

## TERRESTRIAL LASER SCANNING AND 3D IMAGING: HERITAGE CASE STUDY – THE BLACK GATE, NEWCASTLE UPON TYNE

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### ABSTRACT:

This paper offers a case study on the recording of a section of wall on a complex heritage building, the Black Gate in Newcastle upon Tyne. The paper adopts case study methodology to assess the appropriateness of using a long range scanner based upon pulse technology for the recording of part of this historic structure and describes the scanning instruments adopted as well as the selection of appropriate software for the pre-processing and documentation. The study offers an overview of the survey planning stages, field operation, and processing of 3D point cloud data using the third party software adopted, including problems encountered. Issues emerging are discussed, in both the 2D and 3D modelling of detailed surfaces from point cloud data, and in the process of software selection, data preparation and export, pre-processing of point cloud data, meshing and the creation of 2D geometry and 3D animations. The paper describes the end results offered as deliverables for this project, and offers recommendations for a working method that can produce data suitable for producing stone-by-stone elevation drawings. The work processes and cost / time indicators are included in this case study and conclusions will consider whether the technique adopted could lead to an improved solution for heritage recording compared to those traditional techniques which are currently employed to produce stone-by-stone elevations. Areas for future research are identified.

## 1. INTRODUCTION

### 1.1 Overview

Proposals to construct a lift tower against the north wall of the Black Gate, the thirteenth century barbican of the Castle, Newcastle, will require the production of detailed elevation drawings for the purposes of consent applications and architectural annotation. The building represents a challenge to traditional techniques, being composed of a range of walling fabrics (coursed and random ashlar masonry, rubble corework, and both hand-made and mass-produced brick) on a structure presenting a complex geometry in a restricted and visually-constrained location. Indeed, the inherent practical survey difficulties have meant that this is the only major secular medieval building in Newcastle without detailed elevation recording. As such, it represents a good subject for a long-range laser scanner evaluation, using pulsed, time-of-flight technology. The results detailed below can provide an interesting comparison with techniques traditionally employed to produce “stone-by-stone” elevation drawings.

### 1.2 Laser Scanning Instrumentation

Laser scanning technology is typically classified as either phase-shift based or as pulsed time of flight (TOF). Phase-shift scanners send out waves of varying lengths to the target object and measure the phase shift in the returned waves of infrared light to calculate data points with X, Y, Z and I (Intensity) information. Phase-shift laser scanners are able to capture large datasets quickly but have a limited range (10-70 metres typically). TOF scanners have a much further range (up to 2000 metres) but aren't able to capture high density scans as quick. For example, the Leica Scanstation 2, which is TOF based has a maximum instantaneous scan rate of 50,000 points per second (from the Leica product datasheet), but their phase-based scanner, the HDS6100, is rated as 10 times faster. The School of the Built Environment at Northumbria University purchased a Leica Scanstation 2 (Figure 1) which utilises pulsed scan laser

technology, a built-in colour camera and an integrated dual-axis level compensator. It has a field of view of 360 degrees around the horizontal and 270 degrees over the vertical plane. The manufacturer's datasheet states the range to be 300 metres if the target is 90% reflective and the scan rate to be a maximum of 50,000 points per second.



Figure 1. Leica Scanstation 2

It was selected from a range of scanners as the School's work is focussed on building architecture and city modelling therefore the extended range was seen as favourable over the alternative phase-based scanner technology.

### 1.3 Site Planning Considerations

When planning a laser scan project it is important to understand the layout of the subject and the terrain where it is located. A site visit should be one of the first tasks undertaken on any project. It can provide important data that can influence the kind of equipment to be used, the time it will take to setup and scan, as well as addressing issues of safety (especially when dealing with old derelict buildings that may be in a state of disrepair). The site location of the Black Gate is shown in Figure 2, just a few hundred metres north-west from the Tyne Bridge in Newcastle upon Tyne.



**Figure 2. Black Gate Location Map**

The Black Gate is located on a sloping site; Figure 3 shows the rear of the site with the boundary being the wall in the foreground of the image.



