digital cultural heritage: FUTURE VISIONS

Edited by Kelly Greenop and Chris Landorf

Papers presented at the *digital cultural heritage: FUTURE VISIONS* Conference
19–20 April 2017 in Brisbane, Australia
http://digitalculturalheritageconference.com/

Russell, J and Mitchell, D (2018)
Practical applications of digital technologies in the conservation, management and education fields by Scotland's national heritage body.
In K Greenop and C Landorf (eds) *Proceedings of digital cultural heritage: FUTURE VISIONS*. Brisbane: Architecture Theory Criticism History Research Centre, School of Architecture, The University of Queensland, pp 152-172.

ISBN 978-0-646-98233-5

The University of Queensland
AUSTRALIA

The convenors of the *digital cultural heritage: FUTURE VISIONS Conference* acknowledge the generous support and sponsorship of the Architecture Theory Criticism and History Research Centre at The University of Queensland and the Ian Potter Foundation. Thank you also to the peer reviewers who gave their time and expertise to the refereeing of papers, the State Library of Queensland who hosted the event, and Carmen Armstrong who provided invaluable project management support.

The papers published in these proceedings are a record of the conference mentioned on the title page. They reflect the authors' opinions and, in the interests of timely dissemination, are published as submitted in their final form without change. Their inclusion in this publication does not necessarily constitute endorsement by the editors.

Editors: Kelly Greenop and Chris Landorf

Design and Production: Mark Fletcher

Publisher: Architecture Theory Criticism and History, The University of Queensland

The Conference Convenors received a total of 44 abstracts. Abstracts underwent a double-blind peer review by two members of the Conference Organising Committee. Authors of accepted abstracts (32) were invited to submit a full paper. All submitted full papers (18) were again double-blind peer reviewed by two reviewers. Papers were matched as closely as possible to referees in a related field and with similar interests to the authors. Sixteen full papers were accepted for presentation at the conference and a further 6 papers were invited to present based on submitted abstracts and work-in-progress. Revised papers underwent a final post-conference review before notification of acceptance for publication in these conference proceedings.

Please note that papers displayed as abstracts only in the proceedings are currently being developed for submission to a digital cultural heritage special edition of an academic journal.

COLOPHON

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Practical applications of digital technologies in the conservation, management and education fields by Scotland's national heritage body

Abstract

As early adopters, Historic Environment Scotland continue to pioneer practical applications of digital technologies in conservation management and education. Applications for educational purposes are illustrated via Scotland's new building conservation centre for research and education, and in estate management. An innovative digital national asset management system is outlined.

Keywords: Laser scanning; asset management; conservation; condition monitoring; HES-SIGMA; engine shed; BIM

Introduction

Historic Scotland, the predecessor body to Historic Environment Scotland, showed early interest in the use of digital documentation for cultural heritage. Ben Kacyra *et al* submitted a patent for a laser scanner in 1999[1] and the field quickly developed for industrial applications. The original driver of and intent for the technology, was to capture as-built information in the petrochemical, power and manufacturing industries by using lasers to measure triangulated measured points at rapid intervals to create a 'cloud of points'. This cloud of points provided a line of sight measurement approach to surfaces providing millions of measured points in rapid time compared to traditional survey approaches. In addition to providing spatial information in terms of an XYZ co-ordinate, the laser scanner also provided information on the reflectance value of the surface being measured, which showed some promise in the differentiation of materials.

Figure 1. Pictish carved stones captured with 0.5um using a Leica T Scanner. (Source: courtesy of CDDV).

The cultural heritage sector quickly realised the benefits of a documentation system which could provide highly accurate spatial information. In Scotland, the technology was applied to the documentation of carved stones of the early Christian period, particularly those of Pictish origin (Figure 1). A centuries old tradition of drawn and photographic survey had started to move towards a new era. Early systems around 2000 and 2003 were slow in data capture and could be difficult to use, but the principal challenge was in data manipulation because of the lack of bespoke software, large file sizes and data compatibility with other industry software. Some of these challenges continue today to some extent, but both hardware and software have progressed significantly.

