# Two Avenues for Data: Rosslyn Chapel as a Terrestrial Scanning Case Study

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**ABSTRACT**

Constructed between 1440 and 1486, Rosslyn Chapel has had a difficult history. It has suffered vandalism and neglect during the Protestant Reformation, used as a stable for Oliver Cromwell's horses during the English Civil War, unsympathetically renovated during the 1800's and nearly blown-up by the suffragette movement in 1914. During the 1950's the Chapel has suffered a failing roof in combination with an unsympathetic application of a white cementitious paint to the interior – essentially locking in the moisture into the stone.

As part of an on going research partnership, Historic Scotland and Glasgow School of Art systematically digitally documented the interior and exterior of the building and grounds over a three-day period. The purpose of the project was to implement a full 3D terrestrial laser survey of the existing structure to document its current physical condition and to help guide conservation techniques. Of particular concern was the structural integrity of the main vault during the replacement of the existing roof. Fourteen cross-sections were cut through the scan data to determine the exact thickness of the vault.

As part of the presentation material for the new Chapel interpretive centre, the terrestrial scan data was used to generate a 3D model and subsequent 3-minute animation, depicting the evolution of the Chapel from it's construction to the Protestant Reformation. In addition, a Percepteron system was used to generate sub-centimetre scans of 10 interior sculptures. The data was used to generate a series of photo-real animations, telling the story of each sculpture.

Current terrestrial laser scanning technology is capable of delivering visually rich dimensionally-accurate 2D and 3D digital images that, when combined with advanced imaging and animation processes, can become valuable resources for both conservation and public interpretation. Over a three-day period in March 2009, a combined team from the Digital Design Studio at the Glasgow School of Art and the Conservation Group at Historic Scotland digitally photographed and terrestrially laser scanned Rosslyn Chapel and surrounding property.

Initially the Rosslyn Chapel project was undertaken for the following reasons:

- To thoroughly document the physical condition of the building.
- To look at how the latest 3D digital technology can be blended with traditional conservation techniques.
- To assist the RCT and associated construction contractors by providing dimensionally accurate CAD drawings and 3D models during their conservation project.
- To understand the potential of terrestrial laser scanning for recording built heritage, particularly structures historically difficult to record due to their geometric complexity, and ones that are increasingly exposed to changing environmental conditions.

Along with,

- Provide photorealistic 3D images and animations to enhance public dissemination through the new Rosslyn Chapel interpretive centre and website.
- Provide the CyArk Foundation with appropriate data to assist in their mission to digitally preserve globally significant heritage sites.

## 1. BACKGROUND

Rosslyn Chapel is a 15th century medieval stone chapel located in Roslin, Midlothian Scotland. It is internationally renowned for its mixture of ornate pagan and Christian sculpture as well as its links with the Knights Templar, Freemasons and more recently the Holy Grail. Since the 15th century the building has survived vandalism and neglect during the Reformation, been used as a horse stable by Cromwell's troops during the English Civil War, unsympathetically renovated during the 1800's and nearly blown-up by the suffragette movement in 1914.

In 1954 the Ancient Monuments Branch of the Ministry of Works issued a structural report on the physical condition of Rosslyn Chapel. It indicated concern regarding the physical condition of the interior, in particular the considerable amount of cyanobacteria growing on the inside of the choir roof and high levels of moisture throughout the building. In an attempt to address the problem, the interior surfaces of the Chapel were scrubbed with wire brushes and a solution of silica fluoride of magnesium initially was applied. An additional coating of a white cementitious paint containing shellac was also administered. Unfortunately the paint acted as a seal, preventing water from naturally moving through the stone[i].

In combination with a leaking roof, the stone became saturated with water and soluble pollutants, fostering further surface decay. The paint also covered the varied stone colours[ii].

Image One: Chapel exterior with temporary protective metal shed roof

Image Two: Chapel vault with original exterior vault roofing removed and HDS6100 scanner in place

In 1995 it was determined that the saturated stone and high levels of humidity had to be immediately addressed and in 1997 a temporary, freestanding steel roof was erected over the entire Chapel to allow it to dry out.

Another concern for the Chapel is that the visitation has risen from approximately 10,000 a year to 150,000 since the release of Dan Brown's novel and subsequent movie The Da Vinci Code. The increased tourism footfall has resulted in worn flooring and a marked increase in the levels of humidity and condensation within the building.