**Figure 3. Black Gate View From Rear**

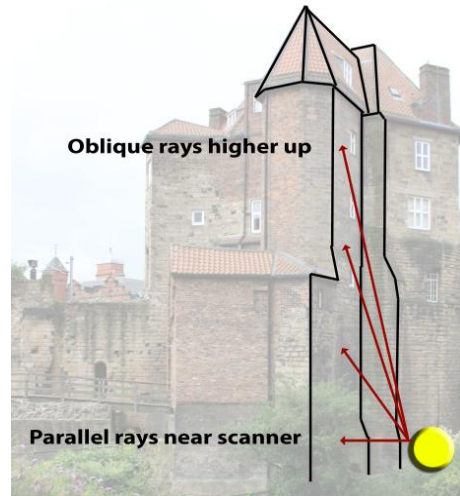
The building height is over 20 metres tall but the boundary wall to the north (shown in Yellow in Figure 4) is less than 3 metres away from the building.



**Figure 4. Black Gate Site Boundary Constraints**

On the other side of the boundary wall is dense foliage, bushes and trees. The facade of interest in this project is shown in light

blue on Figure 4, thus the only location suitable for the scanner to capture the necessary data was inside the boundary, in-between the facade and the wall (the red dot in Figure 4). The result of this scanner position is that the scanning laser orientation is parallel to the lower section of the wall but as it travels further up the wall the angle becomes more and more oblique, as shown in Figure 5. The impact of this can be clearly seen when we look at the top of the facade on the point cloud results (Appendix A).



**Figure 5. Effect of Scanner Location on Laser Angle**

## 2. CASE STUDY

The focus of this case study was to analyse the methods that could be employed to record and produce a stone-by-stone record of part of this historic structure using point cloud data as the source.

Figure 6 shows the typical masonry used in the construction of the facade.



**Figure 6. Typical Masonry Detail**

At the outset of this study the end product was always envisaged to be some form of CAD scaled drawing from which measurements could be derived. This method is in addition to those described by (English Heritage, 2006). The requirement to record the information in CAD format resulted in various methods being investigated.

1. CAD polylines traced around each stone shown in the point cloud
2. CAD polylines traced around each stone shown on a polygon surface model that was generated from the point cloud

3. Scaled orthogonal views of a textured polygon surface model
4. Scaled orthogonal views of the rendered point cloud.

One of the main factors taken into consideration was the time it took to take the raw point cloud data from the scanner and process it into a suitable CAD drawing deliverable. The various software packages investigated all had a mixture of automated tasks and manual tasks which would impact the time to get the end product.

Leica, the makers of the Scanstation 2 provide their own Leica Cyclone suite of software for capturing, registering and manipulating the point cloud data.

Leica Cyclone is comprised of individual software modules such as Cyclone-Scan (used by the laptop that controls the scanning to set variables such as resolution, defining scan marker positions and setting the scan boundaries), Cyclone-Register (used to enable multiple point clouds taken from different locations to be aligned correctly to produce a larger registered dataset), Cyclone-Model, Cyclone-Survey etc.

Leica also have a family of plug-ins called CloudWorx that allow point cloud data taken from Cyclone to be viewed in native applications such as AutoCAD, Microstation, PDS and PDMS. At Northumbria University the main CAD software package used by staff and students is AutoCAD and thus CloudWorx was used with this application for this case study.

### 2.1 CAD Polylines Traced Over the Point Cloud

This method involved using the CloudWorx plug-in with AutoCAD to view the point cloud data (Figure 7 shows the overall point cloud loaded) and then used standard CAD drawing tools to trace the perimeter of each piece of stonework. There was no automation available using this method, it had to be executed manually (Garcia, J.L.L., et al., ed., 2008). Compared to tracing over regular and coursed brickwork the process of tracing stone, rubble and random masonry isn't

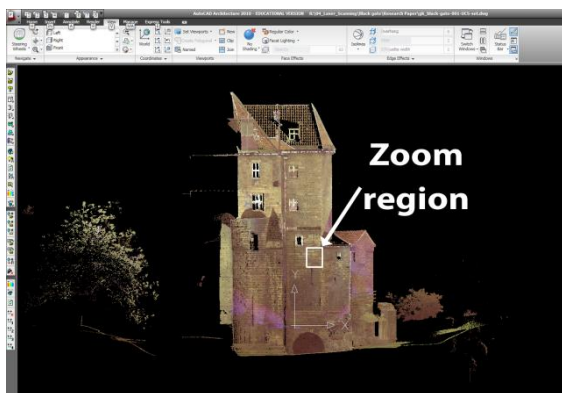


Figure 7. Point Cloud within AutoCAD, overview

At first glance this approach seemed like it would provide a suitable outcome because the view of so many data points appeared to be clear and concise, however, limitations soon became apparent when starting to trace the stonework.

