

Survey data enhancement and interpretive works for the recording and conservation of Pendragon Castle

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35.1. Introduction

This paper will describe the capture of digital data by means of photogrammetry and instrument-based survey, and its onward processing using Intergraph's MicroStation PC (Version 4) to create an enhanced archaeological record and analysis, and conservation works specification, for the ruined masonry structure of Pendragon Castle (Cumbria, UK). The criteria for software selection will be examined, and an appraisal of MicroStation's performance compared to other CAD systems will be reviewed.

35.2. Pendragon Castle

Pendragon is a late Norman moated castle situated in the Mallerstang valley south of Kirkby Stephen (Cumbria NY 782 027). The standing masonry consists of a substantial ruined square tower with a garderobe turret projecting diagonally from the south-west angle and rising to three stories. The interior is at present filled with earth and fallen debris (Fig. 35.1).

Originally built in the second half of the twelfth century, the castle was modified during the course of the medieval period and repaired by Lady Anne Clifford in 1660. Abandoned in 1680 following the death of Lady Anne, it was finally dismantled by the Earl of Thanet c. 1685. The Buck brothers engraving of 1739 (Fig. 35.2) shows three stories more-or-less complete, but by 1773 Thomas Pennant's view shows that the upper parts had fallen (Curwen, 1913, 121-124; Jackson, 1990, 77-79). Further sections of the walls collapsed during the 1920s, and in 1962 the monument was acquired by Mr Raven Frankland. Limited clearance and consolidation works were undertaken by the owner, together with masons from the Ministry of Works, during the 1960s and 1970s, but by the late 1980s, English Heritage considered that the monument was in need of a comprehensive programme of repair and conservation.

35.3. Data capture

In 1990, William Binney Associates (WBA) were appointed by Mr. Frankland, with assistance from English Heritage, to investigate the most appropriate method of survey of the monument, and to act as commissioning agents for the preparation of that survey. An accurate survey and record of the fabric, in both elevation and plan, were seen by English Heritage as the first step in the conservation process, so that informed judgments could be made by WBA when drafting the contract specifications for repair. These specifications were to be of a very detailed nature to allow the appointed building contractor to be instructed on a stone-by-stone basis.

Three methods of elevation survey were examined:

- Hand measurement
- Rectified photography
- Photogrammetric survey.

Following advice from English Heritage, a preliminary assessment of these different methodologies and their relative costings was undertaken by WBA, based partly on information supplied by Lancaster University Archaeological Unit (LUAU).

35.3.1. Hand measurement

The option of carrying out the whole survey by hand measurement was rejected for both practical reasons and the likely prohibitive costs. Although feasible, because of the relatively small size of the monument, the multi-plane elevations would have required the erection of complex cantilevered scaffolding, and posed difficulties in ensuring a reasonable level of accuracy. It was also felt that the obviously long, slow, and labour intensive nature of this approach, together with the increased safety problems, would be an inappropriate and uneconomic use of limited time and resources.

35.3.2. Rectified photography

Hand measured survey in combination with rectified photography was considered both feasible and practical, especially if an outline photogrammetric plot was also made available as a control base. Although not as accurate a technique as photogrammetry, rectified photography can be adequate for flat areas of elevations with little architectural detail. However, given the very irregular nature of the surface and the variety of wall planes, it was felt that extensive hand measured control would have been required to relate the different photographic images. Moreover, trial conversions of scanned raster images into vector format produced extremely large files; consequently it was concluded that the technology was not, at that stage, sufficiently advanced to warrant its use on this project.

35.3.3. Photogrammetric survey

The third option, that of a full photogrammetric survey, proved to be not only the most accurate and efficient methodology, but also, interestingly, the most cost-effective means of recording the structure. The capture and plotting of as much photogrammetrically derived data as possible would require a shorter field season for enhancement and interpretive works, as well providing a CAD digital record, and thus a considerably more flexible product.

It was therefore recommended that a photogrammetric survey be commissioned in accordance with the standard specification as issued by English Heritage (Dallas, 1990); data



Figure 35.1: View of the west elevation, west face.

capture and photogrammetric recording being sub-contracted to Photarc Surveys Limited of Wetherby. Two-dimensional co-ordinate data acquisition in digital form was specified to facilitate subsequent manipulation in a CAD system.

