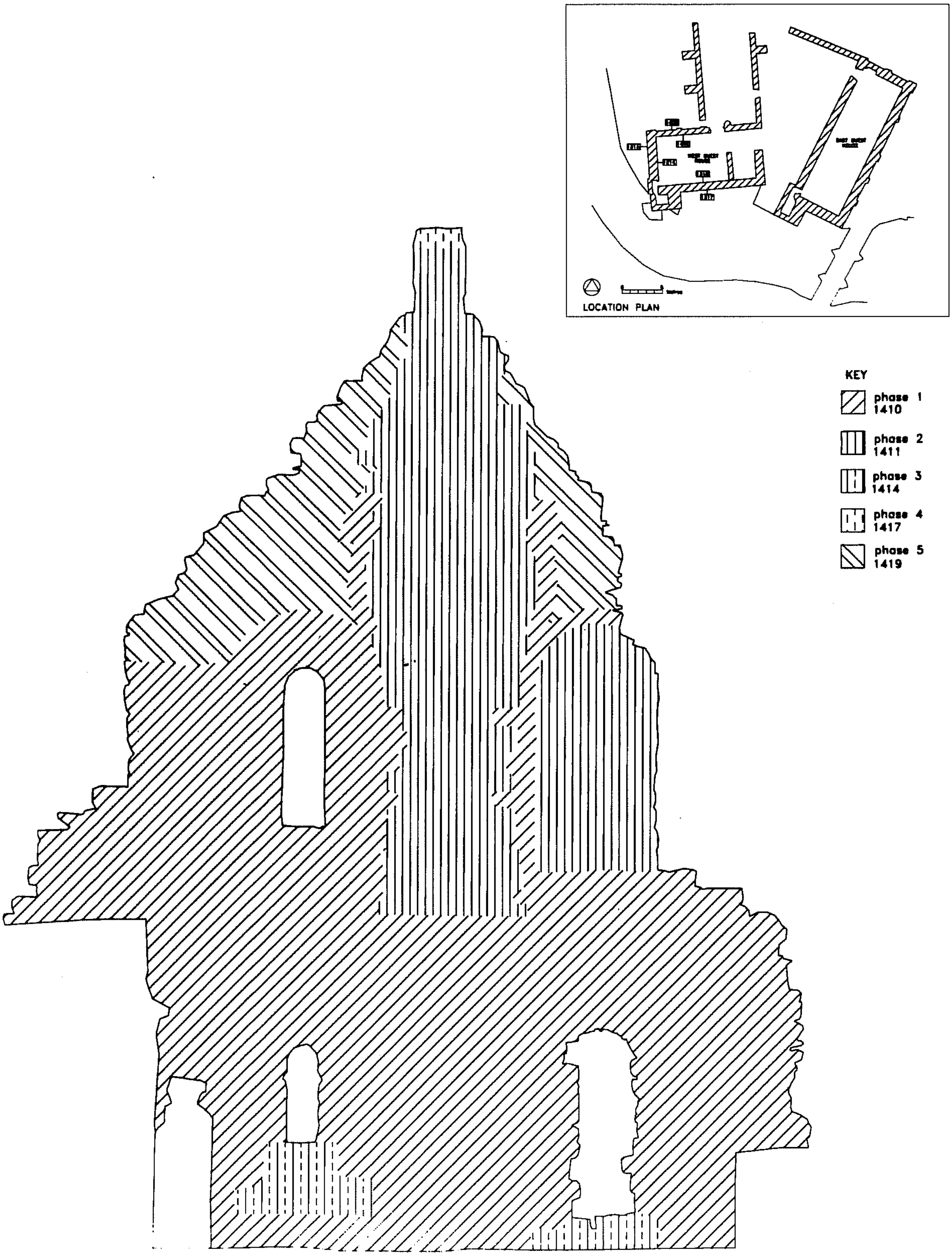

Figure 10. Fountains Abbey. West Guest House. Primary phasing established from building and repair phases identified in the fabric, plaster and decorative features. Original plot at a scale of 1:20.