In order to trace the stonework the view shown in Figure 7 would not suffice, it needed to be zoomed in to pick out the masonry detail. For clarity the images have been made black and white and the colours inverted.

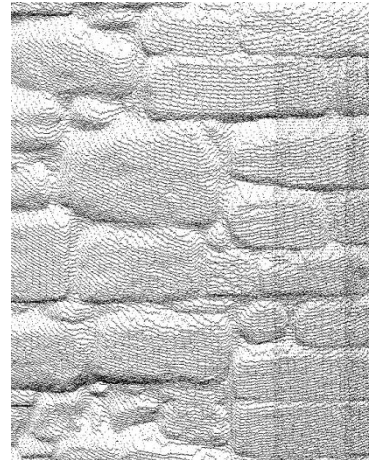


Figure 8. Point Cloud within AutoCAD, zoomed in

Using the zoom tools within AutoCAD it was possible to focus on a region and to see a reduced point cloud density. However, without the density of the points at a high enough level it became difficult and inaccurate to trace the edges of the stonework.

To overcome this, the scanner settings could have been set to their maximum level but at the extreme expense of time. As noted in section 1.2 the Leica Scanstation 2 does not collect data as fast as a phase-based machine, and when the resolution is set to maximum it can take several hours to perform a single scan.

Another limitation that must be considered was the actual coverage achievable by the scanner in the context of the site. Being sited close to the wall the laser of the scanner can only register a point on details it can see, otherwise it records nothing, leaving a 'shadow' in the point cloud.

Looking at Figure 8 closely it can be noted that the bottom edge of the stonework has many recorded points whereas the top edge of the masonry is either low density or has no points at all. When tracing the edge of a stone in these 'shadow' areas the accuracy of the drawing cannot be as high compared to areas with good coverage.

The facade of interest contains approximately 2000 pieces of stonework and each would need to be traced manually. Figure 9 shows the result of just four pieces of stonework being traced.

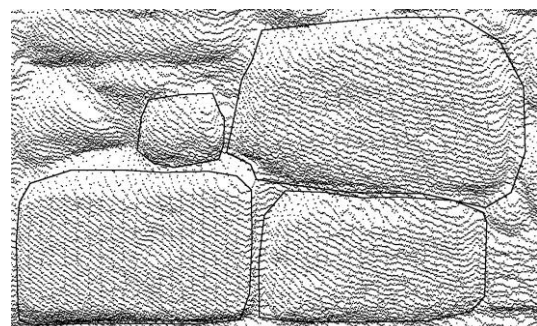


Figure 9. Traced Stonework from Point Cloud

It took 2 minutes to trace the four stones. To trace 2000 stones would take approximately 1000 minutes or nearly 17 hours to perform. Human error in determining where the edge of a stone is located is a negative factor in this method.

## 2.2 CAD Polylines Traced Over a Polygon Surface Model

This method aimed to reduce the error of determining the edge of a stone by first triangulating a polygon surface over the point cloud. The assumption here is that having 3D polygon data draped over the shadow areas would make it more accurate when tracing using polylines, rather than guessing when tracing over the top of a sparse point cloud.

There are many commercial pieces of software that are able to convert point cloud data in to a triangulated mesh model. Table 1 records some of those available.

Software	Website
VRMesh Studio **	<a href="http://www.vrmesh.com">www.vrmesh.com</a>
3D Reshaper **	<a href="http://www.3dreshaper.com">www.3dreshaper.com</a>
Rapidform XOS/Scan **	<a href="http://www.rapidform.com">www.rapidform.com</a>
Geomagic Studio **	<a href="http://www.geomagic.com">www.geomagic.com</a>
Silverlining	<a href="http://www.farfieldtechnology.com">www.farfieldtechnology.com</a>
3D Reconstructor 2	<a href="http://www.reconstructor.it">www.reconstructor.it</a>
Polycloud	<a href="http://www.menci.com">www.menci.com</a>
PolyWorks	<a href="http://www.innovmetric.com">www.innovmetric.com</a>
Leios	<a href="http://www.egsolutions.com">www.egsolutions.com</a>

**Table 1. Point Cloud to Mesh Software**

The purpose of this study was not to analyse each software application on the market, nor indeed investigate their advanced settings to produce the most ideal triangulated mesh.