Historic Scotland purchased its first laser scanner in 2003. It subsequently entered into a research partnership with the Digital Design Studio at the Glasgow School of Art in 2005 who had developed expertise in digital modelling and had an interest in using laser scanning and other data capture technologies. Ben Kacyra established CyArk, a US non-profit to promote digital technologies for culture heritage after he saw the destruction of the Buddhas of Bamyan in Afghanistan in 2001. CyArk identified Scotland as a leader in the application of such technology to cultural heritage purposes and established a close relationship. Historic Scotland formed an innovative commercial partnership between the two public bodies to maximise the benefits to Scotland and the Centre for Digital Documentation and Visualisation (CDDV) was created in 2008. This LLP has delivered a wide range of domestic and international projects since inception (Wilson *et al.* 2013).

Cultural diplomacy

In 2008, the Minister for Culture in the Scottish Government agreed that Scotland would digitally document Scotland's five World Heritage Sites to contribute to the digital archive that CyArk were creating, and that a further five international sites would be delivered for the purposes of cultural diplomacy and for extending opportunities for Scotland to develop its expertise further. The project was titled the Scottish Ten, delivered by Historic Scotland, Glasgow School of Art and CyArk. In Scotland, Edinburgh, New Lanark, Neolithic Orkney and the island of St Kilda were digitised by using airborne liar, terrestrial laser scanning and sub-millimetre hand scanning datasets combined with digital photogrammetry (Wilson *et al.* 2011). Mount Rushmore in the United States, Rani Ki Vav Stepwell in India, the Eastern Qing Tombs in China, the Sydney Opera House in Australia and the large cantilever cranes in Japan were documented in partnership with local heritage bodies to encourage technology transfer (Wilson *et al.* 2011). The designation of the Forth Bridge as Scotland's sixth World Heritage Site in 2015 prompted this too to be laser scanned, to date the largest and most complex project of its kind and completed late 2016.

In 2010, the First Minister of Scotland announced that Scotland would deliver the Rae Project, digitally documenting all the historic assets in State Care, comprising 345 of Scotland's most important places.

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Figure 2: Forth Bridge point cloud. (Source: courtesy of CDDV).

This project remains live and underpins our approach to asset management in Historic Environment Scotland.

Towards a management tool

In 2011, CDDV was commissioned to look at a 3D asset management system based on the point cloud developed from laser scanning at the World Heritage site of Schonbruun Palace in Vienna. In reality whilst the documentation of the site was a significant success, the software available at this time and the integration of datasets and spatial information proved too complex a challenge to create a workable and useable system. The principal was sound–a three-dimensional database based on unique xyz co-ordinates and tagged as geo-locators seemed logical.

The digital documentation of the Sydney Opera House under the Scottish Ten project is aligned with the building management team pushing forward with the creation of a digital asset management system within a complex and busy historic asset and performance venue. The laser scanning work

completed under the project provided the first 'as built' data for the Opera House since its completion in 1973. Access to every surface of the building proved technically challenging and the experience of rope teams gained at Mount Rushmore proved invaluable. The Opera House continues to be at the forefront of digital management of historic assets, building from the spatial data capture of the Scottish-Australian-American team.

