

TOWARDS A STANDARD SPECIFICATION FOR TERRESTRIAL LASER SCANNING IN CULTURAL HERITAGE – ONE YEAR ON

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ABSTRACT

The development of a specification to standardise the capture, presentation and delivery of point clouds for cultural heritage applications is a necessary step in the acceptance of laser scanning as an every day survey technique. For a number of years English Heritage, England's national body for the conservation of cultural heritage, has maintained a specification stating the requirements for the capture of metric survey data by photogrammetric, rectified and orthorectified photography, REDM and hand methods. The development of laser scanning and its obvious potential in cultural heritage has led to the development of a similar set of standards for this new technology.

This project, through consultation with English Heritage, users and manufacturers, sought to develop standards that were relevant and applicable to the instruments currently available for laser scanning. The project also aimed to steer the development of laser scanning by outlining to manufacturers and developers the particular requirements of cultural heritage survey. Due, however, to the rapidly evolving nature of new technologies it is anticipated that the specification will continue to be adapted over the next few years. This paper reports on the document's development one year on from the project's end. It will provide an example of the use of the specification on a terrestrial laser scanning project in the UK, in addition to discussing and summarising the benefits and issues that have arisen. This will include a summary of the economic benefits of the specification. It is hoped that the work will lead to an increased use of laser scanning for cultural heritage in the UK, in addition to ensuring the expectations of end users are managed.

1. INTRODUCTION

This paper describes the development of an addendum to the Metric Survey Specification of English Heritage (Bryan and Blake, 2000) covering the collection of survey data by terrestrial laser scanning. It details the work that has taken place since the outline provided by Barber et al. (2003) and describes the final draft presented to English Heritage in December 2003. Throughout the project the addendum was reviewed by a steering committee of users and providers. It was drafted in two parts. Part One provides a user guide that gives examples of use and provides general guidelines and discussion. It is intended that this user guide supports the standards provided in Part Two that forms the specific contractual requirements placed on the surveyor. For generic requirements, that is those that relate to any type of survey, the reader is referred to the existing Metric Survey Specification.

One of the most challenging decisions in defining a standard survey specification for a new technology is deciding the appropriate time at which to undertake such a task. Until maturity, new technologies, such as laser scanning, often experience rapid development that makes the development of standards difficult. This could result in wasted effort or, even worse, lead to a stifling of the technology by restricting its application. Nevertheless, it was decided that sufficient work had been previously undertaken to warrant the definition of a standard survey specification. Indeed, far from restricting application of the technique, it was believed that a specification would actually encourage the use of laser scanning and

subsequently increase the value of such survey work to the end user. Nevertheless, throughout the project the steering committee strived to make the addendum as flexible as possible while still placing firm requirements on the provision of data. This was a key factor addressed by presenting the addendum in two parts.

The scope of the specification was defined before work began. The term laser scanning covers a broad range of measurement techniques including airborne LiDAR and close range systems. Both of these techniques have been shown to have applications in recording cultural heritage (Beraldin et al. 1998; Beraldin et al. 2002; Bewley 2003). However, as the project was originally seen as an extension of the current metric survey specification, which specifically deals with buildings and small sites rather than regions or small artefacts, the addendum was defined for terrestrial scanners that are most applicable to these scales. This means that data from, for example, a close range laser scanner may not be efficiently collected using the addendum in its current form. Also whilst the addendum relates to the scale of survey addressed in the current document it does not attempt to replicate traditional products which tend to record the position of edges, instead concentrating on the recording of surfaces, to which laser scanning is more suited.

Indeed, the project restricted itself to specifying for the most appropriate methodologies for collecting data and providing that information in a universal and well documented manner. It did not attempt to specify the processes required to implement data from terrestrial laser scanning into everyday use. The implementation of

scanning would have required investment in hardware and software, which may have required the adoption of proprietary formats and products. This was beyond the scope of the project. Therefore, the addendum aimed to facilitate the capture and delivery of data that would be easily transferable between different software systems in the future. Collected data includes the scan data itself, in un-registered and registered form, images showing the data collected, photographic images of the subject and control information providing the ID, X, Y and Z coordinates of each control point.