However, this study did take a random sample of software (denoted by \*\* in Table 1) and analysed the time it took to convert the same point cloud data in to a triangulated mesh. Where possible no filtering or noise reduction were used as the preferred settings necessary to investigate this were beyond the scope of this study.

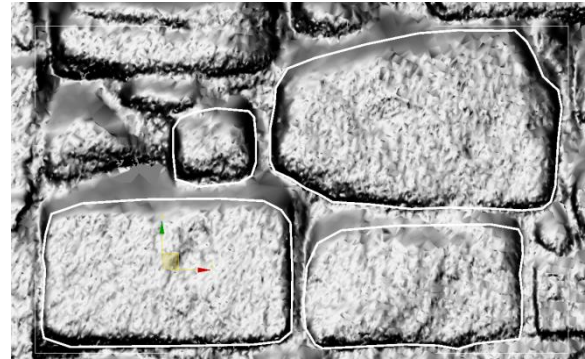
Software	Time taken	Triangles
3D Reshaper	14 mins	4,159,653
VRMesh Studio	6 mins	3,881,740
Rapidform	3 mins 30 secs	2,542,186
Geomagic Studio	1 min 20 secs	4,127,064

**Table 2. Point Cloud Conversion Results**

The results of this test show that Geomagic Studio processed the data in the fastest time and produced a mesh with almost the same number of triangles as the slowest performing piece of software. Further research to investigate why there is such deviation in processing time would require further investigations, for example, does the software utilise multiple core machines efficiently? This was deemed outside of the scope of the case study.

All of the software packages evaluated can export a triangulated mesh to a variety of 3D file formats so they can be used by all of the major 3D modelling and CAD packages.

Figure 10 shows a viewport capture from Autodesk 3D Studio Max Design 2010 of the triangulated surface mesh from Geomagic Studio. The image is clearer to understand than the point cloud dots from Figure 9 but the areas with least point cloud information (the top of all stones) are still noticeable.



**Figure 10. Polygon Surface from Point Cloud**

The process of tracing to create the polylines is still very much a manual process and still takes the same amount of time as performed previously, 2 minutes for four stones or 17 hours for the whole facade. In favour of this method is the fact that the surface rendering of the masonry now enables the user to see slopes and indentations thanks to the way the virtual light interacts with the surface. Arguably this should increase the precision of the users' interpretation of where the edge of a stone is located. The accuracy in the less dense areas is still going to be much lower than the high density areas.

## 2.3 Scaled Orthogonal Views of a Textured Polygon Surface Model

This method aims to increase the accuracy of the stonework tracing by applying a photographic texture on to the polygon model. In order to be successful the method requires a polygon mesh (i.e. from Geomagic Studio) and a high resolution image of the facade that has been corrected for camera lens distortion.

The production of the image to make this method work is a complicated and detailed process that can be hindered by many factors ranging from the weather when visiting the site, restrictions in viewing the facade due to obstructions/terrain to the camera equipment itself.

In order to be an improvement over method 2.2 the images will need to be of sufficient resolution so that when zoomed in to areas of detail there are enough pixels to assist the user in tracing the perimeter of each piece of stonework. The four stones used previously cover an area of approximately 1.13 metres wide by 0.68 metres high. Using Figure 10 as reference the image of the four stones would need to be in the region of 215 pixels wide to offer the correct clarity.

This equates to a scale of resolution of 190 pixels per metre, which can be rounded to an easier to calculate 200 pixels/metre or 1 pixel = 5mm. Over the whole façade, which has an approximate size of 6 metres wide by 20 metres tall, the image resolution would need to be 1200 pixels by 4000 pixels. Wherever possible the best situation is if the subject can be taken with a single image because multiple images would need stitching together which will incur errors during the process.

