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3D DOCUMENTATION AND DIGITAL HERITAGE

A. P. SPRING
PhD (PubRoute 2)
2019

3D DOCUMENTATION AND DIGITAL HERITAGE

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A thesis submitted in partial fulfillment of the requirements of the Manchester
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Work (Route 2)

Department of History, Politics and Philosophy
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Summary Document

Citation Index Journals

1. Spring, A. P. 2015. "Creating Substance from a Cloud: Low-Cost Product Generation," *IEEE Computer* (February): 67-74. [Impact Factor 1.940]
2. Spring, A. P., & Peters, C. 2014. "Developing a low-cost 3D imaging solution for inscribed stone surface analysis." *Journal of Archaeological Science*, Vol. 52: 97-107. [Impact Factor 3.061]
3. Spring, A. P., Peters, C., & Minns, T. 2010. "Using Mid-Range Laser Scanners to Digitize Cultural-Heritage Sites," *IEEE Computer Graphics and Applications* (May/June): 15-19 [Impact Factor 1.640]
4. Spring, A.P. 2016. "Retrospective computing and consumer-led development," *IEEE Annals of the History of Computing*, (April / June): 66-71. (also republished in *IEEE Computing Edge* (July 2016): 52-57) [Impact Factor 0.619]

Selected by the Institute of Electrical and Electronics Engineers (IEEE) to be republished in *ComputingEdge* - a monthly publication made up of the most significant articles from the top 13 publications of the IEEE.

The *Annals* article was also referenced by Joe Decuir and Ronald Nicholson - system architects and hardware engineers for the Amiga computer discussed. Referenced in the article:

DeCuir, J., & Nicholson, R. H. 2016. The Amiga: A Hardware Engineering Story: Advancing multimedia computing capability. *IEEE Consumer Electronics Magazine*, 5 (4), 57-67. [Impact Factor 1.434]

Book Chapters

1. Peters, C. & Spring, A. P. 2014. "Digital Heritage, Industrial Memory and Memorialisation", In Orange, Hilary (ed.) *Reanimating Industrial Spaces: Conducting Memory Work in Post-industrial Societies*, Left Coast Press, Ch. 11.

Industry Publications

1. Spring, A. P. 2011. "Preserving the Past and Shaping the Future," *Geomatics World* (November/December 2011): 16-18.

2. Spring, A.P. 2012. "The Third Industrial Revolution," *Geoinformatics* 15 (7): 32-34.

3. Spring, A. P. 2013. "Is the Tablet an Enabling Technology," *Geoinformatics* 16 (2): 30-32.

4. Spring, A.P. 2014. "HxGN Live 2014: workflow infuses services and solutions," *Geomatics World* (September/October): 24-26.

5. Spring, A. P. 2015. "Laser Scanners and the market in 2015," *Geomatics World* (May/June): 19-20.

Abstract

This Doctor of Philosophy by Published Work (Route 2) examines the cultural, theoretical and technical considerations in place when *Cultural Heritage* (CH) also becomes digital heritage. These aspects have ended up neglected or misunderstood because they lie between the competences of the technical and cultural worlds. The aims of best practice and long-term data considerations run across all publications; as do the objectives of examining human to human-object interactions with digital technologies, exploring workflows for long term data retrieval and digital technologies to document artefacts and landscapes. They are manifested through all publications with some of the obvious examples being:

- a) theoretical considerations, in particular Immanuel Kant's Empirical Provenance and the concepts of cultural memory and data narrative
- b) the marriage between theoretical and applied science
- c) recognising that 3D imaging does not operate within a vacuum and is tethered to a broader ecosystem of information and communication technologies (ICT)
- d) the idea of cultural memory, and how the long-term survival of digital or non-tangible information is reliant upon, in this case, human-computer interactions.
- e) the way in which hardware and software feed into material culture and cultural memory.

These considerations are necessary in order to give data a coherent and long-term narrative. It is clearly outlined in the *IEEE Computer Graphics and Applications* article and is also explained in broader theoretical context via the book chapter *Digital Heritage, Industrial Memory and Memorialisation*.

User community-led developments and workflows are strong themes running across all publications. Digital workflows and associated material cultures have become distributed. They can no longer be solely defined by centralised or otherwise grounded means of production. This is especially so in the wake of big data or crowdsourced data. Prior to these conditions,

linear workflows and Fordist modes of production regulated information flow and development. These are also examined and challenged across the publications submitted.

Highlights

- 3D image data has been identified as having two immediately distinctive qualities via my research:
 - *Through the aesthetic - the visual quality of 3D data*
 - *On a forensic or investigative level: where all aspects of data production and data use are considered in overall interpretations*
- The origins of structure from motion (SfM) based solutions are also identified and explained.
- The link between laser scanning, photogrammetry and SfM is identified and explained
- Overall, a data narrative based on forensic science is provided. It provides long term value to digital information flows eg. Empirical Provenance.
- The importance of user-led development and the power of digital technologies as information and communication technologies.

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1. Introduction

This Doctor of Philosophy by Published Work (Route 2) seeks to address a fundamental question pertaining to the production and use of digital information in cultural heritage (CH) based applications. In particular, how does the heritage researcher or practitioner as user-creator make the application of digital technologies to an artefact, building or scene, into a sustainable act or action in the long term? Overarching themes that feed into this question are expressed through my work by considering the positions of cultural memory; digital literacy; the digitisation of material culture, as well as human and non-human influences on information production. These are common threads interwoven through all of the professional and peer review documentation submitted for this Doctor of Philosophy by Published Work (Route 2).

CH is defined within the parameters of current UNESCO guidelines as the physical and intangible attributes of a society from past generations. In the case of this study, the focus is on those physical attributes. The recording, dissemination and storage of the digital surrogates of this physical CH is a growing phenomenon, yet often researchers have overlooked the issue of sustainability. That is, in terms of the use of digital technologies for cultural heritage preservation over a long-term period. Part of the issue is access to technologies.

This body of published work seeks to examine 3D imaging and human-computer interaction from a long-term perspective, bridging the gap between research from the technical and the cultural spheres. Recording and interpretation of Cultural Heritage through digital means involves a more subtle and complex understanding than is currently the norm. The key aims and objectives behind my investigations were:

1.1 Aims and Objectives

Aims

- To address the long term theoretical and practical benefits of digital information use in CH and related material cultures
- To develop an understanding of best practice in 3D imaging workflows in CH

Objectives

- To examine the use of digital technologies to document artefacts and landscapes
- To assess human and human-object interactions with digital technologies within CH and related contexts
- To develop a workflow for long term data preservation of CH applications

1.2 Research Context

The use of digital media in Cultural Heritage (CH) applications is linked to the surge in microcomputing for general users, which was fully in place by the late 1990s. Facets of this market-building process is examined in the *IEEE Annals of the History of Computing* article. It explores how digital technologies like computers are also material culture - indicators of how user-creators interact with and preserve technology over time. In the case of George R. Robbins, the Commodore engineer who also engraved his motherboard designs with B 52's song titles, these Amiga-based examples show how product creators also imbue parts of their own Cultural Memory into their product (Reading 2014). *Retrospective Computing and Consumer-Led Development* puts decentralised modes of production - now tethered to digital technologies - into historical context. The decentralised workflows discussed also bridge to the 3D documentation elements of this Doctor of Philosophy by Published Work (Route 2), which is seen in all other publications. The role of user communities in shaping and ensuring the long-term survival of digital information is a foundation stone of all the articles.

Though the technological development and growth in information production / use has been exponential since the late 1990s, institutional and bureaucratic frameworks for data capture still remain two dimensional (including where perspective is concerned) for the most part. Indeed, the long term theoretical and practical benefits of digital information cycles require further exploration and explanation. When applied to CH, digital workflows require a multidimensional approach that is flexible to change over time. Data acquisition should be explored in a way that accommodates for future-proofing information (Keightley and Pickering 2014). This includes the use and retrieval of data in the long term.

Data generated throughout the publications (using predominantly time-of-flight and phase-shift laser scan data) is given a metanarrative. This metanarrative is explored through ideas pertaining to a philosophy of knowledge and comparative techniques like photogrammetry and laser scanning. Data production and workflows feed into the Kantian notion of *Empirical Provenance* (Kant 1781) – see *Using Mid-Range Laser Scanners to Digitize Cultural-Heritage Sites* - a template of best practice that gives information a Culture Memory as part of the validation process.

1.3 Survey in a Digital Age

The origin of the word 'survey' is about overviews, 'looking over' the objects, landscapes, opinions or of whatever the 'surveyor' wants to get an overview. It condenses large amounts of potential data into a smaller, more manageable dataset that can be more easily processed. The difference with digital surveys is that there is less of a reduction in the dataset, because computer processing power now permits the management of larger datasets. It is this management of data that is the main issue, rather than the generation of vast amounts of laser and imaging data. The creation of programs with sophisticated algorithms underlies the management of data. Hence the use of the term 'document' rather than the analogue term 'record'.

Photogrammetry existed before digital technologies were adopted on a mass scale. Whereas, lasers and laser scanning coincided with its emergence. Photogrammetry is the process of obtaining metric information about an object or scene using photographs. Laser scanning uses its own independent light (in the form of a laser) to document an object or scene as a 3D image, otherwise known as a point cloud.

1.4 Digital Survey Tools as Agents of Preservation

Documentation encompasses the way information is collected, processed and archived. It can include multidimensional workflows, the remediation of data and digital preservation tools - tools where documentation signifies the creation of 'born archival' records also. In other words, each record has undergone some form of processing even before it can be viewed. In conventional surveying or recording methods, the basic processing and archiving of records could take more time than both the actual recording and interpretation. This instantaneous archiving is essential to the digital records as there are so many being generated rapidly. There is no longer time to archive records in the traditional paper way without developing a backlog. A major consequence of this instant archiving is that digital data has to be treated in new ways to enable criterion-based 'data mining' instead of the selection of individual slices of data. The digital archives must be in the form of point clouds and tag clouds that permit the retrieval of data connected by similarities and keyword searches.

1.5 Holistic Approaches: Digital Information and 'New' Medias

The nature of digital data is that it no longer depends on single source recording. There is no longer a direct relationship between the object and the image as in the traditional linear workflow. Different sources of data such as aerial photographs, video, documents and other materials can be linked in a variety of Spatial Information Systems (SIS) like CAD and GIS (Yin 2017).

In fact, even in an apparently single-sourced model like that composed of scandata from a number of overlapping scans, the scans represent different moments in time and therefore slightly (or sometimes very) different conditions. The scans have to be registered together to create the model which is then not just a model of an object, but the interplay of the performances of the laser scanner, the operator(s) and environmental conditions.

1.6 Perception via Remediation: Cultural Memory and Information Production

Cultural memory and its relationship to information production is considered from both a technical and theoretical perspective in all works submitted for this Doctor of Philosophy by Published Work (Route 2). For example, it is seen through process or the act of doing via:

- a) the guidelines for information production based on Immanuel Kant's notion of *Empirical Provenance* or *Origin*;
- b) identification of the theoretical camera model that link both photogrammetry and laser scanning as processes;
- c) the impact communities working with and developing cultures of use around technologies have on information flow and perceptions of use;
- d) or greater shifts in information flow linked to broader developments in information and communication technologies (ICT).
- e) recognising information generation / flow as both a technical act and as a form of remediation

1.6.1 Remediation

Remediation is the transformation of data of one format into data of a different format. Point cloud and solid surface mesh information, for example, can be presented in numerous ways. Through proprietary formats like .IMP or .RCP, or via more widely adopted standards like .E57, .OBJ or .LAS. The reason for documenting or scanning an object or scene is ultimately what determines the final output. In changing formats, however, it is not simply a matter of translation as the data itself behaves differently when in a different form in a different environment. For example, the poly faces of a high-density solid surface mesh can translate as megabytes in one file format (.PLY) and gigabytes in another (.DXF).

The following sections of this thesis use remediation to investigate the nature of such transformations – via memory, time and process. That is, to help further explore themes contained through all publications included with this summary document. What at first appears to be technical in nature, such as simple formulaic calculations, becomes a more philosophical consideration of Heidegger's *Being* or *Sein* in various states (Heidegger 1962). For instance, terrestrial laser scanning and digital remediation processes can be placed within time and space, given meaning and memory. As demonstrated in my *Computer Graphics and Applications* article - where scan data gains a future via Immanuel Kant's notion of *Empirical Provenance* or *Origin* - information acquires a position in Real Time. In turn, such data acquires a cultural memory that takes automated processes and gives them an authentic aura -

questioning the fashioning and refashioning of data (Benjamin 2008).
Without this aura, meaningless Fordist products are the only products.

Turning Light into Spatial Coordinates

The first major consideration is that of the simple transformation of light into figures and light-based vectors into Cartesian coordinates. At the simplest modelling level these coordinated points are turned into meshes and models using so-called 'prims' or primitive shapes. After the addition of photographic overdrapes using an inbuilt or external camera attached to the laser scanner, various methods of viewing / displaying the data are available. These include fly throughs, planar and perspective views, as well as photographic versions of these and processes where mathematical principles apply, such as the six degrees of freedom – imposing through design hidden meaning and transformation processes in digitally coordinated space (Besl and McKay 1992).

The second major consideration is how this data can be re-visited, re-tested and therefore re-interpreted. The possibilities include using the overdraped models to take new photograph images and drawings from angles not originally viewed during the original data capture. They also include virtually scanning models for the same purposes. In an archaeological context, this is particularly significant as archaeology is often cited as the science without repeatable experiments (Sutton et al. 2007).

Remediation of the Self via Information and Communication Technologies

Digital remediation is a means through which human agency can be communicated and transmitted - making intangible thought processes or products of the mind tangible. Digital, specifically computer based, environments and processes do not reflect a neutral perspective. Fashioned by the conditions in which they operate digital processes and environments are governed by social and cultural variables and influences. Much in the same way laser scanning or acts of 3D documentation are affected by interior and exterior orientation processes, so too is the individual or self-interaction with digital technologies as part of an information cycle. For example, see how a tablet or smart phone can be used as both a collector, transmitter and receiver of 3D information in Figure A of the *Computer* article 'Creating Substance From A Cloud'. That is, within an evolved symbiotic web – in which the physical components making up the internet and World Wide Web have evolved to communicate high fidelity manifestations of the self. Anthropogenic interpretations of an environment - be it intuitive or digital in nature - always reflect the struggle between individual and communal cognitive influences and processes. Such struggles are an integral part of the remediation of any information relating to time and space.

Refashioning Human Expression and Communication using Digital Media

Technologies are developed based on human desires to extend, augment and articulate cognitive processes. The application of technologies to cultural heritage examples presents a refashioning and refinement of processes based on human needs to reproduce reality. Increased point per second

point capture; shifts from an oscillating to rotating prism in time of flight laser system capture; continued refinement of Iterative Closest Point algorithms and improved integration with other technologies and workflows. All these technical aspects going into that which can make 3D documentation possible also present a constant refashioning of information to give it purpose to the end user. Primary forms of communication based on image production – for instance the selection of area captured in the operating systems view window for a laser scanner - are intertwined with the need for digital replication of coordinated spaces and object view. 3D image production is as much a semiotic process communicating the need to reproduce an object view using digital media - what Saussure referred to as the sound image when linked to cognitive processes related to intuitive space - as it is a way of quantifying an environment as a take away object or digital artefact.

Refashioning object views are not exclusive to 3D documentation or digital remediation. They are easily identified within an analogue context as well. Bolter and Grusin use the cross comparison of the seventeenth-century artist Pieter Saenredam, a photograph by Edward Weston and virtual reality systems as 'attempts to achieve immediacy by ignoring or denying the presence of the medium and the act of mediation. All of them seek to put the viewer in the same space as the objects viewed' (Bolter and Gruin 2000:11). Relationships are mutually beneficial. Fundamental to the remediation process are the ideas and intentions behind data fashioning: adding long term legitimacy and authenticity to data fashioning or refashioning in the process. The technology itself is merely a tangible cultural artefact of

remediated ideas and, in being so, is in a constant state of change or refashioning to meet the demands of changes or refashioning of these ideas.

1.6.2 Authentic and Inauthentic

Authenticity of a point cloud or 3D documentation as a process come from the authentic aura given to a workflow by human interaction (Benjamin 2008). Full automation processes - or, more specifically, the seduction and deception caused by digital processes where skillsets or knowledge base can be taken away - create hegemonic conditions in which an authentic author is lacking unless *Empirical Provenance* or *Origin* is given at a digital reproduction stage (Adorno 2004; Baudrillard 1996). If lacking or absent a dataset loses or lacks authenticity and disregards data capture, processing and archiving requirements. Workflows and information become fragmented in a way that controls skillsets and acquired knowledge bases – centralising an overall understanding of the process with the developers of hardware and software. Human interaction takes on a passive role within the fashioning process. Datasets become inauthentic reproductions lacking full understanding, validation and authentication.

Hyper Reality, Perfect Time and Real Time: Digitising the Authentic Aura

Authenticity does not disappear but needs to be recovered when the authentic aura is lacking (Bolter and Gruin 2000). In the absence of *Empirical Provenance* or *Origin* - where fragmentation of the data production process occurs - actualisation of processes is required, otherwise it remains in a state of perfect time lacking memory or future integral to intuitive space and reality

(Baudrillard 1996). The concept behind the point cloud or solid surface mesh appears lost and a hyper reality transmitting perfect time occurs.

Reversibility of Things: Workflows Based on Knowledge

The concept driving the fashioning of 3D documentation as a process or workflow is never lost but does require knowledge of production and technology to reverse engineer or tease out remediated processes. In the case of the Leica HDS3000 instrument used in my *Computer Graphics and Applications* article, perfect time is created by the point and click nature of the process – data does not have a memory or a future unless the authentic aura is documented. The production process takes on a Fordist approach to human interaction, unlike the decentralised production cycles seen in my *Computer* article, *Geoinformatics 15* article and *Annals of the History of Computing* article. Without memory or awareness of processes or actions going into information production, the user becomes part of the process but does not require an overall understanding of production to make the scanner work or interact with data on a basic level (Benjamin 2008). Hyper reality is created at the data production stage when real time memories appear completely lost but, in actuality, are fragmented and still present (Baudrillard 2004). The point cloud contains more information and clues to its creation than at first glance, or to a novice user creator.

Perception is based on the knowledge base of the user creator interacting with information cycles (Benjamin 2008). At a capture phase calibration to a diffuse light setting gives surface reflectance information, light absorption

properties of the laser in relation to the object of contact and angle of incident at which a beam made contact with a surface. The presence or lack of targets within what Leica Geosystems – the manufacturer of the laser scanner – refers to as a scanworld at a processing phase provides information about the registration process and overall measurement accuracy and potential for repeatability of results. The point cloud retains a form of narrative for production, as explored in depth in ‘Digital Heritage, Industrial Memory and Memorialisation.’

1.6.3 Authenticity and Remediation

Remediation is an active and passive process that occurs whether authentic aura is present or lacking. It is driven by human agency but is not dependent upon sophisticated knowledge bases to take place (Benjamin, 2008). For example, the article ‘Developing a low-cost 3D imaging solution for inscribed stone surface analysis’ was, in part, a reaction to lack of understanding towards how a 3D image can be generated within Archaeology as a discipline. Where the word scanning had become synonymous with the creation of a 3D image – even when no scanning using an active imaging system had taken place. And, the term photogrammetry – the art and science of acquiring measurements using photographs – had become widespread but poorly understood after computer vision techniques made it is easy for non-technical users to generate 3D images from 2D photographs (McGlone 2004). ‘Developing a low-cost 3D imaging solution for inscribed stone surface analysis’ demonstrates that authenticity occurs with remediation when an overall understanding of the processes involved takes

place. On this basis, authenticity and inauthenticity are determined by flows of information and the acquisition and accumulation of a knowledge base.

Phenomenology, Shared Meaning and Digital Remediation

Remediation and 3D documentation processes are dictated by relationships with the human self. For example, laser scanners use a system of information collection designed to be safe to use around the human eye.

Each position at which the scanner is placed is determined by the user. The areas scanned are selected and framed by the user. All point clouds that are created via the act of scanning is determined by the user. All point clouds generated become phenomenon and a visual concept of experience. Every scan position that goes into the final point cloud generated is governed by each perspective from which each individual scan is taken.

In its remediated form, a 3D image generated from a laser scanner or from photographs is more than just the product of a process. It is representative of myriad causal relationships that can be unfolded and identified. Shared experience comes from a sense of commonality requiring a related structure or rules of experience, engagement and background in which the individual can relate to - in this case, 3D information in a collective or communal way. Husserl (1970) referred to this process as *Lebenswelt* or 'the living world'.

Lebenswelt and the Remediation of Scandata

The essence of experience and rules of engagement can be identified within a laser scanning or 2D photograph to 3D image-based workflow. Shared experience come from interpretation, which can be gained from the functionalities, alteration and remediation of information. This includes the use of software to make information more accessible to potential users. Operating and modelling programs like Leica Geosystem's Register 360, for example, allows for point cloud data to be interpreted and given meaning via a user-friendly interface. It does not require a lot of experience with point cloud information or 3D imaging to get useable results. Since it is easy to use, it caters to a broader audience than its technically more sophisticated sister package Cyclone.

Remediation and Leica Geosystem's Cyclone

Cyclone is a piece of software developed by Cyra Technologies / Leica Geosystems to work with point cloud information. It is the successor to Computer Graphic Perception. It was designed to be used in environments when client server-based workflows were popular in 2001. Individual or fully registered point clouds can be combined with other datasets in Cyclone; spit into individual or workflow relevant sections; turned into solids to enhance surface details; or fashioned, refashioned and even remixed to take on an entirely new meaning or state. The features discussed in the list outlined below demonstrate how much human agency and remediation impacts the end deliverable generated from 3D information in a piece of software.

Virtual Surveyor

Virtual surveyor functionality exists within the Leica Geosystems branded operating software Cyclone. This enables the user creator to emulate the field of view and processes associated with the data production on site. Key features and points of interest within the object view can be extracted from the virtual survey. These include functionalities that are apparent in other software packages also.

Meshing

A mesh turns a point cloud into a solid or wireframe surface. Surface features, data voids and mechanical errors at a capture phase can be identified through the process. In a cultural heritage context, the point cloud goes from being a series of points to a solid refashioned surface. Meshing can be used as a useful prospecting tool from which features not necessarily visible in other media can be detected. For example, the inscribed surfaces seen in the *Journal of Archaeological Science* submitted with this thesis.

Overdrapes

The shapes produced in the modelling process lack smooth photometric surfaces. This is the final stage in reconstituting something approximating the original objects. Point clouds, wire frames or solid meshes do not resemble a photo realistic object view of the original object environment. In order to achieve this, they must be combined with another dataset and camera-based capture method. When this takes place point clouds go through several processes of fashioning and refashioning, no longer resembling its state of being at point of capture. Authenticity through remediation shifts away from the laser scanned collected object view back to the view experienced in intuitive space.

Planar & Perspective Photographic Images from Overlay

Perspective shifts further and further away from the point cloud to achieve something that looks more like the original object view. Photographic overdrapes are used to texturise a point cloud that can be navigated in coordinated, digital space. Perspective shots of side, front, back and above views are readily available in accessible, desktop environments. Also giving access to viewpoints not available in intuitive space - perhaps not even physically possible due to hazards or obstacles.

Remediate as Perspective Views

Digital remediation processes pertaining to point clouds retain a multi dimensionality of perspective. Geometrically speaking, point clouds can be used within two dimensional or three-dimensional perspectives whilst also retaining the ability to operate in the fourth dimension of time whether Intuitive, Real or Perfect Time. Fashioning and refashioning data based on this point of view is deceptive in its initial simplicity and accessibility and made more complex by the many agents in place at any one time.

Retake Photographs

In the control space, where an individual point cloud or scanworld sits, there is no limitation of access based on the laws of physics. The control space is a metaphysical environment, negotiable from any angle, perspective or viewpoint. It would, therefore, be easy to screen dumps from any angle more readily than in real life.

Pipe-modelling

Fundamental to the development and adoption of an Iterative Closest Point solution to the registration process was the intended application of laser scanning to industrially engineered environments. Geometrically uniform shapes like pipes - where known measurement and purpose-built design was key to their development - were used as the template for hardware application and software processing. Software functionality incorporated prepared shapes and curves joining points together - refashioning and filtering points to transform them into a coherent humanly understandable morphology. Geometric primitives were used to reduce computer aided design processes into a form of recognition based on a series of defined, basic three-dimensional shapes, such as a cube or sphere. Popular curves, such as spline curves, were fashioned and refashioned alongside other mathematical concepts like planes, Euclidean geometry and polygons to rationalise and interpret the complexities of intuitive space. Spline curves being particularly relevant to object construction due to their flexibility of application and use in the construction and interpretation of complex shapes.

Polylines and Fly Throughs

Polylines and fly throughs are means of selecting parts of the data for guided pathways revealing highlights from the data set. In computer graphics, a polyline is used to refer to a polygonal chain - a series of collected lines. At a remediation phase polyline can be used to fashion and refashion surfaces by deleting point information or directing automated fly through constructed by the user creator. Polylines can be used to control or manipulate object views as part of an image production process, giving a controlled viewpoint.

Remediate as Planar Line Diagrams

Point cloud retains the ability to be refashioned into two dimensional and three-dimensional planar line diagrams. Rules of engagement giving the point cloud shared meaning within its control space is governed by a series of mathematical concepts making sense of the context in which it operates. Even the brush of a computer mouse and movement of its icon across the screen has rationalised meaning and interpretation within the control space.

1.6.4 Remediation Overview

Remediation raises questions pertaining to the authentic and inauthentic nature of point clouds or meshes produced. Such point clouds - as digital artefacts or facsimiles of an object environment - cannot be viewed in isolation to or domination by quantitative processes. Alteration, conversion or even manipulation of datasets on a remediated level at all phases of the information cycle requires as much consideration as intended. In a cultural heritage context, this is vital to long term data validation processes.

Empirical Provenance or *Origin* has been put forward as one way in which memory or metadata can be added to a 3D documentation process. This is also put into practice in the next section of this Doctor of Philosophy by Published Work (Route 2), where a step by step workflow guide is presented for 3D documentation.

1.7 3D Documentation – Step by Step Guide

Accuracy, precision and resolution are fundamental to the creation of a 3D image. They are fundamental, if a 3D image is to have long-term value and meaning. For example, it is most common for resolution to be recognised over accuracy or precision in the 3D documentation process – due to the immediate impact visual information can have. This is especially the case in user networks tethered to Archaeology as a discipline and culture heritage because:

- a) Archaeology and cultural heritage provide examples where the visualisation of an artefact or site has instant recognisable value.
- b) Technical skillsets and understanding vary greatly throughout what are fundamentally process-based communities. For example, photogrammetry or laser scanning often present a steep learning curve to the user once they encounter problems in their data.
- c) Community learning for applied technologies typically operates on a peer to peer basis within Archaeology as a discipline and vocation.

Memory pertaining to process, however, is what gives both a 3D image and 3D documentation practices meaning in the long term.

Resolution is often tethered to accuracy and precision – in this instance a known scale of measurement. All three, however, can be and often are used in mutually exclusive ways. This often occurs without conscious realisation or care so that this common problem with 3D documentation ends up being reinforced by default. For example, a point cloud or mesh can be used to

display a high level of detail via the points and surfaces that have been collected. This does not, however, ensure that all points or surfaces contain information that is accurate or precise.

