ARCHITECTURAL PHOTOGRAMMETRY FOR THE RECORDING OF HERITAGE BUILDINGS: AN OVERVIEW

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ABSTRACT:

In heritage documentation, recording techniques can be divided into two broad categories, namely photographic and non-photographic methods. Photographic methods include a photographic image is fundamental to the whole recording process, such as computer-rectified photography, photogrammetry and laser scanning. Whereby, non- photographic methods are including hand survey and theodolite-based measurements. Three main criteria should be considered when making decisions about the specification of the recording: the cost, technical considerations or logistics and, finally, whether the survey will fulfil the technical and academic requirements and be understood by the end user. Moreover, the choice of the most appropriate and reliable recording methods will depend on the scale and type of building, level of accuracy, and level of recording needed. This paper discusses the application of photogrammetry techniques in the recording of heritage buildings. The principles, accuracy and challenges of the technique are also described.

Keywords: *architectural photogrammetry, heritage buildings recording, building conservation, photographic methods*

INTRODUCTION

The purposes of architectural recording are to accurately represent a building as a prelude to repair or rehabilitation, or to produce an archive record. In this respect, a number of techniques can be relied upon to produce acceptable results, notably architectural drawing and architectural photography. Architectural drawing is a precise and elegant way of transmitting information and ideas about architecture and buildings as a series of graphical elements such as lines, planes and shapes. On the other hand, architectural photography is regarded as the art of photography that offers the potential for recording that no other technique can offer such as providing factual information about buildings. In practice, both methods may involve one or more means of recording.

Photogrammetry is an indirect technique to acquire 3D geometric data without touching, but using images of the object. The architectural photogrammetry was introduced during the late 19th century by the German civil engineer, Albrecht Meydenbauer. Generally, architectural photogrammetric surveys have proven themselves to be of the greatest value in providing drawings for architects and others; almost all the surveys are performed using close-range photogrammetric techniques. Professionals in a number of fields, including architectural and archaeological recording, agree that close-range photogrammetry provides a level of accuracy which is often beyond practical necessity.

Since then, architectural photogrammetry has achieved widespread recognition worldwide. This is in part due to a great increase in the technology of photogrammetry for surveying and recording monuments. In many countries, this technique has been employed rapidly by public sectors such as the Bundesdenkmalamt or 'Federal Service for Historic Monuments' in Austria, the Institut Geographique National in France and the Metric Survey Team of English Heritage in the United Kingdom.

The International Council on Monuments and Sites (ICOMOS) has recommended the use of photogrammetry in the recording of historic buildings and monuments since 1961. Moreover, the International Committee for Documentation of Cultural Heritage (CIPA), is one of the international committees of ICOMOS has promoted the development of this technique within monument conservation services. This includes the production of publications, the organizing of symposia, the convening of meetings of experts, the carrying-out of practical studies and other technical activities. Moreover, most of CIPA's activities have involved numerous correspondents around the world. In addition, the United Nations Educational, Scientific and Cultural Organization (UNESCO) has also organized training activities in architectural photogrammetry in a variety of ways. In fact, in some developing countries, UNESCO has been responsible for equipping photogrammetric units for architectural or archaeological services (Nurul Hamiruddin, 2002).

Many valuable papers and books describing architectural photogrammetry have been published: for example, Dallas (1996), and Ogleby and Rivett (1985) have covered the general principles of architectural photogrammetry. Meanwhile, guidance on practical application has been offered by Dallas (1992) and, Hanke and Grussenmeyer (2002). After the introduction of this technique, many early photogrammetry publications were written in German, French or Italian, but now publications on photogrammetry in English have been increased.

PRINCIPLES OF ARCHITECTURAL PHOTOGRAMMETRY

There are obviously many detailed variations in the drawing format which may be produced in architectural photogrammetry, notably elevations, plans and sections. However, architectural photogrammetry is better for the representation of the facades or elevations of historic buildings and structures, mostly in line drawings.