In addition to the collected data the addendum also outlined the health and safety issues relating to the use of lasers. For this purpose the addendum refers users directly to the current European standard (IEC, 2001). However, to facilitate an understanding of this complicated document the user guide provides a brief summary of the pertinent issues.

In order to provide a case study demonstrating the use of the addendum on an actual site, a survey was undertaken at Clifford's Tower, York. How this survey fulfils the metric survey specification and its addendum will be described along with the benefits and issues experienced during the survey. Prior to describing this survey, however, the role of the specification in the project flowline needs to be defined.

2. THE PROJECT FLOWLINE

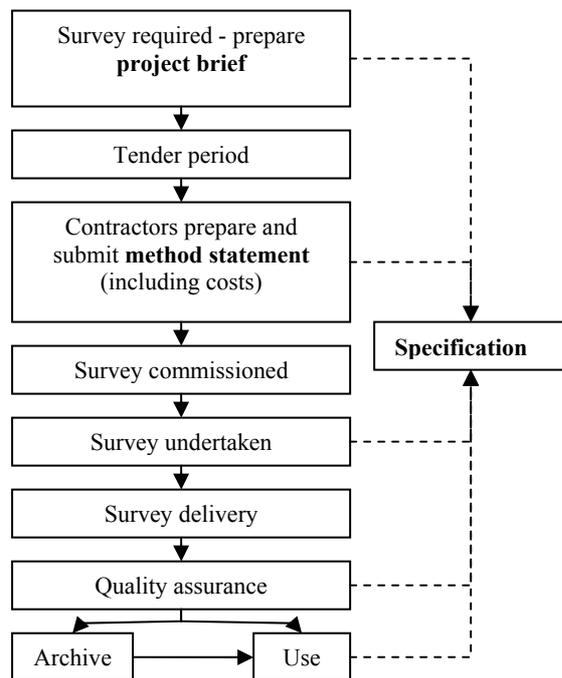


Figure 1. The project flowline (dashed lines indicate reference to the specification).

Figure 1 describes a typical project flowline. After identifying the need for a survey to be undertaken, a project brief is established by the client (in this case English Heritage). The project brief includes information that helps the contractor understand the site-specific needs and requirements of the survey. It is written with

direct reference to the survey specification which prompts the client for the relevant information.

Once the project brief is prepared it is put out to tender and survey contractors provide a method statement detailing how they intend to undertake the survey. This will include the standard topics required for any survey and outlined in the current metric survey specification. This includes items such as a risk assessment and delivery timetable/milestones. The specification will be referred to in order to help the contractor understand how the survey should be performed. The survey will then be commissioned and undertaken. During this work the contractor will generally be guided by the method statement but will also refer to the specification for guidance where necessary. Upon completion the client will use the project brief and standard specification to undertake a quality assurance process before accepting the survey and passing it into the archive and/or on for use.

3. SURVEY OF CLIFFORD'S TOWER, YORK



Figure 2. Clifford's Tower, York.

Clifford's Tower (Figure 2) is the surviving keep of York's main medieval castle (Butler, 1997). It stands on a 14 metre high defensive motte (mound of earth) at the confluence of the River's Ouse and Foss. Although the site dates from 1069, the present day stone tower was built in 1245 under the orders of Henry III using a 'four leaf' design. The tower itself is 15 metres tall with a diameter of 20 metres. Despite a period of neglect by the Tudors, including an enterprising, but un-official, scheme by the tower's gaoler to sell the structure stone by stone in 1596, the tower remained in use until 1684 when it was destroyed by fire. The extreme heat of this fire turned some of the magnesium limestone masonry pink. Since this time the Tower has remained a key piece of York's cultural heritage and become an important tourist attraction.