All of the major upstanding elevations were photographed stereoscopically in black-and-white using a metric camera at a distance of no greater than ten metres from each wall face. A minimum of three targeted points per stereoscopic model were surveyed by trigonometric intersection. Both the stereo photography and instrument survey provided data commensurate with a 1:20 plotting scale, the resulting elevation drawings delineating all visible architectural and stone detail. The return walls at each end of the internal elevations were depicted as vertical cross-sections, and consisted of a line defining the principal wall plane, including sections through adjacent openings and voids which broke the wall plane. The plan data was simply captured as two horizontal sections at arbitrary levels within the structure.

35.4. Recording brief

In 1991, LUAU was commissioned to undertake the necessary enhancement and interpretive works to complete the survey data and produce the required drawn records to serve as the basis for an assessment of the historic importance of the various parts of the fabric, and as the basis for WBA's repair contract specification. For this stage of the work, the English Heritage brief specifically excluded any documentary research or fabric analysis beyond the simple visual identification of areas of recent repair.

The brief required the following tasks to be undertaken:

- elevation survey plots to be checked, amended, and any obscured areas measured and added as necessary to produce corrected record drawings. The size, shape, and position of every stone in the facework and as many stones in the corework to be depicted, together with

the boundaries between the surviving wall faces and core, architectural features, and voids

- overlays to the elevation drawings to be produced showing the location and extent of fabric changes and repairs made by Lady Anne Clifford, the Ministry of Works, and Mr. Frankland
- horizontal section survey plots to be converted to analytical plans showing the extent of the surviving original wall faces and features, and reconstructing such features where sufficient evidence survived
- 1:1 profiles of *in situ* architectural mouldings to be taken, and a catalogue of visible fallen worked fragments assembled, along with an assessment of their original position.

All record drawings (with the exception of the moulding profiles) were to be presented at 1:20 scale, and in hard copy form only.

As experienced CAD users, it appeared illogical to WBA and LUAU that survey data should be collected and processed in digital form, to be edited, interpreted, and corrected only in hard copy. Aside from the inaccuracy and limitations of hand drawing, it seemed perverse to abandon a very complete and accurate database which could be directly extended into the conservation tool and ultimately form the final record of the monument.

It was therefore recommended that the correction, enhancement, and interpretation of the elevation survey data should be carried out in digital form, working directly from the original photogrammetric CAD files.

35.5. Elevation data

In 1991, both WBA and LUAU possessed the facility to enhance, manipulate, and model the existing data, and to generate new drawings in CAD format. LUAU were users of AutoCAD (Release 11) and WBA had been using Versacad for

THE NORTH-WEST VIEW OF PENDRAGON-CASTLE, IN THE COUNTY OF WESTMORLAND.



20.

To the Right Hon^{ble}
Sackville Tufton Earl of Thanet
Baron Clifford's wife's first husband's issue, Lord of Skipton in Warwick
 Hereditary Sheriff of the County of Westmorland.
This Prospect is humbly presented by his Lordship's most Obedient Servants
 SAM^l & NATH^l BUCK



THIS Castle was entirely destroyed A.D. 1245. by y^e Scots under their R. David, and is one of those that were repaired A.D. 1660. by the Right Honourable Lady Anne Clifford, Countess Dowager of Pembroke &c. sole Daughter & Heir to y^e Right Hon^{ble} George third Earl of Cumberland, three hundred & twenty Years after the Scots had destroy'd it. The present Proprietor is the R. Hon^{ble} the Earl of Thanet.
Printed by T. Child, at the Sign of the Ship, in St. Dunstons Church-yard, London. Published according to order of Parliament in March 1739.

Figure 35.2: Buck brothers engraving of 1739.

nearly five years; hence both of these software systems were well known and understood by the project team.

It was felt that, although both systems were well established, powerful, and very reliable, their performance left something to be desired, particularly in the area of file size generation and of the speed with which large files could be manipulated. For this reason, it was thought feasible to investigate the possible use of other software to establish whether any other package was more suitable to the task.

It was first decided to examine the demands placed upon the software by this type of work and then to examine the performance of selected suites of software against those criteria.