Despite the technique having been established in many countries in Europe (e.g. Germany, French, the United Kingdom, Italy, etc.) and providing an accurate recording technique for certain tasks, in the rest of the world (e.g. Malaysia) a large number of architects and building surveyors are still unfamiliar with the technique. The overall cost of this technique remains relatively expensive. As well with today’s practices, only photogrammetric specialists generally carry out the technique, whether they are public sector or commercial survey company. Nevertheless, in some cases, commercial survey companies may fail to produce the satisfactory standard of architectural photogrammetric output, unless they are familiar with the purpose and standard of surveys which are required. This may due to a lack of communication and an appropriate specification.

In theory, architectural photogrammetric surveys have followed the conventional principles of photogrammetry. Like the other techniques, before being employed, it is necessary to consider the purpose and level of the survey, the existence of the subjects and their quality, and available means in terms of equipments, personnel, finance, etc. In this respect, the procedures of an architectural photogrammetric survey might be divided into two main phases, namely the production of photographic images (field work) and the production of drawings on the plotter. Normally, in many cases, the cost of fieldwork is considered to be at least five times less than the plotting process (Nurul Hamiruddin, 2002).

i) Photographic Technique

Generally, the building façade will be photographed to form a single stereo-pair or a series of overlapping stereo-models, depending on the size of the façade or the required scale of the final drawing. Sometimes, in certain circumstances (e.g. due to the nature of buildings and their surroundings), a strip of a number of a few stereo-models is quite usual. Therefore, in the planning of photography of the building façade, it is necessary to determine coverage and lay out camera positions first in order to ensure optimum coverage from the photography. Furthermore, there may be important decisions about the types and lenses of camera being used. Metric cameras, whether single cameras or stereo-metric cameras (in practice, single cameras are found more flexible and stereo-metric cameras are not commonly used nowadays) are widely used in this technique; this is due to its advantages over an amateur or 'non-metric' camera (e.g. view or monorail cameras). The comparison of both cameras may be summarized as below:

Table 1: The advantages and disadvantages of metric cameras and non-metric cameras

Metric camera	
Advantages	**Disadvantages**
• Total stability camera. • Value of the principal distance is accurately known. • High resolving power and distortion- free lenses.	• Expensive cost. • Highly skilled operation.

• Film has minimal deformation.	
Non-metric camera	
Advantages	**Disadvantages**
• General availability. • Flexibility in focusing range. • Motor drive. • Hand-held for simple orientation. • Lower price.	• Suffers from unstable geometry. • Lenses designed for high resolution at the expense of high distortion. • Lack of fiduciary marks. • Small image size.

Technically, this photogrammetric technique have, the ideal ratio of the photo-scale[1] to the survey scale is 1:3, and possibly a maximum of 1:6. For example, if the survey scale is to be 1:50 then the photo scale must be not less than 1:300. Besides, a recommended ratio of the base line of the camera to the object distance is 1:2, thus for an object distance of 30 metres the approximate distance between it and the camera station should be 30m/ 2 or 15 metres (Nurul Hamiruddin, 2002). These are contrasted to the ideal ratio of photo-scale, 1:5 and maximum 1:10, suggested by Whyte and Paul (1985, 293). In practice, wide-angle cameras may provide a smaller photo-scale, but may be inconvenient for photographing lows buildings where only a small part of the format is used. To some extent, enlargement from a photograph to plot scale should not normally exceed x 2 to x 3, in order to maintain the very best standard of accuracy of subject data. In choosing a maximum angle and resolution. Reflex cameras with interchangeable mounted lenses of 28 or 24mm are preferable. Fixed lenses normally have less optical deformation than zoom lenses.