Another issue that may arise is that the equipment may be capable of taking the correct resolution image but the site layout/access may not, or the building is of such proportions that it requires multiple images to be taken. In these cases software would need to be investigated that can very accurately stitch and remove distortion from the images.

## 2.4 Scaled Orthogonal Views of the Rendered Point Cloud

Throughout this case study it has been assumed that to record the masonry information of a heritage building required each and every stone to be traced to produce a CAD drawing. Who will use this drawing and how might they use it?

Once the drawing is handed over to the end user they will import it and if they need to take a measurement they will click in the two locations to get a distance. The points that they click are going to be arbitrary on a case-by-case basis. By snapping to the polylines for their measurement they will be inheriting the errors that were incurred by the user who traced those bricks in the first place.

Manually tracing each brick to produce a CAD drawing does not add any extra information that this next method can produce in a much shorter space of time.

The point cloud data exists as a 3D object that can be viewed by the scanner's own Leica software, Cyclone. Viewing the point cloud can be done in perspective mode or more useful to this method is the orthogonal mode where there are no vanishing points. Because the scanner records the intensity value of returned points (and can also colour the points using its built-in camera) the point cloud view looks realistic, and the point size shown on the screen can be adjusted so that the surface of the building appears to be continuous without any holes.

Viewing the data electronically in this way does not incur the problems of taking digital photography as described previously (lens distortion and stitching of images) and also allows images of extremely large resolution to be created. Once the image is created it can be inserted into a CAD drawing and the appropriate scale applied to fit A0, A1, A2 etc sizes of paper.

With the appropriate orthogonal view setup using Cyclone the user then exports an ortho TIF image at any resolution they desire. This also produces a TWF text file which provides instruction on how to insert the TIF image into an AutoCAD document. TIF images produced are uncompressed and can be quite large in file size, for example, the image taken for this case study was 8000 pixels tall by 5129 pixels and required 117 MB to store.

The above process going directly from Cyclone probably won't produce the best results due to the colours in the image not being contrasting enough or space on the image that is blank could be cropped off to reduce file size. Adobe Photoshop, like most image editing applications, can read in the TIF file and adjustments can be made to make the detail in the image clearer. To produce the desired result in this case study (see Appendix A. Scaled CAD Drawing of Rendered Point Cloud) required the image colours to be inverted so that black became white and vice versa.

The new edited image can then replace the previous TIF so that when the AutoCAD file is reloaded it picks up the new image attachment. At this stage the production of the CAD file is complete but additions such as plotting scales, title blocks etc could be added so that if the file is published it contains the correct information.

## 3. CONCLUSIONS

This case study highlights the importance of always understanding the requirements of the end product and how it

will be used. In this particular example method 2.4 *Scaled orthogonal views of the rendered point cloud* was a suitable solution. However, analysing the available point cloud meshing software was an interesting process to go through and will be a subject for future research.

The end result shown in Appendix A is still not a perfect result and highlights areas that must be considered when using this method. As mentioned in section 1.3 the site constraints meant that the oblique angle of the laser scanner produced sparse data towards the top of the facade. It was mentioned that this could be improved by setting the scanning resolution to maximum at the expense of much longer scanning times. It would be useful to do further investigations about resolution versus scanning time and also if scanning different parts of the facade with different resolutions would provide an improved point cloud solution.

Appendix A represents an orthogonal image of the values of intensity at each point in the cloud. The intensity helps highlight the difference between materials on the facade surface and can be used in an image editing application to enhance this difference. The middle portion of stonework is extremely well defined whereas the top and bottom sections are less so. This is due to the fact that the scanning was performed using different scan areas with each having a different median intensity level.

When these multiple areas of the scan are combined Leica Cyclone can then apply a global colour map, one of the options being intensity. However it applies a single black and white gradient over all of the point cloud which limits the range of values that represent the top and bottom sections. It would be worth investigating if the intensities can be adjusted on each area in the software, or if it must be organised when doing the site scanning. For the same material the closer the object to the scanner the stronger the intensity value recorded at the scanner so balancing intensities becomes a necessary step to produce accurate and clear point cloud renderings.

## 4. ACKNOWLEDGEMENTS

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## 5. REFERENCES

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**APPENDIX A. SCALED CAD DRAWING OF RENDERED POINT CLOUD**

