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**THE APPLIED USE OF ADVANCED DOCUMENTATION TECHNOLOGIES IN HERITAGE
CONSERVATION**

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Abstract

Our built heritage is continuously exposed to profound change, from natural phenomena and climate change to manmade pollution and encroaching urbanism. Cultural heritage sites, which are testimonies of individual uniqueness and the roots of an individual society, are in great danger. Some of them will disappear; others have already disappeared forever. The advent of effective laser scanning, high-resolution digital photography, widespread internet access, and affordable digital storage means this is the first time in history that we can capture and disseminate information fast enough to make a difference.

In 2006 the Digital Design Studio at the Glasgow School of Art and the Technical Conservation Group at 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 organisations have joined the CyArk Foundation whose mandate is to promote and support the documentation of endangered cultural-heritage sites through the use advanced technologies.

Introduction

The Digital Design Studio at the Glasgow School of Art (GSA) and the Technical Conservation Group at Historic Scotland (HS) are in the third year of a collaborative partnership to explore the use of documentation technology in heritage conservation. More specifically, the applied use of 3D laser scanning to record and conserve the traditionally built environment.

The GSA and HS have distinct but complementary expertise. Since 2004, HS has owned and operated a high-resolution, point and shoot laser scanning systems and recently purchased 2 additional terrestrial scanning systems. Since 2004, the GSA has acquired considerable applied research and commercial experience in the area of architectural and heritage visualisation. In addition to its relationship with HS, the GSA recently developed a 3D model of 4 square kilometres of the Glasgow City centre. Over 1400 buildings and structures were individually laser scanned and 3D modelled.

Key questions at the commencement of this partnership between the GSA and HS are:

- What is the potential for laser scanning for recording built heritage, particularly structures historically difficult to record, and ones that are increasingly exposed to changing environmental conditions?
- What practical benefit to building pathology and project management can the technology deliver?
- Can traditional conservation techniques be blended with the latest digital technology for mutual benefit?
- What benefit in understanding and interpretation can digital documentation and visualisation bring in broadening 'access' to the historic environment?



Figure 5: Metal canopy - pre-restoration

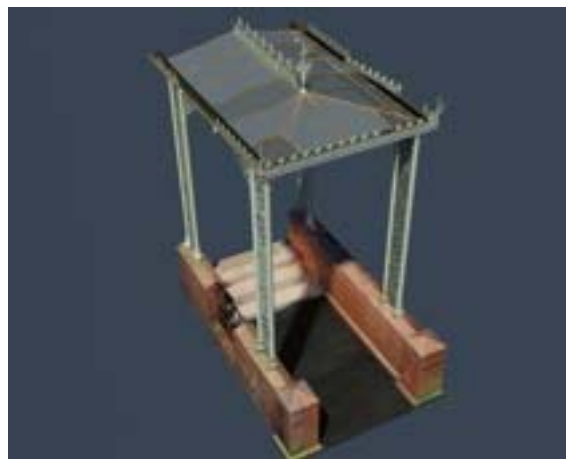


Figure 6: The virtual reconstruction

Historic Canopy, Isle of Bute

In 2007, the partners undertook a small trial project to explore the potential of terrestrial laser scanning in comparison to traditional survey techniques. A small but important cast iron entrance canopy was being restored by grant aid from Historic Scotland. The structure was to be removed from site for more effective conservation work with some elements to be replaced entirely. An informal test of recording approaches was taken from photogrammetry and hand-measured survey to 3D laser scanning. Of the three, laser scanning provided the most accurate and comprehensive results.

One of the principle benefits of the laser scanning was to realize a highly accurate 3D model of the structure, where it was feasible to measure any point within the three dimensional construct to an accuracy of 10mm. The 3D data was also effective in conveying the proper disassembly. The canopy was essentially a kit of cast iron components and the 3D model allowed the structure to be shown in constituent form to aid identification of components.

The speed and accuracy by which highly accurate CAD drawings were realized was seen as a key practical outcome, and that these CAD drawings captured to ornamental detail more accurately than had previously been feasible.

