# THE APPLICATION OF PHOTOGRAMMETRIC SURVEY WITHIN THE CONSERVATION OF THE GREAT CEILING AT PETERBOROUGH CATHEDRAL

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## ABSTRACT

The great medieval ceiling, situated within the nave at Peterborough Cathedral, Cambridgeshire, UK is the only 13th-century painted wooden ceiling surviving in situ in England. A major conservation project is currently underway, aiming to ensure its long-term preservation. This has included a detailed investigation, of both the underlying timber structure and the painted surfaces upon it.

This paper reviews the input photogrammetric survey has made to this project. This has included the generation of both traditional photogrammetric outline CAD drawings, of all the primary architectural features, and the use of digital photogrammetric techniques to produce an orthophotograph of the whole ceiling. Extracts of the orthophotograph have been overlain with the CAD drawings to provide a composite product combining the interpretation of a line drawing and the textural detail of a photograph. This material is currently being used directly on site by the conservators as the basis of their documentation processes.

The project presented many challenges with regard to both the capture of the photography and the survey control as well as the subsequent photogrammetric processing. The most notable of these was problems with consistency of the colour balance of the digital images produced by photogrammetric scanning systems originally designed for aerial photography.

## KURZFASSUNG

Die mittelalterliche Kirchendecke im Mittelschiff der Kathedrale von Peterborough in Cambridgeshire, Grossbritannien, ist die einzig erhaltene bemalte Holzdecke aus dem 13. Jahrhundert in ganz England. Momentan wird ein bedeutendes Instandhaltungsprojekt durchgeführt, das ihre langfristige Erhaltung gewährleisten soll. Dabei wurden sowohl die Holzstruktur als auch die Bemalung detailliert untersucht.

Diese Arbeit untersucht den Beitrag der Photogrammetrie zu diesem Projekt. Dies beinhaltet sowohl die Generation der traditionellen photogrammetrischen Umriss-CAD Bildern von allen primären architektonischen Merkmalen als auch digitale Photogrammetrietechniken, um ein Orthofotograph der ganzen Decke zu erstellen. Auszüge des Orthofotographs wurden mit CAD Bildern überlegt, und damit wurde ein zusammengesetztes Produkt erstellt, das die Interpretation eines gezeichneten Bildes mit dem textlichen Detail eines Fotos verbindet. Dieses Material wird derzeit direkt vorort von Konservatoren als Grundlage ihres Dokumentationsprozesses verwendet.

Das Projekt stellte vor viele Herausforderungen sowohl hinsichtlich der Photoaufnahmen und der Kontrolle der Erhebung als auch der folgenden photogrammetrischen Entwicklung. Bemerkenswert waren dabei die Probleme mit der Beschaffenheit der Farbbalance der digitalen Bilder die von photogrammetrischen Scannersystemen produziert wurden, die ursprünglich für Luftphotographie entwickelt worden waren.

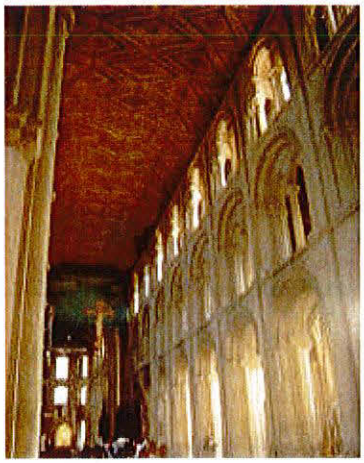

Figure 1 General view of the nave.

## 1 INTRODUCTION

The magnificent wooden ceiling of the nave in Peterborough Cathedral and the intricate painted details covering its entire length, are not easily missed (Fig.1). Dating from around 1210-1230 this extraordinary feature, 62m long, 11m wide and canted on either side, appears as one continuous structure upon which the many images of kings, saints, angels, archbishops and other icons are delicately painted. Only on closer examination does the complexity of the true construction become obvious and the underlying conservation problems start to become apparent. Row after row of overlapping oak boards, were originally held in place by nails driven into the overlying trusses from below (Fig. 2).

Figure 2 Extract from orthophoto showing construction of ceiling.

