LASER SCANNING AND PHOTOGRAMMETRY: 21ST CENTURY METROLOGY

David Barber, Dr Jon Mills
Department of Geomatics
University of Newcastle upon Tyne
Newcastle upon Tyne, UK
E-mail: d.m.barber@ncl.ac.uk, j.p.mills@ncl.ac.uk

Paul Bryan
UK Representative for CIPA
English Heritage Metric Survey Team
Tanner Row
York, UK
E-mail: paul.bryan@english-heritage.org.uk

KEY WORDS: laser scanning, photogrammetry, integration

ABSTRACT
New technologies often turn heads the first time they appear. Laser scanning is one such new technique, which has impressed many users by the ability of point clouds to provide an understanding of complex subjects. Laser scanning holds obvious benefits to architectural recording, however such technology should not be used with blind faith as a solution to all problems. As with all new technological developments, the dissemination of information is a vital part of laser scanning's acceptance into everyday practice. This paper outlines the considerations involved in the application of laser scanning to architectural projects. By examining different scanning systems, issues such as resolution, reflectance and data presentation are discussed. It also emphasizes the now familiar call towards the seamless integration of laser scanning with other methodologies. The development of an integrated system, based on the 21st century technology of laser scanning and the 19th century science of photogrammetry, is seen as a valuable step in the acceptance of laser scanning as a methodology to record and model millennium old infrastructure.

1 INTRODUCTION
For in excess of a century, architectural photogrammetry has played an important role in the documentation of historic buildings and monuments. Waldhäusl (1992) discusses the unchanged demand for architectural photogrammetry, but states that photogrammetry has not achieved success in the rapid documentation of architectural heritage. Maturity into third generation Digital Photogrammetric Systems has improved the capacity of photogrammetry to meet the needs of the heritage community with common deliverables now including orthophotographs and digital surface models in addition to traditional line drawings. Techniques such as digitally rectified photography have simplified documentation and are fast becoming flexible and accessible survey tools (Bryan et al., 1999). Reflectorless EDM measurement is also widely used to create basic frameworks connecting different survey methodologies and is a valuable aid in the fixing of inaccessible detail (Blake, 1998).

Over the past few years terrestrial laser scanning has emerged with the potential to be of major value to the architectural recording professional. The available scanning systems extend to all object types, almost regardless of scale and complexity, thus allowing the contribution of laser scanning in future documentation projects. Scanners may be categorized into two groups: scanners where the scanner to object distance is typically less than 2m, which generally operate on the principle of triangulation, and scanners where the scanner to object distance is typically above 2m, these scanners normally work on a of time of flight principle.

2 CURRENT STATE OF LASER SCANNING

2.1 TRIANGULATION SCANNERS
Triangulation scanners consist of a laser and at least one charge coupled device (CCD) housed in a single unit, the "scanner head". The CCD is used to record the displacement of a stripe of laser light projected onto an object, Figure 1. The geometry between the laser and CCD is known and allows triangulation to be used to determine a point measurement. A full XYZ position can be calculated if the location and orientation of the scanner is known (Fowles, 2000). For some scanners this location may be fixed but other systems use a mechanical arm to record the position of the scanner head, the operator then guides the stripe over the surface of the object. (These arms may be used in their own right as coordinate measurement machines). A second method for the fixing of the scanner head is the use of magnetic trackers enabling movement without physical restrictions, within the range of the tracking system.

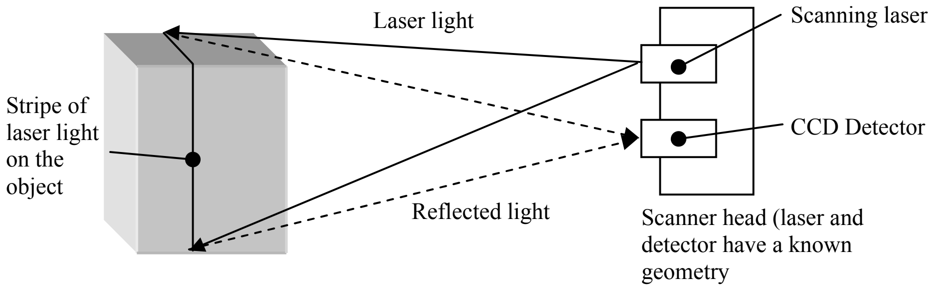

Figure 1: A triangulation system. The laser stripe is sampled along its length.