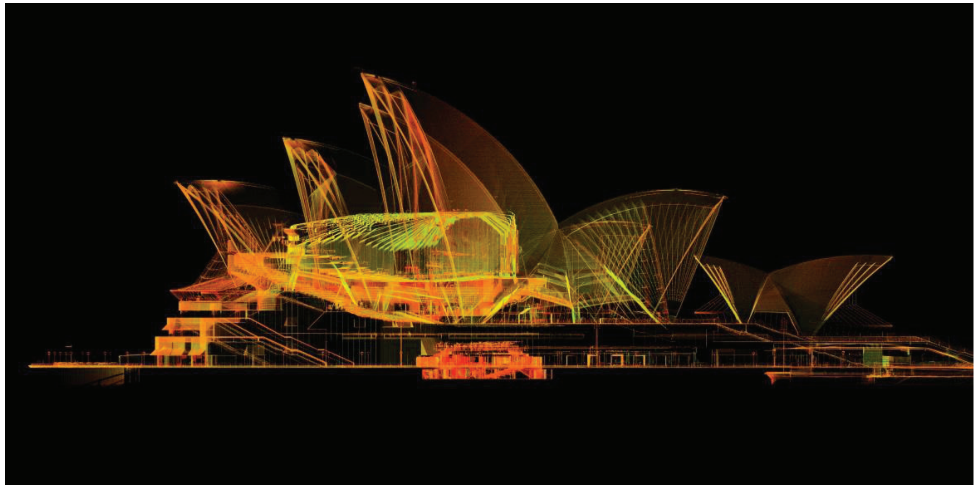

Figure 3: Sydney Opera House. (Source: courtesy of CDDV).

BIM–a tangent to the plot?

Building Information Modelling, or BIM, had its origins in the 1980s but came to prominence in the late 1990s. It came from a different perspective and evolved using architectural CAD type approaches. The US National Building Information Model Standard Project Committee uses the following definition:

> Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility'
> (National BIM Standard – United States 2014)

The UK Government has promoted BIM and its application actively since 2011, with the Scottish

Government following a similar line, stipulating that public capital projects are to be using BIM by April 2017. The UK's BS/PAS 1192 standard is acknowledged as the leading global standard for building information management, and is due to form the basis of an international ISO standard.

The use of BIM and related digital information management processes in the heritage sector is in its infancy. In Scotland, we are currently leading the heritage application of BIM. Whilst Historic Environment Scotland can exclude most of its operations from BIM application, it has chosen not to do so given its strong interest in digital technology. Since 2012 we have explored the opportunities and constraints of the application of BIM in parallel with our digital spatial capture work, developing a Heritage BIM strategy to support the management of the historic environment.

As part of our organisational BIM strategy, we are delivering a pilot HES BIM Project, which aims to investigate the use of BIM processes across four case studies representing a diverse cross section of our portfolio. The principal pilot case study is the Palace Block at Edinburgh Castle where we are using a BIM model to collate the complex asset information of an ancient monument in use, including historic, technical and maintenance information for elements of fabric, infrastructure, mechanical and electrical systems. We are currently exploring how this can be used to assist with operational asset management at one of the key buildings in this, our most visited property, with over 1.5m visitors each year.

Digital data for conservation purposes

At a very simple level the creation of high quality spatial survey data is an important output in itself. We have developed survey standards which extend to performance specifications for fieldwork, processing and data archiving. Early alarmist responses from archival bodies around managing large digital datasets has moved on significantly. Accurate survey and modelling from physical and archival evidence can provide new perspectives.

The ability to record morphological change in surfaces and structures has been of significant benefit. Historic Environment Scotland has had good success in combining digital documentation expertise with the datasets generated through our thermographic work. Thermography and moisture mapping is a commonly used building pathology tool and combining these datasets with 3D models has created a powerful tool for tracking moisture movement and fabric issues.

Figure 4: James V sculpture at Stirling Castle – meshed scan data to model of existing appearance to interpretation of original presentation in the 16th Century. (Source: courtesy of CDDV).

Modelling reconstructive or restorative approaches in order to deliver fundraising campaigns for projects has proven successful for a number of projects in Scotland (Wilson *et al.* 2010). This was most notable in the restoration of the Grand Fountain in Paisley, where

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an unusual cast iron fountain with a bespoke colour scheme by Cottier was modelled from traditional paint analysis techniques, and scan data used to generate 3D models and printed patterns to re-cast missing elements. Practical benefits were also seen in using point clouds to inform conservation decisions (Wilson *et al.* 2012).