## 2. COMPREHENSIVE DIGITAL SURVEY

Prior to the start of the documentation project it was identified that 3D terrestrial laser scanning was the better solution over other forms of documentation techniques to capture the complex building fabric and the detailed stone carved elements. The scanning technology is capable of capturing both simple and complex terrain or building surfaces.

In addition, the scan system records a reflectance value for the substrate. This has significant value for the historic environment where such values of traditional materials such as varying stone types and mortars could be correlated. This provides useful guidance in materials identification and mapping area of stone repair but with the different return signal intensity.

Following on from a number of more straightforward recording projects using terrestrial laser scanning, the team planned the survey of the Chapel to test the quality and speed of the technique. The laser technology is non-obtrusive, capable of scanning delicate surfaces. This minimal intervention and non-tactile technique was seen as beneficial.

The Rosslyn project utilised two a survey-grade Leica ScanStation 2 pulsed high-speed laser scanners and one Leica HDS 6100 phased-based scanner. The ScanStation 2 has a 360-degree horizontal field of view and a 270-degree vertical field of view. It has an accuracy of 6 mm at 50 meters with a range of 300 meters. Most of the laser scanning was taken within 20 meters of the building.

The ScanStation 2 is capable of a point-cloud scan density of 1.2 mm x 1.2 mm at 50 meters but because of the considerable data overlap from the numerous scan stations, the typical set scan density was 8 mm x 8 mm. The tripod-based ScanStation 2 scanner is capable of acquiring data from the line-of-site of the scan head, approximately 1.4 m off the ground. Exterior scanning was done from the ground but also on the temporary roof walkway (Image One) and on the Chapel vault (Image Two).

The HDS 6100 is a phase-based, dual axis system with onboard batteries and an internal hard drive. It offers considerably higher speed scanning than the ScanStation 2 and higher resolution but with only a range of 50+ meters.

The ScanStation was chosen for the longer range exterior scanning and a small number of ‘large’ interior scans with the HDS 6100 used for short-distance infill and interior detail scanning.

### 2.1. Digital Survey - Building Exterior and Property

The Rosslyn site is surrounded by a stone fence and is relatively tight especially along the eastern property line. The ScanStation 2’s were usually positioned within 15 to 20 meters of the Chapel. Approximately ten ScanStation 2 scans were performed with an resolution of 8mm in this area. An additional four scans were done outside of the property at the rear of the building to capture the falling terrain, the back wall of the lower chapel and the back of the temporary roof.

The laser documentation of the Chapel exterior had to both address and avoid the imposing temporary steel roof in place to dry out the masonry. With the completion of new roofing throughout the Chapel, during spring 2010 the temporary shed will be removed. The Chapel documentation project will provide historians and future researchers with a full dimensional understanding of temporary structure in-situ.

Although it was intended to have both the Chapel and temporary shed roof fully documented, it was important to avoid shadows or occlusions cast on to the Chapel by the roof’s supporting structural legs. An additional thirty-eight infill scans were required under the shed roof and between the legs and the Chapel. The scan positions were close to the building, approximately 2 to 4 meters, so the short-range, high-speed HDS 6100 was used.

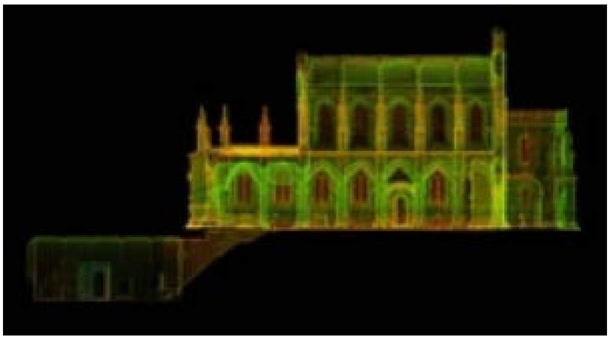

Image Three: Point cloud elevation of the Chapel

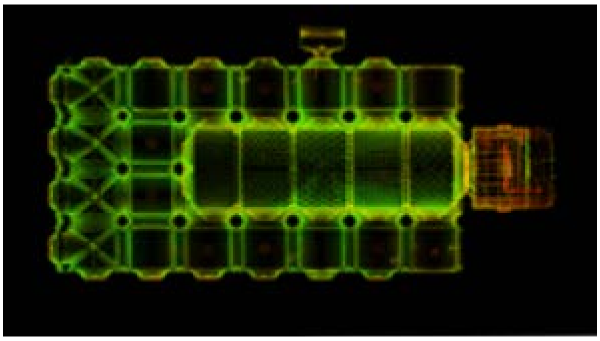

Image Four: Point cloud plan of the Chapel

The temporary shed roof was purposely designed to cover but not contact the Chapel walls, it was structurally sound but would move with tourist traffic or high winds. Excessive movement would set off the scanner's on-board tilt sensor and the scanning would stop. All of the scanning from this position was done with the HDS 6100 during the early morning with no tourist access.