The 2-person laser team utilized a Leica ScanStation pulsed high-speed laser scanner to document the metal and glass canopy. The scanner has a 360-degree horizontal field of view and a 270-degree vertical field of view (ideal for large buildings or the underside of bridges). It has an accuracy of 6 mm at 50 meters with an approximate range of 300 meters. All of the scans taken for this project were within 10 meters of the structure. The ScanStation is capable of a point-cloud scan density of 1.2 mm x 1.2 mm but for this project the typical setting was 1 cm x 1 cm.

The tripod-based terrestrial scanning system is only capable of acquiring data from the line-of-site of the scan head (approximately 1.4 m off the ground) to an object. Anything outside of this view, the top of cornices, window sills, or obscuring the view, vegetation, street signs, parked cars etc. can not be scanned.

Over a 4-hour period, the canopy was scanned from 5 different vantage points as well as being digitally photographed. The intention was to obtain a unified 3D point cloud with high-enough resolution to enable

the creation of 2D CAD drawings. A number of key deliverables to inform and assist the conservation project were developed, including:

- Highly accurate CAD drawings based on the point cloud to direct the restoration.
- The registered point cloud itself as an archival document.
- Wireframe orthographic projections.
- A highly detailed, photorealistic 3D model to represent the 'as-built condition'.

In comparison to the traditional survey (with a total station or theodolite), the speed of documentation was immediately evident as was the dimensional accuracy. Other benefits included the comprehensive



Figure 7: Existing bridge



Figure 8: 3D point cloud



Figure 9: untextured 3D model

nature of the data capture (including the highly ornate but damaged columns) and ease of capturing incidental contextual data such as the entire building facade, most of the streetscape and street furniture and adjacent vegetation.

Linlathen East Bridge

Following the completion of the Bute project, the earliest iron bridge in Scotland (1804) at Linlathen, Dundee was recorded and modelled. Originally a horse-drawn carriage bridge, sedimentation around the piers, adaptation of the superstructure in timber and damage caused by flooding and vandalism had left the bridge in poor condition and one which was exceptionally difficult to measure using traditional survey techniques.

Significant issues for the project will include - as the project is just nearing completion - the incorporation of structural members to ensure the historic fabric is no longer load bearing, and the introduction of parapets, which meet contemporary health and safety requirements for pedestrians and cyclists. The deliverables again included CAD drawings and a photorealistic visualisation to enable the 'virtual removal' of structural interventions to reveal the original aesthetic and design intention.

An important consideration at the start of the project was to thoroughly document the bridge's as-built condition - as an archival record in advance of restoration. The bridge was scanned from 12 different locations, including within the river itself, over a 10-hour period.

The 3D scans were then converted into 2D CAD and a photorealistic 3D model of both the bridge and surrounding terrain. The information was presented to the City of Dundee and incorporated into their restoration tender package. The intention is to show the existing bridge in conjunction with the proposed alternatives. The 2D CAD, animations and renderings will be given to the Council, community and HS to enable a better informed decision on the final design.

As with the Bute canopy, the technology proved to be exceptionally proficient in accurately capturing irregular or twisted objects such as damaged stonework or twisted metal.

Knockando Wool Mill

Complex industrial buildings where the working machinery is inextricably linked to the building fabric poses challenges for recording. The woollen mill at Knockando in the Scottish Highlands reflects regional vernacular construction with industrial process functionality. During the Fall of 2009, the machinery will

be taken out of the building for conservation and the metal and wood section of the mill temporarily dismantled.

To date both the interior and exterior have been comprehensively scanned over a two day period using 2 scan systems. Particular attention was paid to thoroughly document the eclectic assembly of machine parts and hand tools. The point-cloud will provide an invaluable locational record of the artefacts and architecture once this building is reassembled.



Figure 10: Paint and surface analysis

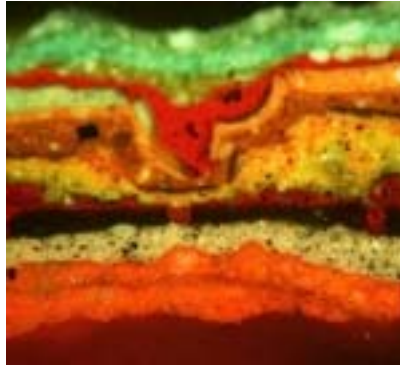


Figure 11: Cross section of paint



Figure 12: Sculpture at fountain mid-level

The Grand Fountain, Paisley

In 2008 the HS/GSA team combined a more traditional conservation assessment with digital documentation and visualisation to maximum practical benefit. The grand fountain, which sits in Fountain Gardens, Paisley, has been identified for a major refurbishment project and Historic Scotland was invited to provide expert advice on this important iron structure. Archive evidence informed us that Daniel Cottier, an important Scottish and later American designer, had executed the decorative colour scheme.