Digital documentation in an emergency situation is perhaps best exemplified by the post fire salvage and recovery operation at the Glasgow School of Art in 2014. Amongst the first people on site were our digital documentation team who were able to document the site as found, and directly prevented the removal of building fabric and so we were able to demonstrate that masonry identified as dangerous, was in fact no different from previous materials, by comparing historic scan data.

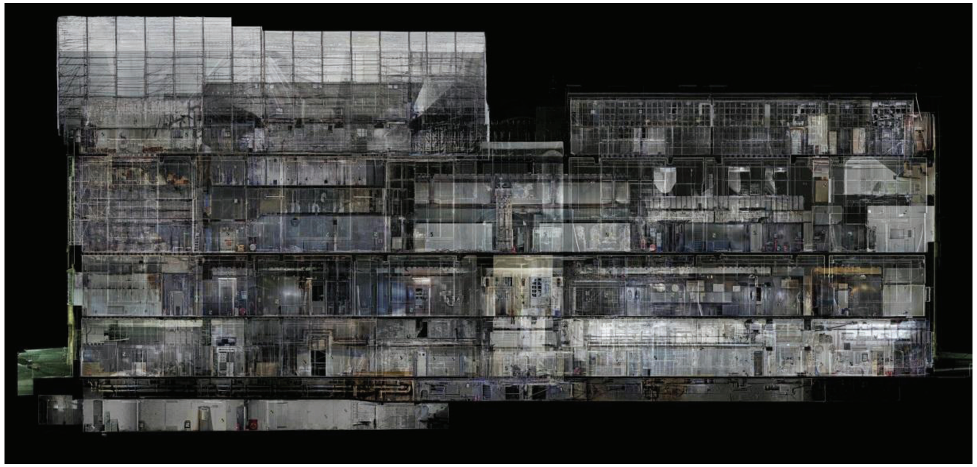

Figure 5: Post fire survey of Glasgow School of Art. (Source: Courtesy of GSA).

Towards a conservation asset management system

Historic Scotland merged with the Royal Commission of Ancient and Historical Monuments to create Historic Environment Scotland in October 2015. RCAHMS had a century old role in documenting the historic environment in Scotland through a range of approaches and making this information available to the public. The new body would retain a key role to continue to care for the national collection of properties in State Care, an unbroken line of some 700 years to the Kings Works.

The management of the properties and associated collections would be undertaken through a formal Scheme of Delegation through an Act of Parliament. This required a transparent system of asset management which provided assurance to Scottish Ministers on the quality of care being delivered, the ongoing condition of the assets and building in mechanisms to deal with the growing impacts of a changing climate in Scotland. The conservation team saw this as both a challenge and an opportunity to shift the focus, performance and outcomes of our core purpose. It was also considered to be an opportunity to bring together our digital documentation expertise, our asset management requirements and enhance the quality of our decision-making information and prioritization, particularly when resources were tight. The initial Estate Asset Management Project (EAMP) covered:

- Legal basis for ownership of assets and resolution of boundaries.
- Consideration of the impacts of a changing climate.
- Assessment of data assets we and our partners held.
- Assessment of asset management models and systems.
- The development of a condition survey metric.
- Baseline condition assessment of Properties in Care and Associated Collections.
- Development of new Conservation Principles, Standards and Specifications and a peer review model.

These projects were mostly completed during early 2015 ahead of the creation of HES on October 1st 2015. Key findings and outputs included:

- Up to date and spatially accurate GIS and CAD plans of our assets across Scotland.
- The need to develop a climate change impact tool as a key management tool.
- An understanding that we held high quality data sets–from archives to technical reports–that were not easily accessible.
- A robust condition assessment tool that incorporated risk to cultural significance.
- A backlog of conservation, maintenance and infrastructure work.
- A need to focus on statutory compliance.

The EAMP project concluded and evolved to a new range of focused projects:

- A Resource Needs Assessment which set out the current and future needs of our assets and how we would adapt and evolve to meet them.
- A Matrix-based prioritisation tool to aid decision making re investment and resource allocation.
- Impact modelling of a changing climate on our properties and rolling out a methodology to the broader sector (required of us under the 2009 Scotland Climate Change Act).
- The delivery of a research project to digitise the condition survey methodology we had developed as part of a larger Asset Management System, PICAMS.
- The design and delivery of that Asset Management System.
- The role of BIM in our work and the Asset Management System.
- The creation of an Asset Management Plan and Corporate Investment Plan.