True 3D documentation is about the reverse engineering of surfaces, as opposed to the individual points collected. For example, it is more often than not that precision is overshadowed by claims of accuracy in photogrammetric and laser scanning based workflows. This is an artefact emerging within standards of practice that stem from the use of pre-existing survey instruments, such theodolites or Total Positioning Stations (TPS).

Instruments where the collection of points are determined mainly by the user, as opposed to software or hardware-based processes and statistical analysis.

The 3D documentation of a surface area is where repeatability of results – the precision of the information collected – is fundamental. That is, to ensuring that accuracy is not confused with resolution. Although accuracy, precision and resolution of a surface area can be mutually exclusive, it is possible for the user as a creator to recognise the interconnection between them. Otherwise, the 3D documentation process will have little to no meaning – should the physical artefact or site be destroyed in the future.

The context tethered to the information will get skewed if memory is not given to the information generated. For example, the user does not have to be a world leading expert on laser scanning or photogrammetry in giving the information context - via metadata or memory through narrative. Step by step guidelines of this nature can be used to work with the complexities involved when generating meaningful 3D documented information in an honest and

meaningful way. In fact, they provide an effective means through which context can be given process in a generalised fashion.

On this basis, the step by step guide outlined on the following pages takes accuracy, precision and resolution into account based on the considerations above, as well as those outlined in section 1.6. They are intended as a quick start and an easy-to-follow guide, that provides the user with information that is useful regardless of their level of understanding of 3D documentation as a process. It lays out some of the fundamentals needed when reviewing and revisiting datasets in the long term.

Step-by-Step Guide:

- Pre-plan with some idea of the end deliverable or use for the information generated.
 - Include an offsite study of the site or artefact being documented. This includes pictures; literature review; data capture planning using maps, photographs and other site information.
 - Peer to peer learning – reaching out to relevant parties who may have an additional insight on a given site, artefact or technology.
 - Consider what the primary or initial use for the information is to add greater context to the information collection process. For example, site analysis, building analysis, plan drawings, 3D print or reproduction, AR / VR display.
 - What equipment is being used? What are the strengths and weaknesses of using these 3D documentation solutions? For example, it is better to use targets on site if accuracy and precision are valued over resolution? If a known scale is needed for your data,

then incorporate targets and / or ground control into the scene. If you are documenting an artefact, ensure that certified targets are included in the scene.

- What software is being used? For example, there are multiple point cloud-based registration software programmes in use. However, each has a different way of doing the same thing based on the experience of the development teams that are building them.
 - How do you plan to archive the information generated? In what format should it be?
 - Who is the intended audience? Honesty improves the likelihood of information retrieval.
- Equipment being used.
 - What equipment is being used for 3D documentation?
 - For example, what type of laser scanner are you using?
 - How does it differ to other laser scanners of the same generation, or older systems developed by the same manufacturer?
 - If it is a camera:
 - What type of camera is it?
 - What sensor does it use?
 - What filter does the camera use when creating a digital photograph? For example, Bayer, CYGM, Fovean, CMYW
 - What is the size of the sensor?
 - What lens or lenses are being used?
 - Are they fixed focal length or not?

- What software is being used to convert 2D photographs to 3D images?
- Is it stereo to stereo or multiview stereo / structure from motion based?
- If you are using equipment or software developed by a product manufacturer, become intimately acquainted with the culture of that company.
- How is scale being added to the scene?
- Will it be a relative scale or absolute scale tied to a world coordinate system?
- Is this something that can be done by using different equipment? Eg. Targets, global navigation satellite system (GNSS) or TPS.
- What file formats are being generated or required?
- File format and output
 - What file formats are being generated?
 - Are they proprietary or open?
 - How does the file format relate to initial end use? Eg. Computer aided design would likely include .DXF; mesh .OBJ or .PLY and 3D print .STL
 - What is the potential unforeseen use for the data generated? For example, could a solid surface 3D mesh of a building or artefact, intended for use in a virtual or augmented reality display, be reused to create a 3D printed model?
 - Will the file or files be converted into other formats to be repurposed? Eg, .E57 for archiving purposes.

- Is it valuable to document this process?
- Archiving
 - Photographs, video and field notes of the process involved in production where possible.
 - Save a copy of all information used in its original state. For example, make a copy of laser scans before they are processed. Or, save all photographs in their original state.
 - Shoot in RAW format if photographs are used for 3D documentation. Even if they are converted to another format as part of the 3D production cycle, shooting in RAW helps to optimise what each photograph can be used for – especially over a long period of time.
 - What file formats are being saved?
 - Should they also be saved in a format that can be retrieved long after a software or current user interface is no longer available? For example, as .E57 or .LAS format or in ASCII or binary form.
 - What media or medium will information be used to archive information?
 - Centralised or distributed computing methods? For example, should one use solid state hard drives, or a cloud-based system; and should hard copy prints of all coordinates contained in a point cloud be retained?

1.8 Industry and Academic Applications

The final consideration is how these digital technologies fit into the cultures and practices of the commercial and academic sectors. This is practically addressed in the *Journal of Archaeological Science* article, where ambient

occlusion shading is used as a gateway to better explain similarities and differences between photography and laser-based 3D imaging. For example, the term 'scanning' has become synonymous with '3D imaging' as a term. Disciplines and literature operating outside of engineering and geodesy-based communities also still struggle to understand the difference between scanning and 3D imaging. Scanning is still being used - even in university environments and research articles - to describe the process of using 2D photographs to create 3D images (Pesce et al. 2016). This is a fallacy created by misunderstanding. Scanning involves an independent light source like a laser mechanically scanning and collecting 3D information from a surface (Gomes et al. 2014), whereas, photographic cameras passively collect surface information based on light exposure in the scene where the photograph is taken (Bedford 2017).

Misconceptions such as the above - about how a technology or technique is able to perform a specific task - develop when hardware and software make the transition to a broader user base. While users may understand how to apply either or both to an application outside the original scope of intended use, they do not need to fully understand why and how software or hardware is designed to work. This is especially the case as it becomes easier to use, and the responsibility of educating new users with diverse skillsets becomes problematic. For example, increased adoption in digital photogrammetry as a 3D imaging technique, which formed around easy to use software like Agisoft PhotoScan, was born out of advancements in the discipline of computer vision. Structure from motion (SfM) and multi view stereo (MVS) based algorithms made otherwise specialist techniques like photogrammetry accessible to a wider audience. This is because they made 2D to 3D easier to achieve: as long as photographs are in focus with enough overlap, anyone can create a 3D object or scene using software that include these algorithms. That is regardless of quality, resolution, accuracy or precision. The work of Noah Snavely is the now famous example that enabled otherwise bespoke research-based software like Bundler to be turned into products anyone could use (Snavely et al. 2006; Snavely 2010).

In order for otherwise specialist technologies to become successful, they must focus on the requirements of a core set of dedicated users at the beginning of their evolution. These users include technically skilled people like engineers or graduate level surveyors, who inform key developments based on the work environments they operate in. For example, the registration algorithms designed for Cyra Technologies computer graphic perception (CGP) software were developed to be used with defined geometric objects like pipes (Kacyra et al. 2002). That was because a main source of income for their laser scanning technologies came from industrial and nuclear plants, as well as oil refineries. Even the size of Cyra Technologies second laser scanner - the Cyrax HDS 2500 - catered to the requirements of a naval contract (Legistorm 1997). It was designed to be small enough to fit through a ship's porthole.

Despite these early developments, technologies like laser scanning and photogrammetry software must become more ubiquitous on a user interface level in order to transition into a marketable product. Again, this is highlighted in the *Journal of Archaeological Science* and Computer articles submitted for my Doctor of Philosophy by Published Work (Route 2). Much of this technology has been led by commercial needs starting with the nuclear, mining and chemical industries. This means that whilst it has a wide range of applications it lacks a solid theoretical framework in a non-technical or engineering sense. Prime examples of such frameworks include the Dublin Core and CIDOC CRM. The Dublin Core provides general standards for digital records. Whereas, CIDOC CRM provides general standards for records of CH.

While Dublin Core and CIDOC CRM work at a bureaucratic level, they do not translate well to applied methodologies like laser scanning or photo-based 3D. For example, the graphical representations included in such documents are incomprehensible to scholars or practitioners working outside of their associated user communities. There is an immediate wall of resistance, which is as bad as the potential commodification of CH via proprietary technologies and workflows.

1.8.1 Academic Publications

Core interconnections and themes running throughout my peer review and industry publications are presented via:

- a) theoretical considerations, in particular Immanuel Kant's Empirical Provenance and the concepts of cultural memory and data narrative, are applied to 3D documentation in the *Computer Graphics and Applications* article. Empirical Provenance is a way of creating a record for how information was generated. Typically, a clear record of how an experiment or project was conducted are included with the end results. Cultural memory and data narrative are interwoven into this idea of Empirical Provenance for digital information like point clouds or meshes. Because each one is a result of and feeds into the information production cycle.

- b) the marriage between theoretical and applied science. This is explored within the *Journal of Archaeological Science* article, which makes the distinction between forms of scientific photography like photogrammetry, standard photography and active and passive 3D imaging. For example, the digitisation of processes that enable a set of 2D photographs to be turned into a 3D image has democratised once highly specialist skillsets. At this stage of ease of use and data production, it is a better understanding of the relationships in play between the camera, lens and environment being documented that gives an added value (of accuracy, precision and resolution). Photogrammetry is as much a school of thought and way of doing, as it can be a taken for granted process or buzzword. This perception also impacts upon the long-term value of the information generated from a point cloud or mesh - especially when perceived notions of accuracy or precision are actually tethered to resolution. The relationship in play within a point cloud numerically is a statistical one. It is about a relationship between points and - in terms of the physical

object being documented - a surface as opposed to a single point on a surface. This means that known metric values spread across that surface which is represented by a distribution of points.

- c) recognising that 3D imaging does not operate within a vacuum and is tethered to a broader ecosystem of information and communication technologies (ICT). The relationships and agency that surround this are examined in the *Computer* article, which also provides a code of best practice in 3D imaging for anyone with access to a photographic camera. It also explores decentralised modes of production and how design processes impact the technologies and workflows being used.
- d) *Digital Heritage, Industrial Memory and Memorialisation* directly feeds into themes that run across all of the articles above. It provides greater context as to how the physical world and physical processes now marry up to ICT and digital examples. It also feeds into the idea of cultural memory, and how the long-term survival of digital or non-tangible information is reliant upon, in this case, human-computer interactions.
- e) Retrospective computing is used within the *Annals of the History of Computing* to address how hardware and software feed into material culture and cultural memory. Amiga computers are used as the example because of their contribution to bring the computer graphics power needed for 3D imaging and rendering into the home. Survival of code and hardware is totally reliant upon the user communities in place. Even examples like B 52 song titles being engraved on hardware by one of the original hardware architects - George R. Robbins - demonstrate a level of interaction that makes the material more than silicon and circuits. It presents a form of emotive design and preservation and the human to information production as a process.

User community-led developments and workflows are strong themes running across all publications. Empirical Provenance or Origin, can assist as a means of tracking and understanding the processes involved in data production from an individual or group. The involvement of individuals and groups can be tracked through the legacy of their cultural memory consciously and deliberately embedded into the datasets. This embedding provides user-creators with an opportunity to track their own or other people's contribution to a data or information cycle - one that is timeless and of long term use. For instance, the information flow and metadata outlined and discussed in my *Computer* article focuses on decentralised workflows - marrying the best of both open and closed technologies for 3D imaging and 3D printing. This same theme of decentralized modes of production also crossed over into the world of *Retrospective Computing and Consumer-Led Development*. In that article Amiga-based computing survived because of its user community and, like trends in 3D imaging and 3D printing, still evolves because of the people working with and creating new (Amiga-based) technologies. In other words, digital workflows and associated material cultures have become distributed. They can no longer be solely defined by centralised or otherwise grounded means of production. This is especially in the wake of big data or crowdsourced data.

Prior to these conditions, linear workflows and Fordist modes of production regulated information flow and development. These are also examined and challenged across the publications submitted. This is in order to meet the needs of recent developments in digital production. The core for this aspect of my work is centred around 3D documentation and CH. Workflows are viewed as multidimensional and far too data-rich and data-dense to micromanage as in the past. A combination of qualitative and quantitative information is used to give data a metanarrative.

The processes involved in the creation of 3D point clouds - albeit by lasers or photographs - provide a relevant example. Point cloud production centres on the processes that go into documenting a scene. On the qualitative end of the scale, there is the performance involved in creating a 3D facsimile of a

scene (e.g. the position at which a scan or photograph is taken, the hardware and software used to collect and process information). The quantitative methods used to process information can, however, remain hidden within this digital-based workflow. They can be less accessible to the user. This is due to the specialist knowledge and skillsets required for a service or solution to work (e.g. the algorithms used to stitch the different viewpoints together as a single 3D image, the laser system or camera sensor and lens used). That is, unless the user is aware of such things, and can label the information with metadata for future use. The latter could be the same person, or someone else once an understanding of the production cycle is gained.

The ways in which 3D data is generated remains, for the large part, overlooked. My article for the *Journal of Archaeological Science*, which uses 3D meshes and depth mapping to analyse inscribed stone surfaces, makes otherwise technical methodologies more accessible. For example, laser scanning is considered part of a wider suite of 3D imaging tools contributing to what are currently referred to as digital documentation processes. Yet its relationship with comparable techniques has been discussed only in my publications, such as the *Journal of Archaeological Science* article. For example, see my discussion on the relationship between structure from motion (SfM), photogrammetry and laser scanning.

Due to the speed and resolution at which they are generated, artefacts and sites become object environments - spatial and temporal representations of the scenes captured. This is key to provenance, contextualisation and accurate, context-aware data retrieval (as opposed to algorithm-based retrieval). Ubiquitous examples of this include digital photographs, which contain Exchangeable Image File Format (EXIF) metadata. This EXIF data embeds the technical information related to the production of a photograph, such as its time of creation and even GPS information in newer cameras. Similar concepts can be seen in SfM based workflows where an error report is given at the end of the processing cycle, or when position tracking is used to determine variations in depth of field. Lack of understanding in terms of

information capture and use - be it a photograph or 3D point cloud - will ultimately create a data crisis in the long run. This is especially the case when super trends like “Big Data” advocate combined data sets and, in the case of 3D documentation, combined sensor use.

1.8.2 Industry Publications

The *Geomatics World* and *Geoinformatics* articles complement and feed into my peer review publications in numerous ways. First, my industry publications address the themes of digital literacy and human / non-human agency outlined at the beginning of this document. Both run strongly through all my work. My written work for publications like *Geomatics World* and *Geoinformatics* have also become a development platform for my research and ideas. Where I have been asked to contribute to the user communities they represent, it is because I am a recognised leader in the field.

Second, each publication is recognised by accredited professional organisations - the Royal Institute of Chartered Surveyors (RICS) and the Council of European Geodetic Surveyors (Comité de Liaison des Géomètres Européens - CLGE). These organisations create standards and award credentials to keep levels of understanding amongst their members to a known degree of competence (RICS 2017; The European Cadastral Surveyor 2007). This dissemination of ideas and understanding occurs via industry professionals or academics acting as mentors, and via committee-based working groups and examination-based learning.

The industry publication route has also provided great insight into peer-to-peer learning (exchange of information and ideas between learners as opposed to from teachers to learners) - how it is emerging as an effective method of teaching. It is enabling knowledge transfer to evolve quickly around applied technologies, such as laser scanning. In fact, peer-to-peer learning is helping to counter the confusion that fast-paced information flows and rapid technology development keep having on user-based understanding. It is enabling people to learn from each other on a regular to

near instantaneous basis, which will only increase in importance as hardware and software simultaneously becomes easier to use. This is largely due to the fact the underlying knowledge economy driving developments only manifests itself through the tools to hand. The actual knowledge base always resides with people developing the software or hardware, so the speed with which knowledge is converted into lay terms and is subsequently disseminated is the key to the success of the knowledge economy.

Spring, A. P. 2011. "Preserving the Past and Shaping the Future,"
***Geomatics World* (November/December 2011): 16-18.**

Preserving the Past and Shaping the Future outlines the networks in place for communities built around 3D documentation. It remains relevant because both the knowledge and resource economies in place also remain largely the same for the most part. A mix of public and private sector engagement - intermingled with institutions like universities, UNESCO and public outreach initiatives. The latter often being geared toward tourism when operating outside of public sector entities.

It is also a good example of the peer to peer driven approach discussed elsewhere in this document.

Spring, A.P. 2012. "The Third Industrial Revolution," ***GeoInformatics* 15**
(7): 32-34

The Third Industrial Revolution provides narrative for the changing face of production and manufacture. It also lay the groundwork for future work contained within *Creating Substance from a Cloud: Low-Cost Product Generation* - particularly when it came to peel back layers of the symbiotic web. It is also an interesting article in that it predates the design workflow based approach that was making its way into humanities and social science-based disciplines by 2018.

It describes the foundations for this in numerous ways. Through the development of apps, especially free or low-cost apps for mobile devices, along with open-sourced hardware that makes digital capture and modelling easier and cheaper. Where crowd-sourced funding and distribution models take 3D image capture into new territory by enabling an individual with an idea turn it into a reality. The final element is that rapid prototyping, which can readily turn these digital products into hard copy in a range of materials from plastics, to metals, to wood - anywhere in the world where they are required, at low cost, and without international transport overheads.

Spring, A. P. 2013. "Is the Tablet an Enabling Technology,"
***Geoinformatics* 16 (2): 30-32.**

Is the Tablet an Enabling Technology highlights the value and ethical importance of better understanding of technologies and their development. For example, the tablet was proposed by Alan Kay in 1968, as a learning aid for children. It is a way of computing influenced by the book as a format - a way of presenting information. The tablet however, only became practical when the infrastructure that forms the physical components of the internet made distributed computing a tool useable in everyday life.

Key elements to this article include detailed consideration of human-computer interaction; commodification of sensors and sensing into digital devices; and how devices can be used to construct a digital self.

Spring, A.P. 2014. "HxGN Live 2014: workflow infuses services and solutions," ***Geomatics World* (September/October): 24-26**

HxGN Live 2014: workflow infused services and solutions breaks out of a one-sided narrative that could have been applied to a series of products developed under one umbrella company like Hexagon AB. It gets to the core of how and why tools are being created - services and solutions that have made their way into education environments. It also explains this with a long-term perspective in mind. For example, the article refers back to Hexagon AB

acquiring a main competitor in 2010, and it also shows how mediocrity is presented as innovation in different communities working with the same technology. See the low-cost 3D printing example that pertains to building information modeling.

Overall, this article makes a very strong statement about who has access to particular technologies; why they have access to them; and what are the underlying motivations driving the developments of the services and solutions to hand. Otherwise seen in my other work through discussions of human and non-human agency and digital literacy.

Spring, A. P. 2015. "Laser Scanners and the market in 2015,"
Geomatics World (May/June):19-20.

Laser Scanners and the market in 2015 bridges the gap between my academic and industry work. Both my *Journal of Archaeological Science* and *Computer* articles are cited. It is also very clear that the intricate details surrounding 3D image-use are well considered. For example, the impact of video game-based depth sensing is outlined; highly influential but seldom discussed people in the community, such as Jerry Dimsdale are discussed; and information standards are well outlined via file format-use and sensor comparison.

The summary at the end of the article also highlights some of the ways in which peer-to-peer engagement as digital literacy must be approached, as well as human and non-human agency:

"Where and how you enter the marketplace is ultimately what should determine which laser scanner to buy in 2015. Choices continue to grow in the laser scanning space, with new developers coming on the scene as each year passes. Which scanner you acquire is much more than just a technical question at this time. It is, in some ways, a highly sociological decision as well. For example, it never hurts to reach out to your contact base to get advice. Laser scanner users are a social group of people, who 9 times out of 10 will go out of their way to help you if they can.

The scanners mentioned in this article have nothing to do with brand preference on the author's part. It is just how they fit into the topic discussed. That said, the author does agree with Jerry Dimsdale that better standards for laser scanning do need to be in place. This includes improvements and a clear direction for file formats like E 57. After all, the main reason MIDI is still the file standard in the music industry is because manufacturers came together to make sure it worked."

2. Overview of Peer Review Publications

Sections 3 to 7 of this document focuses on the key outcome of my peer reviewed publications. Each section looks at the interconnections that run through my work, such as themes of cultural memory, digital literacy and broader influences in play. For example, the latter includes information and communication technologies as they pertain to an evolving infrastructure. For a clear outline of this - whether it is via a symbiotic web or 'Infrastructure of Things' - consult both my *Computer* article and book chapter.

Following on from the discussion at the beginning of each section is both an overview and outcome from each publication. These contain those elements that highlight the overarching intellectual direction of my work, how it blends applied learning gained via industry experience with my abilities to conduct detailed research and information analysis, as well as generate new research. These are some of the key features that make my publications timeless and future proofed.

Bringing my peer review publications in this way highlight that they are more than just based around the technologies used. They take into account long term considerations that the technologies and information generated feed into.

3. Publication 1:IEEE Computer Graphics and Applications

Using Mid-Range Laser Scanners to Digitize Cultural-Heritage Sites

Using Mid-Range Laser Scanners to Digitize Cultural-Heritage Sites was written out of concern for the way data narratives are presented in CH with a lack of clear documentation (and consequently understanding) of process. This is especially the case for 3D information like point clouds and solid surface meshes. Where the culture of use surrounding such information is defined by who has access to otherwise specialist hardware and software, as well as the circumstances in which said technologies are being used. The article contains several themes that intersect and run throughout my work. These include cultural memory; digital literacy; the digitisation of material culture, as well as human and non-human influences on information production (especially when using digital technologies). Industrial heritage was used to create guidelines anyone could use - as a gateway to better understanding both the material culture and technology to hand.

Immanuel Kant's notion of *Empirical Provenance* was applied to laser scanning because it serves up an immediate and practical solution. One that gives useable metadata - attached to both the workflow and the 3D information generated. It provides a form of cultural memory that is otherwise lacking, which ensures context in terms of production will survive over time.

For example, it is a common misconception that metadata can be attached to 3D point clouds or solid surface mesh files using otherwise automated processes. Much in the same way a photograph format like Jpeg or RAW contains EXIF information - providing insight into the processes and mechanics involved in the creation of each image. This is not, however, the case for laser scanning or any 3D image. Cultural memory of this nature has to be ascribed by the user because of the complex nature of the production cycle in place.

The act of taking a photograph is passive in that light enters the lens to reach the sensor. In one respect, this makes the parameters of production more confined and easier to document in automated fashion. Sensor size, focal length of lens used, ISO setting and make of camera are the prime variables attached to the data. Each laser scan, however, is unique in that it is an active process - where the laser retrieves information by making contact with a surface. Where there is already known parameter of accuracy, precision and resolution ascribed to the instrument being used. This is discussed in more detail in another article submitted for this Doctor of Philosophy by Published Work (Route 2) - *Developing a low-cost 3D imaging solution for inscribed stone surface analysis*.

Another notable point to the article is that it introduced the importance of computer science processes like the iterative closest point algorithm to CH. This was discussed in my article four years before it was discussed in mainstream academic publications for disciplines like Archaeology.

3.1 Outline

Here, we explore new, more accessible ways of modeling 3D data sets that both professionals and amateurs can employ in areas such as architecture, forensics, geotechnics, CH, and even hobbyist modeling. To support our arguments, we present images from a recent case study in digital preservation of CH using a mid-range laser scanner. Our appreciation of the increasing variety of methods for capturing 3D spatial data inspired our research. Available methods include photogrammetry, airborne lidar, sonar, total stations (a combined electronic and optical survey instrument), and mid- and close-range scanning. They all can produce point clouds of varying density. In our case study, the point cloud produced by a mid-range scanner demonstrates how open source software can make modeling and disseminating data easier. Normally, researchers would model this data using expensive specialized software, and the data wouldn't extend beyond the laser-scanning community.

Empirical provenance for mid-range laser scanning	Empirical provenance for modeling
■ Scanner model (including technical specifications)	■ Software used
■ Point or target registration	■ Steps undertaken to make changes
■ Software used	■ Any changes in file format
■ Scan position	■ Any changes in resolution
■ Scan direction	
■ Field notes (for example, environmental conditions)	
■ Photographs and videos of the recording process	
■ The resolution selected	
■ Original individual scans before decimation or any modification before combination with other scans and before overdraping	
■ Original photographic panorama before being overdraped on the scan	
■ Any conversions—for example, Cyclone and subsequent file format changes	

Figure 3-1. Checklists for establishing the empirical provenance for mid-range laser scanning and subsequent modeling.

3.2 Outcomes

Open source and low-cost modeling are good ways to preserve data through accessible distribution in the same way that plain text and PDF files have assisted the flow of basic text and 2D images. Accessible distribution ensures many copies are available and that data will less likely be lost. However, wide distribution can lead to loss of data integrity, so it's important that the empirical provenance accompanies the data outlining its creation. The process's relative simplicity makes it accessible to a wide audience, thus bridging the gap between specialists and non-specialists.

4. Publication 2: IEEE Computer

Creating Substance from a Cloud: Low-Cost Product Generation

Creating Substance from a Cloud: Low-Cost Product Generation provides a clear overview of the infrastructure that now drives the adoption of digital technologies. For example, there is no coincidence in terms of timing that once, otherwise specialist, applications like 3D imaging have become accessible to a broader spectrum of users. It has happened at a time when the physical nodes and networks that make up the internet have evolved, such as data centres and internet exchange hubs. A point has arrived where it is easier to transmit and receive complex sets of information.

The article addresses fundamental trends pertaining to information and communication technology (ICT). This includes the development of the internet into a symbiotic web. The symbiotic web allows technologies to become a means of expressing and shaping individual experiences. Such expression occurs because the networks have evolved to a point where they can receive and transmit a variety of media as well as complex data.

At this stage in my research I could draw together all the threads from my previous articles to show the cohesiveness and potential effectiveness of digital technologies to extract multiple datasets tailored to a variety of research questions.

For example, the production line seen in Figure 4-1 walks the reader through a nonlinear workflow, where the production cycle can begin and end at the same point. That being whatever the device, such as the smartphone or tablet in this example.

4.1 Outline

In his 2011 bestseller, *The Third Industrial Revolution*, economist Jeremy Rifkin explains how design and manufacturing have become decentralized

processes that feed into the digital economy. By operating through an infrastructure built on the Internet of Things (IoT), he argues, next-generation information and communications technology (ICT) is replacing factory-based production methods. Delocalized production techniques have developed around computer-aided design (CAD) and manufacturing (CAM), replacing Henry Ford's conveyor-belt assembly line with an anywhere, anytime production line connected through digital devices and ICT.

Affordable 3D printing is one aspect of this transformation, and 3D imaging technologies are an excellent way to understand the Third Industrial Revolution's impact on product development. For example, by implementing more controlled photographic techniques along with an easy-to-use 3D imaging service, anyone with rudimentary photographic skill can turn 2D photos into 3D solid-surface objects.