[1]Photo-scale is the ratio of the focal length to the object distance (formulae; focal length: object distance x 1000)

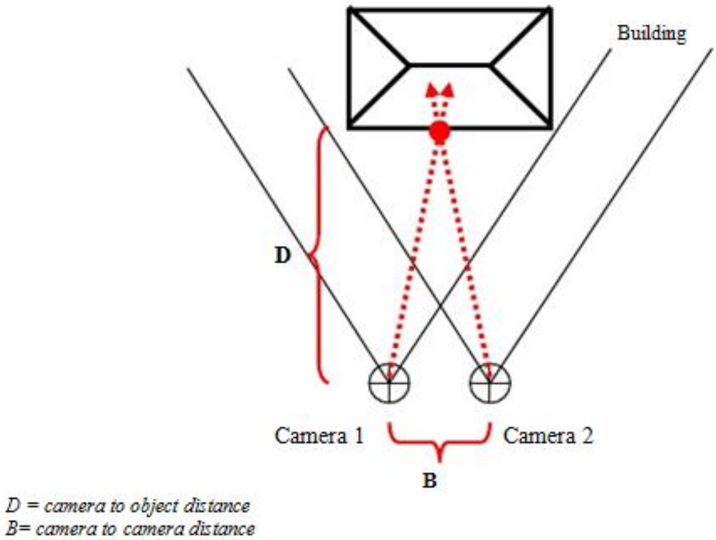

Figure 1: The principle of close-range photogrammetry for photographing a building in order to provide a stereo-pair photograph.

Figure 2: The stereo-photography of Stonehenge taken with Wild P31 metric camera equipped with 100mm focal length lens. (a) Stereo pairs of images (b) The overlapping of a pair of image.
(Courtesy: Paul Bryan, the Metric Survey Team, English Heritage)

ii) Control Measurement

In order to ensure the accuracy of data, appropriate and efficient control measurements are essential. The most thorough and accurate method of control may involves the provision of at least four pre-marked points, co-ordinated by theodolite intersection using two or three rays. This method being very accurate and reliable, it is a time-consuming and expensive process. In fact, it may often take longer than the photographic process. Nowadays, however, the sophisticated total station theodolites (e.g. REDM) speed up the control measurement operation greatly. Alternatively, the basic model of using tape distances and points of known height is also acceptable However; this method is not as accurate and provides no control in depth if cross-sections are required, even though this method is undoubtedly quick and cheap.

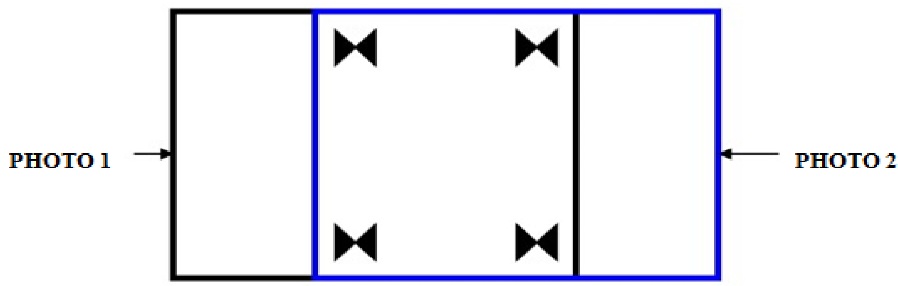

Figure 3: Optimum positions for four control points for controlling one stereo-model.

The use of clear silicone adhesive/ sealant as survey targets in the surveying of the exterior building it is highly advisable. The advantages of this method are that it is quick and can be peeled off completely. Moreover, this may also be considered as a non-intrusive method (i.e. leaving the wall’s surface unmarked and undamaged).

iii) Plotting Technique

Recently, various photogrammetric instruments have become available for plotting from the stereo-model. In the past, two categories of instruments were available: namely, the analogue and analytical plotter, but today digital photogrammetric workstations are also available. In addition, the digital workstation is capable of measuring at an average rate of 100 points per second. These plotters will be also highlighted in the following part of this paper.

Indeed, in practice, the plotting process is the most important stage of architectural photogrammetric technique. Principally, as mentioned earlier, a plotting technique is the systematic process by which the entire subject's features (e.g. materials, elements and characters) are transformed into scaled line-drawings, utilising appropriate Computer Aided Design (CAD) software's; normally, AutoCAD is used or, sometimes, a photogrammetric mapping package. Nevertheless, in practice, there are no standard specifications detailing the way to present the subject being recorded in the digital format; in other words, it is usually determined locally by photogrammetric organizations or companies' special needs and requirements.