Attempts over the years to reinforce these fixings - for example the insertion in 1834 of several long bolts through the ceiling to secure the boards to the roof trusses and the later restoration in 1924 when screws were inserted from above that pierced the underside of the boards - have resulted in a more rigid ceiling structure. But when combined with the ever changing environmental conditions encountered within the cathedral, this added rigidity has prevented the natural movement of the wood and hence caused structural problems of its own, such as the loosening of some of the original nails and the splitting of boards. The current conservation project was therefore aimed at securing both the long term survival and the security of the ancient painted boards in their present condition.

In 1994 the English Heritage Photogrammetric Unit were approached to provide advice to the Cathedral Architect to the Dean and Chapter of Peterborough on the survey requirement within this proposed conservation project. In particular this focused on the potential use of photogrammetric survey techniques to provide the base survey data for both the architects and the conservators to plan and carry out the required treatments. Discussions initially centred around the production of a suitable specification for a traditional photogrammetric outline survey of the entire ceiling, which the Cathedral could then use to procure the required data themselves through commercial survey sources. However it soon became apparent that with so much wonderful detail still on view, the provision of more than just a basic outline drawing would be required and so a scaled photographic montage of the whole ceiling was added to the list. It also became apparent that this project would provide an ideal opportunity to test the application of modern digital photogrammetric survey techniques and some of the new products, such as orthophotography, within an actual conservation environment. It was therefore agreed by the English Heritage Cathedrals Team and the Dean and Chapter, that the Photogrammetric Unit would become directly involved in the production of survey data for the project in order to test out this new technology. All the base survey data - these days referred to as metric survey - that was to be needed by the conservators and architects within the first phase of works, starting at the eastern end of the ceiling, would therefore be provided directly by the Unit. This, and the resulting archive of images, would then go on to form the basis for the commercial procurement by the Cathedral itself of the remaining phases of survey work, as and when the project required them.

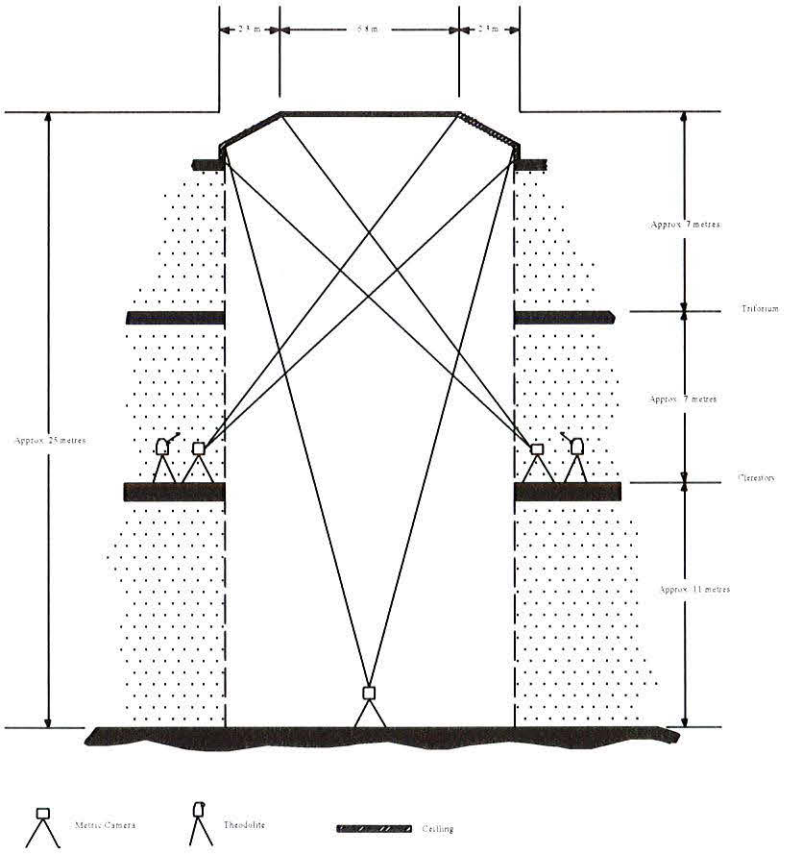


Figure 3 Arrangement of the cameras and theodolite in the nave.