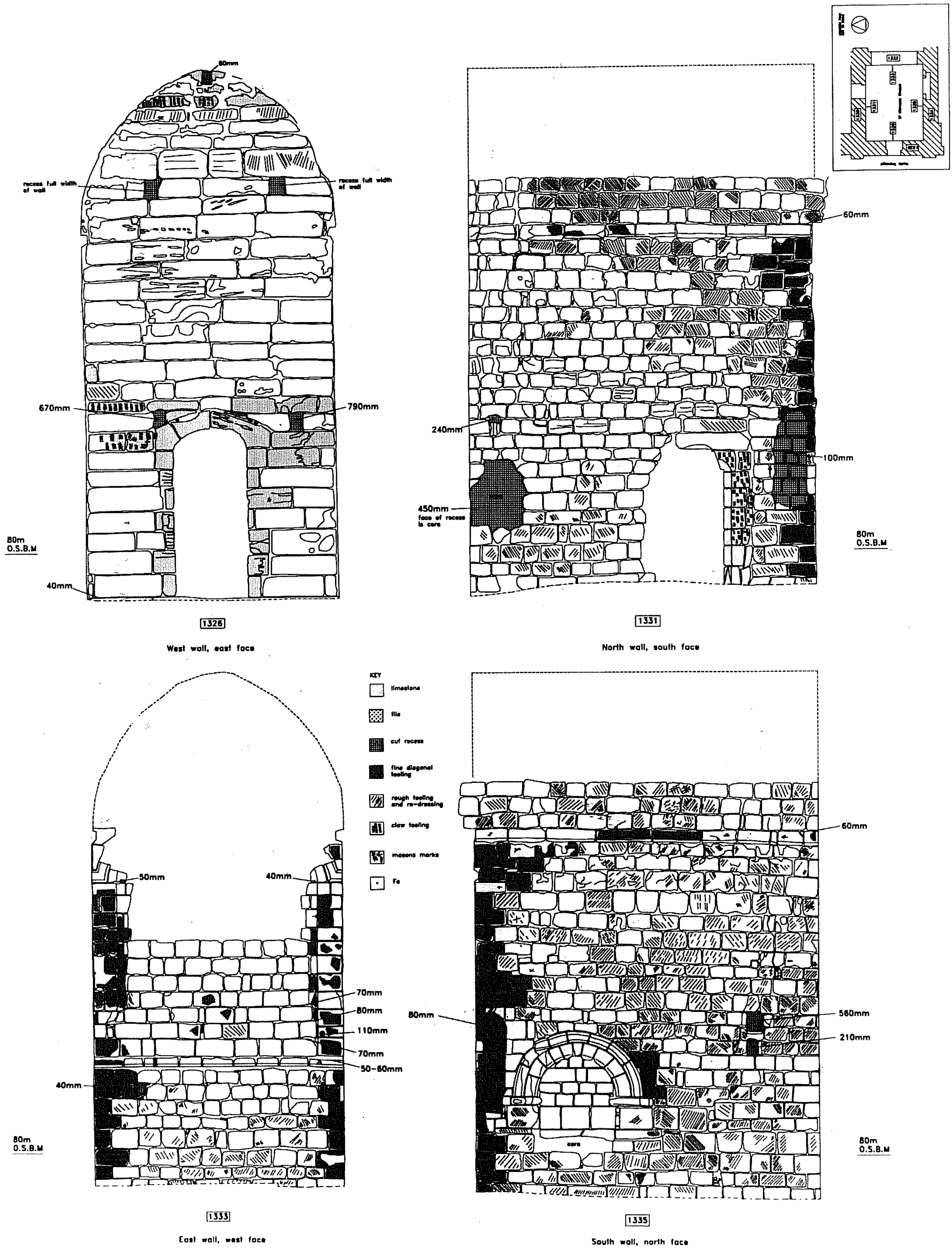

Figure 11. Fountains Abbey. St Michael's Chapel. Due to restricted space we were unable to use photographic techniques, instead a hand survey from a scaffold was digitised into CAD with further hand measured detail digitised and fitted to the drawing. Original plot at a scale of 1:20.

drawing blocks are complete with the archaeological survey data added, they are regrouped to form the final drawing file displaying the full elevation.