In many instances objects are taken to the scanner but the scanners are often capable of being field portable. Figure 2 shows a scan of the Artillery Memorial Hyde Park, London, performed by the Conservation Centre at the National Museums and Galleries on Merseyside. As with many memorials in cities it is particularly at risk from erosion in the corrosive urban atmosphere. This scan was made using a Cyberware scanner and a FARO six-axis mechanical arm. The scan was carried out on site using a tent to protect the scanner from rain and provide some shade from the sun, taking six hours to complete the 1m^2 scan. The level of accuracy achievable with these scanners is typically sub-millimetre, although this is dependent to an extent upon the object and material and the base to distance ratio of the scan. The resolution of measurement along the laser stripe can be as low as 0.2mm (e.g. the laser stripe is sampled every 0.2mm). The density of points in the direction of the scan is dependent upon the speed with which the operator moves the scanner.

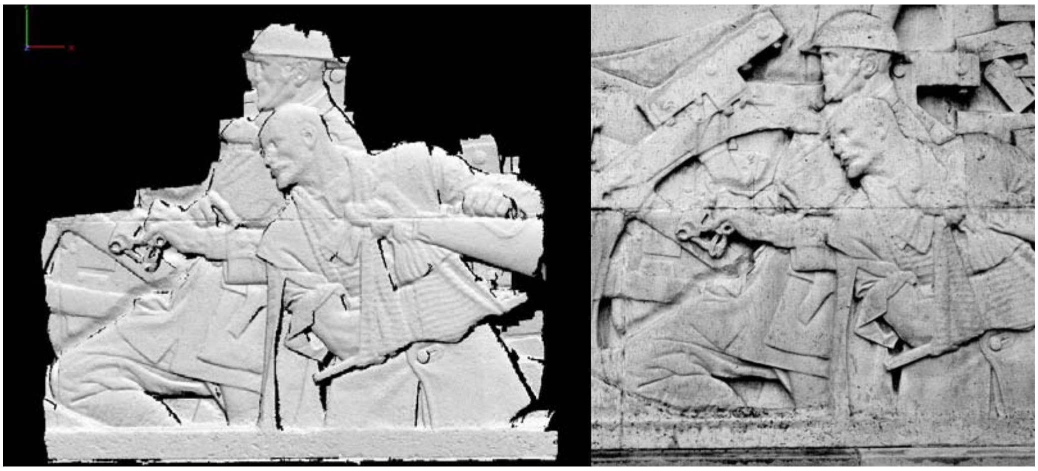

Figure 2: Left, a scan of the Hyde Park Artillery Memorial (courtesy of Stephen Fowles, Liverpool Conservation Centre), and right, an example sub section of the memorial taken from a photogrammetric stereo pair (courtesy of English Heritage).

In some situations other close range systems may be appropriate, such as the Minolta range of VIVID scanners that also operate on triangulation principles but offer a simpler camera-like operation and increased mobility. Beralidin et al. (1998) describe a range of scanners developed by the Institute for Information Technology at the National Research Council of Canada. Canada's National Research Council is also connected to the Arius3D technology (Arius3D, 2001), which uses three laser wavelengths to record an object's true color as well as it's shape to a very high resolution. A further notable system is the Soisic scanner from Mensi that operates on a triangulation principle but operates at a range of up to 20m. This instrument has a quoted standard deviation of 0.6mm at 5 meters range, this value however decreases to 9.6mm at 20 meters (Davies, 2001), demonstrating the effect on precision as the base to distance ratio is degraded.

The requirement of the CCD to be able to distinguish the returning laser light from the ambient illumination places limitations on the range of triangulation systems. Therefore, while these scanners permit high-accuracy, high-resolution measurement, they do not allow efficient measurement of large objects such as facades or whole buildings.