## 2 STEREO-PHOTOGRAPHY

The entire ceiling is approximately 62m in length and 11.5m wide and stands around 25m above the ground floor level of the nave.

Due to the scale of subject, the acquisition of a suitable package of stereo-photography and survey control that fulfilled the general criteria used by English Heritage for architectural photogrammetric surveys, was always going to be problematic as was controlling the variable lighting conditions encountered within the cathedral. Given the dimensions of the ceiling it was decided to use a ground based survey camera rather than attempt to use either a scaffold platform or a hydraulic lift. This would not only provide a more stable, safe platform for the photography but would minimise the disruption to the daily workings of the cathedral. Fortunately the specifications of the ZEISS UMK 30/1318 metric camera, which the Unit already possessed, appeared to fit the bill perfectly. With its telephoto lens, of approximately 300mm focal length, and a negative size of just over 5" x 7" (13 x 18 cm) it was able to provide near perfect economic stereo-coverage of the entire ceiling, as well as maintaining a large enough photo scale of around 1:83 to enable

Figure 4. Stereo pair taken with Zeiss UMK 30/1318 metric camera of eastern most bay

detailed drawings to be generated later. To minimise any potential damage to the nave floor, the camera and tripod were mounted on a dolly, which allowed the whole assembly to be simply wheeled from one camera location to another. Given the symmetrical coverage offered by the UMK, the camera was wheeled straight down the centre of the nave with each photograph being taken vertically upwards under each of the central lozenges.

This resulted in a total of 23 photographs being taken on both colour and black and white negative film, during November 1996, providing 22 stereo models for later processing. In general this arrangement worked very well although the presence of the large Crucifix, hanging down from the ceiling itself, did cause an obstruction and hence required more stereo-photography than originally anticipated.

It was always expected that due to the sheer size of the ceiling the correct exposure of these ground based images, particularly in colour, would prove to be a problem. The combination of the height of the ceiling and the difficulty of safely placing a powerful enough flash system within the cathedral, to illuminate the full width of the ceiling in one exposure, meant that the only feasible option was to use the available natural light. This appeared to be relatively consistent, during overcast conditions, although the effect of light sometimes cascading in through the clerestory windows at upper level, meant that photography had to be taken during late afternoon to reduce the likelihood of flare. On the day of the photography an exposure of 1s at f22, onto Kodak Vericolour colour negative film rated at 160 ASA, seemed to be sufficient although the lighting regime used was to prove a major problem during later processing, particularly in successfully managing the overall colour balance of the ceiling images.

In addition to this ground based photography a series of stereo-images were also taken from the clerestory level using the smaller 5"x4" (13 x 10 cm) format WILD P31 metric camera. These were taken principally to cover the two canted side sections of the ceiling and the vertical ashlar boarding, but to date these have not been required due to the excellent coverage provided by the 23 ground based UMK images.

## 3 SURVEY CONTROL

To enable each of the 22 stereo models to be satisfactorily orientated in either a traditional analytical plotter or a digital photogrammetric workstation, a minimum of 4 control points per model are normally required. Typically these are applied butterfly-style targets, allowing angle intersections from a fixed baseline to be accurately observed. For the ceiling however the safe placement and subsequent removal of around 90 of these targets was deemed impracticable. Therefore it was decided to use points of detail, even though it was accepted that these would not provide the same clarity of pointing and hence level of accuracy as a fixed target and would also take a lot longer to observe. To allow these intersections to be carried out effectively a set of colour prints were made from the stereo-photography which were marked up directly on site, as detail was selected and co-ordinated. The wide platform at clerestory level, on both sides of the aisle, provided the best location for survey observations, giving an excellent view of the ceiling as well as reducing the need for any extreme vertical angle observations to be taken to the points of detail.