Most of the minor editing and the additional annotation can be done by plotting directly onto the drawing. Large areas of missing or additional information need to be digitised from the hand survey and "floated" into position on the drawing using established control points. Any 1:1 moulding profiles will also need to be digitised to form a separate drawing file to compliment the plans, elevations and sections. Two-dimensional polylines not lines are used for both the photogrammetric plots and the additional archaeological data, as they create a sequence of lines that are treated as a single entity and can form a polygon. This is essential when dealing with irregular stone shapes which need to be understood as one entity and not a series of separate lines, particularly as the full range of CAD editing can provide the area and perimeter of a two-dimensional polyline.

A comprehensive list of layers and hatching conventions is used to capture each set of data individually. There is no restriction on the number of layers that can be created, the more used the greater the flexibility in separating the data, but it is essential that they are clearly defined at the start. To ensure consistency, layering conventions have been established that can be understood by all potential end users and cover all the key architectural elements and finishes that form the historic building fabric (Appendix A). Additionally these are colour coded and hatched so that clear distinctions can be made between individual layers allowing interrogation of the survey by isolating and combining data sets as required. It is important to ensure hatching is used throughout, as invariably hard copies of the drawings are used in the first instance for architectural specifications, where colour copying cannot be guaranteed. Textual information on the drawing includes references to the appropriate context, sample or architectural stone number and profile drawing, as well as the dimensions of any offset or recess because hard copy in two-dimensions will necessarily require this information.

Conclusions and future developments

As the graphic presentation of information is the simplest method of rapid summary and exploration of relationships with complex data sets, the advantages of developing a recording programme using digital data are enormous. There is immediate access to the drawings and control of the levels of data visualised. The drawing files are seen as a dynamic data set to which further layers of information can be added, such as proposed and completed consolidation. In addition, the archaeological analysis and interpretation can also be incorporated to form yet another layer of the drawing. The flexibility of the drawing file enables a more informed interrogation of the survey, when formulating ideas about the structure and phasing of a building. The flexibility of data visualisation with CAD is well established, and by linking this to other data sets it becomes far easier to access and use all the available information from one platform. The more data that can be integrated and interrogated within any analysis, the wider the range of questions that can be asked.

Clearly the next process is to bring together all the survey data, not only the graphic and textual, but also the photographic onto one platform. This is now becoming a real possibility and will be achieved in the very near future. However at the moment there is no simple, affordable way of successfully manipulating the enormous data sets we have for each monument. The aim must be a drawing that can be interrogated on every level linking information stored in a database to entities stored graphically.

Although the drawing files we use at present tend to be still two-dimensional, the photogrammetric plots are created initially as three-dimensional drawings and can be manipulated through CAD to create isometric and perspective views (Figure 2). The possibility of entering the archaeological survey as three-dimensional data is now being investigated. So far the manual input of data has proved impractical and very time consuming, but if the field recording is achieved digitally, results prove much more