2.2 Time of Flight Scanners

For longer ranges Light Detection And Ranging (LiDAR) scanners provide an alternative. LiDAR scanners use a pulsed laser to measure the range to a point on an object's surface. Using the time between the emission of a pulse and the detection of the returning energy, the range to the object can be determined. By scanning the laser across the scene and recording the direction of the beam, a series of points can be measured. Scanners of this type include those manufactured by Cyra Technologies, Callidus Precision Systems GmbH and Riegl Laser Measurement Systems GmbH. In general these scanners use a high-speed rotating mirror to scan the laser across a scene. The Cyrax 2400/2500 uses mirrors to deflect the beam in the both the horizontal and vertical axis giving a 40x40 degrees field of view. The system offers a precision of +/-4mm for the measurement of a single point at the one sigma level (Spanje, 2001).

Both the Callidus and Riegl LMS-Z210 scanners use a mirror to deflect the laser in the vertical axis and mechanically rotate the scanner in the horizontal axis. This allows scanning up to a full 360 degrees for the Callidus and 340 degrees for the LMS-Z210. The precision of the Callidus system is quoted at +/-5mm for position measurement up to 32 meters, while the LMS-Z210 has a lower quoted precision of +/-25mm but at a range of up to 150meters for naturally reflecting targets. The Riegl LPM25HA mechanically scans the laser in both the vertical and horizontal planes and offers a quoted precision of +/-8mm in distance measurement (Spanje, 2001).

The resolution of the scan is one of the parameters usually set before scanning. Resolution controls the number of points recorded in a scene and the level of detail visible in a scan. This parameter must be set for a particular range, if a scene has a large depth component the resolution must be selected for one of the distances. It may be necessary to rescan areas at the desired resolution. Toth and Grejner-Brzezinska (2000) discuss the sampling of surfaces for airborne LiDAR systems and the effect upon the representation of a surface; similar principles apply for terrestrial systems.

Reflectance of materials is an issue for both triangulation and LiDAR scanners. If a material does not reflect the measurement beam sufficiently, data capture may not be possible. In some applications, especially the measurement of small objects with a triangulation scanner, the most desirable surface is matt white. This may be artificially introduced using chalk dust or a light coat of emulsion, however in some conservation projects this may be undesirable. Gordon et al., (2001) outline the response of a Cyrax 2400 scanner to red brick and mortar. Red brick was found to respond poorly to the scanner while the mortar provided a good response. As the reflectance characteristics of particular materials may prove to be important in some scanning projects, Gordon et al. suggest the production of spectral response libraries similar to those used in Remote Sensing, which may prove useful data in the application of scanning to different material types.

3 Practical Issues

It is worth considering the practicalities of laser scanning using large object laser scanners with a brief description of a generic system. Figure 3 shows a Cyrax 2400 system to illustrate a typical scanning system comprising of:

- Scanner unit
- Control unit
- Power unit
- Tripod and mount

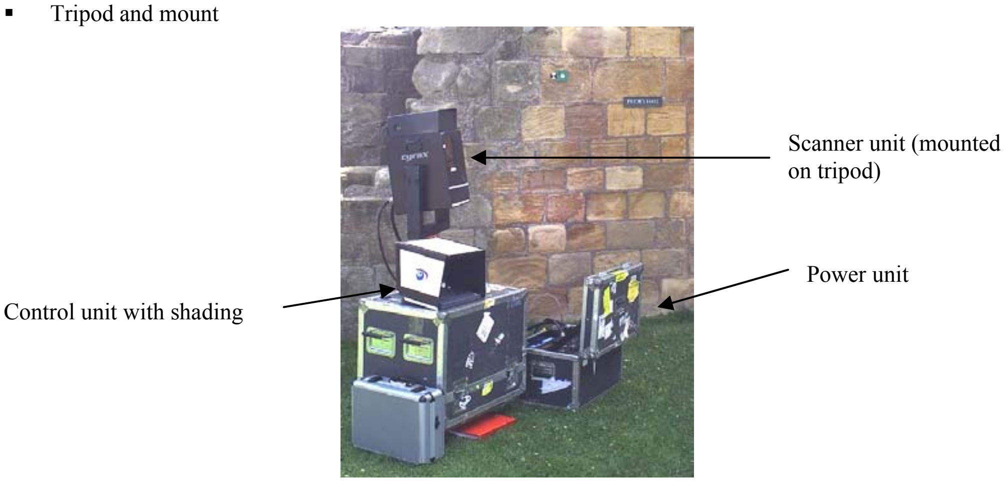

Figure 3: An example scanner system - Cyrax 2400

The scanner unit itself is generally larger than a traditional survey instrument and does not normally house the power source. Control is provided by a laptop computer, which can pose some problems when viewing the screen in bright sunlight. A sunscreen PC would be an ideal, if expensive, solution; good quality shading is otherwise the key. Power generally comes from a battery, in some cases a widely available 12v car battery allowing straightforward replacement in the event of a problem, in other cases a proprietary battery pack is supplied. This generally provides the power for the scanner but not the laptop control unit, so extra batteries for the laptop and some method of charging spent batteries may be required for a full day of scanning. In some cases the use of a portable generator may be more preferable. The scanner normally sits on a tripod, either of normal survey design or specially made. Some systems offer the option of a wheeled tripod, useful for interior scanning but impractical for use outdoors in rough/rocky areas. When LiDAR scanners first made an appearance, they realistically required two people to cope with the size, weight and number of boxes. New scanners now really require only one person, as equipment becomes lighter and more compact. The further rationalization of scanning systems will result in even smaller and lighter systems.

4 ACCURACY AND INTEGRITY

Baltsavias and Hahn (2000) promote the need for reliability indicators in the integration of spatial information. Redundancy is an important part of this process, it has an essential role in photogrammetry and surveying providing assessment of precision, ensuring the integrity of measurement.

When scanning a surface, laser scanners provide a huge number of points that provide redundancy in the measurement of a surface, but redundancy is not present in the measurement of any one of these individual points. Each point has only a precision value propagated from the standard errors of the range and angular measurement. Riegl offer the ability to average scans providing some redundancy of measurement. Here each data point is considered to belong to one pixel on the scan image (see Figure 4 as an example). Based on the values of the horizontal and vertical angles it can be calculated which pixel in the image a particular measurement belongs to (Riegl 2001). By taking more than one scan of the object an average of readings for a particular measurement can be derived.

Baltsavias and Hahn (2000) also state the need for tests on comprehensive datasets in cooperation with industry. The ability of scanners to meet survey type specifications must be investigated to allow appropriate guidelines to be produced on their use. Testing of all types of scanners should follow standardized procedures that produce comparable statistics. The selection of these tests should take into consideration the issues of accuracy, precision, resolution, response to different materials and software processing. Such testing may be as simple as the measurement of an object of known size at different ranges. A simple figure could be derived for the level of conformity the scanner shows to the shape of the object.

Other approaches to the assessment of new techniques have used standardized datasets of particular monuments. One example is the CIPA Zurich City Hall dataset (Streilein et al., 2000), which provides test data for the evaluation of photogrammetric software. A similar archive would be beneficial for laser scanners, however this dataset should include scans of the same subject, for example a building, by different scanning systems. A user could then ensure particular features are evident before commissioning a particular scanner system on a project.

5 DATA PROCESSING AND PRESENTATION

Scanners are not restricted to recording XYZ data, many LiDAR scanners also record the intensity of the returned pulse. The display of point data with the attached intensity can improve interpretation of what may otherwise be a confusing scene. Both the Cyrax 2400/2500 and the Riegl LMS-Z210 record intensity, and as this is based on the sensing of active energy, intensity data is also collected in areas of shadow, or in the dark. The LMS-Z210 also records full colour data based on the passive detection of light at the time of scanning which is useful for the display and presentation of data. Figure 4 shows a single scan made using a Riegl LMS-Z210 scanner, illustrating the intensity, range and full colour data. Note how this data is displayed as an image rather than the commonly seen "point cloud", each pixel on the images has an associated XYZ position. Other scanners such as the Arius3D actively record colour using three laser wavelengths and so record "true colour", regardless of the ambient illumination.

This leads to a discussion on the processing and presentation of scan data. This applies to data from all types of scanners, either triangulation or LiDAR. The first procedure in processing scan data is registration. If the scanner has been moved between scans to cover an object in full, the scans need to be brought onto a common coordinate system. This can be accomplished via the matching of common points within scans and transforming to a base system allowing registered scans to be viewed as one dataset. This process requires scans to contain common points and in some cases it may be easier to register all scans to a common local site grid established by normal survey methods. This way scans that do not overlap can be used in conjunction with one and other. The use of discrete points requires some method of point identification. A common solution is the use of three dimensional shapes that can be reduced to a single point. The Cyrax system utilizes spheres, which once scanned (from any direction), can be reduced to a single point, the Soisic scanner from Mensi also utilizes spheres to register scans. Another solution is the use of flat reflective targets.