In considering an approach to an asset management system, we considered the commercially available asset management systems. There is no bespoke heritage asset management system and whilst there are many high-quality systems available, they are based on asset obsolescence and renewal, which is obviously counter to the objectives of conservation.

Table 1. Objectives for an Asset Management system for Historic Environment Scotland

	Objective	Essential	Desirable
1	The system should fulfil our unique operational needs in managing cultural heritage assets.	X	
2	The system should be able to generate condition inspection information in line with the reporting requirements under the scheme of delegation.	X	
3	Capture Data in digital form throughout the activity and engender greater national consistency.	X	
4	Field use required in remote locations often off line.	X	
5	Able to accommodate our condition monitoring and inspection regime with functionality development possible.	X	
6	User friendly portal or interface to collate and present complex data sets from different locations and formats.		X
7	Able to support access to and retrieval of digital assets including photos, drawings, plans, survey information, spatial data, documents and other records.	X	
8	Able to relate to other internal and external databases, including Canmore, Heritage Management, Collections, Archaeology, BGS databases. Web based potential.	X	
9	Able to be supported by our internal systems staff.		X
10	Modular and flexible to adapt in the future.	X	
11	Incorporate or be designed to incorporate 3D point cloud data sets to use as 3D data interfaces now or in the near future. Able to manage raw data where possible.	X	
12	Able to incorporate the unique digital assets created by HES staff in spatial data particularly.	X	
13	Able to manage BIM interfaces	X	
14	Where development is required, the potential to realise commercial benefits for HES if required.		X
15	Geospatial referencing should underpin the system.	X	
16	The system must increase operational efficiency and be customisable for our user needs.	X	
17	Live and dynamic system that will be interrogable by many different fields.	X	
18	Incorporate legacy data from historical condition surveys.	X	
19	Identify and manage resource needs.	X	
20	Identify and manage inspections, alerts and routine maintenance works items.	X	

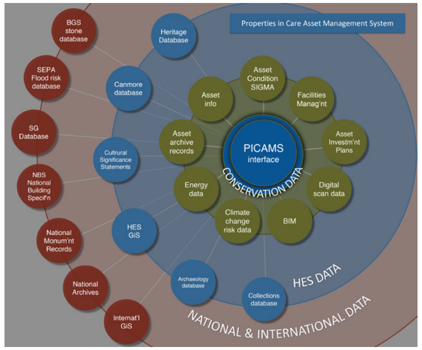

Figure 6: PICAMS outline (Source: authors).

Mindful of our focus on the documentation of digital assets and where this might go in the future, we set out to plan a system that would fulfil our needs but also allow us flexibility in the future as technology evolved, particularly around integration of 3D spatially based models for asset management in terms of a recognisable user interface. Our brief for PICAMS set out the objectives (Table 1).

PICAMS is outlined in Figure 6. At the heart of PICAMS sits a relational database. The condition survey tool, HES- SIGMA, is the critical component in the system and therefore the first element to be developed and tested. Other datasets held within HES include digital image archives, drawing archives (digitised and CAD), designation information, site management information, archaeology datasets and climate change information. In January 2017, the initial development of the HES-SIGMA survey tool was completed and it is now being used as a default condition survey system.

Creating a bespoke conservation survey tool: HES-SIGMA

Previously, conservation architects undertook detailed condition surveys on a site by site basis. The primary aim of this was to generate conservation and maintenance programmes at sites and across the estate for a five-year period. The output format was typically a Microsoft Word document. This was fine up to a point but was inefficient and made it very difficult to collate data and extract national perspectives and priorities or consider trends and impacts.