On this basis a historic paint specialist undertook a complete survey of the fountain to identify the original colour scheme and relate this to the documentary evidence. At the same time, specialists examined the ironwork internally and externally to advise on the condition of the structure and identify missing components. Mounted thin sections were used to build a picture of the historic colour scheme, and trials undertaken to replicate complex bronzed and lacquered finishes. Whilst a normal method of presenting this information would involve hand colouring a sketch, it was decided to use scanning and visualisation to see what was feasible. A presentation to non-technical members of the Council was anticipated to demonstrate what the fountain would have looked like, and could look like again once restored.

The point-cloud data was initially converted into 3D mesh, which was then used to assemble the dimensionally accurate and photorealistic virtual representation. The initial fountain model was kept monochromatic and printed on three sheets of A0 paper. This was used as a marking guide to indicate colour placement. Colour samples were identified from the thin sections and accurately replicated on the rendered 3D model to create a true representation of the original appearance. The fully-textured, photorealistic model was then rendered out for large-scale prints and DVD animations.

The virtual model was particularly revealing in visually demonstrating the glossy quality of the proposed painting scheme. The depth of lustre through the application of many coats of shellac varnish was immediately evident on the virtual model.

The point cloud data was confirmed as being able to create patterns from which to cast missing features of the fountain through rapid prototyping. This was a key outcome since the traditional method of carving a replica wooden pattern would be high cost and often not entirely accurate in design and execution. The CNC approach also had the potential to 'grow' the pattern to account for the shrinkage that takes place in the casting process, where using an original component as a pattern where feasible would result in further shrinkage from the first generation pattern resulting in a casting which was undersized and with some loss of detail.

Dupplin Cross

Due to the large number of carved stone in its care, HS has been using high-resolution hand-held scanners since 2003. The original technology was slow and cumbersome, with simple objects taking 6 or more hours to scan. The technology used on the Dupplin Cross was considerably faster (1 hour versus 3 days) and able to inform both our understanding and conservation for such collections. Unlike the earlier systems where all of the scanning was done indoors, contemporary systems can capture objects within the exterior context. The resolution and accuracy is exceptionally impressive - up to 0.1 millimetre.

An Ogham inscription on the Dupplin Cross dating from 800AD has been scanned on site within St. Serfs Church at 0.5 mm and is currently being prepared for analysis. Scanning and enhancement techniques will allow this inscription to be studied in great detail than was previously feasible.



Figure 13: Dupplin Cross 3D mesh model

Stirling Castle

The documentation of Stirling Castle has been ongoing for 2 years, a large and complex project with a number of logistical site complications. Archive documentation of the site was incomplete despite the site being of international importance. Also, a major project to restore the renaissance palace was due for completion, offering opportunities to document the building interior and exterior. Stirling Castle was a key strategic and royal presence and integral to the history of Scotland. To date over 90% of the site has been scanned, with 4 approaches employed;

- Exterior facade and site scanning using a time-of-flight laser system with a resolution of 1 cm.
- Interior of the palace building using a phase-based scanning system with a resolution of 5 mm.
- Sub-millimetre accuracy using the hand held laser scanning system, particularly of carved statuary on the palace upper levels.
- Aerial LiDAR to record both the urban context and geological features on which the castle sits.

The combination of point cloud data, high definition photography and modelling have been employed to create a highly photorealistic visualisation of the castle, but one which is based on the dimensional accurate point cloud.