An application to replicate a CH monument from a popular 2D camera illustrates the mechanics of this production approach as well as the potential of CAD/CAM practices that align with concepts such as the IoT. The workflow derives from *photogrammetry*, which retrieves measurable data from photos, and uses a service based on *structure from motion* (SfM), a product of computer vision research. However, neither the equipment nor the workflow in the proposed approach is exclusive to experts in those domains; rather, they are accessible to any amateur photographer. The technology is readily available to anyone with access to a camera, the Internet (to work with open source or low-cost user-friendly programs), and a retail 3D printer.

As part of a CH project to examine connections between Great Britain and Germany during the Industrial Revolution, my colleague Caradoc Peters and I investigated several monuments in both countries. As part of this investigation, I applied the proposed production approach to convert 2D photos of one of the monuments to a 3D physical replication. I used the following items in my work:

- a Canon EOS 60D digital single-lens reflex (DSLR) camera and 50-mm Canon prime lens;
- Photo—an Autodesk ReCap 360 service that creates 3D point clouds and solid surface meshes from photos (<https://recap360.autodesk.com>);
- CloudCompare, a program that processes the resulting 3D point cloud and solid surface mesh (www.danielgm.net/cc);
- MeshLab, a program to process and edit unstructured 3D triangular meshes (<http://meshlab.sourceforge.net>);
- MeshMixer, an Autodesk 123D – related tool for 3D mashups and remixes from custom 3D designs or provided models (www.123dapp.com/meshmixer); and
- a Dimension 1200es 3D printer from Stratasys (www.stratasys.com/3d-printers/design-series/dimension-1200es).

This list suggests that point clouds — data points in 3D space — and associated solid-surface meshes could become the new template for design and manufacturing, as the sidebar “Workflow based on Point Clouds” describes.

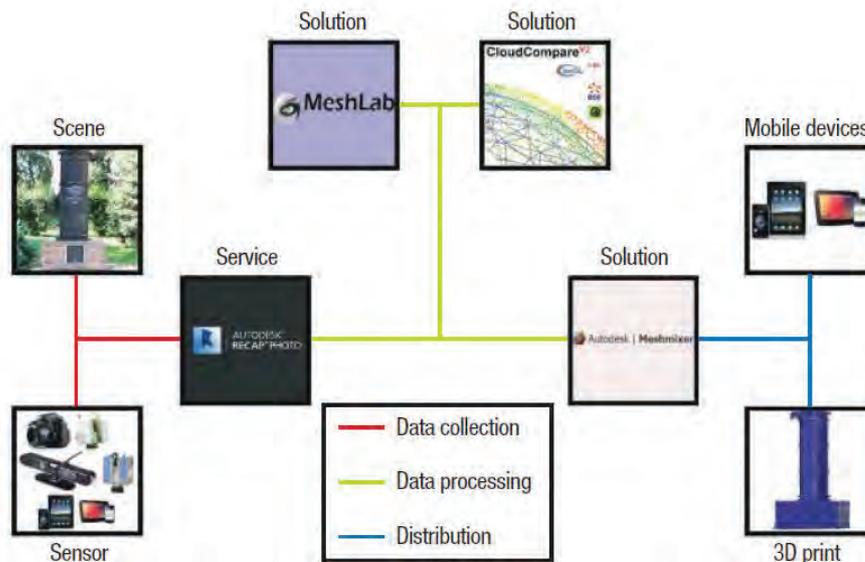


Figure 4-1. 3D Production lines are monetised through services and solutions, with information coming from the user and the sensors used to collect data determining the means of distribution.

4.2 Outcomes

Tools like Autodesk ReCap 360, CloudCompare, MeshLab, and MeshMixer are enabling low-cost, easy-to-use 3D imaging and CAM solutions based on data that can come from any source or location and from users with a variety of skills. Leveraging technology– workflow combinations such as that used to document and replicate the Löbejün monument, any camera, smartphone, or tablet can reproduce an artifact’s actual preservation state. Whether it is through crowdsourced or networked data from the IoT, as-built plans, nonlinear models, or 3D prints, strategies to structure increasing dataflow must become part of creating products in this collaborative era of document, design, and manufacture.

In this respect, the Third Industrial Revolution feeds into the IoT. Both are being presented to general audiences as user-friendly terms—even in the context of 3D imaging and manufacturing. Fundamentally, however, they are used to describe changes that fall in line with the Symbiotic Web or Web 4.0. Internet evolution and the way in which people interact with digital technologies are ultimately freeing up design and manufacturing processes to a wider population, shifting focus from centralized production modes to

more dispersed collaborative efforts, which are often the source of true innovation.

5. Publication 3: Journal of Archaeological Science

Developing a low-cost 3D imaging solution for inscribed stone surface analysis

Developing a low-cost 3D imaging solution for inscribed stone surface analysis was a reaction to growing concerns about digital literacy and information provenance in relation to point cloud-based CH workflows. In particular, the widespread use of terms like scanning when using passive systems of data collection; widespread use of multi-view stereo-based photogrammetry without better understanding of processes involved in the 3D image output being generated; and a need for better discussion around similarities and differences between varying 3D imaging techniques. The superimposition of these themes onto early medieval inscribed stones in the British Isles was logical because:

- a) It furthered my work on information production, context and provenance, which had been examined previously in *Using Mid-Range Laser Scanners to Digitize Cultural-Heritage Sites*.
- b) The inscribed stone surfaces in question could be used to examine accuracy, precision and resolution of 3D information generated - from both lasers and photography.
- c) Historical and documentary evidence could be used alongside the digital surrogates of the material culture to hand. That is, when examining the point clouds and solid surface meshes produced as part of the case study.

This article and *Creating Substance from a Cloud: Low-Cost Product Generation* further emphasise the high regard in which my work is held in professional communities as well. For example, they were directly referenced in *Geomatics World*, May / June 2015. The *Geomatics World* article also touches upon a very important point made in all of my work. That being, the impact of new technologies on user communities is more than technical or

process driven in nature. With the sociological - typically peer to peer interaction based - impact often being overshadowed by the hype cycle in place that drives adoption. Whether it is a CH application or geodesy-driven (like the readership of *Geomatics World*), the same problems apply. Technology is being adopted and getting applied to the built and natural environment quicker than it is being fully understood. The multidisciplinary approach demonstrated in works like my *Journal of Archaeological Science* article seek to help make the transition period easier. Hence, why it brought up otherwise particular and specific discussion points like theoretical camera models - a fundamental topic within photogrammetry as a subdiscipline of geodesy.

5.1 Outline

Using the case study of the Tristan Stone, a 3D imaging solution is used that, unlike texture mapping, provides shading based on coordinates and actual surface information. In other words, a surface is actually mapped and then that data is used to show what is actually on that surface by controlling a light source based on surface features. It is not a relief or impression of 3D. The interpretation is actually based on surface geometry, or the digital mould created from the data. Unlike texture mapping techniques, such as RTI (MacDonald 2011), or computer vision solutions like SfM (Davelli & Signoroni 2013, 577), this technique does not involve a compromise in accuracy in order to get convenience or cheapness. Using what is referred to as a theoretical camera model by photogrammetrists, known parameters and known accuracies are increased along with repeatability of results.

Two sets of data were used as source material for the 3D imaging process. Mid-range terrestrial laser scanning (TLS) and structure from motion (SfM) based photogrammetry were applied to the Tristan Stone located in Cornwall, UK. The inscriptions on the stone have been associated with the tale of Tristan and Iseult from the Arthurian legends since the 20th century (Radford, 1975; Padel, 1981; Padel, 1991; Thomas, 1994), and are currently married to the 5th - 9th centuries based on stylistic dating methods (De

Mandach, 1978; Padel, 1981; Padel, 1991; Okasha, 1993; Thomas, 1994). There are perhaps as many as 1,500 inscribed stones like the Tristan Stone scattered across the landscapes of the Celtic-speaking regions of the British Isles (Forsyth, 2012). Figure 5-1 shows that a problem with inscribed stones is migration, with their current position on the landscape not necessarily being their original location (De Mandach, 1978, p. 229; Davies et al., 2014). Current interpretations of their meaning are based primarily on historical documents and observation-based techniques like raking light (Radford, 1975; De Mandach, 1978; Okasha, 1993; Padel, 1981; Thomas, 1994).

A low-cost computer vision-based solution was devised to identify remains on the surface of the granite artefact. It is outlined in this article and can be applied to other surfaces and materials. It was used to examine features on the stone, which are presented in Figure 5-2. Inscriptions that are no longer visible when examining the monument in situ. Point cloud data generated from a FARO Focus^{3D} phase shift laser scanner and from photographs taken with a Canon 60D digital single lens reflex (DSLR) camera are compared in order to confirm the presence of new discoveries. A computer graphics technique called ambient occlusion (AO) shading, which can be used to enhance features based on surface depth (Langer & Bülthoff, 2000; Borgo et al., 2001), was applied to the 3D data by using software called CloudCompare. It was developed by Daniel Girardeau-Montaut when he was a PhD student working with Électricité de France (EDF) and has been open source since 2009 (Girardeau-Montaut, 2014). The methodology can be used to give an accurate understanding of what remains on the inscribed stone. Information is derived from solid surface meshes or molds created from sensor data. This means that it is a technique not restricted to small objects or monuments. In fact, it can be applied to artefacts, structures or landscapes of all sizes (Zakšek et al., 2011).

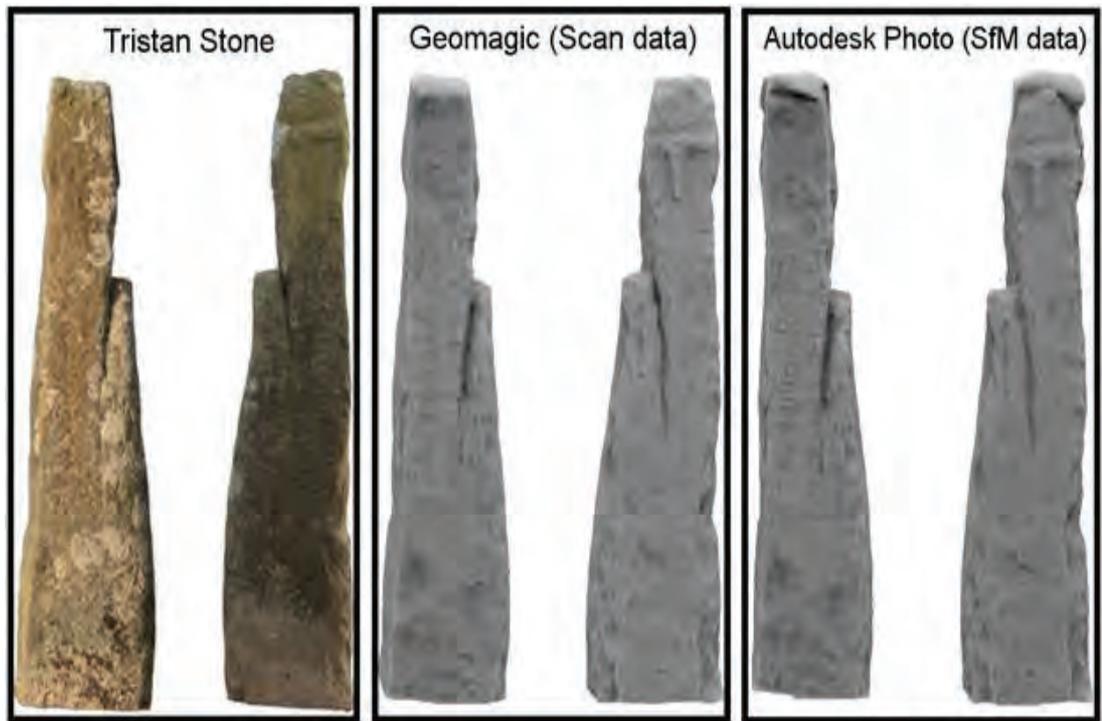


Figure 5-1. A comparison of what the Tristan Stone looks like in situ, through scan data where AO has been applied and through SfM based data where AO has been applied.

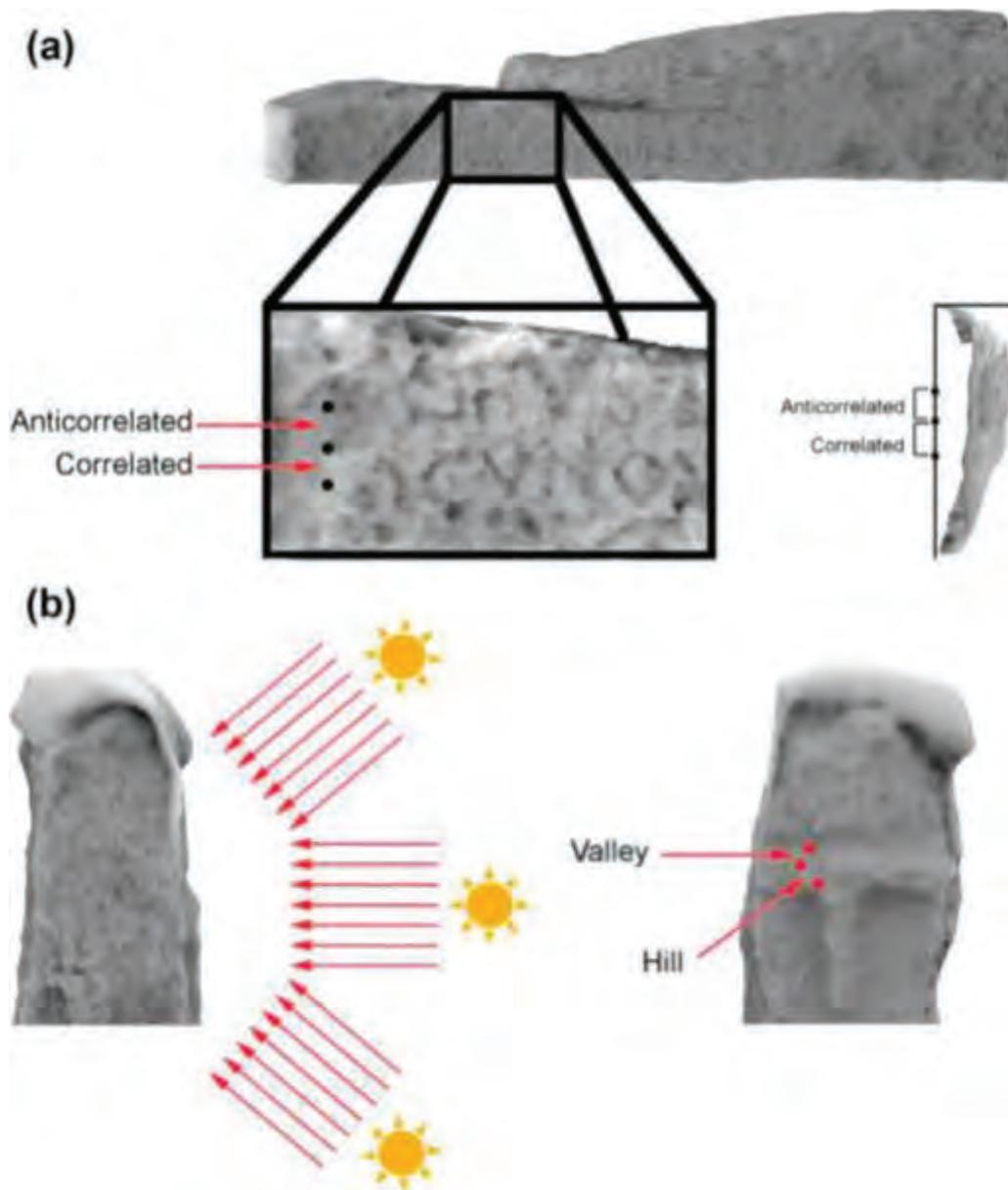


Figure 5-2. (a) The AO process explained in terms of anticorrelated and correlated points, (b) AO process explained in terms of light fields and "Hill" and "Valley" points on surface.

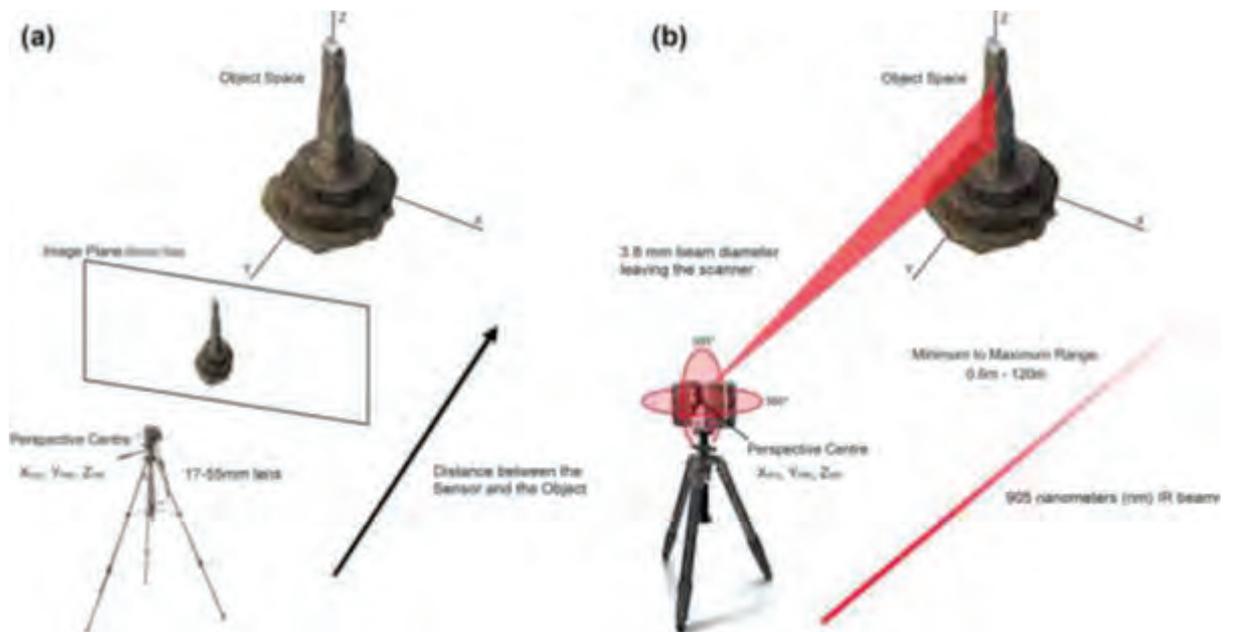


Figure 5-3. (a) Outline of 3D imaging camera model using a photography camera. (b) Outline of 3D imaging camera model using a FARO Focus3D laser scanner.

5.2 Outcomes

With an increasing interest in user-friendly, low-cost solutions to 3D imaging, textures have been preferred rather than a high accuracy level for the surface geometry. It is not necessary to make such compromises. This article has gone some way to demonstrate this by outlining an easy to use workflow that anyone with access to a computer, an internet connection and photography camera can use. Given that the heritage sector is a price sensitive market, especially when it comes to equipment and application considerations, it should be noted that as 3D imaging becomes more affordable it has the potential to be accessed by a broader range of users as well. That is, if information and training are managed with accessibility to services and solutions in mind. Since the Tristan Stone was first documented with the FARO Focus^{3D} in 2010, automated services and solutions have developed to a point where useable results can be generated that are comparable to semi-automated equivalents like laser scanning. Solutions like Project Memento have also been designed with artists and heritage users in mind. The focus is now on the user experience (Kerr, 2002) and to create intuitive UI's that are not cumbersome to use.

5.2.1 Inscribed Stone Data

The inscribed stone data itself was used to explore 3D imaging techniques within the context of their application and intended deliverables. In this case, for demonstrating that the individual commemorated on the so-called 'Tristan Stone' was not Tristan and confirming analyses of the historic evidence. It was also used to present the technologies discussed in a way where they can now be better understood - and used in accordance with this knowledge - by heritage practitioners. Similar results and feature resolution in both datasets suggest the age of affordable 3D will continue to lead to further revision and reinterpretation of material records and cultures. This is especially the case in examples that are well known for being greatly affected by subjective interpretations.

6. Publication 4: Orange, Hilary (ed.) Reanimating Industrial Spaces: Conducting Memory Work in Post-industrial Societies, Left Coast Press, Ch. 11.

Digital Heritage, Industrial Memory and Memorialisation

Digital Heritage, Industrial Memory and Memorialisation provides a theoretical narrative for technologies that are otherwise over complicated for many audiences because of technical jargon and detail. Of particular importance is the discussion of the Infrastructure of Things, as it identifies the preexisting Real Life networks upon which digital technologies now sit such as telegraph, railways, roads and telephones. This is certainly the case when considering the symbiotic web described in my *Computer* article - or the groundwork laid for it in the *Geoinformatics* article Third Industrial Revolution. The fact that display and documentation technologies are also information and communications technologies (ICT) is often overlooked. This Left Coast Press book chapter addresses that directly. It is a prime example of the human and non-human agency in play with digital workflows in general - the Internet of Things.

6.1 Outline

This chapter focuses on the nature and processes of digital technologies and their impact on questions of memory and memorialisation in industrial, here meaning any kind of heritage produced or modified during the Industrial Age (dating from the eighteenth century to the 1940s). Since this chapter deals with digital technologies, some parallels will be drawn to the earlier Industrial Age technologies.

The Industrial Age presents particular problems for memory and memorialisation: whether in terms of public spaces, workplaces or even home environments, most people are confronted with the physical presence of industrial heritage every day. Indeed, some of the tensions in interacting with sites of this period are precisely because they are still active today.

Some industrial heritage is beyond living memory (and is purely memorialisation), some of it has emotional purchase in the sense that the living memory of the deceased was once told directly to those still alive and, finally, the more recent elements are still in living memory. Archive audio and visual recordings blur these memory-distinctions, so they are not as hard and fast as they might first appear. Memory that was living until very recently is of particular interest for public engagement, especially as it relates to spaces that everyone has some experience of in their daily lives. There is a sense of so near and yet so far about such memory.

Navigating the Industrial Age even in physical terms is a difficult call; in digital terms, where engagement has to be engineered, working with memory is highly challenging. Memory holds a threshold position between the more vivid emotional states of nostalgia and nightmare on one side and a sense of place and identity (created in part through memorialisation) on the other. The former states are usually associated with people responding to heritage created in their own lifetimes or perhaps at a stretch those of relatives and close friends they knew, and the latter with people responding to historic heritage beyond living memory. The emotional and psychological consequences of digital interfaces between humans and their industrial past form the main subject of this chapter.

Much of the literature on digital applications in archaeology is overly obsessed with their technical nature. Some of the technical side must inevitably be covered here for the sake of understanding, and a certain amount of space will therefore be given to explaining a range of the techniques (and their implications for memory and memorialisation) before going into specific industrial examples.

6.2 Outcomes

The world of ICT does not immediately lend itself to emotionally charged and authentic interaction with the industrial past. The use of digital surrogates for RL heritage can be networked with careful thought for the contextualisation

necessary for memory and memorialisation to thrive (the Internet of Things). This is mirrored in the physical networks produced by the Industrial Revolution itself (the Infrastructure of Things).

Networks and trajectography are only contributors to the creation of an atmosphere in which memory can prosper. There is a tension built into trajectories, in that they are not a full compensation for the feeling of presence. Many heritage workers have sought to make up for this with realism, especially photorealism. Photorealism on its own is devoid of social interaction and cultural/material cultural interaction. Apart from humans, other organisms and the physical and chemical environment are also actors. Furthermore, one must be aware that there will always be a conflict between the requirements of effective (but 'artificial') digital preservation for future generations and the authenticity offered by 'natural' (or rather naturalistic) ephemerality and decay, insofar as it can be recreated digitally.

7. Publication 5: IEEE Annals of the History of Computing

Retrospective Computing and Consumer-Led Development

Retrospective computing and consumer-led development examines microelectronics as material culture. It looks at cultural memory and digital literacy from within user communities over a long period of time - communities that have grown up around otherwise ephemeral objects like personal computers. The Amiga family of computers is used as a case study because there is no reason why these technologies should still be in use today.

Commodore - the parent company of Amiga computers - went bankrupt in 1994. Planned obsolescence, where a lifespan is built into a product so that buying a new upgrade is inevitable, should have secured the demise of its intellectual properties. This would have been the expected outcome after manufacture of new hardware and software ceased production in the 1990s. It is the user community, however, that now drives and maintains Amiga-led developments. They produce new hardware and software - integrate current technologies like the internet and SDcard storage into these aging computers. The users are preserving technology like conservators, who preserve and maintain artefacts in a museum.

7.1 Outline

The Amiga story began via a startup company with a vision, Hi-Toro (which later changed its name to the Amiga Corporation). The technology that sprang from Amiga eventually got absorbed into Commodore—a company at war with Atari and itself. As an internationally diverse group of users gravitated toward Amiga computers, problems in Commodore also escalated, eventually to a point of no return.

The Amiga was an American product that was hugely successful in Europe. It was the first multimedia computer that was also affordable. In the United

States, however, the majority of users were in the entertainment industry because the Amiga was the only affordable computer that had graphics capabilities and video timing built into it. The turning point for this user trend was the Video Toaster, which was eventually released by NewTek for the Amiga 2000 in December 1990. That instantly made Amiga computers the go to system for high quality, yet affordable media editing and special effects. At the same time, the Amiga 500 had acquired a reputation for being a gaming computer in Europe. It was a serious rival to video-game consoles released by companies like Nintendo and Sega.

The community that built up around the Amiga was strong—so strong that when Commodore imploded the development base for Amiga computing almost immediately shifted from the US to Europe. Operating systems like AmigaOS 4 continue to come out of Belgium, and even today new hardware is being developed in places like Germany, Italy, and Great Britain.

Early online communication tools such as AmiRC were also put in place to support worldwide chatter. In fact, chat rooms, bulletin boards, and online forums have created the foundation for developer networks. Otherwise disconnected enthusiasts, who are detached from one another on a global scale, can come together to form a network online. They have kept the Amiga dream alive.

What can be considered old technology has been kept alive by users, enthusiasts who continue to find new ways to extend the life of otherwise aged computer chipsets. For example, with the aid of PowerPC accelerator boards, the last Amiga computers produced by Commodore in 1992 are still being expanded in order to extend their lifespan. The original Amiga system architectures were flexible enough to enable users to hack, modify, and upgrade the system as desired. Despite a lack of advertising and in the absence of manufacturer-driven guidance, communities of users who still proudly call themselves Amigans have built up around these personal computers from the 1980s and 1990s. Community members have become

developers, communicators, and user creators for older or niche solutions. New developments for these old computers continue to emerge to this day.



Figure 7-1. First comprehensive timeline for Amiga-based technologies and associated user community driven changes.

7.2 Outcomes

Amiga technology came into being decades ago. The concepts (and some of the actual system components) had staying power despite the failure of the original manufacturer. Developers and users around the world continue to push and use Amiga-derived and expanded technology. This is more than retrocomputing as a desire to simply reclaim past computing technology. This is an example of continued technology development by a community of invested users, a sort of consumer-led development.

8. Conclusion and Further Work

8.1 Conclusion

This Doctor of Philosophy by Published Work (Route 2) has considered a long-term approach to digital information production, flow and memory. I have presented workflows for terrestrial laser scanning (TLS), which were developed with long term data acquisition, processing and retrieval in mind. It has also examined “older” material culture based on largely abandoned technologies alongside that of “new” technology - from Amiga based computing to various forms of 3D imaging. That is, in connection with, and juxtaposition to, the relatively young user trends tethered to 3D documentation and production. The overarching theme that emerged is based around the adoption of information and communication technologies (ICT). More specifically, the evolving infrastructures that increase the power and influence of each node within ICT driven networks - albeit a device like mobile phone or an instrument like a laser scanner.