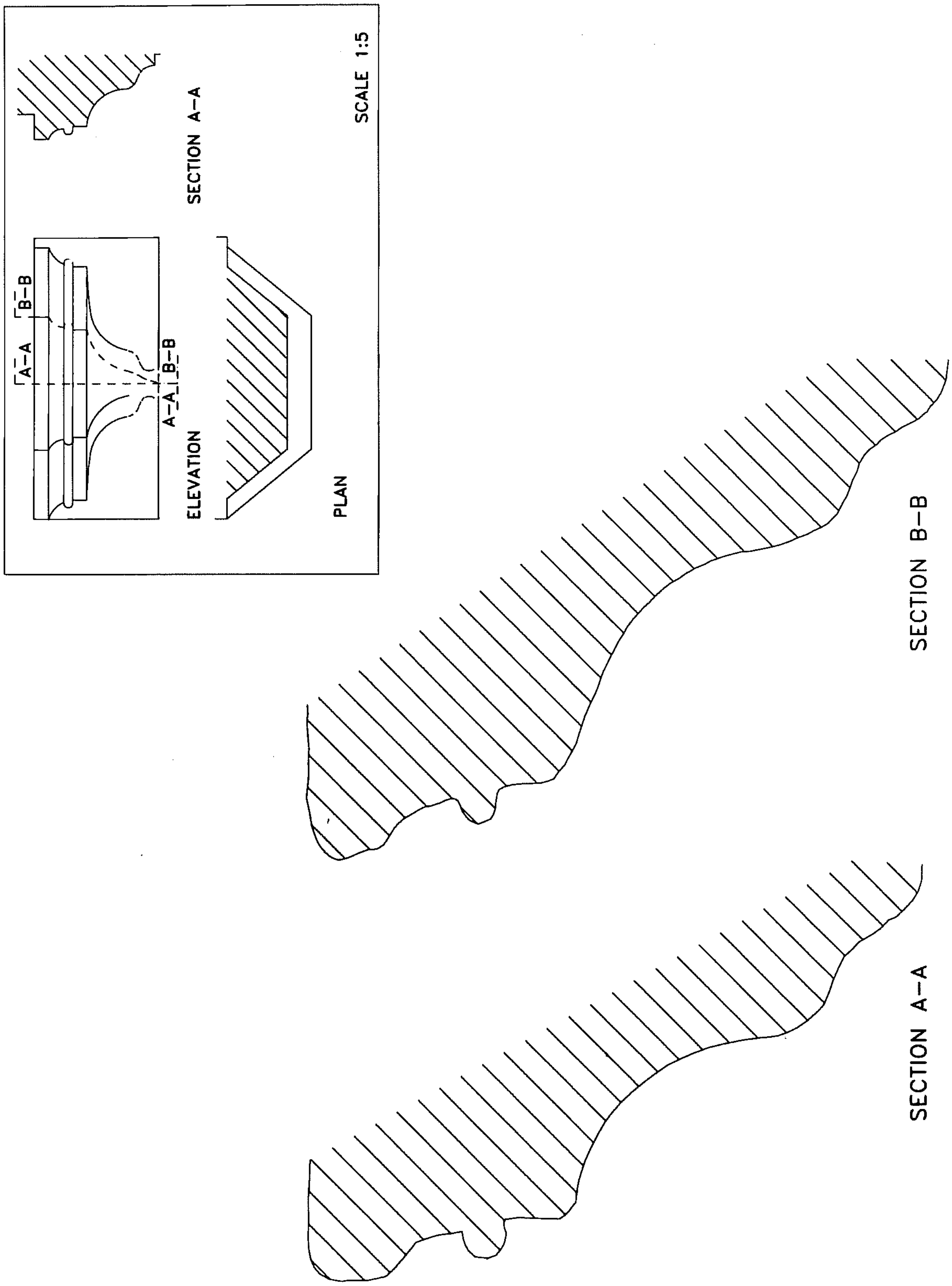

Figure 12. Fountains Abbey. West Guest House. Digitised full size profile and construction of the vaulting corbel from hand survey notes. Original plot at a scale of 1:1 and 1:5.

satisfactory although the resulting drawing file is extremely large and difficult to manipulate.

Much work has already been done in the field of three-dimensional reconstruction using a variety of software packages and modelling techniques. These have been used as part of the archaeological and architectural analysis and interpretation of structures, offering a means of experiencing the building in terms of the volumes created and the design aspirations of the original builders. They are also extremely useful tools for presenting information to the public about the building and how it was used, in a visually attractive way. Recording in three-dimensions will open up the possibility of using our data in this way.

The prospects for creative visualisation from a digital data set are enormous, but we must be aware that the visualisation will only be as good as the raw data. The basic data collection process is still fundamental. AUTOCAD and PenMap and other CAD software packages are the new tools at our disposal which need to be used and managed correctly if they are to be of any use.

GLOSSARY

Base line control. A simple two station reference line.

CAD. Computer Aided Drafting.

Closed polyline. A polyline forming a polygon, ie. the line ends at the same point at which it started.

Contours. Lines joining points of equal height, or depth.

Digital data. Any information stored in a form accessible by a computer. In this case CAD files which represent points and lines using co-ordinates.

Digital orthophotographs. An image in which the actual area represented by each pixel has been adjusted to correct for scale errors due to different parts of the object being at differing distances from the camera, due to tilt or variations in depth.

Digitising. Recording co-ordinates from a plan or photograph using a digitising tablet.