Figure 14: South facade of the Stirling Castle Palace



Figure 15: 3D representation of the South facade

The CyArk Foundation

CyArk is a non-profit entity whose mission is to digitally preserve cultural heritage sites through collecting, archiving and providing open access to data created by laser scanning, digital modelling, and other state-of-the-art technologies. CyArk was founded in 2003 as a project of the Kacyra Family Foundation (KFF), located in Orinda, California USA. As a result of Mr. Kacyra's experience running Cyra Technologies from the early 1990s until 2001, the concept of CyArk seemed an evolutionary way to use static LIDAR in combination with high definition photographs to collect 3D point clouds and photos of heritage sites.

In April 2009, the Scottish Minister for Culture, Mike Russell MSP announced a partnership with CyArk, the GSA and HS to digitally record the 5 UNESCO World Heritage Sites in Scotland using laser scanning technology. Russell also committed the resources to document 5 international sites as Scotland's contribution to global conservation.

Over the next five years GSA, HS and CyArk will collectively document ten sites using a combination of laser scanning and visualisation techniques. This is not entirely altruistic. The sites we are seeking need to offer technological challenges or advance our technological standing, possibly have some link to Scotland past present or future, and continue to build capacity in Scotland in this field. At time of writing we are drawing up selection criteria for sites and projects and seeking to build international partnerships to realize our mission.

CyArk 500

The CyArk 500 initiative is a global effort to digitally preserve 500 of the most important world heritage sites within the next five years. This will be accomplished through an expansion of CyArk's already established worldwide network of partners, who will utilize new technologies to quickly and cost-effectively digitally preserve these sites. The success of the initiative is easily measured by the number of sites digitally preserved, and by the creation of local technology centres.

Why is there a need for the 500? Cultural heritage sites are the tangible testaments of history, a material syllabus of our collective memory. Preserving these powerful, silent witnesses of human history is to preserve our own humanity. We are losing these treasures. The Bamiyan Buddhas, Citadel of Bam, and the Namdaemun Gate are unfortunate examples of just how quickly our heritage can vanish. In addition to singular catastrophic events, there are increasing, gradual threats to cultural heritage sites. Unfortunately, most of these threats stem from a globally accelerating population. It becomes obvious – the time is now. The advent of laser scanning, widespread internet access, and affordable digital storage means this is the first time in history that we can capture and disseminate information fast enough to make a difference.

Future Technical Advancement

The application of high definition photography onto the point cloud has significant potential but requires further research. Due to the human input to the modelling process it is inevitable that there is a degree of interpretation or conjecture at some point within the model. This has caused us a degree of concern in creating an entirely objective record of the structure. Conversely, the point cloud is an entirely objective record of a surface. In recording an XYZ co-ordinate the point cloud is simply a collection of measured points.

In addition, the scan system records a reflectance value for the substrate which it strikes. 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.

A proposed project will look at the documentation of façade loss in sandstone buildings in Scotland with a view to mapping areas of stone repair required and extrapolating these to identifying stone supply and traditional masonry skills repair. Laser scanning also of course offers the potential to re-visit and re-scan to compare degradation and structural movement.

The effective management of the built environment and the impact of development may also be beneficially assessed using a large-scale three-dimensional model. The work of the GSA in creating the Glasgow Model has created a highly accurate data record of Glasgow, but allows new developments in a historic setting to be more fully evaluated by virtually placing proposed structures into the model itself. Laser scanning technology is capable of delivering visually rich 2D and 3D digital images that, when combined with advanced imaging and animation processes, become visually rich resources for education and public interpretation. When a cultural-heritage site is so endangered that it faces destruction, digital documentation may be the only way to preserve it for history.

Conclusion

Advanced laser scanning hardware is expensive, but can provide fast, highly accurate results. The derived point-cloud information can be integrated with other forms of CAD, GIS and traditional survey information as well as other data such as high-resolution digital photographs. Additionally, the proper conversion of the point cloud to 3D and the creation of the 3D models is labour intensive. It also requires skilled staff to develop the data. It is also important to note that laser scanning should be seen as part of the recording 'toolkit'. There are situations where other traditional survey techniques should be employed in preference or in partnership.

The laser-based digital survey provides the soundest foundation record for cultural-resource management. It produces a comprehensive dataset that can be further developed into a diverse set of deliverables serving multiple purposes, including site management, condition assessment, conservation, structural analysis and archaeological interpretation.