Current waves of information production are driven by ICT. They represent an ICT fuelled paradigm shift, which is supported by connected infrastructures and communities built around connectivity, typically via the internet. Devices like smartphones, tablets, cameras and laser scanners have redefined how material cultures and information are documented and recorded. They contain powerful yet easy to use microcomputers and microelectronics - ways to transmit individual engagements or interactions with the world.

As outlined in both my *Computer* and *Geoinformatics* articles, a tablet or smartphone can be used to turn intangible digital heritage into a physical facsimile of an artefact when connected to other users, services and solutions. The Symbiotic Web, also known Web 4.0 and WebOS, has transformed specialist instruments and software, as well as items like consumer handheld devices, into nodes within a digital production line. For example, designs generated using apps like Autodesk's 123D Make get

turned into actual products or working prototypes via 3D printing services like Shapeways.com.

Narratives built around concepts like the Third Industrial Revolution (TIR) - which is discussed heavily in my book chapter - are created in order to examine what is essentially a decentralized means of production. They explore user trends in broader cultural and economic context. Like the Internet of Things (IoT), TIR leans toward the democratisation of information flow - a shift that occurred because of affordable ICT solutions. For advocates of this new digital age, development can now take place on the move, in the home or in social settings like a cafe. That is, alongside traditional institutions of knowledge production like universities or design studio. As with IoT, organic workflows are discussed, and decentralized modes of production are favoured over the rigidity seen in the preexisting conditions, such as factory-based environments.

It is important to consider this shift in digital infrastructure when also considering the position of digital technologies within heritage-based applications. That is because, much like trends tethered to otherwise specialist or fringe 3D technologies, the future of technology use for heritage preservation and documentation is shaped by changes to the overall digital infrastructure in place. They do not exist in a bubble or in user communities detached from this. They all feed into it.

In the same sense, the advent of multimedia computing in the late twentieth century has evolved on a much grander scale through distributed computing in the twenty first century. Graphical user interfaces and multitasking operating systems, which are now a daily commonplace to most people, adapted from mainframe computers that only few people once had access to. These advancements in micro computing also became the foundation stones upon which a ubiquitous personal computing market could develop in the 1980s to 1990s. The ease of use that came a result, was then taken one stage further through the internet. This eventually made computers

handheld, as well as capable of processing complex tasks and information sets from anywhere with an internet connection.

It is important to consider these developments within the context of digital heritage, because the potential amount of information that can be crowdsourced will only increase as time goes on. With this will come issues related to provenance. For example, a photograph taken with a mobile phone or tablet is being collected by a device with multiple sensors but does not necessarily give the user much control over the collection process beyond point and shoot. The Digital Dark Age - once described by Stewart Brand - where collective human intelligence will be cataclysmically impacted by the loss of massive amounts of digital data - has the potential to become a reality. For Brand, even retrieving information in as little as five years' time can be a problem. Given that he first brought this to light in 1999 and little has been done to challenge his claims, the Digital Dark Age is a problem (Brand 1999). Especially in a period in human history where it has never been easier to collect information. That is, without the need to fully understand the how or why that goes into its creation.

This is one of the reasons why it is important to remember that point clouds as 3D images have developed to document a scene to a known accuracy, precision and resolution. My *Journal of Archaeological Science* article was an attempt to reinforce this point. Whether it is a photograph with a known scale added to it, or a laser scan that is produced, point clouds are used to give greater understanding to the actual state of being for an artefact, building or landscape. Unlike a theodolite or total station, which record single known points to add to a coordinate system, point clouds developed to document surfaces. Inquiries about how they compare to the "real thing" will differ depending who is asked. For example, a photogrammetrist versus a computer vision expert.

Digital modes of production no longer follow a fixed linear progression - unlike their analogue counterparts. In other words, creation and assembly no longer begins at point A then ends at point B. People can perform or

complete an assigned task anywhere in a connected world when working with digital technologies or tool sets. For this reason alone, it is fundamental that process, provenance and memory be considered alongside the digital tool sets used in a CH based project. This is both for the reasons outlined in this conclusion, as well as those contained throughout all works submitted for this Doctor of Philosophy by Published Work (Route 2).

8.2 Ethical Considerations

The ethical considerations taken into account when writing all publications submitted for this Doctor of Philosophy by Published Work (Route 2) will also be considered in future work. There were a series of ethical issues requiring consideration throughout my academic and industry work – considerations that will continue to be relevant going forward, working in a dynamic and developing field. Such Key ethical considerations issues include:

- a) Respectful consideration of the user communities that may take interest in my work, with a striving to serve those communities.

One of the failings of technology-driven research can occur when researchers ignore the people who interact with those technologies on a day to day basis. This usually manifests itself through a lack of long term engagement with what is essentially a collective intelligence made up of applied learners, communicators and researchers. These are the types of network that are important to consider from a digital literacy point of view, as they are a valuable resource. They are also a resource that can be respected or exploited. The work of thought leaders like Howard Rheingold and sociologists like Bruno Latour are both good resources for considering ethical practice along these lines. This is especially the case through Latour's work on Actor Network Theory (Latour 2005, pp 32-33; Rheingold 2012).

This type of behaviour usually presents itself in publications in the way the content is deployed. The seduction that surrounds a constant sense of newness is usually the common approach taken. Where the future is always positioned as being almost in sight but, at the same time, also in a constant state of being slightly out of reach. Networks of the producers of digital technologies and these user communities can end up being exploitative - along the lines of what Bruno Latour describes as 'network parasites' in his work on Actor Network Theory (Latour 2005). Producers and researchers may come into a network with their end users in order to extract from it what benefits they can, and then move on to the next network of value to them. The example given by Latour in *Reassembling The Social* is that of how the informant feeds information to the social scientist. That is, in order to give their research overall perspective which, in turn, holds value within their professional network.

My work has never taken this approach. Instead, it has always strived to decipher the trends in behaviour. For example, what trends in behaviour are linked to the use of technologies by both individuals and groups? In particular, I have been interested in what the uses of digital technologies say about the current state of understanding of those technologies. My *Journal of Archaeological Science (JAS)*, *IEEE* articles, *Geomatics World* and *Geoinformatics* have explored these issues. For example, compare issues: compare the theoretical camera model discussed in my *JAS* article, to the symbiotic web identified in my *Computer* article, but developed through my *Geoinformatics* contributions. Also, the narratives outlined in my book chapter to the commentaries surrounding industry developments at events like HxGN Live.

- b) Avoiding commercial and brand-based narratives to ensure the inclusion of less well-known, but equally key contributors.

A direct example of this in my publications is my work on Amiga computers. There I identify and explain where the key intellectual contributions are made to the service and solution developments within my industry output. For

instance, the Amiga line of computers were not viewed as a mainstream success by their designers. They were viewed as computers that were successful in Europe, due to the vibrant developer cultures in place in countries like the UK, France and Germany. Their success in North America remained largely behind the scenes in video production and 3D design communities. It is only with the advent of decentralised media that their contribution to computer science has started to emerge. For example, ray tracing via packages like Lightwave 3D and Virtuality hardware were early forms of accessible 3D and virtual reality systems.

Retrospective computing and consumer-led development is important from an ethical standpoint because Amiga users, and their lingering achievements, demonstrate several points. First, is the pivotal role of user-technology interaction, and how user communities can interact with technologies in ways their designers never intended or foresaw. Such interactions even countered the effects of planned obsolescence, making an otherwise ephemeral material culture manageable and sustainable. Second, if a mainstream narrative of say modular, x86-based CPU, personal computers had been followed in that article, then substantial amounts of information would be lost. Such a narrative might not have understood that custom chipsets had to be used at one stage to make 3D design technologies more accessible. This was due to the limited processing power of computers at the time. It was crucial to explain how hardware, that existed prior to the development of powerful, affordable and dedicated graphical processing units, actually worked.

There is also a third important point around this ethical issue which is supported by my adoption of Immanuel Kant's notion of Empirical Provenance. That is, of course, cultural memory. I needed to outline how a process can be fully documented, and therefore understood, when understanding could otherwise be skewed by one dominant narrative. For example, data is not static and acquires meaning through actions and interactions (cf. Shanks & Tilley 1989). Point clouds generated by laser scanners or photographs are no different in this respect from any other type

of data. It is not just the meaning of the objects recorded by laser scanning or camera, but that of the point cloud itself investigated when cultural memory is given to the information generated. An object is created at a particular time and people interact with it over time, but in the case of a point cloud or mesh, the sum total of both the object and the point cloud or mesh (i.e. the performance at a given moment in time) is presented for future interactions.

The work contained in my publications investigates the nature of the object in its natural context, and follows the role of cultural memory through performance in transforming the nature and relationships of that object over time and through space. Starting with the object and its relationship to the scanner or camera with its operator, the investigation moves to a series of other agents such as targets and climate, as seen in my articles for *Computer, Computer Graphics and Application* and *Journal of Archaeological Science*. The nature of the laser scanner or photogrammetric process itself, and its interior and exterior orientations, are key to the data generated. Further factors influence the data produced in ways not applicable to analogue data, for example, time and space are not the same in a digital context as in their 'real' analogue dimensions.

Finally, once in the virtual or digital space, models produced from point clouds or meshes are then subject to further performance or performativity processes due to the use of the model for display and interpretation. Unlike static images, 3D images or models are of themselves stages for interaction. These interactions, however, differ in content and method from the original objects and invite questions of authenticity in their interpretation.

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10.0 Literature Review

Articles presented in the literature review were selected based on themes, technologies and techniques discussed in the articles presented for Doctor of Philosophy by Published Work (Route 2). Current and future developments are greatly impacted upon by the evolution of user interfaces, touch screen and display technologies, as can be seen in 8.2 and 8.3. In terms of the marriage between computer vision and 3D imaging, the articles presented in 8.1 demonstrate how the increased adoption of otherwise specialist techniques continue to shape hardware, software and applications of use.

10.1 Laser scanning, photogrammetry and computer vision-based 3D:

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11.0 Glossary

Absolute coordinates - X, Y and, in the case of 3D imaging, Z axis used to determine a distance from a common point of origin within a Cartesian system of coordinates.

Augmented reality - usually involves computer and sensor input to enhance an impression of human environment interactions.

Augmented Virtuality - merging real world objects into virtual worlds.

Binocular stereo - the creation of a 3D image or depth map using two images.

Cartesian coordinate system - Known distance or difference between X, Y, Z plane / coordinate based on a difference to a commonly known 0,0,0 coordinate / point of origin.

Global Navigation Satellite System – Autonomous global positioning via satellites. Historically, these have included artificial human made networks like GPS (USA), GLONASS (Russia), BDS (China) and Galileo (European Union).

Internet of Things - The IoT acknowledges that people interpret, synthesize, and communicate their perceptions of the world through any device at hand. It is part of the Symbiotic Web, or Web 4.0, which describes how connectivity via the Internet makes it easier to crowdsource and network data.

Iterative closest point (ICP) - an algorithm used to minimise the differences between point clouds.

Laser - Acronym for Light Amplification via Stimulated Emission of Radiation

Ladar - Acronym for Laser Detection and Ranging

Lidar - Acronym for Light Detection and Ranging

Mixed reality - the merging of real virtual and worlds in order to have digital assets interacting with the physical conditions in place. This usually occurs in real time.

Multi view stereo - 3D reconstruction of an object or scene using 2D images taken from multiple known points.

Photogrammetry - using photographs to retrieve metric information about an object or scene.

Point cloud - a set of information points linked to each other within a relative or absolute coordinate system.

Registration - also known as point matching. The process of finding a spatial transformation that aligns two or more-point clouds.

Relative coordinate - when X, Y, and also Z coordinates (in 3D imaging) have a relative relationship to other X,Y, and Z coordinates.

Scanning - a mechanism that enables a beam of light to be steered in a fixed direction. For example, see the rotating mirror of a laser scanner.

Structure from motion - the difference in movement or motion between each 2D image is used to create a 3D image. There should ideally be 60 % overlap between each 2D image in order for a scene to be reconstructed in 3D.

Symbiotic Web (also known as Web 4.0) - focuses on connectivity of devices, sensors and information on a global scale.

Third Industrial Revolution - used to explain decentralised modes of production developed via information and communication technologies. Jeremy Rifkin described it as third after the Industrial Revolution of the 19th century and Fordist production line model.

Virtual continuum - a continuous scale that charts the range between real and virtual environments

Virtual reality - immersive and simulated environment

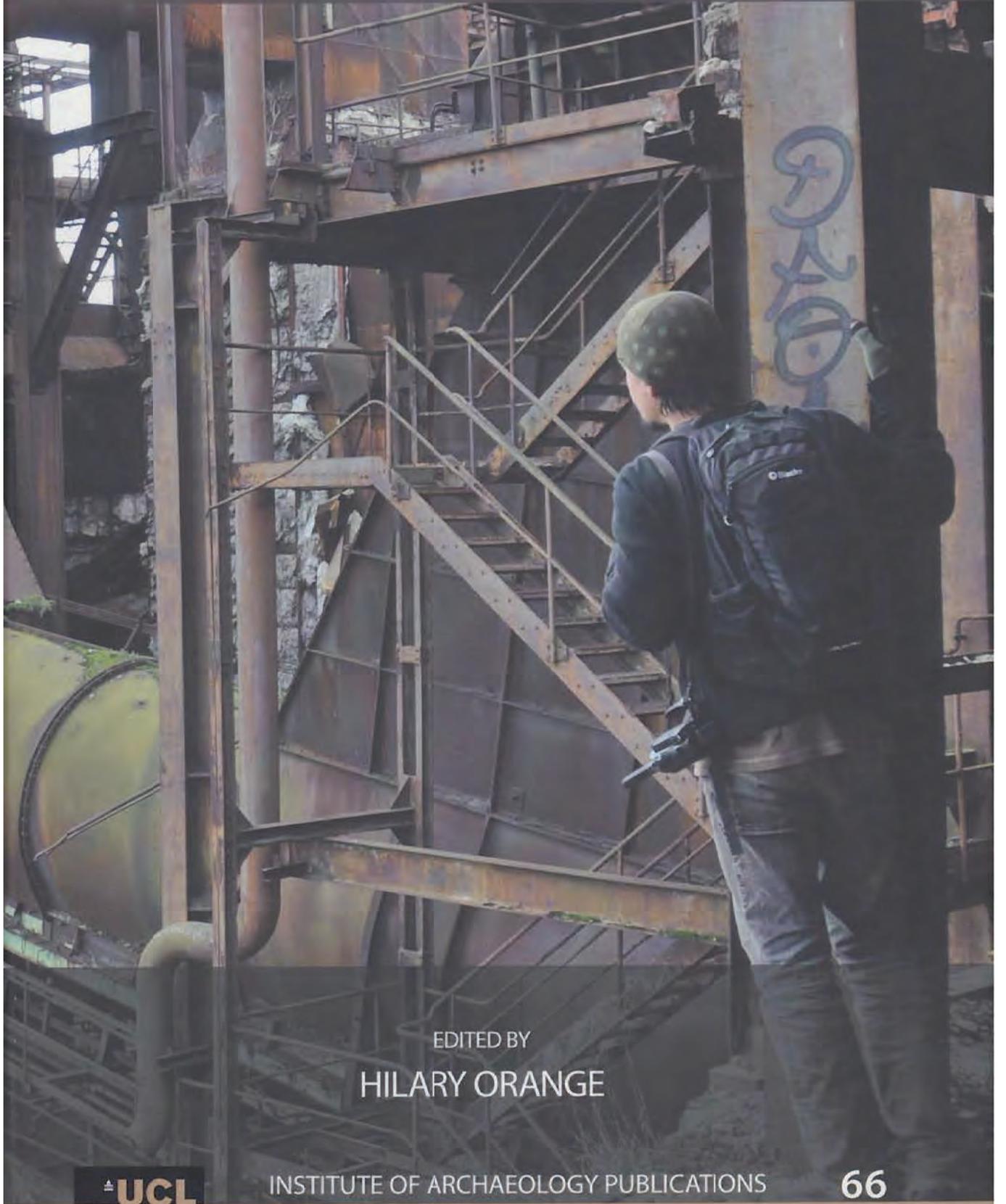
Web 4.0 - connects devices in real and virtual world time. It has also been called the Mobile Web.

Appendix A

Citation Index Publications

REANIMATING INDUSTRIAL SPACES

CONDUCTING MEMORY WORK IN POST-INDUSTRIAL SOCIETIES



EDITED BY

HILARY ORANGE



II Digital Heritage, Industrial Memory and Memorialisation

Caradoc Peters and Adam P. Spring

Introduction

In this chapter we focus on the nature and processes of digital technologies and their impact on questions of memory and memorialisation in industrial heritage, here meaning any kind of heritage produced or modified during the Industrial Age (dating from the eighteenth century to the 1940s). Since this chapter deals with digital technologies, we also draw some parallels to earlier Industrial Age technologies.

The Industrial Age presents particular problems for memory and memorialisation: whether in terms of public spaces, workplaces or even home environments, most people are confronted with the physical presence of industrial heritage every day. Indeed, some of the tensions in interacting with sites of this period are precisely because they are still active today. Some industrial heritage is beyond living memory (and is purely memorialisation), some of it has emotional purchase in the sense that the living memory of the deceased was once told directly to those still alive and, finally, the more recent elements are still in living memory. Archive audio and visual recordings blur these memory distinctions so they are not as hard and fast as they might first appear. Memory that was living until very recently is of particular interest for public engagement, especially as it relates to spaces that everyone has some experience of in their daily lives. There is a sense of ‘so near and yet so far’ about such memory.

Navigating the Industrial Age even in physical terms is a difficult call; in digital terms, where engagement has to be engineered, working with memory

Reanimating Industrial Spaces: Conducting Memory Work in Post-industrial Societies by Hilary Orange, 00–00 © 2014 Left Coast Press, Inc. All rights reserved.

is highly challenging. Memory holds a threshold position between the more vivid emotional states of nostalgia and nightmare on one side and a sense of place and identity (created in part through memorialisation) on the other. The former states are usually associated with people responding to heritage created in their own lifetimes or perhaps at a stretch those of relatives and close friends they knew, and the latter with people responding to historic heritage beyond living memory. The emotional and psychological consequences of digital interfaces between humans and their industrial past form the main subject of this chapter.

Much of the literature on digital applications in archaeology is overly obsessed with their technical nature. Some of the technical side must inevitably be covered here for the sake of understanding, and a certain amount of space will therefore be given to explaining a range of the techniques (and their implications for memory and memorialisation) before going into specific industrial examples.

The ‘Infrastructure of Things’ and Other Theories

We use three bodies of theory to broadly discuss the issues and implications of the use of digital technologies within industrial heritage: (1) social presence theory; (2) The ‘Parliament (and Internet) of Things’; and (3) trajectography.

Social Presence Theory

The first of these bodies of theory concerns the realm of human emotional connectedness and human memory in the sense of responses to culturally, socially and emotionally linked stimuli. A key tool in resolving the difficulty in marrying living memory and memorialisation is social presence theory (Short et al. 1976), which states that a medium’s social significance is increased by the degree of social interaction that it offers. However, social interaction is simply not enough to reanimate heritage because social interaction on its own does not necessitate a material context.

As Champion (2011, 72–74) points out, cultural presence which includes memory involves human agent ↔ object ↔ human agent three-way interactions, not simply two-way human agent ↔ human agent interactions. The object in these interactions can be any object or structure. In digital terms, this can involve human operators achieving a feeling of embodiment (feeling physically drawn in), a feeling of embeddedness (being socially or emotionally drawn in) or finally feeling that they can inscribe themselves (leave some mark or modification) into the digital environment. This last feeling is arguably the most important in digital environments that can seem cold and distant. People often feel more of a sense of connectedness with the past if they can touch objects from the past. Such object-mediated interaction between people is vital to many cultures, especially in host–guest relationships (Candea and da

Col 2012). Indeed, Pye (2012) considers that museums should see engagement with artefacts as part of their story, and that full access enhances understanding.

The Parliament of Things

The ‘Parliament of Things’ (Latour 1993, 144) is a metaphor for object-mediated interaction which involves people and things. Just as there is a ‘Parliament of People’ for human–human interactions, there is a Parliament of Things which involves object–object and human–object interactions. Interactions, impedances and change are important in creating realism, because ‘real life’ (RL) involves experiences that are not all smooth and easy. Digital worlds thus require a careful blend of authenticity versus convenience, and a careful blend of ephemerality versus durability to engage the Parliament of People as well as the Parliament of Things. Although heritage workers may in many ways be justified in resisting decay, ephemerality is an important part of atmosphere and presence, as RL does involve decay. Decay, change and ephemerality are object-mediated, and the last two can also be directly human-mediated. The ‘Internet of Things’ (a term that Ashton [2009] adapted in 1999 from Latour [1993, 144]) has become an expedient concept for describing the interaction between humans and a range of nonhuman digital devices and media. All these are seen as ‘actors’ in the functioning of the Internet.

This interaction is crucial for both rational and emotional understanding. Latour later argued (2004) that because the public have been taught to consider the role of things separately from that of human actors, elites such as politicians, scientists and pressure groups have been given free rein to interpret nature or materiality for society as a whole and have thus been able to manipulate reality to their advantage. Like the Parliament of Things, the Internet of Things could be a truly democratising force if it were to include things—objects and places—as actors to speak for themselves. Allowing things or objects to change digital environments lends realism, while ordinary human actors inscribing or leaving traces of their activities in these environments affords a sense of connection and identity. In other words, heritage workers and the public need to engage with active things directly—whether virtual or indeed physical—if they are to achieve a connection with the past. Indeed, even nonspecialists are able to create and critique using widely available free-ware or low-cost versions of digital applications (Peters et al. 2008, 64).

Just as there is an Internet of Things, so we argue here that there was also an ‘Infrastructure of Things’ in the Industrial Age. This largely physical Infrastructure of Things including railways and urban centres is still there, parallel to the largely virtual Internet of Things (although the latter can sometimes have physical consequences). The infrastructure spawned by the Industrial Revolution was as much about communication as production. This communication was indeed world-changing (and still is where it survives) despite much of it being intangible and therefore ephemeral in nature. On the other

hand, much of it was also physically transformative. Many of the advantages and disadvantages of that revolution continue as trends today, and ephemeral technologies like the telegraph and the telephone are paralleled in the digital world. This means that it is easier to compile otherwise scattered resources in one place, sort them or filter them much more easily and distribute them to more people.

As for authenticity, remediation of data can blur the boundaries between soft and hard copy. Hard copy gives a greater sense of completeness in that it more readily engages all the senses, but it weathers and decays. Soft copy is more selective and appears less authentic, but it freezes time and does not decay (unless it is deleted). In that sense, although less interactive, it is truer to the past it captured than any original material evidence. Vandalism, decay, restoration, demolition and looting are all processes that can bring authenticity into question even where reconstruction or repair subsequently takes place. While physical context is subject to change, soft copy can permit the recreation (and even restitution) of context, or can be used to monitor long-term change in context (compare with Barnes 2002).

For instance, there is an example of restitution (and reconciliation) in the return of a sixteenth-century Renaissance painting—the *Nozze di Cana* by Veronese—looted from Italy in 1797 by Napoleon's troops. Held in the Louvre, the painting was reproduced as a facsimile, and this facsimile was placed back in the original context in the monastery of San Giorgio Maggiore in Venice (Latour and Lowe 2011, 2). It is a challenging example in that the reproduction looks real, but is not the actual painting. It demonstrates a way of resolving underlying conflicts (which have their roots in the industrial past), at least in their physical manifestations. It also illustrates the temporal and spatial tensions brought about by digital technologies.

Trajectography

Such tensions are found between digital heritage that does not decay or move (i.e., that is not active like Heidegger's concept of *Dasein*) and the material heritage that does decay and move (i.e., that is active like Heidegger's concept of *Sein*) (see Heidegger 1962). The former is more authentic in that it is more like the original condition of the object, but less authentic in that it does not behave in a way that natural objects do: it gives preference to appearance over spirit. This also applies to an original context in that a looted painting has a history or personality that is lost if that history is removed or forgotten. Restoring context can rob power and vitality from the object in that the tensions created in past engagements with the object will no longer be so apparent.

The telepresence of digital formats likewise threatens the existence of localised geographies (Virilio 2005, 9), but at the same time heightens access to social and cultural interaction. Locality, context and identity are usually seen as key to imparting meaning. However, in the Digital Age, meaning can

be contextualised by networks instead. In this new world order, the telepresence offered by virtual reality (VR) redefines what is local and what could be termed ‘meta-local’, the ‘de-territorialized meta-city’ according to Virilio (2005, 11). In fact, in *Open Sky*, Virilio (2007, 129) contests the relevance of geography and proposes trajectography, the pathway between spacetime and matter, as now more appropriate; for instance, flight paths and fly-throughs as forms of digital presentation.

On the other hand, trajectories are not the equivalent of traditional linear histories and geographies. A trajectory lies within networks of infinite possibilities. Connections exist between many points of data in all directions. A trajectory is simply one potential linear set of connections amongst many. Trajectories depend on the question posed, or the aspect of the data being interrogated, as networks are by their nature open (Boltanski and Chiapello 2005, xxiii). Objects and human actors themselves lie on a number of trajectories.

Human minds are not simply adaptable and multifaceted like Swiss Army knives; they are unpredictable and creative (Mithen 1998, 64). Humans can be different sorts of actors under different circumstances: the idea of identity comes from attempts to categorise individuals on the basis of a collective assessment of many individuals (Boltanski and Chiapello 2005, 171). Thus, humans can act as nodes for a number of apparently unrelated networks. When viewed as trajectography, geography is composed of networks (or point clouds) of inscribed nodes (locations inscribed in terms of associations including memories), which can act in both linear and nonlinear ways. In other words, geography is not actually linear in its distribution (locations are scattered in all directions), but it can be viewed as linear when travelled through (in the sense of a flight path). Each node can thus be part of more than one geography or trajectography, whether in space or in time (see the case of Norrköping later in this chapter).

The development of digital techniques is a rapidly changing field, which has in many ways outpaced the ability of those involved in industrial heritage to engage with it fully. To disentangle these issues further, we now consider the approaches and techniques of memory work in digital heritage by outlining three basic strands of digital technology: (1) digital capture and documentation; (2) digital representation, visualisation and dissemination; and (3) digital archiving. Each strand is considered in terms of its potential: as these areas demonstrate, digital technologies are at every step in the process of engaging with the industrial past.

Digital Capture and Documentation

Digital engagement with heritage begins with the act, or rather performance, of digital capture (the equivalent of analogue surveying and recording primary data). The performance is not simply an interaction between human and

machine. Wrapped up in the performance is a series of interactions that have the potential to capture a sense of presence. The human and its machine are not the only actors in the Internet of Things. Subsequent processing of the data creates filters that potentially obscure that original performance. The nature of the individual performance of digital capture will be lost in the combined point cloud and multimedia environment, which then becomes a collective performance of memorialisation.