The scanning of the Lady Chapel and Choir roof areas were achieved by positioning the scanner along the temporary steel roof gangway. The HDS 6100 was used in twelve locations at this height. At this time in the project, the original exterior vault roofing was still in place.

Due in part to the visual imposition of the shed roof and the required client deliverables; the use of referenced (nodal ninja) digital photography onto the point cloud was not initially incorporated into this project. Textures were generated using a Nikon D3X digital camera (24.4 megapixel SLR) with a

**2.2. Digital Survey - Building Interior**

In conjunction with the exterior scanning, the interior of the Chapel including the Lower Chapel, the Lady Chapel, the Choir, the Victorian baptistry and organ loft were also done. Particular attention was made to capture the three pillars and the Choir ceiling. It should be noted that even though the 1950's surface application of a cementitious slurry had a detrimental affect on the stone interior, the white paint colour and consistent coating throughout provided the nearly-perfect scanning surface.

An initial four scans were done of the interior using the ScanStation II at a 6mm resolution. The scanner was placed in the main Choir area and within the upper organ loft. As the ScanStation 2 has a greater range over the HDS 6100, the intention was to fully capture the detail of the vaulted ceiling as well as acting the primary scan data.

Although the HDS 6100 is capable of scanning to a distance of 40+ meters, the columns along the Choir and Lady Chapel as well as the individual vaulted ceilings along either side of the Choir required individual scanning to avoid occlusions. In total, fifty-six scans of the interior were performed with the HDS 6100 at the 'high' resolution setting with a 6.3 x 6.3mm point spacing at 10 meter range.

To enable a seamless connection between the registered interior and exterior point cloud data, two HDS 6100 scans were done at the thresholds of the North, South and Baptistry doorways.

## 3. DATA PROCESSING

The onsite terrestrial scanning lasted for three days; with the three scanners acquiring a tremendous amount of laser scan data. Approximately 4,123,446,300 points were taken. The documentation was supplemented by the use of high-resolution panoramic digital photography using the Nikon D3X.

For production purposes the data was reduced and then broken into four main groups: interior, exterior building, exterior grounds, and the vaulted roof. Initially the sixty-eight interior scans were combined through feature registration within Leica Cyclone software. The registered interior scans were then combined with the exterior scans through feature registration, a connection made through the interior/exterior threshold scanning.

## 4. POINT CLOUD ANALYSIS - CHAPEL VAULTED ROOF

During the summer of 2009, RCT was in the process of undertaking a large-scale conservation project at the Chapel. As part of the project the vaulted roof was rescanned for two reasons;

- A major concern was the removal and replacement of the existing chapel roof covering. Through earlier survey analysis, the thickness of the vaulted roof and structural integrity of the supporting stone structure were identified as problematic. Planning for the restoration was critical as there was a potential for damage or possible collapse.
- It was the last opportunity to document the bare stone finish before the new lead coverings were to be applied. Information that future conservationists, contractors or researchers may find important.

Over a 4-hour period eight scans were done with the HDS 6100 at the middle resolution setting with a 12.6 x 12.6mm point spacing at 10 meters range. The unique access enabled the full documentation of the exterior vaulted surface including the individual stones, mortar and connection of the vault to the walls.

To provide the roofing contractor with a better understanding of the depth of the vault, eight lateral cross-sections and four longitudinal sections were derived from the combined interior and exterior point cloud data (Image Seven). The location of the sections were initially selected by reviewing the 3D point data in Leica Cyclone then drawn up in 2D CAD format using Autodesk Architectural Desktop in combination with the Leica Cloudworks plugin.