35.5.1. Task identification and criteria for software selection

Editing and enhancing basic photogrammetric survey drawings makes several heavy demands upon CAD software. The following tasks and criteria for selection were considered:

1. The software must be capable of drawing closed polygons to represent stones or mouldings, so that these are capable of being stored and manipulated as single elements.
2. The closed polygons must be capable of shape modification and of having vertices added or removed as part of this editing process. If each entity has to be broken into its constituent parts and these edited individually, this makes electronic editing tedious, slow, and probably uneconomic.
3. Given that photogrammetric survey drawings are usually large and contain a great many individual elements, systems which use a compact data structure and generate relatively small data files will offer considerable advantages. This is particularly significant with regard to the speed of graphic manipulation (panning, zoom-

- ing, etc.), and also to "picking" operations where large (and slow) files have to be accessed to locate individual elements. An ideal system will manipulate large files rapidly and also generate a very economical data structure. Display list processing was discounted from our considerations given the file size and nature of operations; to be effective it would have called for abnormally large volumes of RAM on either the graphics processor or the computer.
4. Reference files are an invaluable method of separating different types of information which need to be stored and/or displayed to satisfy various needs (chronological, architectural etc.), or as a means of breaking down very large files into manageable parts. The advantage of this method over layering is that only the reference file in use at any given time is loaded, thus relieving the processor of any overhead imposed by suppressed layers. When used as a means of breaking down very large files into manageable units this also offers advantages in terms of simple file transfer.
5. Photogrammetric survey drawings are normally specified as being plotted in a single line thickness with interpretive works specifically excluded. Enhancement involves identifying and delineating different elements and is likely to be simplified greatly by the flexibility and variety of methods of forming groups for editing; the ability to form groups by fencing irregular polygons was found to be a most useful facility.
6. The ability to simultaneously display multiple active views of the file is a great help to productivity since it allows the operator to view the detail, the local, and the global area of editing together, and to monitor changes made instantaneously.
7. The ability to correct minor dimensional inaccuracies by localised scaling is useful if scaling can occur in-

	<i>AutoCAD</i>	<i>Versacad</i>	<i>MicroStation</i>
1. Draw closed polygons.	Yes, but requires 2 separate operations.	Indirectly — shape is drawn then converted to symbol. Limit on no. of symbols.	Yes, direct.
2. Edit closed polygons.	3 stages — break then edit, then re-form entity.	Symbol must be exploded, edited and converted back to symbol.	Yes, direct.
3a. File generated for same size drawing.	2.39 Mb.	2.8 Mb - this was DXF imported file edited to remove redundant information.	0.9 Mb.
3b. Autocad DXF conversion file size 2.54Mb.		Converted to 2.44Mb.	Converted to 0.314Mb.
3c. Speed of manipulation on files approx. 1.2 Mb.	Slow — display list disabled (full).	Slow — display list disabled.	Fast — subjectively it appeared to re-draw a window at the same speed or faster than Versacad files of 0.6 Mb using display list.
3d. Picking/moving or editing 1.2Mb file.	Slow	Slow — approx. 2–3 s. delay before object is picked, text moved very slowly.	Picking object is instantaneous. Text blocks can be moved in real time.
4. Reference files.	Yes, but indirect, lacks facility of MicroStation to easily generate separate ref. files.	No.	Yes. Very large files can be broken down into workable ref. files, each of which has the same layering capability as the original.
5. Group forming by irregular polygon fence.	No.	No.	Yes.
6. Display of several active views simultaneously.	Yes — up to 2 active windows at any time.	No. Several views available on viewport but not simultaneously active.	Yes. Multiple views active on both screens.
7. dBASE link.		Yes but only via symbol attributes.	Yes, direct interface to dBASE and Oracle written into the software.

Table 35.1: Software appraisal.

8. In addition to the graphical representation of the monument, a great deal of other data is also collected and stored during the course of the survey and the conservation process. This information is most readily managed using a database system. The ability to interface this system with the drawings presents a number of interesting possibilities, one of which could be the relationship of the characteristics of the fallen fragments to both the plan, and to a cell or symbol library of each of the stones.
9. The ability to output files in other formats offers the facility to manipulate files in “illustration” software to present information in a more pictorial form.

Aspects of general capability, facilities, precision, and usability were also considered but for simplicity have not been included here.

35.5.2. Software appraisal

A preliminary investigation of software already known to WBA included AutoCAD, Versacad, Fastcad, Robocad, Spirit, and MicroStation. Cadvance was not investigated since no local

user or dealer could be located to make a preliminary appraisal. Macintosh based software was not investigated.

Fastcad was rejected since the impression gained at the time was that the software was relatively immature and lacked some of the features of the more developed systems.