As a key tourist attraction for the city there is a need to balance the conservation of the tower with providing the facilities and services required by visitors. The risk of further damage also requires an archive of survey data. For example, although the motte is out of bounds to the public its un-fenced grassy slopes are attractive to visitors and gradual damage to the motte is inevitable. The tower has also developed a noticeable lean due to gradual subsidence, first noted in 1315. Finally, although photogrammetric data is available for the tower itself, no

survey has ever been undertaken of the motte. It was decided, therefore, to select the tower as the final test site for the project where a survey would be undertaken to mirror the commercial survey process.

3.1 The project brief

The project brief was based on the existing metric survey specification and the addendum produced in this project. It outlined the extents of the required survey, the necessary point density, the control system to be used and the deliverables required.

3.1.1 Point density and measurement precision: In laser scanning point density and measurement precision are directly linked. Without high density point measurement features cannot be accurately described. Without accurate measurement they cannot be accurately located. The addendum provides two methods for defining an appropriate point density. The first is using a standard table to suggest an effective point density and precision for a particular scale of survey. This method of referencing the required survey precision to the scale of the required output reflects the method used for photogrammetric survey, where required precision is based on the line width of the final product. Whilst this method is not directly suited to laser scanning, it was included to preserve parity with the existing document. The second method allows point density to be defined based on a minimum feature size. For example, the brief may state that the minimum feature discernable in the point cloud should be 10 mm in depth (in the direct of the measurement) and 10 mm in width and height (perpendicular to the plane of the scan).

In the case of Clifford's Tower, three major areas were defined for survey. Firstly a topographic survey of the motte was required at a scale of 1:100 which based on the standard table required a point density of 25 mm (with point measurements with a 1σ precision of +/- 25 mm). Secondly the exterior of the tower itself was required showing features of 10 mm in size or larger. Finally, detailed scanning of a window on the South-West lobe was required, showing features of 4 mm or larger.

The addendum's user guide contains an equation that allows the appropriateness of the chosen point density to be assessed:

$$Q = 1 - \left(\frac{m}{s} \right)$$

where Q is the quality of the data, m is the point density on the object and s is the minimum feature size. Using this formula a value can be obtained to indicate the likelihood of a particular feature being detectable. For example, a point density of 5 mm on a feature 10 mm in size would give a value of 0.5, or a 50% confidence that the feature would be visible. This equation leads to very high point densities being required in order that the features, typically surveyed using photogrammetry, can be detected in scan data. Although possible using close range scanning, terrestrial laser scanning is clearly unsuited to recording very small features and it serves to further emphasise the fundamental role of laser scanning in surface measurement.

3.1.2 Control: The project brief also outlined the required control system. In the case of Clifford's Tower, as with most of the survey commissioned by English Heritage, all scan data was to be registered to the local site grid. A pre-established network of control points in the site coordinate system around the base of the tower was provided by English Heritage.

The addendum sets out clear requirements for the control of scan data using resection calculations:

- each scan must contain at least four appropriately distributed XYZ control points (these should be measured using techniques that allow an accuracy of twice the value of the accuracy of a single point)
- the residuals of the registration process (the process of transforming the raw scan data to the site system) and the geometric precision of the estimated parameters should be noted in the survey report. These should be shown to be equal to, or better than the accuracy required by the final point cloud.

The addendum also allows for registration to be performed using surface matching techniques, but as all survey data of sites and monuments has to be registered to a local site grid targeted control points are still required. A total of n+3 appropriately distributed targets are therefore specified when using surface matching techniques, where n equals the number of scans in the survey. When scanning is performed from a known position, for example when an instrument is located above a control point, only 3 XYZ targets are required per scan.

The specification requires that artificial targets are used and that they must be carefully placed to avoid obscuring important details or being close to large depth discontinuities. The use of natural control points is not recommended by the addendum except where unavoidable, and then only points away from edges may be used.