Through a long association with British Geological Survey in Scotland, we were aware of a field based survey system for geological data gathering using a geospatial relational database on an ArcGIS system. The SIGMA system allowed BGS to capture data in the field remotely before uploading to a central system. An initial research project has led to the development of HES-SIGMA, an evolution of the geology tool for application to historic sites (Historic Environment Scotland 2015). HES have worked with the British Geological Survey (BGS) since 2015 to develop this integrated digital site assessment system that provides a refined survey process.

The new HES-SIGMA system essentially stores and presents conservation and maintenance information for our sites; with the additional capability to use the information to plan effective programmes of conservation and maintenance by answering the simple *what, who, why, where and when* questions either for an individual site or the entire estate at a particular point in time or over a period of time. It is a live system that can be interrogated in many ways, including geo-spatially, and is linked to many other datasets within, or external to HES.

Users can populate custom-built data entry forms to record maintenance issues and repair specifications for architectural elements ranging from individual blocks of stone to entire building elevations. Photographs, sketches, and digital documents can be linked to architectural elements to enhance the usability of the data. Predetermined data fields and supporting dictionaries constrain the input parameters to ensure a high degree of consistency and facilitate data extraction and querying.

Presenting the data within GIS provides a versatile planning tool for scheduling works, specifying materials, identifying skills needed for repairs, and allocating resources. The overall condition of a site can be monitored accurately over time by repeating the survey at regular intervals (e.g. every 5 years). Other datasets can be linked to the database and other geo-spatially referenced datasets can be superimposed in GIS, adding considerably to the scope and utility of the system. The system can be applied to any geo-spatially referenced object in a wide range of situations, thus providing many potential applications in conservation, archaeology and related fields.

Key to HES-SIGMA is the capture of the data used to measure condition. The methodology for calculating this condition indicator is set out in the HES document *Baseline Condition of the Properties in the Care of Scottish Ministers, October 2015* (Historic Environment Scotland 2015). Each element is recorded spatially within the condition data capture process

Figure 7: Field trials of SIGMA system. (Source: Historic Environment Scotland).

as a Monument Observation Point (MOP) and is given a Condition Indicator. This indicator measures the urgency of the action required together with the risk presented to the cultural significance or physical access to the monument by not carrying out that action. It is an Urgency x Risk score with an inbuilt measure of the potential loss of cultural significance and access for each element. The Urgency is attributed as a numerical value between and 1 and 6, representing defined time bands ranging from immediate to within ten years. The Risk is attributed as a value between 1 and 3, quantifying the risk of no action as either serious, significant or negligible.

From the original BGS SIGMA, unique GIS layers were developed for a number of pilot sites. This included dictionaries pertinent to the monuments, in itself a challenging task given regional variations and traditions. New survey fields and templates were developed and trialled in the field alongside condition survey fields and maintenance actions required which could generate work tasks and resource indicators (Tracey *et al.* 2016).

The highly variable nature of the historic assets required prolonged development of a standard lexicon and being flexible enough to deal with any asset. That the assets we care for are essentially fixed, allowed us to build accurate site by site frameworks that will be viable for some time. The defined and restricted fields and dictionaries developed are of critical importance to providing consistent and sound analytical data.

The key features of HES-SIGMA are:

- Individual architectural elements are recorded as separate entities associated to individual sites (e.g. buildings) and are fully linked to the site to which they belong by means of a unique identifier, GPS location and data fields with supporting 'site hierarchy' dictionaries.
- Predetermined data fields and supporting dictionaries guide and restrict the range of conservation and maintenance properties that can be recorded, ensuring a high degree of consistency in the dataset.

- Conservation and maintenance properties can be recorded for the different architectural elements of an individual site.
- Once the survey is complete, the recorded data can be interrogated directly in the database or visualised within a Geographic Information System (GIS).
- A report generator tool enables the data to be output in the form of tailored Microsoft Word documents, thus suiting any project requirement.