The Cyrax system supports a process of scanning targets at a high resolution and centroiding to determine a single point. The use of reflective targets is also possible with Riegl scanners.

More common in the registration of close range scans is the matching of surfaces, although this technique is also used in large object scanners. This allows overlapping areas of scan data to be matched together; the redundancy involved in this method may lead to a better solution than the use of discrete points alone. Surface matching has been implemented in some applications in photogrammetry (Rosenholm and Torlegard, 1988).

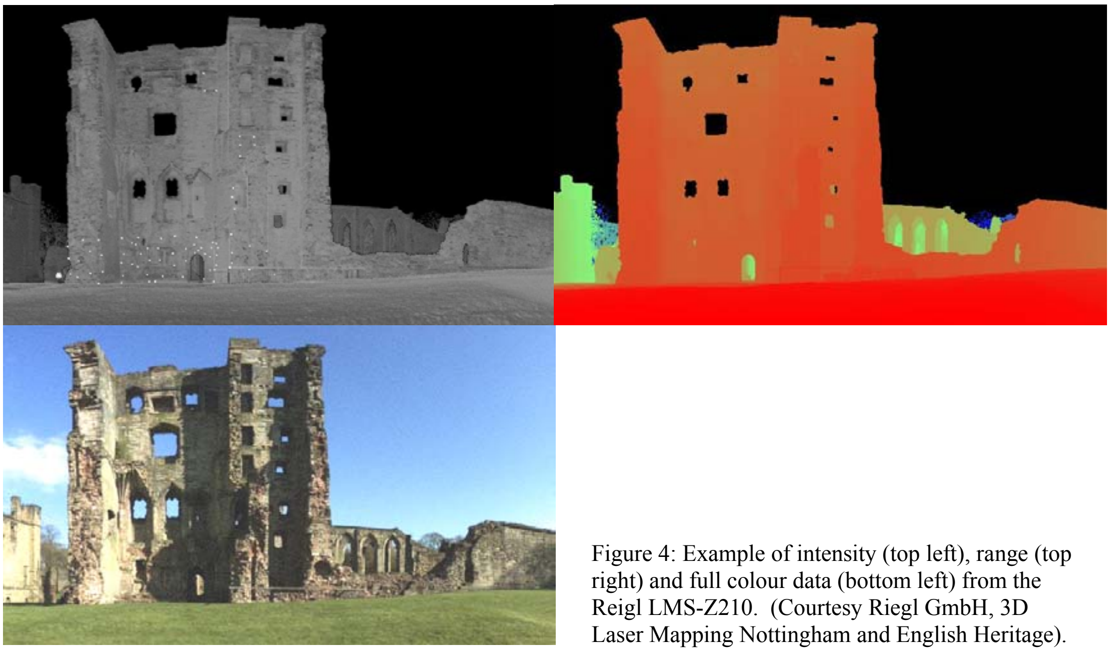

Figure 4: Example of intensity (top left), range (top right) and full colour data (bottom left) from the Reigl LMS-Z210. (Courtesy Riegl GmbH, 3D Laser Mapping Nottingham and English Heritage).

The methods employed in turning a point cloud into a useful product vary and will depend upon the subject and application. Fitting CAD primitives to point clouds is a popular approach in some modeling and industrial applications. Software such as Cyra's Cyclone and Mensi's 3Dipsos software allows this. Beraldin et al. (1997) reports that algorithms used to rigorously fit planar surfaces to some areas of point data deliver a more precise determination than predicted. Many architectural and heritage subjects however are irregular and would not suit this method of processing, therefore it is more likely a mesh will be used to display the scanner data. Meshing is also an accepted method used to process data of small objects such as archeological artifacts.