Robocad was rejected because the “drawing board” interface was inherently limiting and the system lacked the degree of precision necessary.

Requests to a local dealer of Spirit for appraisal software received an unhelpful response.

Two survey companies approached both recommended MicroStation as being powerful, reliable, quick, and very easy to use. It was decided to appraise the two existing suites, AutoCAD and Versacad against MicroStation to see whether a change would be sufficiently beneficial.

A simple comparison of the three software packages with respect to the criteria discussed above was carried out as shown in Table 35.1. As a consequence, it was decided that the advantages of MicroStation over the other systems were sufficient to strongly warrant its selection for use on this project. In particular, the speed of operation, the ability to form complex shaped groups easily, and the facility to produce closed polygons directly and edit them directly, was so superior in MicroStation that the cost of changing software, with all the

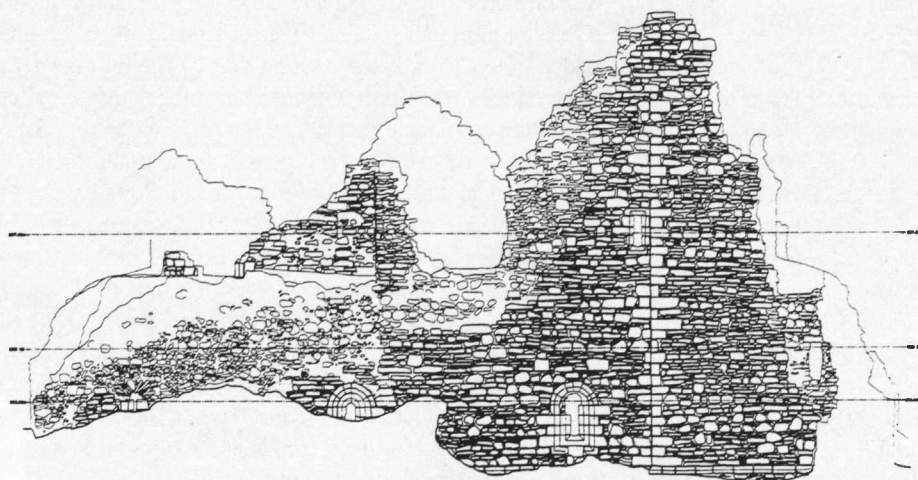


Figure 35.3: West elevation, west face: enhanced record drawing.

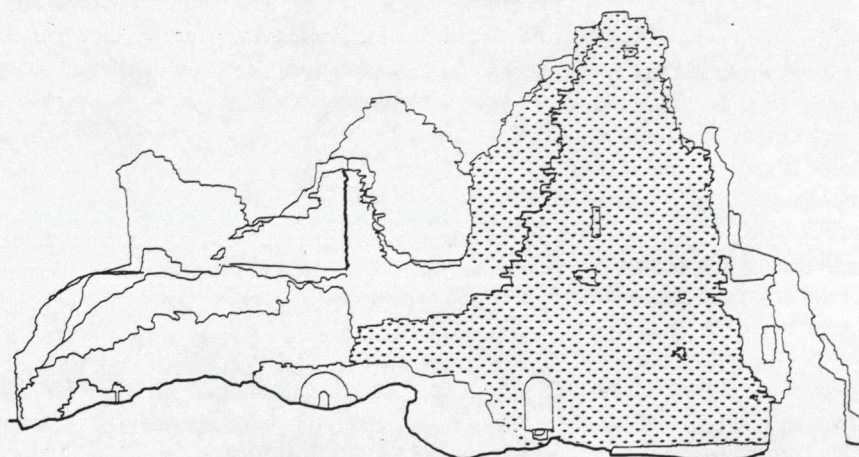


Figure 35.4: West elevation, west face: interpretive works record drawing.