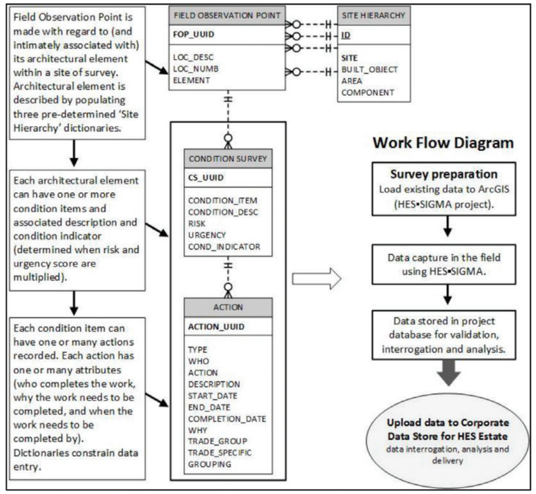

Figure 8: Integrated logic and workflow for HES-SIGMA (Source: courtesy of BGS NERC).

HES-SIGMA allows data to be downloaded to the tablet field device at base, including other data files, maps and photographs. On site, observations made by the field operative relating to condition and maintenance issues are recorded against architectural elements. Prior to recording observations, the location of the architectural element is identified by clicking on the desired position within the site polygon to create a new 'field observation point' (FOP). Once the FOP has been created, a 'Switchboard' form automatically opens allowing the user to enter additional location information using 'site hierarchy dictionaries'.

Each site has pre-developed 'Site hierarchy dictionaries' to ensure consistency across the dataset and between users, and to provide the ability to monitor maintenance issues on the same architectural element over time. This also allows for data analytics on an ongoing basis by conservation staff. On the 'Switchboard' form, location information and architectural element descriptions are input; photographs, sketches and samples (e.g. stone, mortar) can be attributed to the architectural element described; and access to the more detailed data entry forms for recording condition and maintenance 'issues' is provided. Photographs taken in the field, along with sketches, can be retained in the system and hand writing recognition and field selection is used for data input.

'Description', 'Risk', 'Urgency' and 'Condition Indicator' observations on condition and maintenance issues are attributed to each architectural element in the 'Condition Survey' form. Actions can be recorded, again using a pre-determined dictionary of actions, and a timescale attributed. The specialist skills required may also be identified to quantify resource requirements and generate work packages for specialist conservators, engineers etc. HES-SIGMA field data is uploaded to the central database on return from the field. It is also designed to automatically generate standard reports from the field survey such as work packages.

Applications in education and training

At an early stage of digitally documenting heritage assets, it was clear this was a powerful tool for education purposes. An early perception that this was an ideal route for engaging 'digital natives' in terms of young people, was somewhat flawed because it assumed that the digital models in themselves would sufficiently impress a young audience. The acceleration of gaming technology and the expectations of young people in this regard meant this quickly became irrelevant. Indeed, many young people pursued 'retro technology' where blocky and unrealistic visualisation was considered favourable.

We consider the following to be most attractive in this regard:

- Remote access to sites which are not available due to location, cost, safety or conservation requirements.
- Visualisation of assets which have been lost and virtually reconstructed
- Re-creation of historic locations or events for the purposes of interpretation.
- Providing high quality replica objects or scaled buildings from datasets which can be handled and used as teaching tools.
- Combining traditional conservation and analytical techniques to present data sets in a different way.
- The ability to manipulate datasets to provide unique perspectives on structures – cross sections and perspectives.
- The ability to virtually construct and deconstruct in order to illustrate technical and construction approaches.

St Kilda, a remote and sensitive archipelago of the West Coast of Scotland, is a World Heritage site for natural and cultural reasons. Digital documentation of the island, the extant building features and details have allowed us to create a high quality digital model which can be used to virtually transport visitors to this location. In combination with 3D audio, this can become a powerful experience. The burial chamber of Maeshowe is not accessible to all, given the low and long entrance passageway. A high quality digital model as an immersive 3D experience allows visitors to experience the site remotely. This approach cannot replace the authenticity of the real but it can add value in many ways.