At the time of the survey, December 1996, there was no fixed survey grid existing around the cathedral into which these observations could be tied. Therefore a total of 20 temporary survey stations were set out on a local grid at clerestory level within the nave of the Cathedral, from which intersection observations to 87 points of detail were taken on both faces using a LEICA TCA 1103 total station theodolite. The motorised horizontal and vertical circles and onboard PCMCIA data storage card of this theodolite greatly facilitated the observation work. The observations were all computed off site using the Landscape processing package to provide the required 3D co-ordinates. This processing provided 85 detail points where the height residual between observations was less than 5mm, and only two where the error was 6mm. Due to the anticipated problems in observing to points of detail instead of fixed targets, these observations were deemed acceptable for the processing work anticipated. Also the arrangement selected on site provided at least 6 control points per stereo-image and hence a greater degree of redundancy during the orientation processes to come.

## 4 DRAWINGS

The initial requirement for the Peterborough project was to provide a set of traditional photogrammetric line drawings. These were to be printed on A1+ sheets at a scale of 1:20, and were to cover only the visible architectural detail within the first 7m of ceiling at the very eastern end of the nave - which was to be the physical extent of the first phase of conservation works. In addition a set of smaller A3 format drawings at the larger scale of 1:10 ( Fig. 5) would also be needed during the actual conservation works on site. These would allow the pinpointing and referencing of all visible structural features such as nail heads, screw threads and tie bolts, as well as the painted detail itself, that can only be seen when viewing the ceiling from close proximity.

In discussion with both the Cathedral conservation consultant and Architect, the precise level of detail for the survey was agreed. Photogrammetric plotting was commenced during December 1996 by the Photogrammetric Unit using a LEICA SD2000 analytical plotting machine. All of the detail was recorded commensurate with the standard specification for such English Heritage surveys, although the CAD layering convention was reduced down to include only three basic layers - Boards, Fixings and Painting. During this initial plotting work a number of interesting problems arose.