Dyeline techniques. A plan copying system using ultra violet light sensitive paper.

DXF. Drawing Exchange Format.

Fiducial marks. Marks on the negative plane of a metric camera which appear on the photograph. The positions of these marks are known and thus allow a check for film distortion and flatness to be carried out and provide a reference for their correction.

Hard copy. A copy on to paper or film.

Layering. The process of assigning different types of information to different CAD layers. This is analogous to using overlays in traditional drafting.

Liquid crystal glasses. Glasses with liquid crystal lenses which allow 3D viewing of the stereo-model by alternately switching on and off the left and right lenses in synchronisation with the left and right images on the monitor, by means of an infra red emitter.

Micron resolution. In the context of scanning this refers to the area on the original represented by one pixel of the digital image.

Mosaic. A process whereby a number of photographic prints are joined together to produce an image of a subject which could not be covered by one photograph.

Negative plane. The plane of a camera or enlarger in which the film or negative lies.

Optical square. A double prism used to set out right angles.

Orthophotograph. An image produced by the rectification of the original image in which the effects of camera tilt and depth variations in the object have been corrected.

Pixel. The smallest unit of a digital image.

Point by point recording mode. The data collection mode which involves the operator defining a line by digitising selected points along its length.

Polarising glasses. Glasses with lenses which cut out light waves with one particular orientation. To allow 3D viewing on a computer monitor, the polarity of one lens is at right angles to the other. The stereo-images are given corresponding polarity and displayed alternately but very rapidly so that each eye sees the relevant image almost constantly.

Polyline. The term used by AutoCAD to describe lines made up of a number of segments but which behave as a single entity.

Real time display. The display of points and lines as they are recorded.

Reflector. A prism at the target that reflects a signal back to EDM instrument.

Scanning. Using a scanner to convert black and white or colour photographs into digital grey levels or red/green/blue colour separation images.

Sectional elevation. View of a building revealed by a cut or section line.

Spot meter. A photographic light meter which can be aimed at a remote object or spot, to determine the required shutter speed and lens aperture.

Stereo-model. The 3D optical illusion which appears when overlapping photographs are viewed stereoscopically.

Stream digitise mode. The data collection mode which involves the operator moving the measuring mark along a line while the computer, automatically digitises points at preset intervals.

Surface model. A mathematically defined surface which fits to all the 3D points generated by the digital workstation.

Survey control. The framework of points or reference lines necessary for mapping survey detail in correct orientation.

Taped triangulation. Position fixing by measurement from three known points.

Three-dimensional wire frame model. CAD generated model producing a 3D image using a framework of lines and points.

Theodolite. A surveying instrument used to precisely measure horizontal and vertical angles.

Transformation facility. A command which allows the application of mathematical transformations to CAD drawings. Transformations consist of rotations, shifts and scale changes, allowing the use of locally orientated co-ordinate systems.

Traverse. A series of control points or stations linked by rigorously observed angles and distances.

Two point intersection. 3D triangulation by theodolite.

Virtual reality. A computer generated model which is viewed in 3D and updated interactively so as to give a realistic impression of movement in the virtual world.

APPENDIX A.

1. CAD LAYERS FOR PHOTOGRAMMETRIC RECORDING

Layer 1	MAJOR- this is to include all structural elements except for those specified in layers 2 to 8.	**White**
Layer 2	COREWORK - where exposed by the facing stone no longer existing.	**Red**
Layer 3	WINDOWS/ DOORS/ FIREPLACES - this is to include all jambs, sills, voussoirs, lintels and the surrounding stonework.	**Yellow**
Layer 4	ARCHITECTURAL FRAGMENTS - corbels, architrave, mouldings.	**Green**
Layer 5	SCULPTURAL DETAIL - figures and carved detail.	**Cyan**
Layer 6	SERVICES - drainpipes, lightning conductors, etc.	**Magenta**
Layer 7	TEXT/ NOTES	**Blue**
Layer 8	CONTROL POINTS	**White**
Layer 9 and 10	These are to remain blank unless a particular architectural element does not fit into the previous eight layers.	