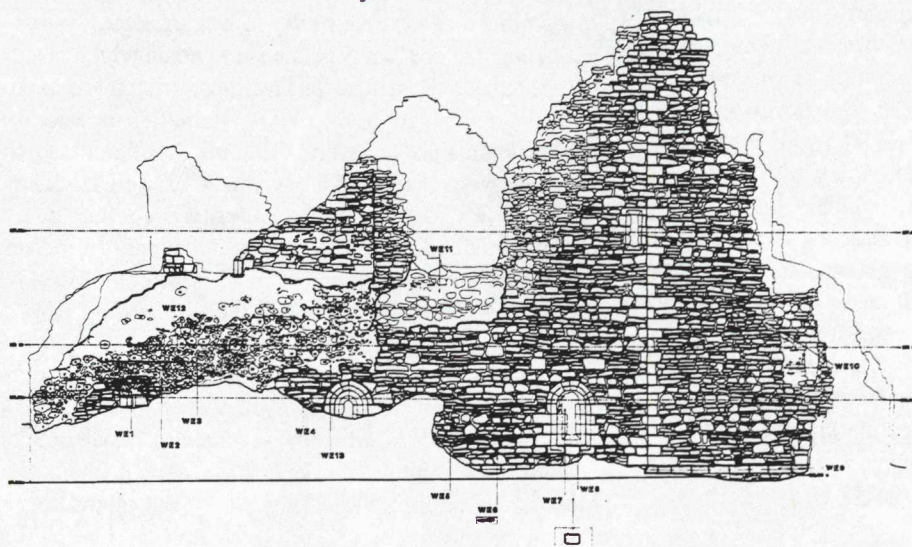


Figure 35.5: West elevation, west face: conservation specification drawing.

inherent on-costs of training, hardware driver and file format changes etc., could be readily justified.

35.5.3. Hardware requirements

For efficient processing of the digital data files, the acceptable hardware platforms and peripherals were found to be two screen systems comprising:

- PC-486 computer with 8Mb of RAM and a large, fast hard disk.
- High resolution 1280 x 1024 colour monitor with graphics accelerator card for rapid manipulation, coupled with a separate VGA monitor to display menus and keyboard commands etc., and an active full view of the elevation being worked on. This allowed the whole of the large screen to be used for detail work whilst retaining a global view of the full elevation.
- Large digitising table (preferably A1 or A0), with four-key puck.
- Large multi-pen flat-bed or drum plotter (preferably A1 or A0).

35.5.4. Processing of elevation data in MicroStation

Field verification and additional hand measured survey were undertaken by LUAU over a period of three weeks in December 1991. The installation and training in MicroStation took three days in January 1992, and once operational, the editing and manipulation of the photogrammetric digital data was shared between LUAU and WBA over a period of six weeks.

Enhancement was accomplished in a variety of ways: either drawn directly on screen from the dimensional data, or by digitising from hard copy drawings or large scale details prepared manually on site. The latter process related to the traditional method of editing and correction, but the former is both more accurate and easier for any experienced operative to carry out; not least because it requires only one interpretation of the survey data between capture and incorporation into the drawings. The process does, however, require that the CAD operator should have a good understanding of the actual object which is being drawn: if not involved in the data capture, they need to be familiar with the detail they are drawing. To this end, large, clear photographs proved to be invaluable (Fig. 35.3).

This process of editing minor corrections (fortunately very few) revealed a number of idiosyncrasies in the original photogrammetric data, the most frustrating of which was the fact that the boundary lines of elements were not distinguished from the drawings of individual stones. The separation of such elements, while not crucial in hand editing of hard copy, is important in CAD. The removal of a boundary line to find the stones below only partially drawn was alarming at the very least! As a consequence, modifications have now been incorporated into the specification for further photogrammetric recording of the remainder of the monument when it is exposed.

The boundaries between facework and corework, projecting and recessed planes, certain architectural detail, and the vertical sections, were kept on separate layers which could then be displayed or plotted on their own as a matrix for interpretive or other information (Table 35.2).

As mentioned above, the brief for the interpretive works was limited to identifying and attributing the areas of successive alteration and repair of the monument from the time of Lady Anne Clifford to the present day. The number of these interventions was small and could be adequately recorded by the addition of hatch patterns to the relevant areas. Separate levels were allocated to each period; these could then be displayed and plotted, either together or individually, and either superimposed on the full stone-by-stone record or only on the boundary layers for clarity (Fig. 35.4).

To keep the main files to a workable size, the interpretive works and boundaries were transferred to reference files which could be viewed and/or plotted individually or attached to the main files to use in conjunction with them. Any amendments or updating of either the main or reference files could be transferred by re-attaching reference files. Common level allocations were retained on both sets of files.

The repair specification drawings were produced directly from the record drawing files after analysis on site and consideration of the necessary conservation measures. Those parts of the monument requiring large scale detail treatment were identified by simply enlarging the relevant areas from the drawing files. Textual information was imported directly from Word 5, which ensured consistency between the drawings and specification documentation. Different scaled drawings were also plotted to give A3-sized ready reference sets (Fig. 35.5).