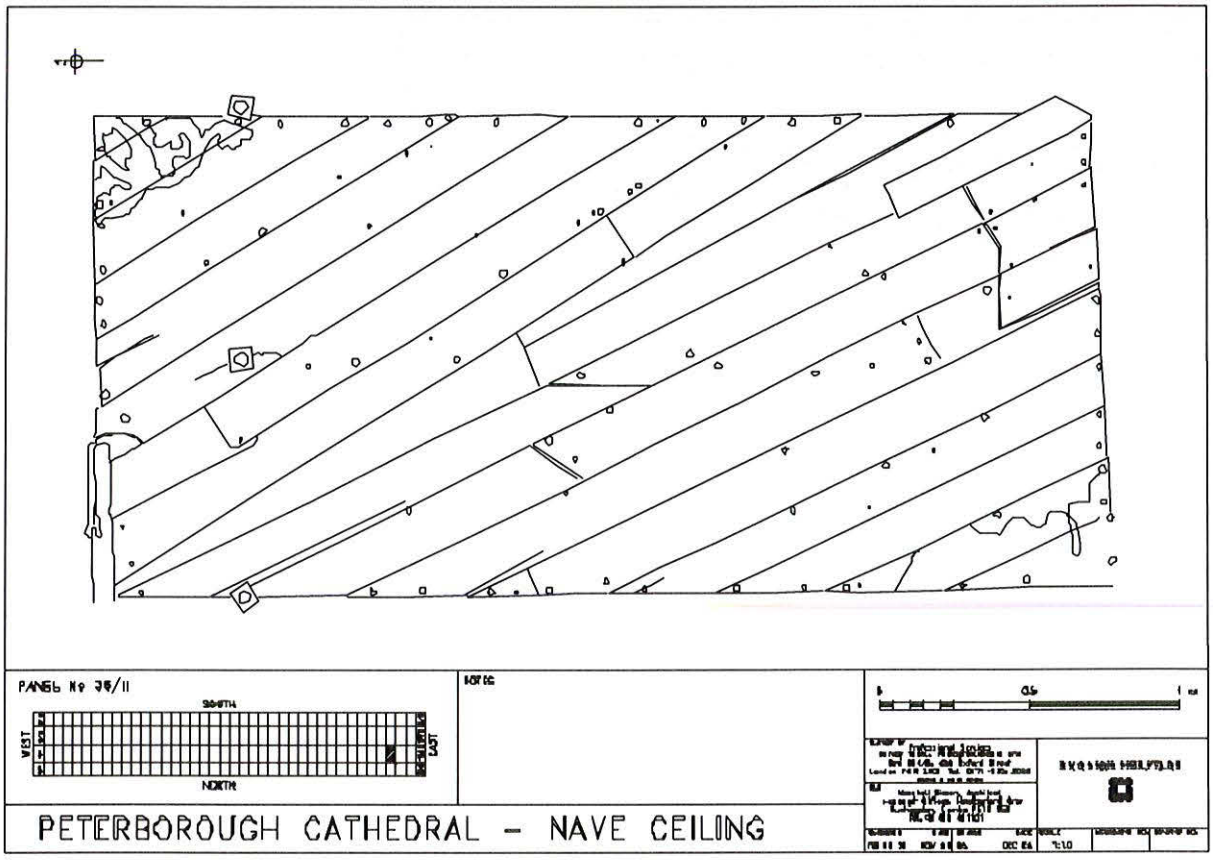


Figure 5 Drawing extract taken from base photogrammetric survey

The first was how best to represent each of the oak boards that made up the actual ceiling. As each board actually overlapped its neighbour it was impossible to accurately record all four sides, as one side was often hidden from view. Therefore it was decided that where part of a board was hidden by the overlap of another, the visible edges would be plotted as an unclosed 3D polyline.

Secondly as some of the painted detail was difficult to interpret successfully as a line, particularly when viewed at high magnification, it was decided not to plot any of this detail other than a basic outline, and infill the remainder with a scaled photographic image.

Finally some of the fixings within the ceiling itself, such as the original nails and the later inserted screws, proved very difficult to differentiate between during plotting. Therefore simple circle symbols were used to denote all similar features. Although each fixing would be recorded at the correct diameter, they would require verification by the conservators themselves, from the scaffold, when the actual works commenced on site.
Using this initial plotting work as a benchmark, it was possible to provide an accurate estimate to the architect on the anticipated time, and hence cost, of photogrammetrically processing the remaining 55m of ceiling to the same level of detail using the existing

stereo-photographs and survey control data produced by Photogrammetric Unit. This information has already been used in the successful procurement by the Dean and Chapter themselves, of the next phase of base photogrammetry through the commercial sector and the data is already being used by the conservators on site.

## 5 THE USE OF ORTHOPHOTOGRAPHIC IMAGES

As noted earlier, little of the painted detail was recorded as line work. Instead, a scaled photographic image was to be utilised and it is here that the application of digital photogrammetric techniques, and the introduction of the digital orthophotograph, was to become crucial to the documentation part of the project.

The Photogrammetric Unit already had experience of digital photogrammetry through the survey of the standing stones at Stonehenge in Wiltshire. As with this survey, the original colour negatives were scanned at 22.5 micron resolution, using a Zeiss PS1 photogrammetric scanner, yielding files of around 120MB each. These were imported into a Helava DPW770 digital workstation, running SOCET Set software, and processed to form a complete digital orthophotograph (Fig. 6) of the entire ceiling at 5mm resolution and a file size of 90MB.

Figure 6 Unformatted version of the complete orthophotographic survey processed at 5mm resolution

Considering the use of detail points only for the survey control, and the observation and photography over a 25m range, the errors achieved during the orientation of each of these models were deemed perfectly acceptable for the production of an orthophotograph - mean RMS errors of the X, Y and Z co-ordinates of the 87 control points were 3.4mm, 6.0mm and 11.6mm respectively.

Extracts from this complete orthophotograph have since been provided, in digital form, to the conservators working directly on the ceiling (Fig.8).

Using CorelDRAW these images have been imported into their own site based computers located on the scaffold platform above the nave, to provide a full colour backdrop to the outline line drawings, previously supplied and imported via DXF format.