For instance, the workflow behind digital colour is not a unilinear process from one device to a printed image. As ‘device-independent’ colour, derived from a variety of sources of capture and indeed outputs, digital colour now demands star-shaped workflows for its capture, documentation and reproduction (Stone 2003, 193–195). Performance matters because the temporal dimension, or more accurately spacetime dimension, is now analysable, as we demonstrate here. The trajectory of the performance reveals the relationship between human investigator and historic object, and permits more critical approaches to the data analysis.

The way the data are linked to the performance is clearer because there is no discernible time difference between the capture of data and its initial documentation (the processing of data is largely automatic). There are two main categories of data capture: photometric and geometric. Capture is thus either the passive recording of light data (photometric) or the active production of laser beams that are reflected off surfaces and recorded on their return to the instrument (geometric). After automatic archiving, software then adds documented actions such as stitching the data together, modelling the point clouds and adding light sources.

Photometric Techniques

Many digital capture techniques start with photographs. In the first instance, photometric technology seems more evocative of memory and reality than anything geometric. Three-dimensional (3D) photometric models with visual textures can be accurately reproduced. Photographs can record views of objects faster and less selectively (though there is still an element of selection) than illustration. For all that, photorealist models though do not necessarily appear real, as visual realism is only part of what creates a realistic atmosphere (Champion 2011, 63).

Photometric techniques give people superhuman powers of analysis that lend a potentially unreal feel to the experience of engagement with them. In terms of the methods of quantitative analysis, the key difference with digital photography is that algorithms in computer programmes can be used to process the digital data from the photographs to retrieve information not available (at least readily) to the human eye. For instance, finite element analysis (FEA) is a new type of digital analysis which uses the wireframe model created from

high definition (HD) point clouds and tests it for stresses and strains as in the use of mechanics to test integrity of structures, and to test the forces exerted by historic instruments as well as industrial and natural processes (see Keypour et al. 2007).

In this section we look at a range of techniques and their power to create presence. We begin with epipolar images with perspective views, then move to images stitched together to create panoramas, and finally move to photogrammetric models based on point clouds generated by parallax from many epipolar images. Point clouds are dense groupings of measured points that are produced with both photometric and geometric digital techniques.

Epipolar Imagery

The simplest form of 3D photometric documentation is epipolar imagery. By photographing an object from different angles, something akin to a perspective drawing is achieved. Programmes such as Adam Technology's 3DM Analyst use parallax to generate perspective through epipolar images. Epipolar images are the first stage in the production of panoramas or full 3D photogrammetric models, though they are equally useful as a tool in themselves.

For instance, we produced epipolar images from industrial artefacts and sites during fieldwork in Saxony-Anhalt, Germany, in 2011 using 3DM Analyst. One example, a Welsh cylinder for a Watt-type steam engine imported to Germany, posed an interesting challenge. Now monumentalised in a village called Löbejün in southern Saxony-Anhalt, not far from Halle, it stands on a commemorative pedestal in a garden (Hebestedt and Siemroth 1996, 68–69).

The epipolar image in Figure 11.1 clearly shows the eighteenth-century inscription recording the cylinder's origins at the Pen-y-darren Works in Merthyr Tydfil. These works later manufactured Richard Trevithick's 1802 steam locomotive (Dickinson and Tittley 2010, 67). It is a reminder of the role of this village and its surrounding area in the very early stages of the Industrial Revolution in Germany as well as its international trade links. A utilitarian object, designed as a part within a moving engine, has been transformed into heroic statuary, especially with its central location within the garden. The present context of the village is agricultural, with greened-over mining waste belying the faux-rural nature of the area. The intimate setting of this small (and now relatively neglected) garden together with the anthropomorphising treatment create a tension between the strong identification with industry that has characterised the area for much of its recent past and the present ecological ideology behind the wider landscape transformations. Indeed, the image on the plaque at the back of the pedestal (Figure 11.2) shows the cylinder in its original industrial context as part of the first steam engine.

Epipolar images are useful for such small-scale memorials, reflecting something of the intended grandeur of periods where perspective views were



Figure 11.1. Epipolar image of the Löbejün cylinder, Germany (using Adam Technology's 3DM Analyst). Photograph © Adam P. Spring.



Figure 11.2. Plaque from the back of the Löbejün pedestal. Photograph © Adam P. Spring.

instrumental in the memorialisation process, just as perspective drawings disseminated the ideal view of the memorial beyond physical RL visitors (e.g., Turner 2005, 290). Even where perspective drawings are lacking, their influence governed the placement of monuments and the way in which people engaged with monuments. There is a long history now of critiquing the use of the modern Western ‘scholastic’ or scientific view in documenting the past (compare with Bourdieu 1998, 127–140). It is therefore important to consider the appropriateness of the technique in question, for there is an opportunity amongst the wide range of techniques to select those that bring out potential past perspectives and indeed provide a tool to investigate meta-memory. In this example, epipolar images reflect an historic way of viewing monuments in their settings.

Panoramas

Digital panoramas can be achieved by stitching individual images together using a programme that recognises common shared points. One of the most impressive projects to use panoramas is Antarctica Virtua (Morse 2009). Here, a virtual environment (VE) using digital elevation models (DEMs) based on maps, aerial photographs and satellite images recreated the station set-up at Cape Denison by Sir Douglas Mawson’s Australian Antarctic Expedition of 1911. The original wooden huts of the expedition preserved by the harsh, cold and dry conditions of the southern continent now form Mawson’s Huts Historic Site (Australian Antarctic Division 2007).

The VE was then projected on to the hemispherical wall of a dome via a curved mirror at the top of the dome using a warping algorithm (Bourke 2008, 2009). Bourke’s iDome project used the Unity game engine to allow for interactive engagement with the VE of the dome. Visitors to this VE can explore the site and its environment in geometric 3D, but then enter panorama bubbles. Once inside a bubble, the user can rotate the image to reveal a panorama of the area. Some bubbles are inside the huts, which have been reproduced as a 3D CAD model where a view of the conditions inside the huts can be explored.

Digital Photogrammetry

The basic principle behind digital photogrammetry is the idea of parallax, where points in one image match those in another. The relative position of the camera ($x, y, z, \omega, \phi, \kappa$), sensor size and focal length of the lens can be used to create a scaled 3D image of the documented scene. One of the key differences between photometric techniques and geometric techniques is that the former is better at reproducing texture and colour; Figure 11.3 shows an image of the Carnon Stream Cornish engine house in Cornwall (UK), toggled between point cloud and photometric model (in 3DM Analyst). Free and easily



Figure 11.3. View of Carnon Stream Engine House, Devoran, Cornwall, United Kingdom, toggled between point cloud and photometric model (using Adam Technology's 3DM Analyst). Image © Adam P. Spring.

accessible programmes like Photosynth and 123DCatch (less accurate but still photorealistic) could engage more people in emotional, creative relationships with the past. The lighting and angles of capture are personal performances on a particular day and add craft to the experience.

Geometric Techniques

Digital geometric techniques are more expensive than photometric techniques and do not have the same degree of photorealism, but they do have some advantages. Relying on lasers and sound waves to ascertain distances as well as mechanical and optical components for angles, they do not rely on external forces, including light, to generate results. They can therefore work in dark caves and deep seas where photometric technologies would have more problems.

Terrestrial mid-range scanners, the most commonly used digital geometric technology (after total stations), are suitable for recording sites rather than landscapes. These yield considerably higher definition records than conventional total stations at a faster rate. They generate point clouds at a million points a second, and even late-1990s models generated point clouds at a hundred points per second.

Point clouds do not automatically form models or render themselves (Figure 11.4). Capture and modelling are personal human-scanner performances. Technical awareness and interpretation play a significant part. For example, in Grass Valley, California, in 2009, Spring and Barton included fixed-survey targets, 360-degree HDR panoramas and photo-documentation in their workflow while laser-scanning the North Star Mining Museum (see Figure 11.5). Alongside measurement accuracies, and through point clouds containing local coordinate information, they documented the fieldwork and

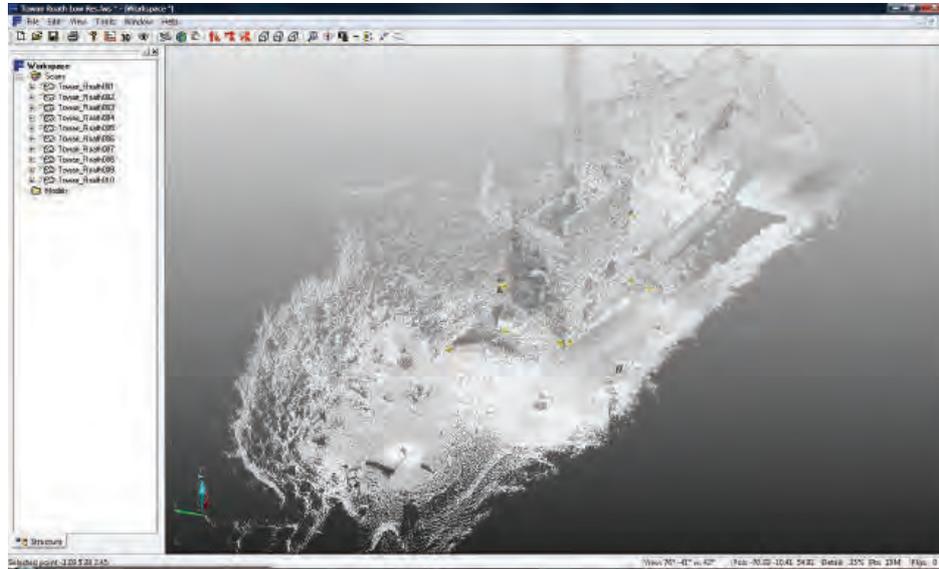


Figure 11.4. Point cloud of Towainroath Engine House, St Agnes, Cornwall, United Kingdom, generated by a FARO laser scanner. Image © Adam P. Spring.



Figure 11.5. Spring and Barton with Leica laser scanning equipment at North Star Mining Museum, California, United States. Photograph © Adam P. Spring.

personalities involved in data production. Memory is key to documentation in a digital world where manipulation of imagery is relatively easy.

Digital Representation, Visualisation and Dissemination

Public engagement is a fairly well explored area of digital technologies (De Cindio and Peraboni 2011, 93). Industrial heritage is especially suited to this aspect because people readily relate to the contexts, particularly industrial spaces of the more recent past. Industrial heritage is familiar yet distant in a way that unnerves and provokes nostalgia.

Apart from display (a line of research in its own right), experiments in creating authentic experiences can reveal new insights into the original experiences of the Industrial Age. Sophistication of representation is not necessarily the most realistic or authentic in social presence theory, as discussed earlier in this chapter (Champion 2011). Interactivity and engagement between humans and things is particularly important. In Katz's "The Digital Citizen" (1997), active participation is required lest individuals experience alienation.

Augmented Reality

Augmented Reality (AR) can be seen as an experimental stage between virtuality and reality composed of virtuality, augmented virtuality, augmented reality and reality (Saggio and Borra 2011, 59–60). Virtuality is very much an unfettered experimental state, and reality is a bounded, already tested state. AR applications lend a freedom to experiment with other realities within the bounds of reality. For example, the user can point a smartphone down a street and see the same view from photographs and other images from a range of periods. The user can thus begin a personal dialogue with the past.

Audiovisual Guides

Audiovisual aids can be downloaded from a dedicated website to smartphones for a basic AR experience. In Norrköping in Sweden, Tavanti and Rankin (2010) explored the ideas of 'memory holes' from George Orwell's *Nineteen Eighty-Four* (1949) and 'reading the city', which draws on Benjamin's concept of the city as text: in *The Arcades Project*, conceived between 1927 and 1940, Benjamin (1999) compiled quotations from original sources together with his own reflections as a commentary on the early consumerisation represented by nineteenth-century arcades in Paris. Thus, instead of a single narrator describing political and economic trends in urban Industrial Age landscapes, the city is presented as a montage of individual fragments of personal memory. The 'memory holes' in the Norrköping study were audio devices in the form of funnels for listening, and the text-based memories appeared as touchscreens on walls (Tavanti and Rankin 2010, 180).

Websites Using Data Matrix Codes and Applications

The dedicated website is highly likely to be the first port of call when deciding to visit a heritage site. Hosting multimedia, including geographic information systems (GIS), video, 2D photos and 3D visualisations, can enrich a basic AR experience. For instance, Parks Canada has launched six apps for Apple and Android smartphones and a proprietary device called Explora at the Lachine Canal National Historic Site (Lanktree 2011). These georeferenced tours guide people through the canal park and enable visitors to plan their trip flexibly around particular needs and preferences. In another case, the Museum of London's Streetmuseum provides scenes from the past to superimpose over modern locations to give more of a sense of past activities and events (Lucas 2010).

In recent years, new methods of access link the visitor direct to websites. Data matrix (DM) codes like Semacode, Aztec and most notably QR (quick response) enable rapid access to information when scanned by mobile devices. These codes are a subtle alternative to conventional notices or information boards. An excellent use of QR codes is the Derby Museum and Art Gallery, which contains collections of archaeology, minerals, mathematical and scientific instruments and paintings of industrial significance by Joseph Wright (Stanley 1976). The museum uses Wikipedia's new facility QRpedia to link objects on display to Wikipedia articles; the information is continuously reviewed and updated by users and Wikipedia moderators. Visitors are eventually required to reference these articles, leading them to source materials. The articles are also translated into parallel language versions of Wikipedia. One of the mineral specimens, a piece of matlockite, has had its text translated into more than 40 languages (Moyes 2011). These translations are not simply verbatim translations, but are tailored to the cultural context of the language's speakers. All of this not only saves the curators time, but also enhances the experience for visitors, who become active participants.

Visualisations

3D visualisations save substantial time, cost and effort compared with physical models. However, they are not simply models that can be manipulated, orbited and rotated. They act as virtual testing grounds at any scale and form the user may choose, such as fly-throughs, animations and avatars. Unfortunately, they can suffer from emptiness or artificiality. Ironically, the more photorealistic they are, the more they generate feelings of artificiality or, worse, nausea and spookiness (Champion 2011, 66). The problem is that they are not matched by equivalent realism in the other senses and especially not matched by social and cultural interaction that would be expected in RL.

The heritage charity CyArk has done much to counter these problems with their educational packages. Visualisations come with panoramas, videos, still

images, scale drawings and educational materials as part of specifications demanded by CyArk's collaborators. The target users are schools, colleges, self-learners and academic researchers. Furthermore, CyArk's collaborations with Historic Scotland, the Glasgow School of Art and Leica Geosystems attempt to capture something of the emotional and psychological in their choice of subject matter, such as the World Heritage site of New Lanark, Scotland. New Lanark was a state-of-the-art industrial settlement for the manufacture of cotton textiles, created in 1785 by David Dale. Robert Owen, Dale's son-in-law and a leading figure of the Scottish Enlightenment, developed New Lanark into a model community including education for the children of the workers (Scottish Ten n.d.).

Aside from point cloud-based visualisations, there are visualisations that use CAD programmes to model industrial heritage. In Spain, Rojas-Sola and Castro-Garcia (2011) have modelled hydraulic olive presses which were in use from the end of the eighteenth century until the early twentieth century. Such modelling is not restricted to simple renderings of colour and texture overlaid on geometric models. Digital lighting can be used to pick out detail and increase realism (Rojas-Sola and Castro-Garcia 2011, 6722–6723). This includes the realism and authentic look of the object as well as important details. The increasing power of software to enable photorealism means that modelling is less an analytic tool in the traditional sense and more a documentation tool. The application of algorithms (mathematical instructions which extract data relevant to a particular question or proposition), or the qualitative selection of data using applications (subsequent to the modelling), form the analytic phase. They should not therefore be considered as complete models for cultural presence without additional interactive features.

Hyperreality

Hyperreality platforms, or experimental worlds such as Second Life and Open Sim, test social scenarios that would otherwise not be readily or affordably testable, or at least conceivable within RL. On the other hand, social interaction involving twenty-first-century people may contravene the social norms of the past due to a lack of sufficient constraint infrastructure in such platforms.

An example of industrial heritage in Second Life was a reconstruction of the Crystal Palace and its Pompeian Court exhibition (Earle and Hales 2009). The Crystal Palace, a glass hall built to house the Great Exhibition of 1851, was originally constructed in London's Hyde Park. In 1854, the Palace was rebuilt in Sydenham, London, where a series of educational exhibits of reconstructed buildings from past civilisations were constructed for public viewing. The Crystal Palace burned down in 1936, so only the terrace upon which it rested remains. Pompeian Court, as one of these reconstructions, is interesting

not so much for the Roman archaeology, but for Victorian views of the ancient past. The project engaged with schools and used Heads Up Devices (HUDs), touchscreens like those in arcade games. To engage with the Victorian mindset, text was provided from the original 1854 guidebook (Earle and Hales 2009, 12).

The main problem with hyperreality is that the localised and the particular are delocalised and universal. The absence of a cultural context both in spatial and social terms challenge the notion of reaching back to a culture that is so near (within living memory) and yet so far.

Gaming (Serious Games)

Another way to understand heritage is through studies of active engagement such as ‘serious games’. This discipline/genre is extremely diverse, but the connecting factor is that the games serve purposes beyond mere entertainment (Susi et al. 2007). In heritage applications, it includes testing human–object and human–environment interaction, as well as promoting learning by communicating key information around museums and heritage sites (Anderson et al. 2009). A project in Aalborg, Denmark, used mobile phones as a means of interesting young people in industrial heritage (Jensen 2009). The project’s alternative reality games or augmented reality games (ARGs) involved quests, treasure hunts, adventures and interactive storytelling where the mobile phone user became part of the story. For instance, the Vera ARG from the western part of Aalborg asks participants to help a 10-year-old child called Vera from the 1930s. Vera lost her memory, and participants have to find parts of modern Aalborg dating to her time—such as schools and factories—so she could remember her past.

Haptics

Haptics is all about the sensation of touch, which is perhaps the ultimate connection in terms of human agent–object relations. The directness of touch makes it useful in creating atmosphere, which is essential in promoting a sense of presence. In the Civic Museum of Como in Italy, Rizzo and Garzotto (2007) used tangible user interfaces (TUIs) in a project called *The Fire and the Mountain* to explain/explore the relationship between humans and fire from prehistory to the present, including ironworking and coalmining. Children aged eight to eleven were given four interactive installations operated by means of touch: a virtual book, a talking dictionary, research tables and Coal Cave (an AR display created using a projector and audio system). The installations worked best with contextual affordances from the designed environment (visual and audio cues) and the social environment (the behaviour and interactions of other children). The visual and audio cues indicated the nature of the environment as well as the children’s interactions with it:

sound reverberating in the cave and the fact that objects moved, like the virtual book's pages turning.

Other haptic devices generate tactile feedback. The University of Southern California's virtual Interactive Art Museum allows visitors to touch and feel objects normally off limits using a PHANTOM device from SensAble Technologies (Brewster 2005). This delivers programmable tactile sensations of texture and shape. The museum had a collection of 150 teapots from all around the world as its initial selection available for virtual touching (Butler and Neave 2008, 135).

Rapid Prototyping

Even more direct physical interaction with objects can be achieved with rapid prototyping (Spring 2012). Rapid prototypers are essentially 3D printers that print models in a range of substances, including plastics (Dellepiane et al. 2011, 49). In fact, going backwards and forwards between digital mockups (DMUs) and physical mockups can help reverse-engineer past machinery. Laroche et al. (2008) investigated the workings of an early twentieth-century salt-washing machine from Batz-sur-Mer in Brittany, France, using this two-way process of digital and physical modelling.

Digital Archiving: Born Archival

At the core of contextualisation and identity (concepts vital to memory and memorialisation) in the Digital Age are networks. Networks provide the anchor for localising objects and information. The Industrial Age witnessed the unprecedented growth of physical networks so that routes like the Orient Express railway across Europe, the Cunard Line cruise route across the Atlantic, and Route 66 highway across the United States started to challenge the concept of locality. There is sense in which the Infrastructure of Things heralded the idea of trajectography long before the Digital Age, due to the way that objects and structures became associated with these routes as much as, or even more than, their immediate location. Supporting settlements and structures became dependent on the routes for their existence.

Archives and Authenticity

Archives similarly need constant networking to survive. Fortunately, all digital data is 'born archival' (Kunze 2008). That is to say that it automatically comes with key archival data such as date of creation, size and format. This should normally make data readily distributable. Despite this, there are huge differences in compatibility, metadata (or category types) for digital records are not always consistent and the rapid pace of change in technology means that storage has to be a very active process with constant monitoring. This is all the

more significant when human participation has been reduced by the introduction of automatic processes. While such automation may reduce human error or potential bias, there is a danger of loss of authenticity.

Authenticity is further threatened by the huge power of digital technologies to manipulate data, whether from a benign or malign intent. Mudge et al. used Kant's idea of 'empirical provenance' (Kant [1781] 2003, 61) to develop metadata designed to track all changes to the data from capture to publication (Mudge et al. 2007; Mudge et al. 2008). A simple and effective way of ascribing memory to a workflow is to include experiential data, such as audio and visual recordings of fieldwork activities. First applied to polynomial texture mapping (or reflectance transformation imaging), the concept has since been expanded to include photogrammetry and laser scanning (see Spring et al. 2010).

Social Networks as Archives

Social networking and social bookmarking now allow for a personal involvement in archiving. This is a form of direct engagement, which is key to the act of remembrance. Flickr, though clearly designed for sharing images through a social network, has become an archive of stock images. Although the quality of images is by no means guaranteed, the size and range of the database of images outstrips many professional sites. Photosynth is an archive of 3D images from all over the world, including many industrial sites. It permits georeferencing through Bing maps and satellite images, even allowing the point cloud to be fixed on and aligned to features on these maps and images. Dropbox is a site that the user can set up to archive personal research files and to share them where desired.

While archiving vast amounts of data is a potentially robotic process, there is room for research into more human-friendly retrieval methods. Social networks as described in this chapter may be one of the more fruitful lines of inquiry.

Discussion

Much of this chapter's investigation concentrates on the arrival of networks and the decline of traditional notions of locality. It is worth considering the additional effects of speed. Even though networks lead to the decline of traditional notions of locality, they also have bolstered authenticity and presence. The speed of these networks, though, is an important additional factor. The Industrial Revolution brought the world railways, automobiles and metal steamships on the one hand, but also the semaphore, the telegraph and the telephone on the other. Virilio has argued through his concept of 'dromology' that technology is about 'the science (or logic) of speed' (1977, 47), which

leads to changes in power, conflicts and accidents. The electronic revolution of the late twentieth and early twenty-first centuries has further increased the levels of speed. Along with faster physical travel, there is information and communications technology (ICT)–based communication, which is yet significantly faster with more photorealistic representational quality. There is an aggressive, demanding aspect to the greater speed of access to information. This is partly driven by the colossal datasets and the limitations of human processing power.

The speed and universality of information retrieval may cause a disconnect with the past, even the industrial past, in that users effectively have superhuman or ‘posthuman’ powers of knowledge and awareness unavailable to their forebears to interpret archaeological sites and historic buildings. Even when considering supermodernity—the very recent and present past of the late twentieth and early twenty-first centuries—there can be a disconnect if ‘thingliness’ or materiality is left out of explanation; even sometimes, in extreme circumstances, an inability to comprehend some of the most traumatic events of recent times (González-Ruibal 2008, 251). It is not merely that people are disconnected by not being present at dramatic events or at sites of those events, and not merely by not being present in the basic daily routine of places of the past. The problem goes beyond that and is deeply embedded in the nature of the digital media that people attempt to use to describe, interpret or engage with the past.

As Turkle has written, ‘If photography is a new way of seeing, simulation is that and more: a new way of living, both a change of lens and a change of location’ (2009, xi). People often accept the superficial business of operating computers and digital media without understanding the underlying assumptions and processes built into computers and their software. In the routine of daily life, they come to accept a new way of thinking and a new way of operating quite uncritically, and thus miss significant departures from previous ways of thinking. In this way, users’ enhanced power in historic VEs gives access to areas and views that would have been limited to public access in the past (and indeed in the present).

Sites that are off limits or no longer there, at least in their past form, can be accessible virtually and will increasingly be so in the future. For archaeology, this is particularly concerning because past ways of thinking have been a core part of the discipline’s mission statement since the introduction of the post-processualist and cognitive paradigms. Indeed, because archaeology has not contributed to the development of either computer hardware or software, or to the development of the Internet, it has been a passive receiver of technologies designed by other disciplines (Huggett 2004, 81–82). Often this means there is a fetishism for the latest technology that does not have anything to do with needs or effectiveness. In addition, Huggett (2004, 86–88) has drawn attention to arguments about male bias in computer archaeology, and how

‘scientism’ drowns out not just ancient ways of thinking, but also emotional connectedness.

One of the main problems that dogs these powerful digital techniques, therefore, is how to bring in elements of time for reflection rather than robotic action. More time is required to consider the real social and cultural barriers to the past, including bygone attitudes, customs and ways of interacting with material culture. Reflection is a prerequisite for memory, and is so far lacking in much of digital archaeology and heritage, barring a few islands of good practice which actually recognise the issues and tackle them directly (for instance, Champion [2011] and Latour and Lowe [2011]). Users must encounter real social and cultural barriers, including bygone attitudes, customs and ways of interacting with material culture, to gain a truly experiential understanding of the past.

Another serious problem is that of authenticity of experience where ‘digital surrogates’ are offered as substitutes for actual physical artefacts and structures (Peters et al. 2008). For something to provoke a sense of memory, it has to feel real. Digital technology is nowhere near producing things that are authentic to all senses and to all psychological, social and cultural conditions. Whether recording (or rather capturing), analysing, displaying or even storing the memories and memorials of industrial heritage, digital methods are fairly unforgiving in terms of exposing gaps in understanding of the social, cultural and emotional/psychological realms. Failure to adequately represent these is immediately and starkly noticeable.

Finally, another weakness of digital technology is that it can be highly ephemeral and easily deleted, modified or corrupted. It requires constant curation, perhaps more so than physical heritage. This curation is not without cost in time, money and effort. Yet, the rewards for curation are tremendous in terms of the sheer quantity and quality of data that can be stored. Without constant renewal and networking, the ruins of digital records are not faded images and eroded sculptures; they are either inaccessible or just not there at all.

Conclusions

The world of ICT does not immediately lend itself to emotionally charged and authentic interaction with the industrial past. The use of digital surrogates for RL heritage can be networked with careful thought for the contextualisation necessary for memory and memorialisation to thrive (the Internet of Things). This is mirrored in the physical networks produced by the Industrial Revolution itself (the Infrastructure of Things).

Networks and trajectography are only contributors to the creation of an atmosphere in which memory can prosper. There is a tension built into trajectories in that they are not a full compensation for the feeling of presence. Many heritage workers have sought to make up for this with realism, especially

photorealism. Photorealism on its own is devoid of social interaction and cultural/material-cultural interaction. Apart from humans, other organisms and the physical and chemical environment are also actors. Furthermore, one must be aware that there will always be a conflict between the requirements of effective (but ‘artificial’) digital preservation for future generations and the authenticity offered by ‘natural’ (or rather naturalistic) ephemerality and decay, insofar as it can be recreated digitally.

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Retrospective Computing and Consumer-Led Development

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The Amiga story began via a startup company with a vision, Hi-Toro (which later changed its name to the Amiga Corporation). The technology that sprang from Amiga eventually got absorbed into Commodore—a company at war with Atari and itself.¹ As an internationally diverse group of users gravitated toward Amiga computers, problems in Commodore also escalated, eventually to a point of no return.