The meshing of scan data can include some control of the mesh density based on the complexity of the surface, for example large flat areas require fewer triangles than more detailed areas. This allows some control over the size of the model produced, retaining detail where required but removing unnecessary complexity in other areas. The planning of scanning projects should ensure sufficient data is collected to fully record a subject. However the use of a mesh to surface the scan data may result in small holes where data has not been captured, for example where reflectance is low or where practical issues prohibit satisfactory coverage. Further processing may therefore be required depending on the desired product. Any further processing will be based upon an operator's judgment rather than actual data; having implications in the future use of such data, such as in building analysis. It is important that a detailed record of the processing carried out is retained within the project metadata.

The display of a point cloud is the most basic level of viewing scanner data and when viewed dynamically, rotated, panned and zoomed on a computer, point clouds are an excellent tool for simple interpretation. However, when displayed static it can be argued that they lose much of their value. Point data may also be displayed as an image making it familiar to users, but unless the data cloud is of a sufficient resolution the image may appear small or blocky.

Traditional presentation of survey data includes line drawings, orthophotographs and, more recently, rectified photography. Figure 5 shows a traditional line plot produced in a Zeiss P3 photogrammetric plotter working to an English Heritage Survey specification (Bryan and Blake, 2000). It is a typical product of architectural photogrammetry. Figure 5 also shows a scan of the same facade using a Cyrax 2400 scanner, with a point spacing of 25mm; it has been meshed and lit in an attempt to show features similar to those on the line plot. It is clear that the scanner data does not immediately show the same level of detail as the line drawing but the effort required to produce the scanner data is lower, consequently survey costs may be reduced. While the line drawing required photography to be taken followed by eight hours of plotting, the scanner data was captured in 15 minutes and meshed on site. However currently a stereo pair is an accepted archive in documentation projects and is only used for plotting when, or if, required. What is the archive product from laser scanning?

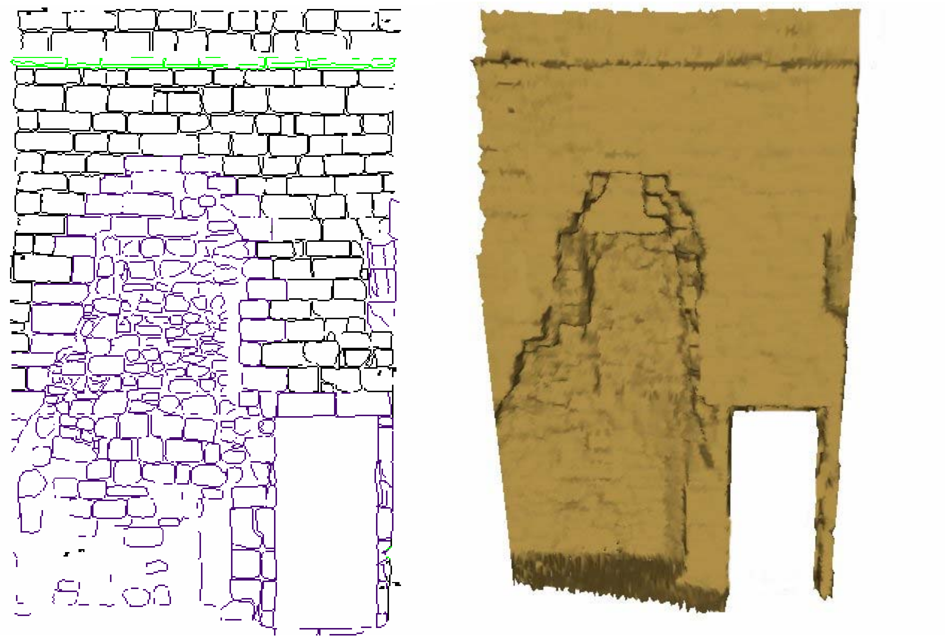

Figure 5: Left, an example of a traditional photogrammetric line plot and right, a meshed point cloud collected by a Cyrax 2400 scanner,

Figure 6 shows a point cloud captured by a Callidus scanner. The points are coloured based on the value of the normal to that point. This is an effective method allowing the differentiation of planes and immediate visualization of edges. This scene consists of over half a million points collected in just a few minutes; note how the resolution of the scan degrades towards the edge of the scene. Figure 6 also shows a rectified photograph from the same project rectified to a plane. Clearly each dataset contributes its own specific information. The image provides information on the materials and colour of the object while the scan data shows the topography of the scene, (as with all scan data this is more evident when the scan data can be manipulated on a computer).