In considering the degree of accuracy of the plotting process, two factors might be considered in practice initially: namely, the accuracy inherent in the actual plotting process and the accuracy in graphic terms. An acceptable error of the drawing should not exceed 0.2mm to 0.3mm (in relation to the nearest control point). In many cases, different plotter-operators will produce a different quality of drawing. In other words, the degree of accuracy desired is dependent on the degree of the experience and skill of the operator.

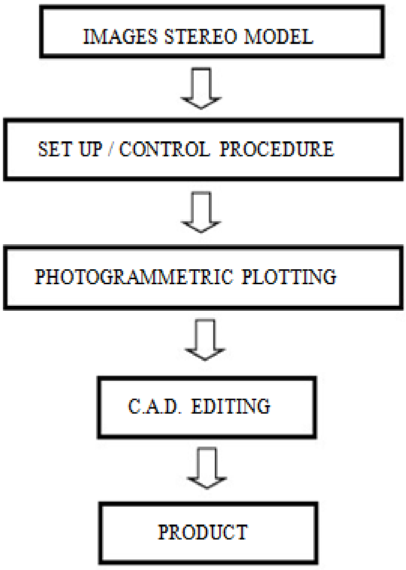

Figure 4: The basic diagram of the photogrammetric plotting process.

Practically, in architectural photogrammetric surveys, accuracy of 10 to 20mm is acceptable for surveys at 1:50, whereas accuracy of 5 to 10mm with survey scales of 1:10 to 1:20, and at smaller scales of 1:100 to 1:200, accuracy of 30 to 50mm are considered satisfactory. For most practical applications, the plot scales of 1:50 or 1:20, or a combination of both, are highly recommended. The acceptable accuracy of plot scales may be defined according to the purpose and level of a survey as in Table 2 and Table 3.

Table 2: The typical plotting scale use in the building survey.

Purpose of survey	**Plotting scale**
Alterations and extentions	1:100 or 1:50 depending on the size of the building and the purpose of the survey.
Installation of new services	1:100 or 1:50.
Installation of fittings	1:20 or 1:10.
Buildings of architectural or historic interest	1:100 or 1:50 for floor plans and elevations, depending on the size of the building, and 1:20 or 1:10 for specific features of interest.
Block plans	1:500 with attention given to the shape of the site.
Structural surveys	Usually only floor plans are required, being to a scale not greater than 1:100.

When dealing with existing buildings, the degree of detail of the subject to be drawn is still a vitally important decision. For example, in some cases where there is good ashlar, at 1:50 scale, it would be adequate to use a single line of mortar joints. However, if the stone is irregular or the width of mortar joints exceeds 30mm, a double line is expected. Nevertheless, it is highly recommended that the stone is drawn individually by showing the jointing in its exact position. In addition, this may be most useful in the alterations or repairs of the structure, and may also provide good evidence for archaeological investigation.

Figure 5: The plotting process using analytical plotter Leica SD 2000.
(Courtesy: The Metric Survey Team, English Heritage)

Figure 6: Digital Photogrammetric Workstation
(Source: English Heritage 2011)