The Amiga was an American product that was hugely successful in Europe. It was the first multimedia computer that was also affordable. In the United States, however, the majority of users were in the entertainment industry because the Amiga was the only affordable computer that had graphics capabilities and video timing built into it.² The turning point for this user trend was the Video Toaster, which was eventually released by NewTek for the Amiga 2000 in December 1990.² That instantly made Amiga computers the go to system for high quality, yet affordable media editing and special effects. At the same time, the Amiga 500 had acquired a reputation for being a gaming computer in Europe. It was a serious rival to video-game consoles released by companies like Nintendo and Sega.³

The community that built up around the Amiga was strong—so strong that when Commodore imploded the development base for Amiga computing almost immediately shifted from the US to Europe. Operating systems like AmigaOS 4 continue to come out of Belgium,⁴ and even today new hardware is being developed in places like Germany,⁵ Italy,⁶ and Great Britain.⁷

Early online communication tools such as AmiRC were also put in place to support worldwide chatter.⁸ In fact, chat rooms, bulletin boards, and online forums have created the foundation for developer networks. Otherwise disconnected enthusiasts, who are detached from one another on a global scale, can come together to form a network online.⁹ They have kept the Amiga dream alive.

What can be considered old technology has been kept alive by users, enthusiasts who continue to find new ways to extend the life of otherwise aged computer chipsets. For example, with the aid of PowerPC accelerator boards, the last Amiga computers produced by Commodore are still being expanded in order to extend their lifespan. The original Amiga system architectures were flexible enough to enable users to hack, modify, and upgrade the system as desired. Despite a lack of advertising and in the absence of manufacturer-driven guidance, communities of users who still proudly call themselves

Amigans have built up around these personal computers from the 1980s and 1990s. Community members have become developers, communicators, and user creators for older or niche solutions. New developments for these old computers continue to emerge to this day.

Motivations for Continuing Development

Prototyping and testing next-generation Amiga computers (such as the AmigaOne) can be expensive when conducted on a small scale. However, this development initiative and effort typically is not done in hopes of a return on investment, rather it comes from people “with a mission.” The motivation is probably not simply nostalgia for keeping the old Amiga machines going—plenty of machines have become obsolete and forgotten by their one-time users. Partly the motivation may be to keep the Amiga community and style of computing alive, a type of creative computing that is geared toward artists, videographers, graphic designers, and the like in addition to the technically minded.

More than that, the motivation seems to include remembering and revisiting ideas otherwise buried in “modern” computing. For example, there are people emulating Amiga chipsets in freely available software like WinUAE as well as community preservation packages like Amiga Forever from the Cloanto Corporation. (These can be used on current computing platforms without having to buy new hardware.) One might say that retrospective or retro computing is about progress and is driven by recognizing, understanding, and building upon past achievements.

Within the user communities¹⁰ of retrocomputing platforms like Amiga (networks that are active on a global scale) are dedicated individual champions of the community’s mission. One such individual is Trevor Dickinson, a geologist by training, business angel in his day-to-day life in New Zealand, and cofounder of A-EON Technology, a company that manufactures AmigaOne systems. Despite the fact that development money from corporate America dried up long ago, Amigans like Trevor have kept what might be considered an otherwise defunct platform going. They are developing new hardware, building Amiga-based and Amiga-like operating systems for PowerPC¹¹ and x86 PCs¹² as well as fully utilizing social media for worldwide brand communications.¹³

Other Aspects of Amiga Retrocomputing

In addition to developing updated operating systems and hardware, Amiga users also breathe new life into

aging chipsets. For instance, PowerPC-based expansion hardware was first developed by Phase 5 Digital Products¹⁴ after Commodore had gone bankrupt in 1994. Developers are still driven by a philosophy introduced into their community by the original Amiga development team. Their line of thinking is to generate computing solutions that are consistent, simple, and enjoyable by design.¹⁵ When the user interface named Intuition for the original Amiga 1000 was developed, interactions between the user and the computer achieved this goal. As Director of Intuition, RJ Mical still believed this when talking about the system on its 30th birthday in 2015: “In my opinion, the Amiga gets to claim its place in the development of technology in modern civilisation.”

In this instance, the lessons learned have become apparent to retrocomputing enthusiasts over a notable period of time. Computer hardware, video-game systems, and operating systems are being kept alive by a core group of users. Progress is no longer defined by a traditional company or corporation-driven business model. Instead, ongoing developments are an unforeseen byproduct of a consumer culture, which has evolved beyond the intended commercial life cycle for a product.

In the place of centralized development workflows are enthusiastic user-creators located all over the world. These people have remained loyal to a technology when mass appeal has shifted to the next-best thing. As a cofounder of the company that developed the AmigaOne X1000 PowerPC, Trevor Dickinson is again a prime example.

The Amiga brand changed hands several times after Commodore went bankrupt.¹⁶ A nostalgia based spinoff company called CommodoreUSA even formed in 2010.¹⁷ It sold repackaged Intel PCs running a Linux-based operating system up until its founder, Barry Altman, died unexpectedly in 2012.¹⁸ Almost 20 years after the demise of Commodore, it was clear Amigans remained hungry for new hardware and software. Still lacking, however, was a sustainable development model that could make this a reality. It wasn't until Trevor Dickinson formed A-EON Technology in 2009 that this came about.¹⁹ A-EON Technology even developed working agreements with other AmigaOne hardware developers, such as ACube Systems.²⁰ In other words, sustainable development came about from within the Amiga community itself. Trevor wanted to support new hardware.²¹ As a result, a British company called Varisys soon designed moth-

Amiga computer hardware, video-game systems, and operating systems are being kept alive by a core group of users.

erboards called Nemo, in homage to Jules Verne,²² to run AmigaOS 4.²³

A-EON Technology released its first PowerPC-based computer, the AmigaOne X1000, in 2012.²⁴ It was developed around a P.A. Semi (originally Palo Alto Semiconductor) dual-core CPU and Nemo motherboard.²⁵ Because of A-EON Technology's relationship with Varisys, XCore chips were also used for Nemo.²⁶ The origins of this software-designed silicon technology—programmable semiconductors geared toward consumer-level manufacture—stemmed from a student project at the University of Bristol in England.²⁷

XMOS designed chips are one of many features used to make motherboards like Nemo easy to expand and customize. Expansion was first incorporated into “classic” hardware by people like Jay Miner, the engineer considered to be the father of the Amiga. In fact, it was this ability to expand and customize the original chipsets that enabled the long-term survival of Amiga-based computing in its wilderness years.

The XMOS XS1-L2 124 chip was renamed Xena for the X1000 because Dickinson wanted to keep with tradition. He had been a devotee of Commodore-branded computers since the days of the 4032 (PET),²⁸ and Amiga chips had been referred to by female names since Agnus, Denise, and Paula.¹ This was the chipset designed for the original Amiga 1000. Material quirks from the Commodore years were also added to the motherboard. For example, hardware engineers like George R. Robbins engraved B-52's song titles onto their work. The Amiga 500 and 500+ featured “Rock Lobster,” the Amiga 600 had “June Bug,” the Amiga 1200 contained “Channel Z,” and the Amiga CD32 was “Spellbound.”²⁹

Trevor's motivations for developing updated Amiga systems were personal and linked



Figure 1. Trevor Dickinson running a demonstration of the AmigaOne X1000 computer at Amiga 30, held at the Computer History Museum on 25–26 July 2015. The A1222 computer (Tabor board) can also be seen on the table (far right).

to his deep understanding of the Amiga community. His aim to create new hardware has been further cemented through the release of the AmigaOne A1222, X5000/20, and X5000/40 in 2016.³⁰ Developments were not primarily based on monetary gain, or his experience as a successful businessman: “To be perfectly honest, I really had no idea if the AmigaOne X1000 would sell or not. As a long time Amiga enthusiast, I knew there was a pent-up demand for more powerful modern AmigaOS hardware. After all, I wanted one myself!”³¹

Personal desire did not cloud Dickinson’s judgment, however. By the time A-EON Technology was formed, his experience in business steered design processes in the right direction:

We took a phased approach to developing the Nemo motherboard for the A1-X1000. The first step was a proof-of-concept and we pre-funded US \$115K for initial development and prototyping. Five prototypes were manufactured for stress testing and porting AmigaOS 4. After review we took the decision to make a number of minor design improvements and create a revision 2 motherboard. Revisions cost more time and money and delay. Prototypes are also very expensive because they are made in very small volumes and can cost up to USD \$5000 per board.¹⁹

The Cyrus and Tabor motherboards followed Nemo. They were used for the AmigaOne X5000/20, X5000/40, and A1222. Like Nemo, they were also named after characters from *20,000 Thousand Leagues Under the*

Sea by Jules Verne. Part of the development process for Cyrus included 50 beta testers from the Amiga user community. Incorporating XMOS technology into its design brings a flexibility of use familiar to anyone who has worked with programmable chips.³² The idea of using programmable chips to build new hardware was taken to a new level within the Amiga community by Dutch electrical engineer Dennis Van Weeran in 2006.³³ He used a field-programmable gate array (FPGA) chip to create the MiniMig, which is open-source hardware that replicated the Amiga 500.³⁴

A-EON Technology drew inspiration from all parts of Amiga history when designing its computers. For example, the AmigaOne X1000 combined expandability, implemented by the original Amiga development team, with ideas taken from independent developers like Van Weeran. In a more playful gesture, the B-52’s song titles “Breezin” and “Topaz” also made it onto the Cyrus and Tabor boards. Their predecessor, the Nemo motherboard, encouraged AmigaOne X1000 owners to “Keep This Party Going.” The Cyrus and Tabor motherboards also incorporated Freescale chips, much like the Efika series of motherboards produced by Genesi. (The move to Freescale by A-EON Technology was after P.A. Semi was acquired by Apple. In 2015, Apple announced that it may consider using its own custom chipsets for iMac and Macbook from 2016 onward.)

Integrated Retail

I see the timing of the resurgence in Amiga-infused hardware as feeding into broader changes taking place in the world of product development, marketing, and distribution. Information and communication technologies have increased the likelihood of independent or small-scale production taking place. For example, digital distribution sites like Steam provide an outlet for game developers.³⁵ They enable user creators to have direct control over how they reach a customer and sell their products. This distribution model was also introduced into the Amiga community at Amiwest 2014, where the creation of Amistore was announced.³⁶ Through the social networking aspect of such online stores, a shift in consumer culture has occurred that has been referred to as *integrated retail* by Sears-run iRLabs.³⁷

When Amiga Turned 30

The first Amiga computer turned 30 years old in 2015. There were celebrations all over

the world to mark the occasion throughout that year, including a two-day event held at the Computer History Museum in Mountain View, California, on 25–26 July 2015 (see Figures 1 and 2). As someone who attended Amiga 30 USA, it was interesting to observe the new information that came out of the event. Dave Morse, the businessman behind Hi-Toro and Amiga Corp., was seen as being a main driver for making the original Amiga development team what it was.³⁸ Joe Decuir and Ron Nicholson, the first two hardware designers to work closely with Jay Miner, also shed new light on how the Amiga system architecture came about.³⁹

New operating systems descended from the original AmigaOS were also on display at the 30th anniversary event at the Computer History Museum. AmigaOS 4, AROS, and MorphOS evolved from the last operating system released by Commodore, Workbench (part of AmigaOS) 3.1. AROS is open source and can run on most computing platforms. AmigaOS 4 and MorphOS are primarily PowerPC based.

Prior to the Amiga 30 events, there were also efforts to bring the user community together online. For example, a location-aware approach was developed in 2011. User maps created in Google Earth⁴⁰ show where Amigans are based to encourage peer-to-peer engagement. Graphical representations of user numbers have also been created for different countries. These graphs show that the independent developer model now in place has resulted in a shift such that the majority of hardware and software development (and user culture as well) is now happening in the European Union, not in the US. That said, Googlers like Christian Stefansen have ported the Amiga 500 version of AmigaDOS to the Chrome Internet browser.⁴¹

Conclusion

Amiga technology came into being decades ago. The concepts (and some of the actual system components) had staying power despite the failure of the original manufacturer. Developers and users around the world continue to push and use Amiga derived and expanded technology. This is more than retrocomputing as a desire to simply reclaim past computing technology. This is an example of continued technology development by a community of invested users, a sort of consumer-led development.



Figure 2. Dave Needle standing next to the first Amiga computer to come off of the production line at the Sanyo factory in Japan. Dave was a hardware engineer and renaissance man of the original Amiga development team. With RJ Mical, Dave went on to cocreate the Atari Lynx and 3DO games consoles. Early RISC-based prototypes of the 3DO were also designed on an Amiga. This photo was taken by Adam Spring as Dave prepared a display for the Amiga 30 USA event held at the Computer History Museum. Dave passed away on 20 February 2016.

Acknowledgments

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4. The rights to AmigaOS 4 were granted to Belgium-based Hyperion Entertainment after a legal battle with Amiga Inc. ended in 2009; see www.hyperion-entertainment.biz/.

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7. A-EON Technology (www.a-eon.com) stemmed from a partnership between AmigaKit.com owner Matthew Leaman and Trevor Dickinson.
8. AmIRC (www.amirc.org) is the Internet relay chat client for all Amiga and Amiga-like computers.
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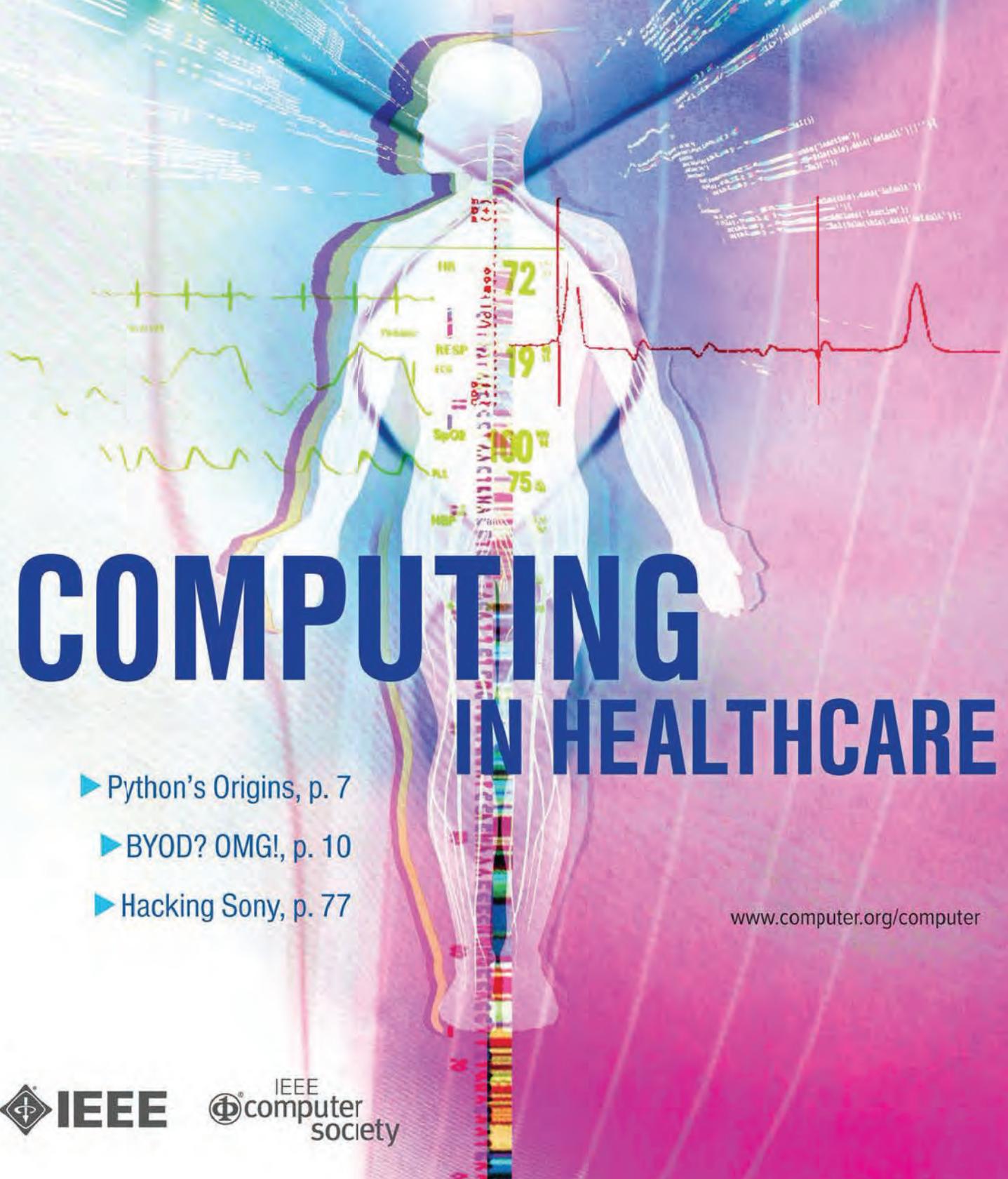


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Creating Substance from a Cloud: Low-Cost Product Generation

Adam P. Spring, University of Plymouth

With a more controlled way to capture images, services to generate and process 3D data point clouds, and a 3D printer, amateur photographers can convert 2D photos into physical 3D objects.

In his 2011 best seller, *The Third Industrial Revolution*, economist Jeremy Rifkin explains how design and manufacturing have become decentralized processes that feed into the digital economy.¹ By operating through an infrastructure built on the Internet of Things (IoT), he argues, next-generation information and communications technology (ICT) is replacing factory-based production methods. Delocalized production techniques have developed around computer-aided design (CAD) and manufacturing (CAM), replacing Henry Ford's conveyor-belt assembly line with an anywhere, anytime production line connected through digital devices and ICT.

Affordable 3D printing is one aspect of this transformation, and 3D imaging technologies are an excellent way to understand the Third Industrial Revolution's impact on product development. For example, by implementing more controlled photographic techniques along with an easy-to-use 3D imaging service, anyone with rudimentary photographic skill can turn 2D photos into 3D solid-surface objects.

An application to replicate a cultural heritage monument from a popular 2D camera illustrates the mechanics of this production approach as well as the potential of CAD/CAM practices that align with concepts such as the IoT. The

workflow derives from *photogrammetry*, which retrieves measurable data from photos, and uses a service based on *structure from motion* (SfM), a product of computer vision research. However, neither the equipment nor the workflow in the proposed approach is exclusive to experts in those domains; rather, they are accessible to any amateur photographer. The technology is readily available to anyone with access to a camera, the Internet (to work with open source or low-cost user-friendly programs), and a retail 3D printer.

As part of a cultural heritage project to examine connections between Great Britain and Germany during the Industrial Revolution, my colleague Caradoc Peters and I investigated several monuments in both countries. As part of this investigation, I applied the proposed production approach to convert 2D photos of one of the monuments to a 3D physical replication. I used the following items in my work:

- ▶ a Canon EOS 60D digital single-lens reflex (DSLR) camera and 50-mm Canon prime lens;



WORKFLOW BASED ON POINT CLOUDS

A point cloud documents a scene in 3D in the same way a photo documents a scene in 2D. Its z-coordinate adds depth to the scene collected in 2D that contains x and y coordinates. Services like Photo from Autodesk ReCap 360 exploit the idea of 3D documentation, adding the z coordinate in the 3D generation of conventional 2D photos.

The point cloud signified a move from linear 2D processes to nonlinear workflows centered on a 3D model,¹ and by the late 1990s, a commercial market had started to form around the point cloud as a usable framework in computer-aided design software, similar to AutoCAD.² Point clouds can be generated via structure from motion-based services and solutions using little to no calibration. Agisoft PhotoScan (www.agisoft.ru) and Autodesk 123D Catch (www.123dapp.com/catch), as well as Photo, use SfM and multiview stereo (MVS) image-matching solutions to turn 2D photos into 3D point clouds and surfaces.³ SfM produces usable 3D results because it is looking primarily for matching points in a scene. Photos and images can come from any source, from a digital single-lens reflex (DSLR) camera to a search engine, and even crowdsourcing from multiple cameras and users worldwide.³

3D imaging technologies now let users collect as-built information at unprecedented resolution and scale. Because of this paradigm shift, it has become easier to document a building or cityscape with subcentimeter accuracy.² This ability to collect in situ information with 3D imaging technologies is an important part of a cultural heritage workflow

that captures an artifact's or site's remains without risk of contamination. 3D imaging technologies give heritage practitioners the ability to examine sites or artifacts in the same amount of detail as a forensic scientist would a crime scene.

In terms of Jeremy Rifkin's *Third Industrial Revolution*, the point cloud is a visual medium and an agent for social and economic progress. It is comparable to the steam printing press or early forms of electronic communication in that it can transmit an idea or provide a better sense of context. The Building Information Model (BIM), for example, is an infrastructure and asset management strategy that uses point clouds to create intelligent objects linked to numerous forms of information.⁴ Industry cultivates point cloud use through workflow models based on information and communications technology (ICT). The Rip-Mod-Fab or Capture-Compute-Create workflow models employed by Autodesk are good examples.

Figure A shows one such model, in which services and apps replace centralized fixed production modes. Users with no specialty skills collect scenes through sensors in inexpensive equipment and send them to cloud-processing services, export and refine them through low-cost or open source solutions, and disseminate results through an ordinary mobile device or 3D print out.

In this new workflow model, data informs design and manufacturing, and performance—the way in which the user and equipment interact with the object being scanned—dictates practices. Performance in this context is important because even

- ▶ Photo—an Autodesk ReCap 360 service that creates 3D point clouds and solid surface meshes from photos (<https://recap360.autodesk.com>);
- ▶ CloudCompare, a program that processes the resulting 3D point cloud and solid surface mesh (www.danielgm.net/cc);
- ▶ MeshLab, a program to process and edit unstructured 3D triangular meshes (<http://meshlab.sourceforge.net>);
- ▶ MeshMixer, an Autodesk 123D-related tool for 3D mashups and remixes from custom 3D designs or provided models (www.123dapp.com/meshmixer); and

- ▶ a Dimension 1200es 3D printer from Stratasys (www.stratasys.com/3d-printers/design-series/dimension-1200es).

This list suggests that point clouds—data points in 3D space—and associated solid-surface meshes could become the new template for design and manufacturing, as the sidebar “Workflow based on Point Clouds” describes.

DOCUMENTING THE SUBJECT

The subject of the sample application is a steam cylinder used in a Watt engine water pump that once serviced copper mines

in the Saxony-Anhalt region of Germany and is situated in Löbejün. The Mansfeld Museum in nearby Hettstedt houses a replica of the engine that contained the cylinder. Figure 1 shows the monument and its proximity to the museum.

The cylinder was cast in 1788 in Glamorganshire, Wales, and later exported to Germany, where it formed part of that country's first steam-powered pumping engine and was in use until 1848. In 1934, the cylinder was mounted on a pedestal to commemorate Germany's first use of steam power.

Documenting the cylinder's history is part of a cultural heritage project that is examining the impact of British



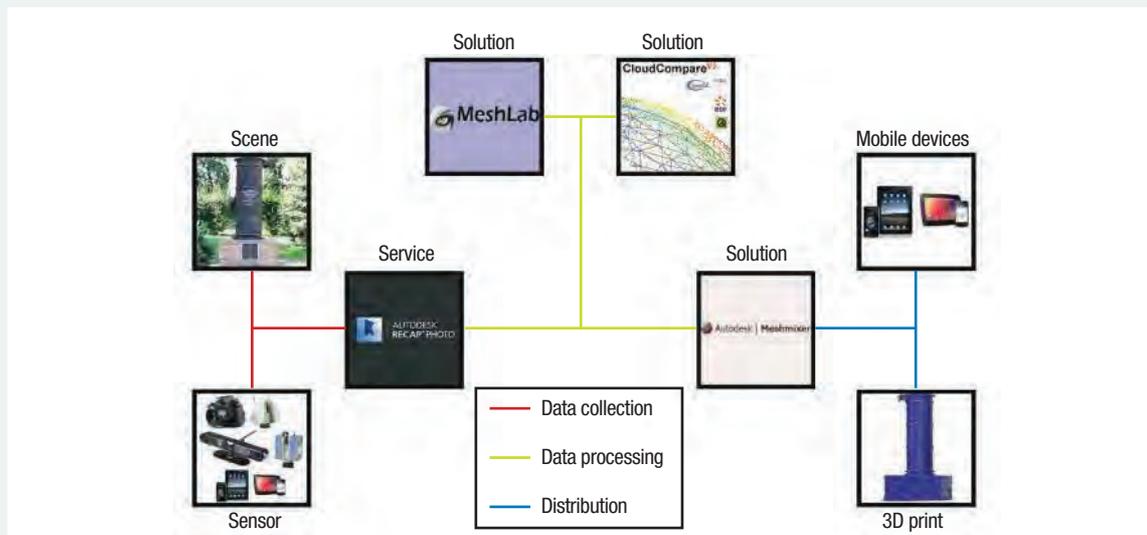


Figure A. Service- and solution-based 3D production line. Collected data enters a service to convert 2D images to a 3D point cloud and mesh, which solutions like CloudCompare and MeshMixer refine. Users can then export and process data in a form suitable for a 3D printer or mobile device.

individual users never produce exactly the same set of data every time.⁵ The Löbejün monument workflow followed this model in that the preservation state informed the production and reproduction cycle. The only modifications were to delete unwanted data and fill any gaps in the generated 3D mesh; both steps were necessary to reproduce the monument as an authentic 3D printed facsimile.

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mining technologies and workforce emigration in Germany in the late 18th to early 19th centuries. The project's goal is to record site features and artifacts in a way that merges geographically disconnected information and creates a single channel for disseminating results. It is one of many projects that are exploiting the new relationship between IoT and 3D imaging technology. The sidebar "Technology, 3D Imaging, and the Internet of Things" describes this relationship in more detail.

DATA CAPTURE

The photogrammetric specifications for documenting the monument, shown in

Figure 2, came from Adam Technology (www.adamtech.com.au), an Australian company that converted its analog stereo plotter solution into a software package called 3DM Analyst in the mid-1990s. The specifications are for a camera using the Advanced Photo System type-C (APS-C) image-sensor format—specifically, the Canon EOS 60D—with focal length and aperture considered alongside their equivalents for a full-frame 35-mm camera. APS-C is approximately equivalent in size to negatives of 25.1 × 16.7 mm (aspect ratio of 3:2), which is much smaller than the 36 × 24 mm for standard 35-mm film.

Sensor size and type are directly

related to pixel size and resolution and thus help determine the optimum resolution for creating a 3D point cloud or solid surface mesh from the camera's output. Because most standard lenses are designed for full-frame camera sensors, when a DSLR camera sensor is cropped, the lens' focal length increases.

Figure 3 shows adjusted Canon EOS 60D settings to improve subsequent 3D image translation. Photogrammetrists refer to this process as *interior orientation*—linking known parameters to the sensor. For the Löbejün monument shoot, I put the camera's APS-C sensor in aperture priority mode (AV) with auto rotate switched off and used an





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FIGURE 1. Steam cylinder monument in Löbejün, Germany, and replica of the steam engine that contained the cylinder at the Mansfeld Museum in Hettstedt.