3.1.3 Data voids: The addendum requires that areas where data voids are anticipated to be unavoidable should be highlighted in the method statement before survey is undertaken.

3.1.4 Supplementary data: The project brief also defines the data required in addition to the scan data. In this case narrative (i.e. non-metric) photography was required at each scanner station to aid interpretation, in addition to non-metric photography of relevant features, such as mouldings, carvings and existing damage to the Tower's fabric.

3.2 Pre-survey deliverables and certification requirements

In addition to the standard information outlined in the current metric survey specification, a description of the proposed point density and potential data voids, the technical details of the proposed scanning system are also required.

In the case of Clifford's Tower a Cyrax 2500 laser scanner was chosen with a quoted point measurement accuracy of +/- 6mm (1σ). The manufacturer's technical specifications of the system were provided as part of the method statement. In addition, certification that the scanner is in good working order is required. The standard testing of scanning instruments is currently an area of much research. No standard test is available to provide an indication of if the scanner is working as required. In this case an array of scanner targets were scanned and compared against surveyed measurements. The scanner was shown to be operating to within its stated precision. To ensure quality control in the future use of laser scanning it is essential that the next generation of laser scanners are provided with certificates after each (regular) service showing they are operating within their stated technical specification.

3.3 Survey methodology

In pre-planning a total of four primary scanning stations were estimated to provide 90% coverage of the tower. This includes areas at high level and required no platform to allow access. However, approximately one metre at the base of the tower is hidden by the motte when viewed from ground level. In order to eliminate these data voids a number of fill-in scans were required. The problem was compounded by the 40 x 40 field of view afforded by the Cyrax 2500. Fewer scans would have been required if using a scanner with a 360 degree field of view. In order to account for this a standard topographic survey was also undertaken in order to ensure a full record of the motte. This is given in Figure 3. The outline of the tower was created from the scan data, whilst the remaining survey was collected using a total station.

Additional control stations were established on the top of the motte where necessary and linked to the pre-established site control. Each scan contained at least four reflective control targets with an average precision of 2 mm in X, Y and Z axes. Surface matching of overlapping scans was not used.

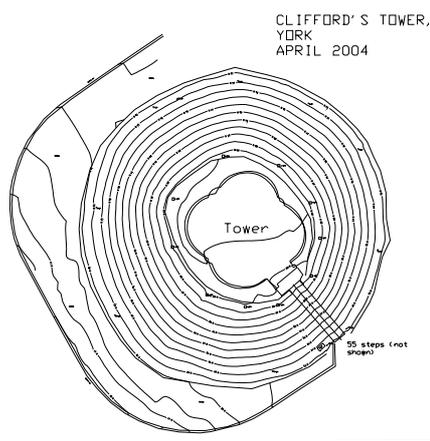


Figure 3. Topographic Survey with the Tower outline recorded using scan data.

Data voids, due to temporary obstructions such as vehicles and pedestrians moving during the scanning the

scan, were minimised by the selection of appropriate scanning stations and survey times.

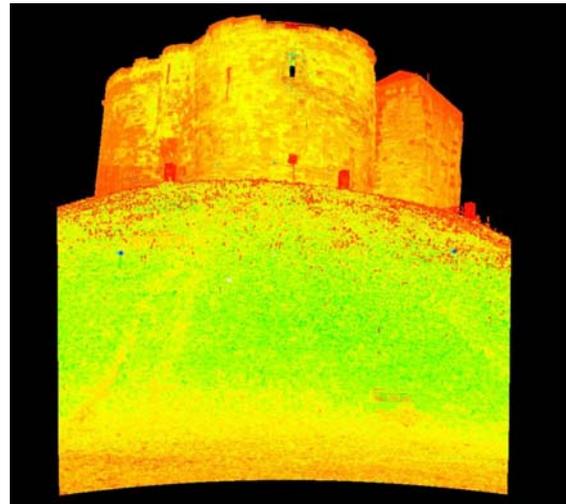


Figure 4. A scan of the tower from street level.