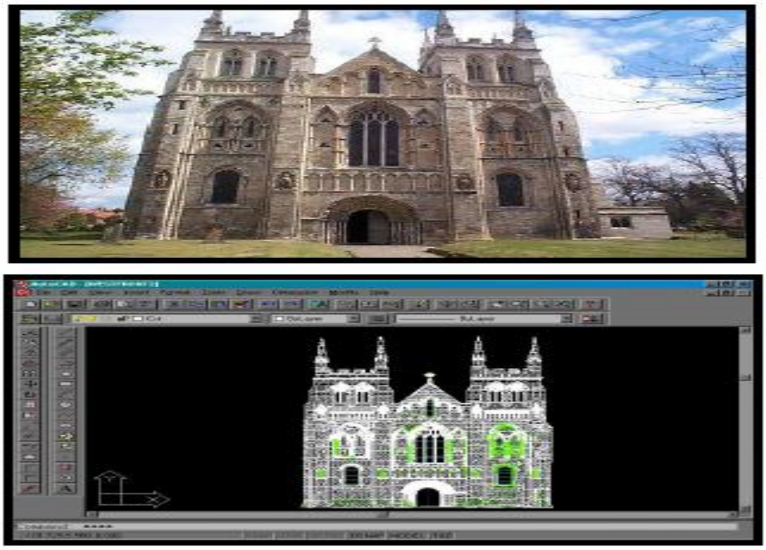

Figure 7: Selby Abbey, Selby West Yorkshire: (top) Photographic image (below) Photogrammetric output in CAD format prepared by the Downland Partnership Ltd. (Courtesy: Field Archaeology Specialist Ltd.

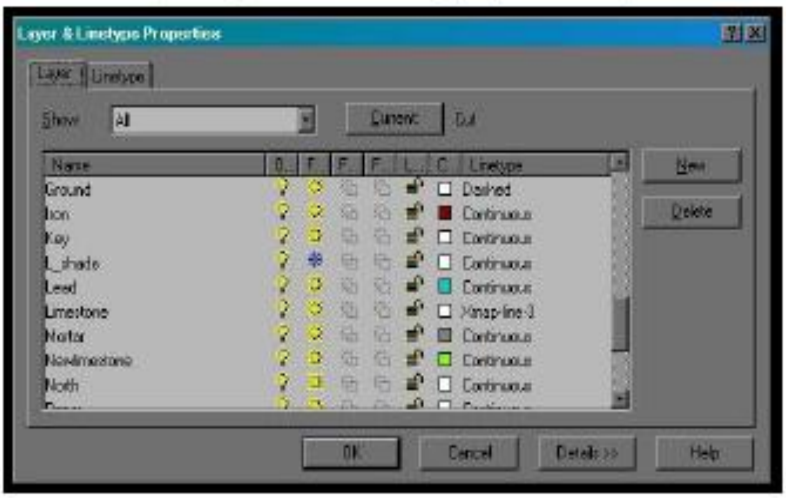

Figure 9: Selby Abbey, Selby, West Yorkshire: CAD layer and lin type properties used for the photogrammetric survey. (Courtesy: Field Archaeology Specialist Ltd.

ACCURACY

In order to check accuracy of photogrammetry data, the author has conducted a test measurement into the chancel of St Mary's Church, Studley Royal as a case study to compare between onsite measurement and the photogrammetric recording of the building. The Metric Survey Team of English Heritage photo grammetrically surveyed the external and internal walls of the chancel. For dimensional accuracy, eight test measurements were made at various convenient places across the length of the east façade of the chancel (Figure 9), which is the most complicated and highly detailed structure. Moreover, the test measurements were taken equally between horizontal axis and vertical axis on the façade in order to achieve a better comparison. Nevertheless, these test measurements were carried out within the band up to three metres above the ground level of the façade; this was due to a difficulty in measuring the upper area without the assistance of a platform or a ladder. However, these measurements were sufficient for the level of the study.

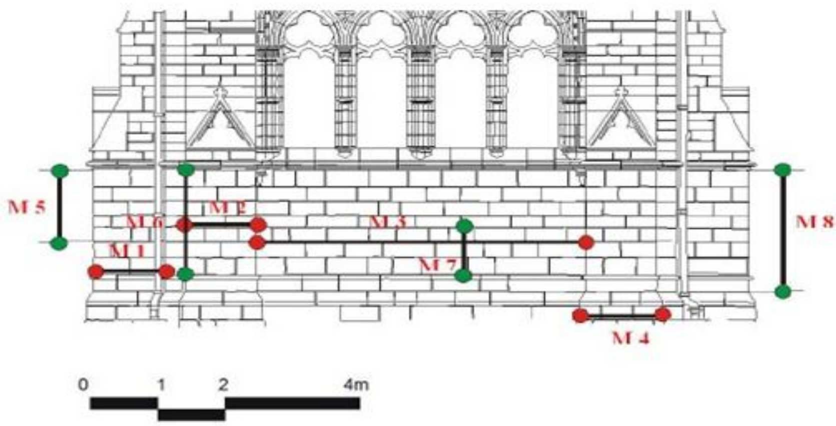

Figure 9: The channel east façade showing the location of accuracy chaecking between distance on the façade and distances on the 1:20 scale plotted drawing