ISO setting fixed to Canon's ideal sensor setting of 100 for sunny daylight. I set the aperture to 5.1—the equivalent of 7 or 8 on a full-frame camera—and, after automatically adjusting the focus, switched the focus setting to manual.

Although Photo automatically calibrates the images, regulating pixel information according to variables like surface reflectance and depth of field improves the quality of the meshes generated.²

The need for such regulation stems from the difference between photogrammetry and computer vision. Photogrammetry uses known distances and variables to derive metric value from images. 3DM Analyst, for example, creates 3D models by evaluating each stereo pair. In contrast, solutions based on computer vision concepts, such as SfM, generate 3D projections from photos using image resolution, the shapes within the image, and bundle adjustment based on multiview stereo scene reconstruction.³ SfM-based generation does not require calibrated images,² and, in this respect, it is in line with the solid-surface modeling

techniques in computer graphics.⁴ Before it crossed into surveying-based applications, SfM was popular in disciplines such as robotics as a relative navigation tool that used scene reconstruction to guide vehicles or robots.

In photogrammetry, camera settings and shooting conditions are the camera model's interior and exterior orientations. Each camera model links known variables, such as focal length, to the creation of multiple photos, or photo batch. Photogrammetry adjusts the camera lens and sensor settings according to the scene's environmental conditions. For example, the base-to-distance ratio (the distance between each image in relation to the camera's distance from the object) can improve the quality of a 3D projection from a photo batch.

SfM-based solutions like Photo are similar to photogrammetry software like 3DM Analyst in that the 3D production cycle is linked to the camera location's six degrees of freedom: x , y , z , ω (ω), ϕ (ϕ), and κ (κ).³ Because it is adjustable, scale is arguably

the seventh degree of freedom in a camera-based 3D workflow.

Observance of the common camera parameters in Table 1 and adherence to the shooting recommendations in Table 2 will improve image continuity in an SfM-based projection.

GENERATING THE 3D OBJECT

I photographed the monument moving left to right in a circular pattern, making sure that the depth of field was consistent across scenes and that I documented as much of the monument as possible. Having some of the surrounding area in each photo improves the likelihood of successful batch processing in Photo by matching surfaces for an otherwise geometrically regular object to the correct viewpoint and image.

I ran 102 images through Photo along with measurements from placing two standard rulers on the monument. The goal of this extra step was to add metric information to the scene through Photo's registration function in the Advanced Tools setting (Photo-to-3D interface), which also allows users to choose the photos for adding texture to the surface of the newly created 3D mesh.

Before running images through Photo, users can save the resulting 3D scene in the .rcm, .obj, .fbx, .rcs, or .ipm format. I chose to export the Löbejün monument scene in .rcm and .obj at maximum resolution. Photo took 2.8 hours to generate the scene and upon completion sent an email notification to my account.

PROCESSING AND EXPORTING THE SCENE

Figure 4 shows the 471-Mbyte .obj file that contained a 3D mesh consisting of



Camera Name:		Canon 60d	
Camera Details	Width	Height	
Number of pixels:	5184 x	3456	Image size: 17.9 megapixels
Image sensor dimensions:	22.3 x	14.9 mm	Field of View Crop/Lens multiplier: 1.6 x 1.6
Actual focal length of lens x adapter:	50	mm	Equivalent 35mm camera focal length: 81 mm
Actual aperture:	f/	5.1	Equivalent 35mm camera aperture: f/8.2
Focus distance:	3.00	m	Depth of field: 2.82m - 3.21m
Desired circle of confusion (diameter):	2.5	pixels	Hyperfocal distance: 45.63 m
Size of each pixel in CCD array:	4.30 x 4.31	um	3DM Analyst camera calibration settings: 0.00430 x 0.00431

FIGURE 2. Canon EOS 60D digital single-lens reflex (DSLR) camera specifications linked to photo rectification and photo resolution in accordance with the Adam Technology shooting framework in 3DM Analyst.



FIGURE 3. Adjusted Canon EOS 60D settings to improve 3D image translation. Using these settings maintains continuity between each image and can thus improve the resulting 3D projection.

TABLE 1. Common camera parameters and their relation to 3D projection.

Resolution	Depends on sensor and lens	Environmental factors can affect photo resolution, such as lighting, surface reflectance, and weather
Focal length	Measure from lens to sensor	For each shoot, maintain same focal length and focus setting to rectify the photo batch and ensure undistorted images
Sensor size	Depends on camera	Affects 3D projection resolution
Lens	Each lens has a perspective center that determines camera position	Better information is collected at the center of the lens—this should be considered when shooting stereo pairs, as should angle of incident of scene shot in relation to the object
Auto rotate	Automatic rotation	Disable to lock down photo's x and y coordinates
Pixel size	Optimum resolution for collecting data	The Canon EOS 60D has a photodiode pitch of 4.3 μm, which is a resolution linked directly to its internal sensor
Native ISO setting	Depends on sensor	Shooting at this setting in ideal lighting reduces photo's digital noise
Aperture size	Depends on application	Affects depth of field



TABLE 2. Photo-shoot recommendations to improve 3D projection.

Base-to-distance ratio	Manipulating the ratio adds scale to a photo shoot; for example, a scene 1 km away from the camera has a 1:1 scale if each camera position is 1 km apart
Scene composition	Placing targets in a scene provides scale and known geometry; make sure as much of the object or scene as possible is in each photo
Capture mode	Using a monopod, tripod, or automatic trigger can improve a photo shoot; for example, all these items can help blur reduction in low-light shooting
Scope	Where possible, take each photo to ensure a 60 percent overlap; take stereo pairs in landscape and portrait views with auto rotate switched off



FIGURE 4. 3D scene of the Löbejün monument in Photo. The scene represents a triangular mesh of 5.63 million triangles. Users can view a generated mesh at reduced resolution before exporting it as a .rcm, .obj, .fbx, .rcs, or .ipm file.



FIGURE 5. The Löbejün monument printed on a Dimension 1200es 3D printer from Stratasys. The final print was 19 cm high with a 10 × 10 cm base.

5.63 million triangles. I ran the .obj file in CloudCompare and MeshLab before exporting it to MeshMixer as an .stl file.

CloudCompare

CloudCompare began as part of a PhD project at Télécom ParisTech in 2004 to improve 3D imaging workflows in industrial plants in France and became open source software in 2009. It uses an octree file structure that splits large datasets into eight manageable interconnected sections. Users can then highlight a particular section and remove redundant or otherwise unwanted data as needed.

For the Photo scene in Figure 4, CloudCompare pared the file to 97.1 Mbytes. I simply chose the Segment function and deleted unwanted data outside the highlighted area. If datasets prove too large, users can process them through Photo at a lower resolution. An alternative is to export the datasets to CloudCompare through

Photo at the maximum resolution and then select CloudCompare’s meshing function to reduce the number of triangles or segment the file. Autodesk is also beta-testing Project Memento (<http://labs.autodesk.com/utilities/memento>), a meshing solution for larger files.

MeshLab

MeshLab is open source 3D modeling software that originated as a course assignment at the University of Pisa in 2005. Although it has difficulty handling more than 300 Mbytes of 3D data, its functions and file export options make it a useful processing tool. Among these options are the ability to export files in .stl, the standard 3D printing format, and to present 3D data on a smartphone or tablet running either Android or iOS (available from Google Play or iTunes, respectively).

MeshLab exported the 97.1-Mbyte CloudCompare .obj file as a 47.3-Mbyte .stl file, which was then ready for the software that would prepare it for 3D printing.

MeshMixer

MeshMixer, developed at the University of Toronto, is an Autodesk tool for working with unstructured polygonal meshes, providing functions such as mesh cleanup and surface sculpting and modeling, including surface extrusion.

I imported the MeshLab file of the Löbejün monument into MeshMixer primarily to fix holes in the mesh—essential to printing the artifact in 3D. MeshMixer automatically highlights any holes, which users can fill by selecting the Analysis function and clicking on Inspector. MeshMixer identifies holes as various colored balls, which





TECHNOLOGY, 3D IMAGING, AND THE INTERNET OF THINGS

Since its conception as the Parliament of Things in 1991, the Internet of Things (IoT) has slowly penetrated mainstream computer science to the point that researchers are beginning to see it as the foundation of the Third Industrial Revolution; indeed, Cisco Systems recently dubbed it the Internet of Everything. Despite its seeming rebranding, however, the underlying philosophy—humans and objects are independent agents in knowledge distribution and communication—has remained constant.¹

The IoT acknowledges that people interpret, synthesize, and communicate their perceptions of the world through any device at hand. It is part of the Symbiotic Web, or Web 4.0, which describes how connectivity via the Internet makes it easier to crowdsource and network data. Workflows such as that used for the Löbejün monument can help people make better sense of the considerable data now at hand.

Because information generated in this manner is subject to human error, processes like 2D and 3D image production always have room to improve. Smartphone and tablet technologies, for example, have made it easier to apply the IoT to 3D imaging.² Cloud-based services like Photo leverage the IoT and Third Industrial Revolution concepts to make ICT easier to understand and use, supporting notions such as as-built and as-designed information. By eliminating the parts of a process that used to be accessible only to domain experts or large manufacturers, services like 123D Catch and Photo are reshaping computer-aided design and manufacturing on a daily basis.³

At the same time, data is becoming increasingly easier to collect, use, and distribute, which is creating gray areas in this industrial revolution. Cultural heritage documentation is one such area. Solutions such as those used to document and

replicate the Löbejün monument impose structure on this freely obtained data—in this case, by assigning parameters to 2D images that make them easy to replicate in 3D. At the same time, the workflow emphasizes affordability and adaptability and represents the best fit for the given application. Other applications might use different parts of the workflow, depending on the services and solutions desired.

Attempts to impose structure are also evident in numerous product refinements. 123D Catch appeared in May 2011 as a desktop-based portal that sent photos to the cloud for processing and in 2012 extended its services to smart technology users through an iOS application. Photo's vendors released it in 2013 as ReCap Photo to serve as the professional equivalent of 123D Catch. By February 2014, they had refined ReCap Photo to support GoPro cameras, texture and mesh display, smart cropping, and boundary selection, and they had given it a new user interface.

Affordable depth cameras from companies like Prime Sense, makers of the active triangulation sensors inside Kinect for Xbox 360, have enabled 3D imaging, point clouds, and solid surface meshing for a broad range of users. Acquired by Apple in November 2013, PrimeSense also supports middleware and application development through OpenNI, software development kits, and websites.

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users can see and resolve by double clicking on the Auto Repair All option.

The Löbejün monument mesh had several holes, including a large one in the monument base, which MeshMixer represented as a red ball. Although Auto Repair All worked fine in this case, I could have also filled the base by clicking on the red ball, selecting Edit, and clicking on Erase and Fill. The program would then insert a predetermined

shape from the selection on the screen's left side. Users can adjust the shape's form and size by reducing it in the Tools Properties window or smooth the shape by clicking on the Modify Selection and Smooth Boundary options.

Finally, users can extrude flat surfaces through the Edit function, which is useful in printing otherwise flat or paneled scenes, such as wall inscriptions or rock art.

The latest version of MeshMixer also links to Autodesk's 3D printer utility (<http://apps.123dapp.com/3dprint/install.html>), which is compatible with affordable systems like MakerBot, Stratasys's Objet500 Connex, and Objet Geometries' Alaris30. In May 2014, Autodesk also launched Spark (<http://spark.autodesk.com>), its open source platform for developing 3D printers. The first system to come out of the Spark





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initiative was Ember. Other open source 3D printing projects include RepRap (<http://reprap.org>), which came out of the University of Bath, UK, in 2005.

3D PRINTING

I imported the .stl file into the CatalystEX operating software of the Dimension 1200es 3D printer and manually input surface dimensions. Figure 5 shows the output.

Although a 3D printer was readily available, I could have used other services to create the replica. For example, Autodesk's 123D Make (www.123dapp.com/make) can convert an .stl file into slices that a regular printer can print on cardboard. Online services like Shapeways (www.shapeways.com) also let users upload a file onto the company's server, specify the print medium from various materials, and request shipping. Users of any 3D print program can disseminate their results on community websites such as MakerBot's Thingiverse (www.thingiverse.com).

Tools like Autodesk ReCap 360, CloudCompare, MeshLab, and MeshMixer are enabling low-cost, easy-to-use 3D imaging and CAM solutions based on data that can come from any source or location and from users with a variety of skills. Leveraging technology-workflow combinations such as that used to document and replicate the Löbejün monument, any camera, smartphone, or tablet can reproduce an artifact's actual preservation state. Whether it is through crowdsourced or networked data from the IoT, as-built plans, nonlinear models, or 3D prints, strategies to structure increasing dataflow must become part of creating products in this collaborative era of document, design, and manufacture.

In this respect, the Third Industrial Revolution feeds into the IoT. Both are being presented to general audiences as user-friendly terms—even in the context of 3D imaging and manufacturing. Fundamentally, however, they are used to describe changes that fall in line with

the Symbiotic Web or Web 4.0. Internet evolution and the way in which people interact with digital technologies are ultimately freeing up design and manufacturing processes to a wider population, shifting focus from centralized production modes to more dispersed collaborative efforts, which are often the source of true innovation. **■**

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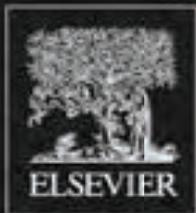
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Developing a low cost 3D imaging solution for inscribed stone surface analysis



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ABSTRACT

The article uses a 3D imaging based solution where surface shading is determined by surface geometry. It is applied to inscribed stone surfaces in order to examine lettering and other carvings dated to the 5th - 9th centuries AD. Mid-range terrestrial laser scanning and structure from motion (SfM) based photogrammetry were cross-examined in order to create a low cost, but nevertheless highly accurate solution to 3D imaging that requires a computer, a camera, open source software like CloudCompare and a SfM based service called Photo located at ReCap360.autodesk.com. Ambient occlusion (AO) shading was used to show improvements made to the SfM data, which was achieved by adding known parameters to all photographs used. It simulates the direct light components of a light source so that exposed areas appear lightened and enclosed areas (like crevices and incisions) appear darkened. In the case study, AO was used to differentiate lettering in the inscription from damage and weathering on the granite surface of the Tristan Stone, as well as picking up a previously unnoticed wheel-head cross. This particular inscribed stone is located near Fowey in Cornwall, UK, and was known as the Long Stone before its name was changed on British Ordnance Survey (OS) Maps in 1951. The Tristan Stone was the first artefact to be scanned by the FARO Focus^{3D} laser scanner after its release in 2010.

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1. Introduction

Using the case study of the Tristan Stone, a 3D imaging solution is used that, unlike texture mapping, provides shading based on coordinates and actual surface information. In other words, a surface is actually mapped and then that data is used to show what is actually on that surface by controlling a light source based on surface features. It is not a relief or impression of 3D. The interpretation is actually based on surface geometry, or the digital mould created from the data. Unlike texture mapping techniques, such as RTI (MacDonald, 2011), or computer vision solutions like SfM (Davelli and Signoroni, 2013, 577), this technique does not involve a compromise in accuracy in order to get convenience or cheapness. Using what is referred to as a theoretical camera model by photogrammetrists, known parameters and known accuracies are increased along with repeatability of results.

Two sets of data were used as source material for the 3D imaging process. Mid-range terrestrial laser scanning (TLS) and structure from motion (SfM) based photogrammetry were applied to the

Tristan Stone located in Cornwall, UK. The inscriptions on the stone have been associated with the tale of Tristan and Iseult from the Arthurian legends since the 20th century (Radford, 1975; Padel, 1981, 1991; Thomas, 1994), and are currently married to the 5th - 9th centuries based on stylistic dating methods (De Mandach, 1978; Padel, 1981, 1991; Okasha, 1993; Thomas, 1994). There are perhaps as many as 1500 inscribed stones like the Tristan Stone scattered across the landscapes of the Celtic-speaking regions of the British Isles (Forsyth, 2012). Fig. 1 shows that a problem with inscribed stones is migration, with their current position on the landscape not necessarily being their original location (De Mandach, 1978, p. 229; Davies et al., 2014). Current interpretations of their meaning are based primarily on historical documents and observation based techniques like raking light (Radford, 1975; De Mandach, 1978; Okasha, 1993; Padel, 1981; Thomas, 1994).

A low cost computer vision based solution was devised to identify remains on the surface of the granite artefact. It is outlined in this article and can be applied to other surfaces and materials. It was used to examine features on the stone, which are presented in Fig. 2. Inscriptions that are no longer visible when examining the monument in situ. Point cloud data generated from a FARO Focus^{3D} phase shift laser scanner and from photographs taken with a Canon 60D digital single lens reflex (DSLR) camera are compared in order

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to confirm the presence of new discoveries. A computer graphics technique called ambient occlusion (AO) shading, which can be used to enhance features based on surface depth (Langer and Bühlhoff, 2000; Borgo et al., 2001), was applied to the 3D data by using software called CloudCompare. It was developed by Daniel Girardeau-Montaut when he was a PhD student working with Électricité de France (EDF), and has been open source since 2009 (Girardeau-Montaut, 2014). The methodology can be used to give an accurate understanding of what remains on the inscribed stone. Information is derived from solid surface meshes or moulds created from sensor data. This means that it is a technique not restricted to small objects or monuments. In fact, it can be applied to artefacts, structures or landscapes of all sizes (Zakšek et al., 2011).

2. Methods

2.1. Why the Tristan Stone is such a useful example for AO

Early Medieval in date, the Tristan Stone is one of many inscribed stones found all over the British Isles - predominantly South West England, Cornwall, Ireland, Scotland and Wales (Edwards, 2001, 2007). Used as memorial stones, the now weathered granite surfaces of the examples in Cornwall have often fallen prey to unresolvable disputes and speculations as to their meaning (Petts, 2002). The Tristan Stone is no exception.

The Tristan Stone was originally referred to as the Long Stone before its official change on Ordnance Survey Maps in 1951 (De Mandach, 1978, p. 227). The change reflected a linkage between the name of the individual commemorated on the stone with that of Tristan from the Arthurian legends. William Camden in 1586 was the first to record the name. He read it as 'Cirusius' (Gibson, 1722, p.18). Later in 1754, William Borlase made a more detailed drawing of the stone, again confirming the name as 'Cirusius' (Borlase, 1754, Fig. 2). It was only with a growing interest in ancient scripts, particularly uncials (influenced by Greek script), that new interpretations came in. In 1876, Hübner suggested that the first two letters were in fact an uncial 'D' with the curved side facing backwards (Hübner, 1876, p.7). This led to the idea that the name was actually 'Drustanus' and perhaps a Latinised form of 'Tristan'. Raleigh Radford (1951, p.117) and later Charles Thomas (Thomas, 1994; pp.279–280) championed this idea, even leading to the official OS name change for the stone. This interpretation was never fully accepted. Macalister (1945, pp.465–466) and Okasha (1993, pp.92–94) have both preferred to stick to the original interpretation on the basis that the script appears to be largely Roman capital letters and that they saw the 'C' and the 'I' as being distinctly separate.

Historians, however, have been unimpressed by the Tristan arguments. A study by Rachel Bromwich (1953) demonstrated that the Tristan legends were of diverse Celtic origins from different parts of the British Isles. Moreover, the idea that Tristan had been based in Cornwall only came about in the 12th century. Despite this key finding, archaeologists like Radford chose to ignore the historic evidence and debate the supposed physical evidence of the Tristan Stone inscription (Hutton, 2006, p.45). The Tristan Stone inscription remains the main archaeological evidence for the Tristan legend in Cornwall. This is why the 3D depth images generated by the laser scanner and by DSLR based photography are so important in providing an objective account of what remains on the surface.

Given the reinterpretation and renaming of the stone, the area perceived by some to depict the name 'Drustanus' was the point of interest when the scan data and photographs were used to document it. In Fig. 3a, AO shading was used to examine remains on the area where the archaic form of Tristan is meant to exist. This helped demonstrate clearly that the backwards curve and the vertical line

are separate. They represent a 'C' and an 'I', not a backwards uncial style 'D'.

Apart from discerning lettering in the inscription, AO helped pick out the full extent of the cross design on the back. A number of the past commentaries on the Tristan Stone have noted the presence of a tau-cross (a cross in the shape of the Greek letter 'τ') – for example William Borlase (1754, Fig. 4), Emil Hübner (1876, p.7) and Elizabeth Okasha (1993, p.92). One author, Samuel Lysons (1814, p.ccxix) however notes 'a plain cross'. The AO from this study has revealed that the 'tau' shape was simply the unweathered portion of a wheel-head cross.

2.2. Camera model

It is important to distinguish between a fixed 'camera model' required for accurate measurement such as used here and a flexible 'camera model' used in vision techniques designed for navigation. The latter vision techniques ultimately need calibration to achieve any sort of accuracy.

'Camera model' is a term used to identify all variables associated with data collection in a 3D imaging workflow. The camera in this sense is seen as a measurement device collecting point or coordinate data. The model is also known as the collinearity model, and is used to work out the relationship between coordinates in the image or sensor plane (Schenk, 2006, p.59). This includes the relationship between the image and object points collected, which concur at the perspective centre of the sensor (Matthews and Noble, 2008, p.2). Fig. 4a and b show how the camera model can be used to discuss parameters for the interior orientation or properties of the sensors used. Table 1 is also used to explain image plane (sensor size) seen in Fig. 4a in more detail.

The relationship between the image and object points generated is also impacted upon by the exterior orientation or properties of the scene documented (Matthews and Noble, 2008; Spring et al., 2010). Exterior orientation includes variables like the distance between the sensor and the object, the distance between each camera position, light conditions, the reflective properties of a surface or any variables external to the sensor that affect the quality of the data collected (Matthews and Noble, 2008; Spring et al., 2010). The camera model can be used to refer to a laser scanner, which is also known as a depth camera (Cui et al., 2010), or indeed, to refer to a stills camera used in photography (Schenk, 2006, p.59). For example, the focal length of the lens, the size of the sensor and the amount of light let into the Canon 60D DSLR camera were known parameters when the Tristan Stone was documented.

The differences and similarities between laser scanning, photogrammetry and SfM are based on the camera model (Matthews and Noble, 2008; Spring et al., 2010; Westoby et al., 2012). As discussed in 3.1 for the FARO Focus^{3D}, the camera model for a laser scanner is based on the type of laser system used for data collection. Included in this is the beam diameter (3.8 mm), the method employed to collect data (phase shift) and the frequency the laser is set to (Dassot et al., 2011; Chow et al., 2012; Wunderlich et al., 2013). In this instance the Focus^{3D} was set to 905 nm or infrared (IR) on the electromagnetic spectrum (Dassot et al., 2011). In laser scanning the camera model is a mechanically fixed parameter (Van Genechten et al., 2008) much like in affordable consumer driven photography. For example, the camera sensor used in a mobile phone.

Conversely, 3D point clouds generated from photographs and SfM can be improved by having a rudimentary knowledge of photography or photogrammetry (Matthews and Noble, 2008; Chandler and Fryer, 2013; Spring, 2014). This is especially the case in a DSLR based workflow where focal length is not fixed (Adam Technology, 2010). Where lenses are interchangeable,



Fig. 1. a. The Tristan Stone and its location in the British Isles, b. Its location in Cornwall, c. Migration pattern of the stone as outlined by De Mandach, 1978.



Fig. 1. (continued).



Fig. 1. (continued).

sensor size increases the amount of data that can be collected and users have greater control over the DSLR camera functions (Spring, 2014). In other words, higher resolution point clouds can be produced from photographs when the user has a greater understand of, and more control over, how the image is produced (see Fig. 4a

and Table 1). Known parameters and some form of calibration can be applied through the camera model in place (Matthews and Noble, 2008; Spring, 2014).

It is the camera model that differentiates a photo based 3D point cloud generated from SfM and a 3D point cloud intended to be used

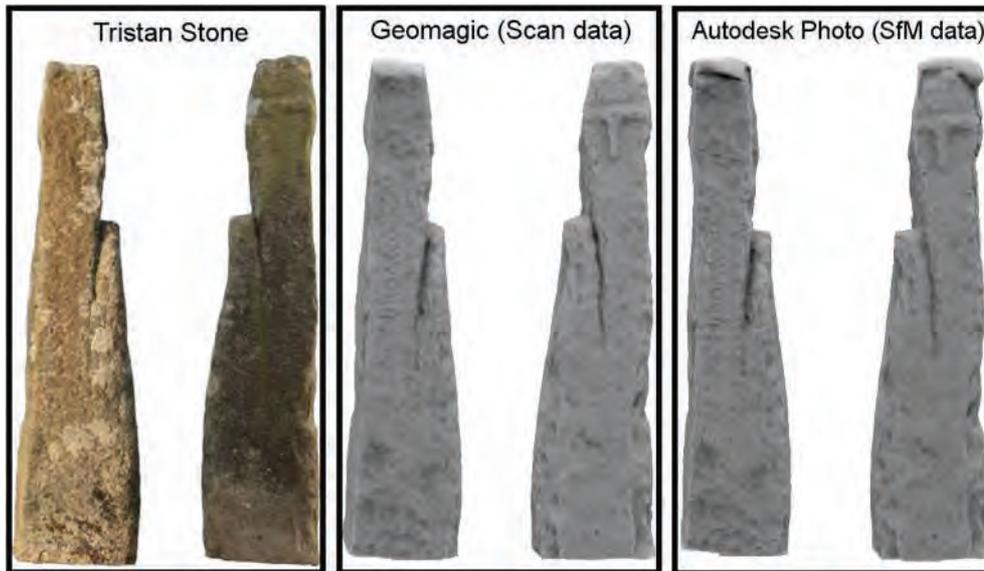


Fig. 2. A comparison of what the Tristan Stone looks like in situ, through scan data where AO has been applied and through SfM based data where AO has been applied.

for more accurate photogrammetric purposes (Hartley and Mundy, 1993; Chandler and Fryer, 2013). By combining elements from both workflows, the user benefits from the ease of use associated with SfM and the known resolution of data that is essential to photogrammetry (Hartley and Mundy, 1993). This is because photogrammetry is the art and science of using photographs to acquire metric information from a scene (Light and Jensen, 2005), which also predates digital computing (Hartley and Mundy, 1993; Luhmann et al., 2006). Whereas, SfM is a computer vision based technique originally designed for scene analysis and the remote navigation of unmanned systems and vehicles (Besl, 1987; Gage, 1995).

SfM has a flexible camera model until calibration parameters are added to the workflow being used (Chandler and Fryer, 2013; Crandall et al., 2013). As long as there is matching overlap in a group of photographs, a 3D point cloud can be generated using SfM even if a photograph is of low resolution (Snaveley et al., 2006). SfM can generate a 3D point cloud based on images taken from multiple viewpoints, otherwise known as Multi View Stereo (MVS), and corresponding geometry of shapes within a scene (Snaveley et al., 2006; Crandall et al., 2013; Koutsoudis et al., 2013). Overlap (ideally 60%), depth of field and base to distance ratio from the sensor to the object should always be considered when a photograph is taken (Matthews and Noble, 2008; Spring, 2014).