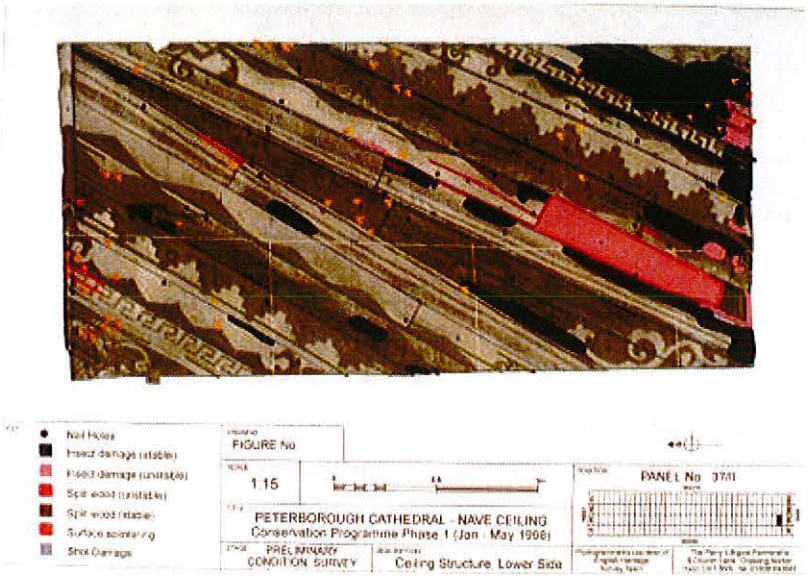


Figure 7 - Extract from preliminary technical survey

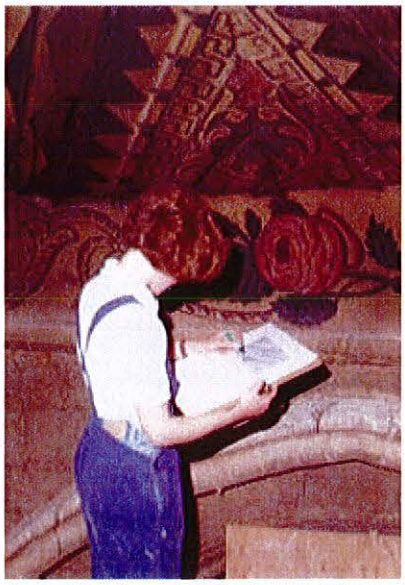

Figure 8 - Conservator using base survey on site

Additional details have then been measured on site and inserted into these base drawings prior to printing at an appropriate scale - in this instance 1:15 for immediate use on site (Fig.7). Together they have provided both this preliminary condition survey and the rest of the project with a completely new level of documentation.

## 6 DISCUSSION

Even though the size of the ceiling provided a challenge in its own right, the major problem encountered during this project was the colour balancing of the 23 colour images used during the production of the orthophotographic mosaic. Although geometrically correct scans were utilised the slight variations in exposure within each colour negative, caused apparently by the use of natural light, appeared to have upset the automated process usually utilised during the scanning of aerial imagery. This resulted in individual scans that were incorrectly colour balanced, and when mosaiced together, produced a very fluctuating colour image even after attempted correction using Adobe Photoshop. Alternative scanners were used in an attempt to minimise this problem, but accurate colour balancing still remained an issue eventually requiring re-scanning of the base imagery onto Kodak Photo-CDs in an attempt to produce colour images that could be evenly mosaiced together. It is now interesting to note the release by some software developers of image balancing *wizards* that could potentially take such a fluctuating image and automatically balance out the colour variations to produce a completely even image. Having such routines already installed within a digital photogrammetric environment would have greatly aided the presentational aspect of this project and no doubt other close-range projects.

Since this project has been completed, a number of developments have occurred in theodolite/EDM technology which may have aided the progression of this survey. The introduction of total stations equipped with inbuilt REDM, working in a truly coaxial arrangement to precisions of at least ±3mm, would have effectively halved the necessary survey control work. They could also have allowed more control points to be observed, using polar observations rather than intersection, and provide more redundancy within the processing stages. Within the latest phase of conservation work on the ceiling, REDM equipment has actually also been used to aid the survey and recording of the roof structure above, to which the ceiling is attached.