All dimensional distances on the façade had been properly measured by hand using tape measurement and were later compared with the same points on the plotted drawing at 1:20 scale. The comparison of results is summarised in Table 4 below.

Table 3: The checking table for accuracy between distances on the façade and the distance on the 1:20 scale plotted drawing

Measurement		Distance on façade (mm)	Distance on 1:20 scale plotted drawing (mm)	Error/mm
Horizontal	1	1065	1070	+5
	2	1040	1040	0
	3	4870	4900	+30
	4	1245	1250	+5
Vertical	5	1230	1230	0
	6	1800	1800	0
	7	800	805	+5
	8	2085	2090	+5
			Total Average Error	+6.25

In practice, the standard level of accuracy of architectural photogrammetry is dependent on the standard of cartographic accuracy, which is tolerant to 0.18 mm standard line width. Therefore, the maximum acceptable error at a scale of 1:20 is ± 3 mm and ± 9mm at a scale of 1:50. In this respect, the result above gives an average error of +40 mm on the horizontal axis, together with an average error of +10mm on the vertical axis, so that the total average error is +6.25 mm overall. Taking the total average over 9.9 metres, the façade dimensional length offers an error of approximately 0.6mm per metre, which is clearly within the acceptable error limit of photogrammetric plotting.

CHALLENGES TO THE APPLICATION OF ARCHITECTURAL PHOTOGRAMMETRY

Since the 1960s, a great deal of photogrammetry work has been achieved in Europe and the rest of the world. However, the application of laser scanning has recently become increasingly sophisticated as the technology develops. In general, laser scanners are divided into two types: close-range scanners and medium- to long-range scanners. Close-range scanners using triangulation (15-30cm in range) are mostly suitable for small complex objects such as sculptures and archaeological artefacts. On the other hand, medium- to long-range scanners (approx. 12-150m) are suitable for much larger subjects (e.g. the building interior and exterior) (Barber 2001, 1). In principle, a laser scanner consists of a laser and a charged coupled device (CCD) similar to those found in a contemporary digital camera; the CCD is used to record the displacement of a strip of laser light projected onto an object.

Today, on the market, various types of scanner are available, such as Cyrax 2500, Leica ScanStation, Quantapoint, LMS Callidus, LiDAR, Soisic Scanner, Riegl LMS Z210, etc. All these types, of course, have different abilities, data-handling issues, and practical concerns for further investigation. For this reason laser scanning has recently been used experimentally in the recording of historic buildings by many agencies, in order to assess the current efficacy of such a method.

Figure 10: Cyrax 2500 *Figure 11: Leica- Scan Station*

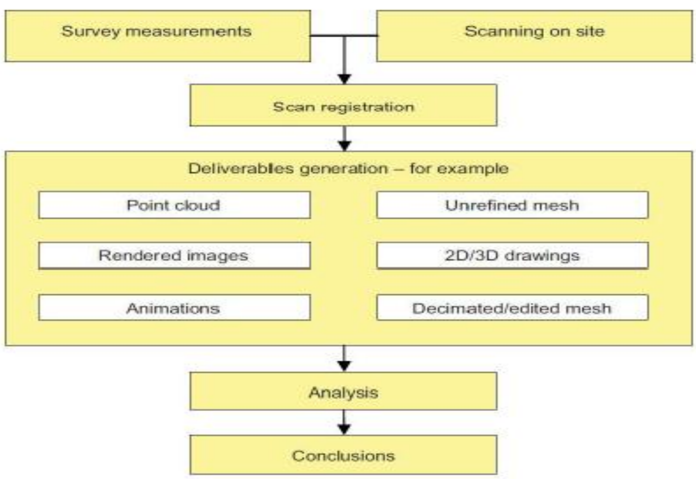

Figure 12: A typical laser scanning workflow (Source: English Heritage, 2011)