Image Five: 3D Mesh Model of Chapel exterior – metal shed roof virtually removed

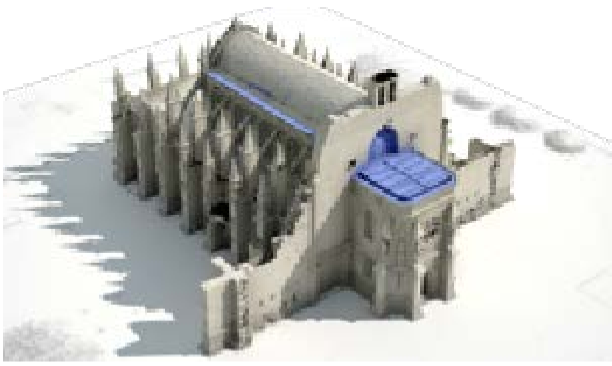

Image Six: 3D Mesh Model of Chapel exterior with modeler interventions indicated in blue

Image Seven: Cross-Section of Chapel Vault

In this situation, the terrestrial scanning system proved beneficial over traditional survey systems such as the Total Station in that the scanner provided comprehensive surface documentation (millions of points) as opposed to individual point documentation. As both the exterior and interior were fully scanned and properly registered, sections could be easily cut through the data to provide the contractor with a precise depth of the stone vault[iii].

## 5. 3D DEVELOPMENT

Although the point cloud is considered an objective record of a surface, the resolution of the triangle mesh or the processing algorithms are subjective decisions. While software can mesh without operator intervention, it is not truly objective. In addition, the creation of visually compelling, photorealistic 3D architectural models require a highly skilled computer operator. It is inevitable that during the removal of point cloud artefacts and 3D modelling there is a degree of interpretation or conjecture.

Based on the scan and photographic data, two models will be derived; an ‘objective’ 3D model generated through meshed scan data with any involvement by the 3D modeller being visually documented, as well as an animated photorealistic 3D model to enhance public understanding of the structure.

Due to the considerable amount of laser scan data acquired during the project; a 3D model of the Chapel was developed based entirely on the registered, processed and then meshed scan data. Any additional geometry added by the 3D modeller was specifically identified within the model with an identified material/colour and layer within 3D Studio Max.

The conversion of individual points into a triangulated 3D mesh is computationally intensive and requires a high-end computer workstation. The acquired Rosslyn point cloud was already reduced to 7% of its original size yet the meshing of the Chapel data still required to be split into four sections. Each section needed to process individually within InnovMetric PolyWorks v.11 and then combined within 3D Studio Max.

In a complex surface like the one of the chapel, there were numerous small areas that were not visible to the scanner. For example the underside of interior surfaces, hidden areas due to the temporary roof structure, and difficult to reach areas such as the roof of the baptistry. These areas resulted in blank spots within the meshed data.

Larger surface areas that were scanned but not meshed due to insufficient data such as the roof of the baptistry were filled with modeller derived geometry. It would be impossible to position the scanner, even with many set ups, in such a way that all surfaces could be documented.

Any geometry added to the model by modeller through PolyWorks or 3D Studio Max but was properly identified through layer and colour identification.

In addition to the development of the ‘objective’ 3D dataset, a photorealistic 3D model was also developed. The purpose of the model was to generate images and animations for the RCT website and Chapel interpretation centre. The animations take a building back to it’s main structural elements and ‘slice’ through the building and present it in unusual visual ways.

Similar to the objective model, the photorealistic model was based on the meshed point cloud data. Unlike the objective model, additional modeller infilling was not identified within the geometry.

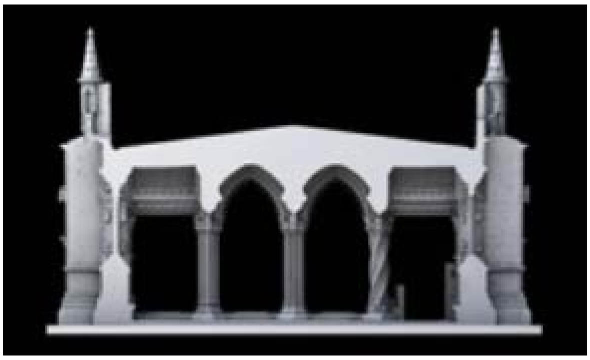

Image Eight: 3D Cross-section rendering from the meshed point cloud data, highlighting the 3 colums

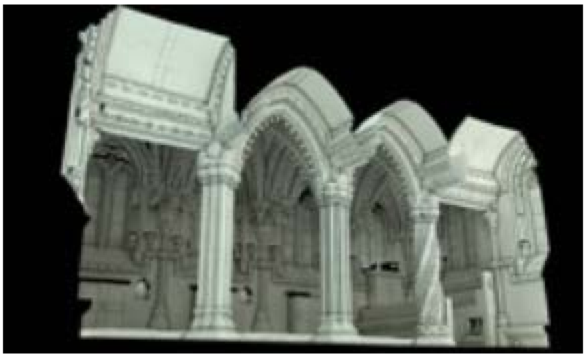

Image Nine: Rendering from the meshed point cloud data, highlighting the 3 columns