35.6. Plan data

For the plans of the ground, first, and second floors of the monument, it was decided not to use the horizontal section data provided by Photarc Surveys Limited, but to conduct new instrument-based survey control by means of a total station facility, linked to a portable data logger with full micro-computer data transfer capability.

35.6.1. Survey methodology

Extensive edits and additional detail were needed to enhance the basic photogrammetrically derived plans and, as none of the original ground survey control marks survived, the decision was taken to initiate a new ground survey. It was felt that in conjunction with the ACADD Microsurveyor software used by LUAU, the use of total station instrumentation would allow a rapid and accurate survey to be carried out.

Total stations can generate survey data which is accurate to ± 20 mm. on the ground, and by transferring this data straight from the data logger to the CAD system, this numerical accuracy is maintained. Ideally, the survey methodology should also satisfy representational accuracy, as well as being efficient and fast. To an extent these criteria conflict, so a compromise methodology is necessary, inevitably requiring an intermediary hand measured stage to transfer the basic survey frame to a completed enhanced record drawing (Figs. 35.6 and 35.7).

Three-dimensional co-ordinate data was captured from a number of detail points surveyed with respect to a control network which was typically accurate to between ± 5 and 10mm. Each point was marked on the fabric in chalk to aid its identification during the subsequent enhancement stage.

Level	Name	Line Width	Colour	Colour No	Style	Pen No	Pen
1	Facing	0.35	Red	3	2	2	Black
2	Facing			3	0	2	
3	Facing			3	0	2	
4	Facing			3	0	2	
5	Facing Out	0.35	Yellow	28	0	2	Black
6	Facing Rep	0.35	Pink	5	0	2	Black
7	Facing Rep			5	0	2	
8	Facing Rep			5	0	2	
9	Facing Rep			5	0	2	
10	Facing Repts Outline	0.35	Yellow	36	0	2	Black
11	Core		Orange	6	0	1	Black
12	Core			6	0	1	
13	Core			6	0	1	
14	Core			6	0	1	
15	Core Outline	0.25	Yellow	20	0	1	Black
16	Core Repairs	0.25	Grey	9	0	1	
17	Core Repairs			9	0	1	
18	Core Repairs			9	0	1	
19	Core Repairs			9	0	1	
20	Core Repairs Outline	0.25	Yellow	44	0	1	Black
21	Profile section	0.7	Aq Blue	7	0	3	Black
23	Ground Line	0.7	Green	2	0	3	Black
25	Moulding Line	0.25	Purple	13	0	1	Black
26	Text 2	0.6	Red	35	-	5	Red
27	Shadow Line	0.6	Aq Blue	7	0	3	Black
28	Text	0.2	Red	51	-	1	Black
29	Title	0.2	White	16	0	1	Black
30	Wll edg proj	0.5	Red	19	0	3	Black
31	Facing reced	0.25	Grey	48	0	1	Black
32	Face rec out	0.25	Yellow	52	0	1	Black
33	*Face uncovered	0.35	Green	26	0	2	Black
34	*Core uncovered	0.25	Lt blue	31	0	1	Black
40	DOE MOW	0.3	Purple	69	0	-	Pink
41	DOE MOW II	0.3	Blue	71	0	6	Orange
42	FmkInd/DOE	0.3	Blue	73	0	7	Blue
43	Frankland	0.3	Green	66	0	8	Green
44	*Lady Anne	0.3	White	24	0	8	Green
49	Outline of work	0.3	Lt Blue	39	3	6	Orange
50	Redundant level	-	Green	50	-	-	-
52	Vegetation	0.3	Grey	8	0	8	Green
53	Background	0.2	Purple	101	0	1	Black
54	Hidden line	0.2	Lt Blue	87	3	1	Black
55	Datum line	0.2	Grey	112	1	1	Black
56	Datum text	0.3	Red	115	-	2	Black
57	New facework	0.3	Red	85	0	5	Red
58	New corework	0.3	Blue	41	0	7	Blue
59	Hatching	0.2	Grey	64	0	1	Black
60	Redundant level	-	Green	50	-	-	-

Table 35.2: Level symbology for elevations.

For this second stage, the digital data was plotted onto stable polyester film and the architectural detail hand drawn in the field with respect to the survey points. The resulting plots were then digitised for incorporation into MicroStation.