A standard form was used to record information such as control points names and the weather during each scan. With some additional effort such details could be recorded with the scan data improving metadata management. For the most part the weather remained dull and overcast during the survey. The addendum prevents scanning from taking in place in weather conditions that may affect the quality of the collected scan data. However, although light rain did occur on one occasion it was not considered sufficient to prevent scanning taking place. Additional data to aid interpretation was collected throughout the survey. This included high resolution photography and sketches. For example, on the North East lobe an area of brick work that could have been misinterpreted as an error in the scan registration was supplemented by additional narrative photography.

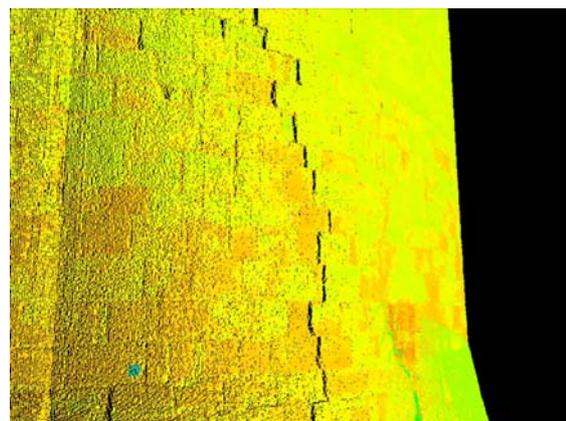


Figure 5. Potential mis-registration

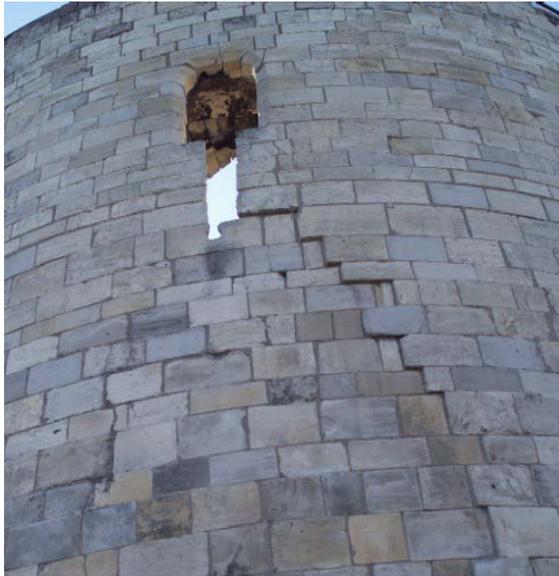


Figure 6. Narrative photograph showing actual feature

Registration was performed in Cyclone V4.1 and showed average residuals of 4 mm. Including this office work the survey took approximately 12 man days to complete.

For health and safety purposes only trained operators are allowed to operate the laser scanner on site. This request is in accordance with the relevant European Standard (IEC, 2001). This training was provided by the manufacturers of the scan system. The existing Metric Survey Specification requires signs to be displayed during survey work to inform members of the public that work is underway. For laser scanning, this sign must also warn visitors that lasers are in use. The addendum prohibits the use of Class 3B and Class 4 lasers from use.

3.4 Delivery of survey data

The addendum requires standard deliverables to be provided for every survey. These form the record that will be deposited in the national archive. These are the:

- project metadata
- raw scan data/transformed scan data (to be stated in the project brief)
- scan meta data
- control information
- registration information.

A hard copy survey report providing witness diagrams, details of control observation, the results of the registration process and all site/field sketches is also required.

3.4.1 Project metadata: This includes the name of the site, the purpose of the survey, the number of scans taken and the total number of points collected. It also includes reference to the raw data collected and a plan outlining the extent of the survey.