6 INTEGRATION

The value of complementary data with respect to material types and topography is clear from the above example, but what about more complex integration of techniques? Integration of airborne LiDAR systems with imagery is becoming a familiar call, especially where DEM extraction struggles in urban areas; Toth and Grejner-Brzezinska (2000) suggest integration of airborne LiDAR with imagery at three levels.

- A visual backdrop.
- Redundancy to LiDAR data acquisition.
- Providing an attractive price/performance ratio (and an attractive fall back in unexpected situations).

These suggestions are equally valid for terrestrial applications, where the problems of surface extraction are more pronounced due to the amplified discontinuities typically found in a scene.

Integration should not be limited to image based methods, traditional survey techniques still have a role. How best to integrate scanning with current survey techniques stems from a fundamental understanding of the needs of the end user. The typical product required from photogrammetry is a line drawing or orthophotograph. The product required from laser scanning, or the most appropriate type of application to apply laser scanning to, is currently indistinct. Scanning has been implemented in a number of projects, many of them concentrating on visualization. Such models are impressive but are best viewed as a computer displayed 3D model. This may not be suitable for a skilled craftsperson attempting to recreate/repair parts of a historic monument. What is the ideal product? The end user must answer this and the surveyor must attempt to fulfill the specification with the most appropriate techniques available.

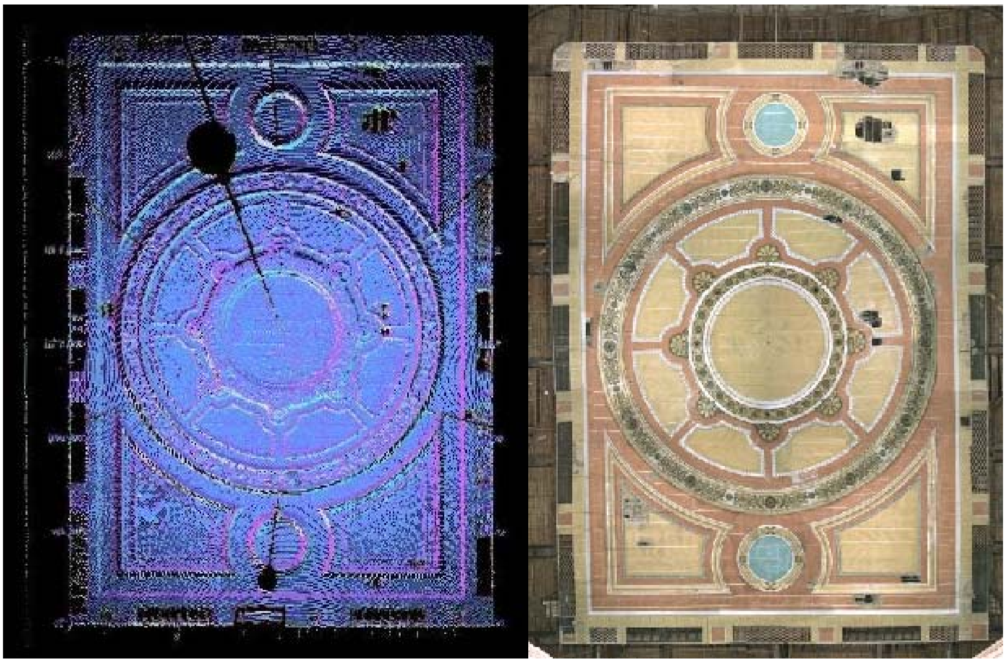

Figure 6: Left, Example scan of a ceiling at Alexandria Palace, UK (courtesy Callidus GmbH/Jenoptik and Alexandria Palace), and right, rectified photography (courtesy English Heritage).

7 Conclusions and Recommendations

This paper has provided a description of some of the laser scanning systems available and has reviewed how accuracy and integrity currently fit into laser scanning compared to photogrammetric methods. With this in mind it has outlined the need for the testing of scanners and the need for comparable statistics and data sets. The presentation of data has been discussed and compared with line drawings and rectified photography, it is clear that the type of product that can be produced by laser scanning is not the same as that traditionally produced by architectural photogrammetry, although its value as a data source is acknowledged.