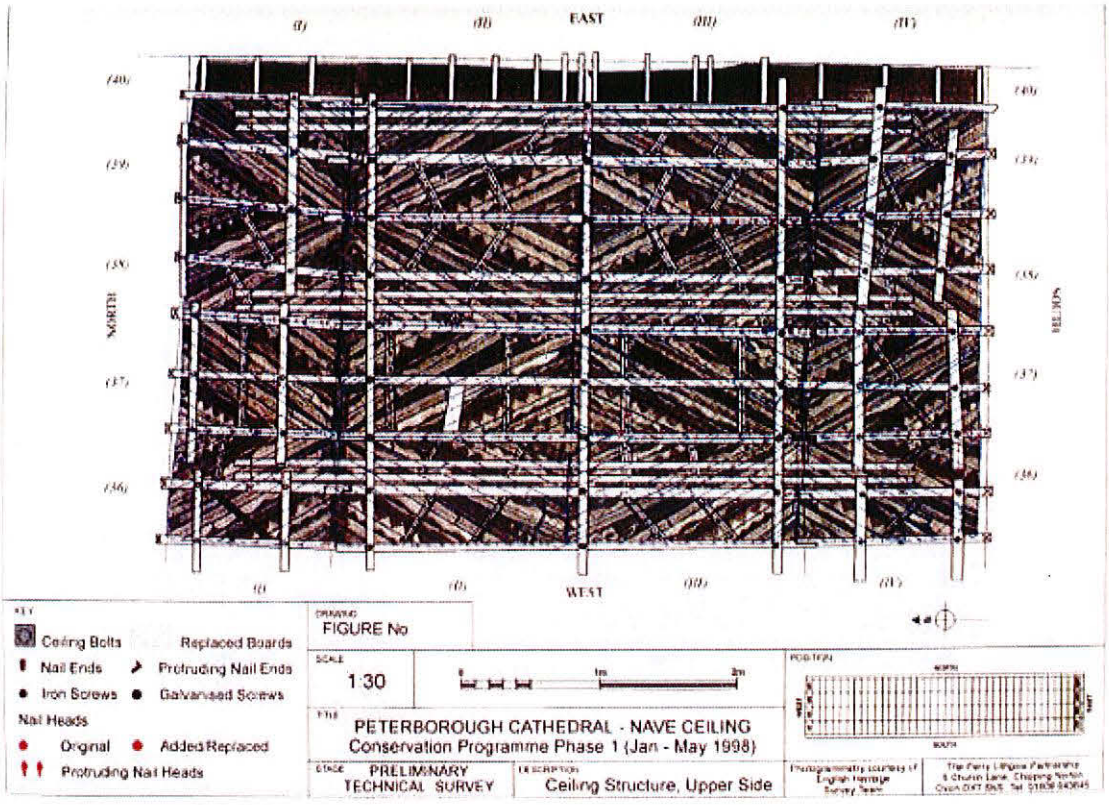


Figure 9 - Extract from preliminary technical survey showing upper ceiling structure overlaid onto underlying ceiling detail

By remotely tracking around the edges of the many timber elements in this confined space, a three dimensional profile of each beam has been produced More detailed hand measurements have then been added to form a plan of each section of roof, which combined with the actual ceiling survey from below, forms a complete picture of the design and formation of the structure (Fig.9).

## 7 CONCLUSION

The lessons learnt during this survey, and the imagery already generated, are continuing to contribute to the progression of this project as subsequent phases of treatment are all planned, programmed, procured and executed based upon this base set of data. An important archive of high quality, stereo images also now exists and the use of the orthophotographic image, rather than a basic rectified photo-montage, has added to the documentation stage of the conservation work by greatly reducing the need to record every element of detail as a line. Work still obviously needs to be done on the scanning and processing aspects of the technology used, to ensure that the accuracy of the colour balancing can match that of the image geometry. However the image files generated have been manageable within standard off-the-shelf drafting packages by the conservators themselves and have been easily combined with line data from a number of sources to produce the required composites. Therefore it is safe to say the great ceiling at Peterborough Cathedral has now been successfully surveyed using a combination of both traditional and modern photogrammetric survey techniques.

## ACKNOWLEDGEMENTS

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