The digital reconstruction of the 1938 Empire Exhibition in Glasgow by Glasgow School of Art has created a high quality digital model of an important architectural event showcasing the modern movement in a range of buildings and features. Developed with a peer review group of architectural historians, this model allows us to digitally transport students from what is now a green field site. The tour leader deploys the same narrative as if they were leading a walking tour.

Evolving corporate thinking around the first national Historic Environment Strategy 'Our Place in Time' synthesised through our Corporate and Directorate Plan, had prompted us to shift our thinking in broadening the impacts, outcomes and leverage our conservation work could deliver. Central to this was the delivery of the Engine Shed in Stirling, which was conceived to be a national and international centre for building conservation. Open to the public, the Engine Shed aims to engage a new generation with their built heritage, create informed clients and raise standards in building conservation. Central to this is formal and informal education space and research activity through our well established technical, scientific and digital research.

The facility is designed to position centuries old traditional skills and materials alongside new digital technologies and research. The integration of these approaches is designed to send a message to visitors in that cultural heritage is not only valid for its own sake, but for the sustainable benefits it can continue to bring now and in the future.

A 3D 4k projection auditorium provides a location where we can bring remote heritage to Scotland. Based on our experience of the auditorium created by the Glasgow School of Art, whilst the quality and visual impact is key, the underpinning knowledge and expertise remains critical. In that respect, the expertise of a narrator in the room as the audience explores an ancient Indian step well or stands atop the Sydney Opera House provides an authoritative perspective and enhances the experience.

The core exhibit at the Engine Shed is built around displays of traditional materials and buildings, science and technology as applied in the heritage sector. A large map created from satellite images is the key feature in the building. This high-resolution image is in itself of interest, but iPads are used to trigger augmented layers of information from the map. Fifty key Scottish buildings emerge from the map which can be manipulated by the user, representing regional variations or architectural periods in development. Layers of additional information showing climate change models, building stone quarries, underlying geology, locations of designated buildings and other spatial information can be accessed as the system evolves. Our objective for the Engine Shed is to create a melting pot of expertise and innovation, marrying the most traditional materials and skills alongside emerging technologies and science. Our experience has shown that the integration of approaches advances our objectives considerably.

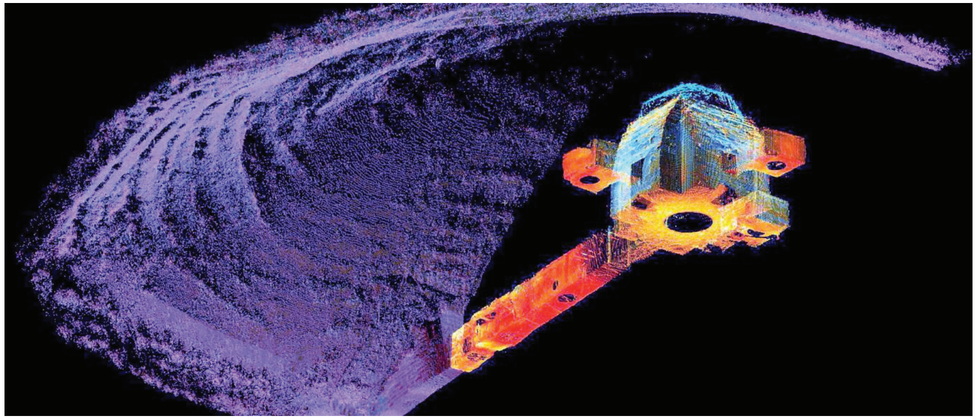

Figure 9: Maeshowe burial chamber, Orkney. (Source: courtesy of the Centre for Digital Documentation and Visualisation).

Notes

1. US Patent 'Advance applications for 3-D autoscanning LIDAR system', US 6781683 B2

Acknowledgements

The authors would like to thank the staff of British Geological Survey in Edinburgh, CDDV and a broad range of our colleagues in Historic Environment Scotland, particularly those in our Conservation team who have been critical to the development of digital technology, research and its application.

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