Some of the main issues to be addressed in laser scanning, and survey techniques as a whole for architectural applications can be summarized as follows;

- Redundancy – how can the essential role of redundancy be achieved with laser scanning?
- Testing – can standardized tests and test data be devised for distribution amongst interested parties with backing from organizations such as CIPA?
- Integration – can the strengths of different survey techniques, including laser scanning be best integrated with the aim to produce a more usable and cost effective result?

Laser scanning is set to become a valuable method of survey and should be embraced by the heritage community. However it is important to pursue rigorous independent testing and evaluation and to provide a standard specification on the use of such systems in order to ensure metric survey recording maintains a reputation for high quality work.

8 Acknowledgements

The authors would like to thank Cyra Technologies, Callidus Precision Systems, Riegl Laser Measurement Systems and 3D Laser Mapping, Nottingham UK, for help with the collection of the example datasets. Thanks are also due to David Sherlock at English Heritage and Alexandria Palace UK.

9 References

Arius3D, 2001. http://www.arius3d.com/technology.html, Last Modified 30 May 2001, Last accessed 13 September 2001.

Baltsavias, E. and Hahn, M., 2000. Integrating spatial information and image analysis – One plus one makes ten, International Archives of Photogrammetry and Remote Sensing. Vol 33, Part B2, pp. 63-74.

Beraldin, J.A., Cournoyer, L., Rioux, M., Blais F., El-Hakim, S.F. and Godin, G., 1997. Object model creation from multiple range images: acquisition, calibration, model building and verification. International Conference on Recent Advances in 3-D Digital Imaging and Modeling, Ottawa, Canada: pp. 326-333.

Beraldin, J.A., Blais, F., Rioux, M. and Cournoyer, L., 1998. Portable digital 3D imaging system for remote sites. Proceedings of the IEEE International Symposium on Circuits and Systems (ISCAS '98), Monterey, CA.

Blake, W. H., 1998. Architectural Survey at Church of St Mary Whitby, International Archives of Photogrammetry and Remote Sensing Vol 32, Part B2, pp. 6-10.

Bryan, P. G., Corner, I. and Stevens, D., 1999. Digital Rectification Technique for Architectural and Archaeological Presentation, Photogrammetric Record, 16(93), pp. 399-415.

Bryan, P.G. and Blake, W. H., 2000. Metric survey specification for English Heritage, English Heritage National Monuments Records Centre.

Cyra, 2000. Cyrax 2500 Product Specification, Cyra Technologies Inc.

Davies, M., 2001. Fundamentals of Scanning Methodology, Seminar by AG Electro Optics at Salford University - 3D Laser Scanning & Modelling.

Fowles, P. S., 2000. The Garden Temple at Ince Blundell: a case study in the recording and non-contact replication of decayed sculpture, Journal of Cultural Heritage 1, pp. 89-91.

Gordon, S., Lichti, D. and Stewart M., 2001. Application of a High-Resolution, Ground-Based Laser Scanner for Deformation Measurements, 10th FIG International Symposium on Deformation Measurements.

Riegl, 2001. 3D-RiSCAN Version 2.24.3.5 Online help.

Rosenholm, D. and Torlegard, K., 1988. Three dimensional absolute orientation of stereo models using digital elevation models, Photogrammetric Engineering and Remote Sensing, 54(10), pp. 1385-1389.

Spanje, W. V., 2001. Product Survey on Laser Scanners… An Overview, GIM International, (1)15, pp. 49-51.

Streilein, A., Grussenmeyer, P. and Hanke, K., 2000. First experiences with the "Zurich city hall" data set for architectural photogrammetry, International Archives of Photogrammetry and Remote Sensing Vol. 33, Part B5, pp. 772-779.

Toth, C. K. and Grejner-Brzezinska, D. A., 2000. Complementary use of LIDAR and stereo imagery for enhanced surface extraction, *Ibid*., Vol 33, Part B3, pp. 897-904.

Waldhäusl, P., 1992. Defining the Future of Architectural Photogrammetry, *Ibid.*, Vol 29, Part B5, pp. 767-770.