Image Ten: Detail rendering of the Lucifer sculpture

Image Eleven: Detail rendering of the Green Man sculpture

**6. INTERPRETIVE CONTENT**

With the terrestrial scanning, data registration, CAD and meshed model complete, a photo-realistic 3D model was then developed based on the original point data. Commissioned by Studio Arc, the animated model was used to explain the original 1440‘s construction process as part of the interpretive centre multimedia content.

The narrative of the animation begins with the Chapel grounds as a green field site then showing the various stages of construction. Guidance on the specific construction methods used at that time was provided by Historic Scotland.

As requested by Studio Arc, the three-minute 1080p Quicktime animation content is projected downwards on to a white oval table within the interpretive centre. The camera position in 3D Max is fixed throughout the entire animation from the sky downwards. Sound effects and period music were added to complement the presentation.

Located within the new interpretive centre, four interactive touch screens allow visitors to explore selected carvings from the Chapel. The touch-screen units are housed within moveable plinths and incorporate flat-screen monitors that allow visitors to tilt the screen to suit their optimum-viewing angle[iv].

Ten interior sculptures - The Mason and Apprentice Pillar, the Dance of Death, Lamb of God, Green Man, Lucifer, Knight on Horseback, Angle Holding a Heart, Seven Virtues and Seven Sins - were individually scanned using a Percepteron sub-centimetre hand scanning system at 0.5 mm resolution.

The acquired scan data was converted into a 3D mesh and 'data holes' filled using PolyWorks. The data was then imported into 3D Studio Max, textured and animated at 1080p. The developed content was then integrated into a series of touch screen panels with corresponding descriptive text.

## 7. CONCLUSION

The comprehensive terrestrial survey of Rosslyn Chapel produced a dataset that provided a diverse set of deliverables. The dimensionally accurate scan data was able to serve multiple purposes, from site management, condition assessment, conservation, structural analysis as well as public interpretation. The generation of multimedia content from the digital data can be of tremendous value in explaining the history and architecture of a particular heritage site.

## 8. REFERENCES

Entwistle, J.A., McCaffrey, K.J.W., Abrahams, P.W., 2008. Three-dimensional (3D) visualisation: the application of terrestrial laser scanning in the investigation of historical Scottish farming townships. Journal of Archeological Science 36, 860-866.

Lerma, José Luis, Terrestrial Laser Scanning and Close Range Photogrammetry for 3D Archaeological Documentation: the Upper Palaeolithic Cave of Parpallo, Journal of Archeological Science 37, 2010. p. 499-507.

Angelo Maggie, Rosslyn Chapel: An Icon Through the Ages, Birlinn Ltd., 2008.

Sternberg, H., T. Kersten, I. Jahn, and R. Kinzel. "Terrestrial 3D Laser Scanning - Data Acquisition and Object Modelling for Industrial As-Built Documentation and Architectural Applications." The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol XXXV, Commission VII, Part B2. 2004. 942-947.

Turnbull, Michael, Rosslyn Chapel Revealed, Sutton Publishing Ltd., 2007.

Whyte, J., Virtual Reality and the Built Environment. Architectural Press, Oxford., 2002.

## 9. ACKNOWLEDGEMENTS

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Studio Arc - Lyndsey Boditch, Bryony Shepard.

Centre for Digital Documentation and Visualisation (CDDV) - In 2010 the Digital Design Studio at the Glasgow School of Art and Historic Scotland signed a multi-year agreement to explore and implement innovative information technologies – relating to virtual reality, telemetry, multi-media and computer aided design - in the service of the explanation and interpretation of iconic sites with geological, historic, social and cultural significance. More recently both organizations have joined the CyArk Foundation whose mandate is to promote and support the documentation of endangered cultural-heritage sites through the use advanced technologies.

Notes

[i] Rosslyn Chapel Revealed, Michael Turnbull, Sutton Publishing Ltd 2007.

[ii] Rosslyn Chapel Revealed, Michael Turnbull, Sutton Publishing Ltd 2007.

[iii] Nic Boyes Conservation - Nic Boyce.

[iv] Studio Arc - Lyndsey Boditch.