The main advantage of laser scanning methods to the architect or others is that it is easy to view the image of the subject being recorded in 3D by zooming in and out, particularly for small areas. In addition, this method is also known as a 'non-contact' recording technique, where no survey marks need be attached to the building during fieldwork (Dallas and Morris 2002, 28). However, Barber (2001, 12) to some extent, makes the point that the main disadvantage of this method is that the laser does not reflect well on some materials. For example, shiny objects can cause too much energy to be returned; whereas, black objects reflect too little light.

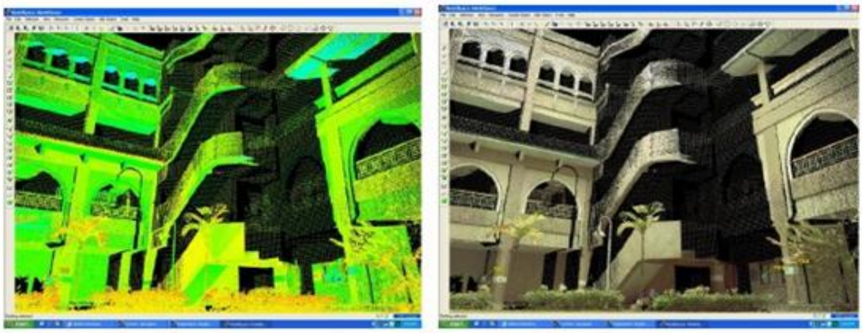

Figure 13: Point cloud images from laser scanning

Figure 14: The Refectory south wall, Dunfermine Abbey (Left) Shown as a laser scenned 'mesh' surface. (Right) Profiles extracted to form a vertical cross section. (Courtesy: R.W.A.Dallas)

From the few experiments done by various professionals such as Barber (2001) and Dallas and Morris (2002), it may be concluded that laser scanning methods are useful in certain situations, notably when a full digital 3D representation of the object is required. However, the method is unsuitable for the production of traditional drawings and plans, particularly in the recording of historic buildings. As a rapidly developing technology, nevertheless it seems to be the case that laser scanning will supplement and may replace some applications currently carried out by photogrammetry. The advantages and disadvantages of laser scanning methods may be summarized as follows:

Tables 4: The advantages and disadvantages of the laser scanning method

Advantages	Disadvantages
• Very precise measurements. • A solution in situations where 3D measurement by other means may be difficult. • Quick in data capture. • On-site scanning is possible.	• Practical limits on the object size and height. • May have difficulties on some material surfaces. • Editing the data to produce meaningful results may be difficult.

CONCLUSION:

In conservation practice, three main criteria should be considered when making decisions about the specification of the recording: the cost, technical considerations or logistics and, finally, whether the survey will fulfil the technical and academic requirements and be understood by the end user. Moreover, the choice of the most appropriate and reliable recording methods will depend on the scale and type of building, level of accuracy, and level of recording needed.

A photogrammetric technique is an ideal recording method to be used for complicated historic buildings with highly detailed and decorated structures and surfaces, and which are also on a large scale. Photogrammetry is increasingly accessible today, compared with a decade or more ago when it generally required the use of specialist analytical instruments. Digital photogrammetry is the technique to which laser scanning is most often compared. In the recording of historic buildings it is widely accepted among surveying professionals that laser scanning has proved to be unsuitable for the production of traditional drawings and plans necessary for planning conservation work. Laser scanning provides data on surface texture which photogrammetry cannot normally provide, whereas photogrammetry provides a clarity of individual structural elements (e.g. stone by stone drawings) which would be difficult to achieve with laser-scanned data without considerable editing of the raw data. In terms of documentation process, laser scanning is always a complex task. In comparison, the photogrammetric solution is a low cost one as the acquisition system is limited to a digital camera and a few accessories only.

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