NOTES

1. Where architectural fragments or sculptural features from part of a window or door, etc, they are to appear within the layer windows/ doors, ie layer 3.
2. When cross-sectional information is to be provided, the layering convention is also to be applied to these cross-sections, depending upon the type of detail that the section is passing through.
3. Areas of erosion or damage that are recorded should be placed in the same layer as the feature it concerns.
4. If there is any doubt into which layer a feature should be placed within, then it should be put in layer 1.
5. Any queries regarding this layering convention should be directed to the Photogrammetric unit of English Heritage, Survey Branch, 429 Oxford street, London W1E 5DB.

2. CAD LAYERS FOR ARCHAEOLOGICAL RECORDING

Number	Name	Description	Colour	Type
0			white	con
1	P	major structure	white	con
2	P	core	red	con
3	P	windows and doors	yellow	con
4	P	architectural moulding	green	con
5	P	sculpture	cyan	con
6	P	services	magenta	con
7	P	text	blue	con
8	P	survey control points	white	con
9	P			
10	P			
11	SS	sandstone	yellow	con
12	LS	limestone	red	con
13	FL	flint	green	con
14	MA	marble	magenta	con
15	SL	slate	blue	con
16	TB	timber	cyan	con
17	TI	tile	red	con
18	BR1	brick	magenta	con
19	BR2	brick	magenta	con
20	BR3	brick	magenta	con
21	CON	concrete	white	con
22	COR	core	red	con
23	MO1	mortar	red	hatch/con
24	MO2	mortar	red	hatch/con
25	MO3	mortar	red	hatch/con
26	MO4	mortar	red	hatch/con

26	MO4	mortar	red	hatch/con
27	MO5	mortar	red	hatch/con
28	PL1	plaster	green	hatch/con
29	PL2	plaster	green	hatch/con
30	PL3	plaster	green	hatch/con
31	PL4	plaster	green	hatch/con
32	PL5	plaster	green	hatch/con
33	REN	render	red	hatch/con
34	LI1	limewash	blue	hatch/con
35	LI2	limewash	blue	hatch/con
36	PA1	paint	red	solid/con
37	PA2	paint	red	solid/con
38	PA3	paint	red	solid/con
39	PA4	setting out lines	cyan	con
40	MAS1	tooling	white	hatch/con
41	MAS2	tooling	white	hatch/con
42	MAS3	tooling	white	hatch/con
43	MAS4	tooling	white	hatch/con
44	GRAF	graffiti	white	con
45	REC	cut recess	white	hatch/con
46	HUN	hungry joints	white	hatch/con
47	TXR	text,recess depth	blue	con
48	TXO	text,offsets	blue	con
49	TXA	text,architectural stone	blue	con
50	TXD	text,other dimensions	blue	con
51	TXN	text,notes	blue	con
52	TXS	text,samples	blue	con
53	TXT	text,title	blue	con
54	DE1	decay under 10mm	yellow	hatch/con
55	DE2	decay over 10mm	magenta	hatch/con
56	DE3	contour spalling	blue	hatch/con
57	DE4	flaking	red	hatch/con
58	DE5	damage	white	hatch/con
59	DE6			hatch/con
60	DE7			hatch/con
61	LD1	thick line, outline	white	con
62	LD2	ground level	white	dash 2
63	LD3	obscured detail	white	dash
64	LD4	line of section	cyan	dashdot
65	LD5	border and title block	blue	con
66	Fe	iron	red	solid/con
67	Pb	lead	green	solid/con
68	Ca	copper	yellow	solid/con
69-78		context		

NOTES

1. These layers are designed for use with photogrammetric surveys only.
2. The layer number, name, description and line-type should never be altered and only in the case of major structural material ie: layers 11 to 18 can the colour be changed.
3. The predominant stone type in any survey must appear as white within the appropriate layer. Any additional stone or material that appears on the survey should assume the colour indicated for the layer.
4. Further layers can be added when needed for individual drawings. Keep a record of all additional layers that you use including contexts. Every context must be recorded as a unique layer.
5. Any enquiries regarding this layering convention should be directed to: The Assistant Inspector, English Heritage, Historic Properties Group (North), 41 Sand Hill, Newcastle-upon-Tyne, NE1 1BR.

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