3.4.2 Scan data: The addendum specifies that scan data should be provided in an ASCII text format simply listing the X, Y, Z coordinates and any intensity or RGB values. Therefore, after scanning and registration using the Cyclone proprietary software, each scan was exported to an ASCII text file.

3.4.3 Scan metadata: Each file of scan data also has a corresponding metadata file. As commercial software does not easily allow the management and export of metadata to the level required by the addendum a separate program was defined to allow metadata files to be created semi-automatically. As detailed in the addendum, images showing the scan data were also exported from Cyclone.

3.4.4 Filenames: The addendum outlines a system that allows file names to be constructed to allow identification of data quickly and easily. This also mirrors the process currently adopted for the output of survey performed by other techniques. Table 1 outlines the method used, where position of the character in the filename.

Position	Description
1-3	Three letter code for monument in question.
4-5	Two numbers representing year of data capture.
6	Code defining data type: L – unregistered scan data K – registered scan data J – scan metadata I – scan registration information G – project metadata H – Survey control information C – image displaying scan data
7-8	Number of scan (leading/trailing zeros to be used). This is not required for the project metadata file or survey control information.

Table 1. Filenaming method

For example the registered scan data collected in scan 3 for Clifford's Tower (CLF) in 2003 is CLF03K03.txt and the corresponding image showing the extent of the scan data is CLF03C03.jpg.

CD's were used to deliver the data of which two copies were provided. In total 28 million points were recorded and 3 CD's were required to supply one copy of the archive. Additional data included images of the sites, images of the collected scan data and diagrams and drawings collected during the survey.

4. ECONOMIC BENEFITS

Use of a specification has several economic benefits. Firstly, it ensures the client has a clear understanding of the survey being delivered. It allows a measurable check against the delivered data thereby ensuring best value. It also minimises occasions when it is necessary to ask for further work. Finally the delivery of appropriate metadata allows quick and easy access to the available data.

5. CONCLUSIONS AND FURTHER WORK

The process of defining a specification has allowed the compilation of the significant issues relating to using laser scanning for the survey of cultural heritage. It has successfully produced a working document that can now be further developed. It is necessary to continue to consider how laser scanning may be used most effectively for the survey of cultural heritage in general. There is also a need to consolidate guidance on laser scanning as a whole, for both airborne and terrestrial systems.

Further work is required to define standard deliverables relevant to cultural heritage subjects. These standard deliverables should reflect the capabilities of the machines on the desktop of archaeology and architecture units. These may be 2D or 3D vector drawings, meshed models using raking light to highlight particular features or perhaps CAD models with annotations providing condition assessment or aiding interpretation. It is also necessary to outline the use of additional data sources to supplement laser scanning and to decide on suitable data formats for the archiving of point clouds.

A further requirement is the definition of the minimum standards for software and hardware to allow archaeologists to view data from laser scanning. The education and training of archaeologists in ways to manipulate this data to improve their interpretation of a subject or site is also a necessity.

Throughout the project, including surveys undertaken at Tynemouth Priory, Newcastle (Barber et al., 2003), it was problematic to undertake effective data management. This made production of metadata difficult and may lead to resistance by commercial contractors to supply the required information. Better data management systems, including archiving systems, would benefit all areas that utilise laser scanning in order to facilitate faster data retrieval.

As detailed in IEC 60825 (2001) class 3B and class 4 lasers have been deemed unsuitable for use in survey applications. Further work and investigation on the effect of lasers of any class on living materials such as lichens or on delicate paint work would be of particular interest.

The specification is now available for use by English Heritage in defining project briefs and by contractors for undertaking surveys by laser scanning. Most recently it has been used by English Heritage in the tendering process for a laser scanning survey of the Chester Amphitheatre site, Cheshire. The addendum is, however, expected to gradually evolve over the next few years to

incorporate both the experience of use and increasing technological advances.

6. REFERENCES

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