This methodology allowed good representational accuracy and was fairly fast in the field; however, it involved double handling at the digitising stage and was therefore slightly inefficient and not exceptionally accurate in absolute terms.

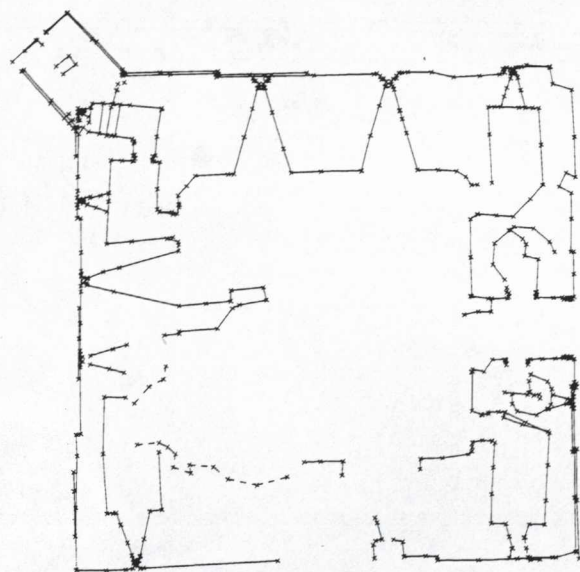


Figure 35.6: Ground plan: digital data plot.

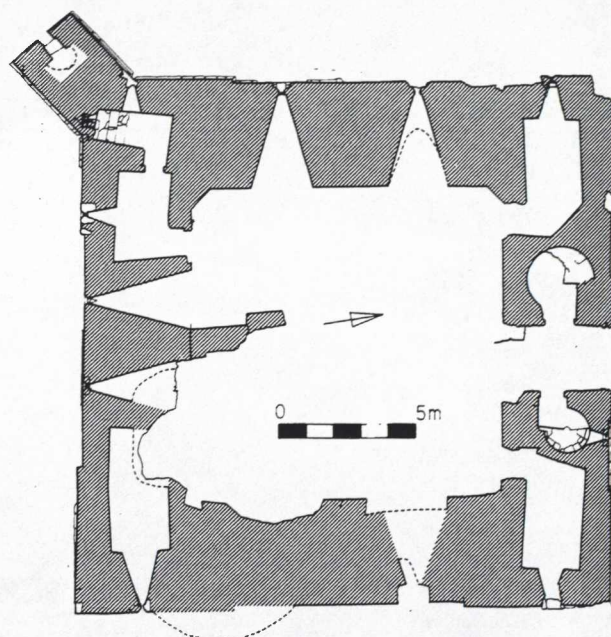


Figure 35.7: Ground plan: enhanced record drawing.

Errors crept in at the digitising and plotting up stages; when tested these were found to be on average $\pm 16\text{mm}$ on the ground (0.8mm at 1:20 plotted scale). Although these errors were within the accepted limits, they were not ideal.

An alternative method was therefore tried. The survey data was again enhanced by hand in the field; however, this time all adjustments were annotated with digital dimensions measured from the survey points marked on the fabric, and recorded numerically onto the field plots. The original digital data transferred into the CAD system was then edited on screen using the correctional information on the field plots.

This method had the advantage that no digitising was required and therefore any distortions within the plotted medium did not affect the final product. However, double handling of the data was still involved, and when the detail was transposed from the field plots onto the screen there was a risk of representational inaccuracy creeping in, even though the detail was located accurately by the use of digital dimensions.

A better solution for incorporating survey data more accurately onto CAD might be the use of a waterproof 386-based pen computer (*e.g.* GridPad) which can run a CAD system using the pen. The survey data could then be digitally transferred from the total station into the GridPad, and the drawings edited directly on screen in the field before transferring the edited file via DXF into MicroStation. There would be no double handling and in theory no resultant representational errors. However, it is yet to be demonstrated whether the current technology is capable of putting the theory effectively into practice, particularly where large data files are concerned.

35.7. Conclusion

Inevitably, during a project of this nature, there were bound to be inefficiencies due to lack of experience with the MicroStation software and because the project brief originally did not anticipate the use of CAD. However, despite this initial learning curve, the survey data enhancement techniques employed at Pendragon Castle were found to be extremely

effective, flexible, and potentially more cost-effective than more traditional methodologies.

Acknowledgements

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