2.3. Digital documentation techniques

In the context of Cultural Heritage (CH), digital documentation techniques like mid-range TLS and SfM have a qualitative as well as quantitative value (Spring et al., 2010; Peters and Spring, 2014). The textured, 3D point clouds generated are open to interpretations that extend beyond the acquisition of metrically accurate data alone. For instance, the application of a FARO Focus^{3D} to the Tristan Stone led to an examination of noise contained within the point cloud generated at the same time as the inscriptions on the granite surfaces. As seen in Figs. 2 and 3, AO shading also increased the resolution of the data and made text more visible to the human eye. Fundamental to the overall workflow was the capture and representation of surface texture, which had been greatly altered by processes like weathering over time. Knowing that the case study

was more a feature mapping exercise made the process of onsite data collection quicker as only local coordinate systems were required. At a minimum x, y, z, red, green and blue (RGB) and grayscale values can be obtained from point cloud data (Ullrich and Studnicka, 1999; pp. 49–56). It should be noted, however, that intensity of signal return is usually a value acquired as well (Höfle and Pfeifer, 2007). Integration and georeferencing of all datasets within

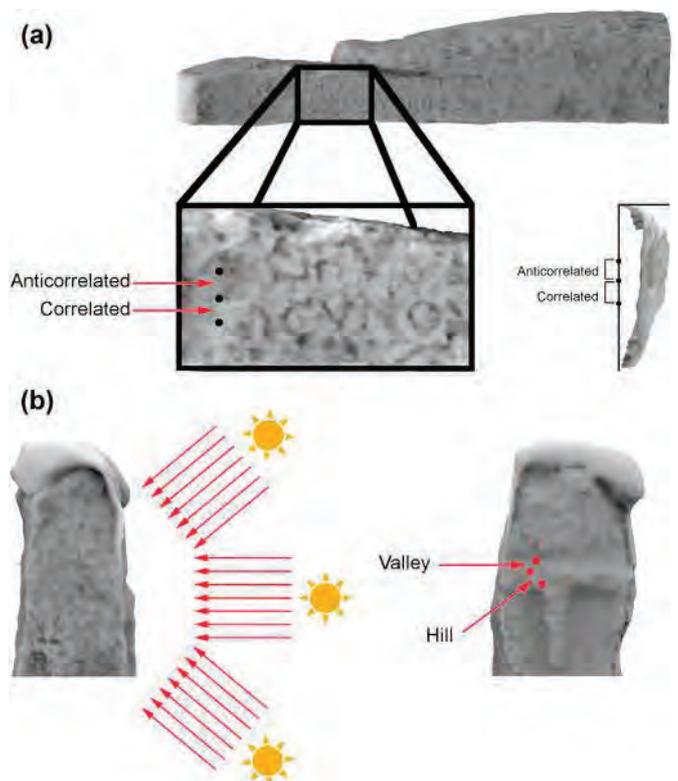


Fig. 3. a. The AO process explained in terms of anticorrelated and correlated points, b. AO process explained in terms of light fields and "Hill" and "Valley" points on surface.

absolute world coordinate systems can still be achieved if additional future proofing becomes a requirement later on.

Understanding how the FARO Focus^{3D} collected data influenced what type of artefact it was applied to and the choice of case study (Spring et al., 2010). The excess number of points generated by the scanner - 976,000 per second - suggested high-resolution surface capture was possible (FARO Technologies, 2010). However, the relationship between the resolution of data captured and the surface feature analysed was ultimately determined by reducing data noise contained within the scan data (Chow et al., 2012; Wunderlich et al., 2013). Though the Tristan Stone represented the first instance in which the FARO Focus^{3D} had been used for CH documentation since its commercial release (Spring and Peters, 2011), the success of the results was only made possible by the knowledge base and skill sets of the users. Noise reduction in the mesh generated was not an exercise that could be immediately conducted by non-specialists or users new to 3D imaging.

2.4. Scan resolution

The stone was scanned at a resolution of 6 mm point spacing over a distance of 10 m. At a capture phase, this meant any point generated closer than 10 m would be less than 6 mm to its nearest neighbour and any points beyond the 10 m mark farther apart. It was an easy and immediate way of setting the scanner to be compensated for what can be an overkill of information. Rapid acquisition of points is a primary advantage of using a laser scanner based methodology. It can, however, also make processing scan data a time consuming exercise. Keeping datasets at a more manageable and immediately processable size made information more accessible.

All point clouds were registered (connected together) in the FARO operating software Scene. It was then exported and meshed in a proprietary solution called Geomagic. Acquired by 3D Systems in 2013 (3D Systems, 2013), the software transforms point cloud

data into solid surface meshes. It uses shape recognition algorithms that identify and focus on the main object in the point cloud (Geomagic, 2014) - in this case the Tristan Stone. This is done in order to filter extraneous noise from the data.

Prior to being laser scanned, a wheel-head cross on the back of the stone had been overlooked. This, in part, can be attributed to a) the coarse granite surface on which it is carved and b) oversight caused by the fact that the lower intact part can appear like a tau (or Greek letter 'τ') cross (cf. Okasha, 1993, p.92); the curve at the bottom of the tau being part of the wheel. The feature was enhanced in Geomagic using high resolution scan data.

3. Laser scanning

3.1. Interior orientation

The FARO Focus^{3D} was launched in Austria, October 2010 (Spring and Peters, 2011). Scans of the Tristan Stone were conducted in December 2010 with one of the first systems available (Spring and Peters, 2011). The Focus^{3D} used a phase shift solution that incorporated a class 3R (a safety qualification) laser 3.8 mm in diameter and set to 905 nm - a frequency in the IR band of the electromagnetic spectrum (Chow et al., 2012; Wunderlich et al., 2013; FARO Technologies, 2010). Measurements are acquired by comparing the outgoing and returning wave patterns of the laser as the scanner collects data (Van Genechten et al., 2008). The behaviour of, as well as noise contained within, the signal returned to the scanner was determined by the reflective property of the surfaces captured - 6 photons for an ideal return (Wallace et al., 2001). In the case of the Focus^{3D}, surfaces that were transparent, black or too reflective would cause issues like beam refraction, diffusion, weak or even too strong a signal return. When the latter occurs the receiver can become overexposed, which can cause additional noise at an information return phase (Chow et al., 2012; Wunderlich et al., 2013). The inclusion of matte white targets into

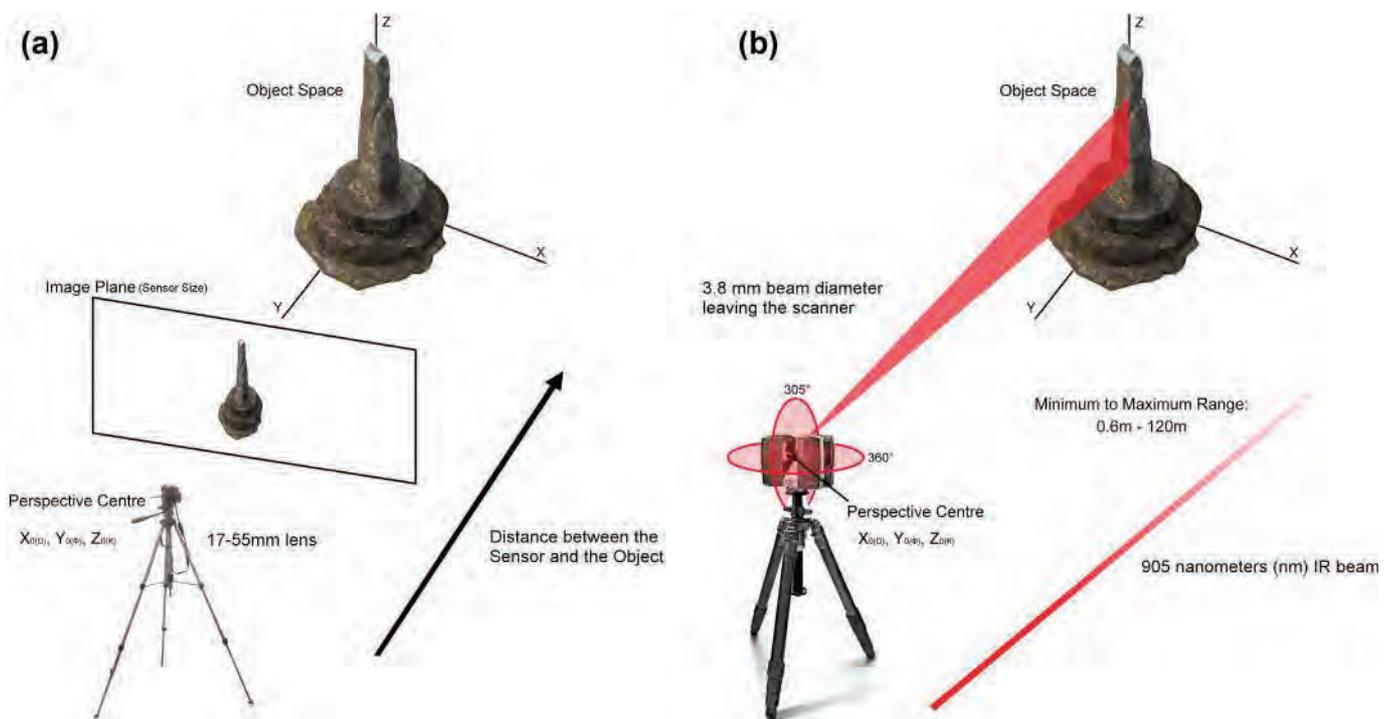


Fig. 4. a. Outline of 3D imaging camera model using a photography camera. b. Outline of 3D imaging camera model using a FARO Focus^{3D} laser scanner.

Table 1

shows how pixel pitch, area and density are determined in the image plane (sensor size) presented in Fig. 4a. The focal length of the lens adds a dimension of scale and resolution that is tied to the image plane (sensor size). It is also linked to the relationship between the distance between the sensor and the object. This is especially the case when the focal length remains the same for all images generated. Switching from autofocus to manual focus once a scene is in focus is one simple way of calibrating a lens. Using a prime lens can also make it easier to improve this part of the data collection process. Auto rotate in the camera function should also be switched off.

Determining pixel values	Canon 60D
Pixel pitch = $\frac{\text{sensor width in mm}}{\text{sensor resolution width in pixels}} \times 100$	Canon 60D pixel pitch = $\frac{22.30}{5196} \times 1000 = 4.29 \mu\text{m}$
Pixel area = $\frac{\text{sensor surface area in mm}^2}{\text{effective megapixels}}$	Canon 60D pixel area = $\frac{322.27 \text{ mm}^2}{18.00} = 18.4 \mu\text{m}^2$
Pixel density = $\frac{(\text{sensor resolution width in pixels})^2}{\text{sensor width in cm}} / 1000000$	Canon 60D pixel density = $(5196/2.23)^2 / 1000000 = 5.43 \text{ MP/cm}^2$

the workflow regulated these variables to an extent by including surfaces quantifiable to the way the scanner viewed the world (Van Genechten et al., 2008). This meant in terms of the IR frequency to which the Focus^{3D} was calibrated.

3.2. Data noise

In the same way the pixels of a digital photograph taken in low light can appear grainy scan data contains noise that becomes visible under certain conditions (Chow et al., 2012; Wunderlich et al., 2013). Environmental conditions, focal length, aperture, ISO and the properties of the sensor determine the extent to which noise is presented in stills camera photography (Matthews and Noble, 2008; Spring, 2014). The equivalent in a mid-range TLS workflow is linked to the interior orientation of the scanner and external orientation parameters that affect data retrieval (Spring et al., 2010). Included in this is the number of points generated per second over a known distance.

The FARO Focus^{3D} was used to document the Tristan Stone based on three known variables: the resolution of data captured, the size of the object documented and the distance at which information was collected. Similar to the hyperfocal length of a photography camera lens, mid-range TLS solutions have a distance at which optimum resolution can be achieved (Matthews and Noble, 2008; Chow et al., 2012; Wunderlich et al., 2013; Spring, 2014). This is a point where noise is not as apparent as it would be if the scene were captured from farther away (Chow et al., 2012; Wunderlich et al., 2013). The FARO Focus^{3D} was no different and knowledge of this was considered prior to its application in a CH based workflow.

4. Structure from motion

4.1. Services and solutions

3D design companies like Autodesk have been making services and solutions more accessible to users since 2009 (Parks, 2012). The move to a symbiotic internet or web, where users work more closely with sensors to document an environment, instigated this change (Aghaei et al., 2012). It has led to user interfaces (UI) being redesigned and made easier to use - to save time at the data processing part of a workflow. 123D Catch - known as Photo Fly when it was released in 2011 (Autodesk Laboratories, 2011) - was the first SfM service to come out of Autodesk based on this development model (Autodesk, 2014a,b,c). Photographs processed through 123D Catch are reduced to 3 megapixel resolution (Chandler and Fryer, 2013). This restriction was removed in a professional version of the service, which was launched in beta with 5 gigabytes of free use in 2013 (Autodesk, 2014a,b,c). It is called Photo, and now offers a free trial or an annual subscription service priced at USD \$55 (at time of publication). Photo is located at ReCap360.autodesk.com.

The free trial now allows for 50 photographs to be processed at a time. Whereas, the subscription service allows for 250 photographs at full resolution or "Ultra" setting (see Fig. 5).

4.2. Autodesk photo

Both 123D Catch and Photo are services that process data using distributed computing (Dikaiakos et al., 2009; Autodesk, 2014a,b,c). Also known as cloud computing, this means that photographs are loaded into the Photo UI located at ReCap360.autodesk.com, a 3D point cloud is generated through a network of computers that share the task of processing the data, and the results are then sent back to the user. The advantage of using Photo over comparable solutions like Agisoft Photoscan (see Agisoft Photoscan, 2014) is that it redirects the task of processing data away from the personal computer. High resolution 3D point clouds are generated in "the cloud", and the user is sent an email link to their data when it has been processed. In this context cloud computing can be used by heritage practitioners to save time and money. It also requires little to no understanding of the technical processes that go into 3D image production in terms of processing photographs.

Photo sends 3D data back to the user as a point cloud and solid surface mesh in .OBJ, .RCM, .FBX, .IPM or .RCS file format. Fig. 5 shows the selection screen presented to the user. There are also options to remove the unwanted data that is not the main focus of the scene, determine and adjust the focal length of the lens used and to add scale to the 3D data generated (Autodesk, 2014a,b,c). The latter is achieved via an easy to use point and pick window. A scale bar can also be used if it is added to the scene before photographs are taken. The UI allows the user to zoom in on a scale area, pick a point, pick another corresponding point elsewhere in the photograph and then add a value by typing it in. All 3D points generated after this step are scaled to this value.

4.3. Project Memento

In the FARO Focus^{3D} workflow, a meshing package called Geomagic was used to remove unwanted data called noise from the 3D point cloud created by the laser scanner. While this process enhanced the surface features documented by the scan data, it also required the person processing the data to have specialist knowledge and skillsets in order to make the process work. Project Memento was launched in beta form by Autodesk Laboratories in 2013 (Autodesk Laboratories, 2014). It is designed to make it easier to incorporate solid surface data into a workflow - to make mesh analysis more accessible to artists and professionals working in sectors like heritage preservation. Once the 3D data had been produced via Photo, the solid surface mesh generated for the Tristan Stone was enhanced in Memento, much as the scan data had been in Geomagic. Fig. 6 shows that specific anomalies in the data, known as "spikes", were removed along with holes, particles



Fig. 5. The Autodesk Photo UI is designed to be easy to use and to provide data that can be used in multiple CAD and CAM based applications.

and tunnels. The UI for Memento was easy to use and similar to the UI created for Photo. Files could be imported in .OBJ and .RCM format and also exported in the 3D print format .STL. Table 2 presents the relationship between Autodesk solutions in more detail and outlines all services and solutions used.

5. Ambient occlusion (AO) shading

In computer graphics, AO shading is used to emulate the experience of depth created by environmental lighting conditions (Blinn and Newell, 1976; Debevec, 1998; Landis, 2002). It is a standard technique employed in the entertainment industry for computer animations, computer generated imagery (CGI) and for video game environment rendering (Landis, 2002). AO provides an added sense of depth to a scene by using light and dark shading to represent surface shape (Langer and Bühlhoff, 2000). It is the digital equivalent to an artist using shading in order to convey the way light impacts upon a scene they are looking to reproduce (Langer and Bühlhoff, 2000). AO shading, however, allows the user to

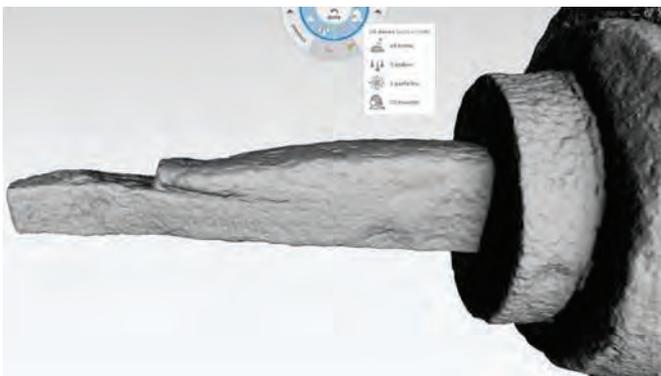


Fig. 6. Project Memento has an easy to use UI and automates mesh analysis and repair functions.

simulate and control light conditions as opposed to being restricted by a daily light cycle.

The technique was first used to enhance features on stone surfaces in 2004 (Duguet et al., 2004). It was applied to an Omphalos in the museum at Delphi, where it was used to enhance small features on the column based on variations of surface depth (Duguet et al., 2004). It works well on aged stone surfaces because only the direct light component of a scene is required. In addition to feature enhancement, it was used because it could also produce a natural lighting effect. This is the lighting effect mostly caused by diffuse reflection from irregular surfaces that would occur in the vicinity of the column. The variant used in CloudCompare is based on algorithms developed by Tarini et al., 2003. It does not require a lot of processing power and can be used on low end personal computers. It allows for quicker processing times because it directly accesses the Graphics Processing Unit (GPU) of the computer (Tarini et al., 2003).

The “Portion of Visible Sky” (qPCV) plugin in CloudCompare calculates the illumination of a point cloud or vertices in a mesh based on a theoretical hemisphere or sphere (Duguet et al., 2004; Girardeau-Montaut, 2014). Fig. 3a and b shows how this process works. The relationship between the points within the local coordinate system in place - statistically known as anticorrelated and correlated points - are used to generate ‘light fields’ from an infinite source with rays that behave in accordance with the geometry of the surface of the Tristan Stone data. CloudCompare enables the user to control the direction of light rays generated, which can be used to control resolution of detail. The more directions the light fields come from the better the resolution as that highlights the reflective exposed areas whilst emphasising areas of low reflectivity. The software also allows for light fields to be produced based on surface normal data collect from a point cloud, or to be sampled from a full sphere and northern hemisphere (Girardeau-Montaut, 2014). Fig. 3b demonstrates that an easy way to consider the behaviour of AO shading is to think of a surface in terms of having “Hills” and “Valleys” (Langer and Bühlhoff, 2000). The way light fields behave within these area can be used to control the way they reflect off a surface - to the point where it can be simulated artificially.

Table 2
presents all services and solutions used for the workflows described in the article.

Services and solutions	Background information
CloudCompare	CloudCompare was initially developed between 2004 - 2007. It was supported by Électricité de France (EDF) who wanted it for internal uses as a monitoring and simulation tool. It made an immediate transition into heritage applications because of the EDF Foundation. It has been open source since 2009.
ReCap360.Autodesk.com	ReCap360 provides services and solutions geared toward what Autodesk is calling Reality Capture (ReCap). It is being used to refine point cloud data for computer aided design (CAD) and computer aided manufacture (CAM) applications. Laser scan data is also supported at ReCap360.com
FARO Scene	FARO Scene is the operating and modelling software for FARO mid-range laser scanners. It is based on technology developed by a German company called iQvolution, which was acquired by FARO Technologies in 2005. It was used to register and export the native .FLS point cloud format prior to further modelling in Geomagic.
Geomagic	Geomagic came out of the North Carolina research triangle in 1997. It is a solution that transforms 3D point clouds into solid surface meshes for use in CAD and CAM based processes. Geomagic was acquired by 3D Systems in 2013, which is the same company that developed the .STL 3D printing file format.
123D Catch	123D Catch is a SfM based 3D imaging service that converts 2D photographs into point clouds and meshes. It is part of a wider suite of solutions brought together under the 123D brand, which are geared toward using 3D data for CAD and CAM based workflows. The professional equivalent of 123D Catch is Photo. Unlike 123D Catch, Photo does not reduce the resolution of photographs to 3 megapixels but does have an annual subscription fee.
Photo	Photo was introduced by Autodesk in 2013. It is geared toward infrastructure, asset management and high resolution data production. Included are otherwise grey area applications like cultural heritage and archaeology. It is located at ReCap360.autodesk.com .
Project Memento	Project Memento was introduced by Autodesk Laboratories in 2013. It is designed to make mesh transformation easier and more accessible to anyone. Similar to 123D Catch and Photo, it is a more automated solution. It has an easy to use UI, which reduces data processing to a series of easy to use functions.

6. Discussion

With an increasing interest in user-friendly, low-cost solutions to 3D imaging, textures have been preferred rather than a high accuracy level for the surface geometry. It is not necessary to make such compromises. This article has gone some way to demonstrate this by outlining an easy to use workflow that anyone with access to a computer, an internet connection and photography camera can use. Given that the heritage sector is a price sensitive market, especially when it comes to equipment and application considerations, it should be noted that as 3D imaging becomes more affordable it has the potential to be accessed by a broader range of users as well. That is, if information and training are managed with accessibility to services and solutions in mind. Since the Tristan Stone was first documented with the FARO Focus^{3D} in 2010, automated services and solutions have developed to a point where useable results can be generated that are comparable to semi-automated equivalents like laser scanning. Solutions like Project Memento have also been designed with artists and heritage users in mind. The focus is now on the user experience (Kerr, 2002) and to create intuitive UI's that are not cumbersome to use.

6.1. Inscribed stone data

The inscribed stone data itself was used to explore 3D imaging techniques within the context of their application and intended deliverables. In this case, for demonstrating that the individual commemorated on the so-called 'Tristan Stone' was not Tristan, and confirming analyses of the historic evidence. It was also used to present the technologies discussed in a way where they can now be better understood - and used in accordance with this knowledge - by heritage practitioners. Similar results and feature resolution in both datasets suggest the age of affordable 3D will continue to lead to further revision and reinterpretation of material records and cultures. This is especially the case in examples that are well known for being greatly affected by subjective interpretations.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.jas.2014.08.017>.

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Using Mid-Range Laser Scanners to Digitize Cultural-Heritage Sites

Here, we explore new, more accessible ways of modeling 3D data sets that both professionals and amateurs can employ in areas such as architecture, forensics, geotechnics, cultural heritage, and even hobbyist modeling. To support our arguments, we present images from a recent case study in digital preservation of cultural heritage using a mid-range laser scanner.

Our appreciation of the increasing variety of methods for capturing 3D spatial data inspired our research. Available methods include photogrammetry, airborne lidar, sonar, total stations (a combined electronic and optical survey instrument), and mid- and close-range scanning.¹ They all can produce point clouds of varying density. In our case study, the point cloud produced by a mid-range scanner demonstrates how open source software can make modeling and disseminating data easier. Normally, researchers would model this data using expensive specialized software, and the data wouldn't extend beyond the laser-scanning community.

The Case Study

Our subject was the Wheal Unity Engine House in Cornwall, UK. This 19th-century building contained a steam-powered beam engine that helped pump mine shafts free of water.

We chose a mid-range terrestrial laser scanner for three reasons. First, it's designed for rapid acquisition of surface data, unlike total stations, which focus solely on capturing individual points. Second, it has the appropriate data capture range in terms of distance for terrestrial land and building recording. Finally, unlike photogrammetry, it isn't affected by surface texture. (However, it's still affected somewhat by surface reflectants.) So, it can deal with both shiny and regular surfaces.

To model the case study, we selected Blender, an open source program.

The Laser Scanner

We used the Leica HDS3000 (see Figure 1), a time-of-flight (ToF) mid-range laser scanner with a built-

in mechanical accuracy of ± 5 mm, a 360-degree horizontal scan window, and a 270-degree vertical scan window. (For a short history of laser scanning, see the related sidebar.) We captured all data using a 3R-rated (a safety classification based on the wavelength and power of the energy produced) green laser fixed to a wavelength of 532 nanometers.

Besides the mechanical accuracy and field of view, other immediate variables related to the scanner's interior orientation affect data capture. These include the range at which we can collect data (realistically, 150 meters maximum) and the signal-return strength, which is affected by both the range and the surface reflectants' quality. The signal-return strength, combined with the mechanical accuracy, affects data noise in the point cloud. This directly affects the accurate representation of key features, such as surface texture, during modeling. To optimize point-cloud registration (a process in which individual points are joined together to recreate the Engine House), users should employ targets purchased with the scanner that are coated in a retroreflective material.

The Target Environment

Measurement accuracy and the subsequent modeling requirements were linked directly to our application's data-processing phase. In this case, the application was a model that required detailed recording of surface textures obtained from high-resolution scans.

The primary goal of data capture and modeling the engine house was to place an example from the Cornwall and West Devon Mining Landscapes World Heritage Site (WHS) in a digital context. The engine house model could then be used in open-access immersive environments such as Second Life for edutainment and WHS site promotion. Using the physically liberating aspect of digital media, disabled users or visitors could access the WHS freely. Furthermore, information could appear on message or video boards in Second Life to assist interpretation. If greater realism was

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Figure 1. The Leica HDS3000 scanner used in our case study. This scanner is a time-of-flight, mid-range laser scanner with a built-in mechanical accuracy of ± 5 mm, a 360-degree horizontal scan window, and a 270-degree vertical scan window.

required, then textures—for example, weathered granite—could be draped over the detailed mesh created from the point cloud.

We captured four exterior scans of the engine house at 30-mm resolution, with an interior scan

at 15-mm resolution. This generated a data cloud of approximately one million points. The data's rate and size would present problems for any user without access to expensive software and specialized knowledge. The capture process produces an overkill of points. This ironically generates data too rich and dense, which makes working with the data problematic in the current processing-power climate. The user can control the density somewhat by setting the point resolution before scanning, but any reduction in point density must be balanced against the resolution of the registered point cloud in its totality. The registration process—derived from Paul Besl and Neil McKay's *iterative closest point* algorithm—also affects point cloud accuracy.²

You can achieve decimation of points in an open source environment during data processing. However, a workflow centered on cultural-heritage preservation would benefit considerably from a more balanced number of points during data capture. This would lessen further alteration of all data, such as decimation or unification, and the associated effects on the data.

Modeling in Blender

We chose Blender for several reasons. In addition to its support community and ease of access, we like its animation functionality. Also, it's a logical

Laser Scanning

Commercial mid-range laser scanning has been available since 1998. Since 2007, its range of uses and applications has become more widely known. However, despite its rapid development as a technology and growth as a commercial market, it still remains at a quasi beta phase. Scanners' interior orientation (laser system and type of beam used to acquire data) vary between manufacturers, who offer a time-of-flight, phase shift, or triangulation laser system for data capture, as well as their own modeling software and file formats.¹

The history of such commercial laser scanners makes them an appropriate subject for our case study. In 1999, Ben Kacyra, Jerry Dimsdale, and Mark Brunckhart's US Patent 5988862, which they had submitted in 1996, came into force. This patent for laser scanning was based on well-tested technologies that radar specialists had used for decades. The main reason for their invention and submission of the patent was a gap in the commercial survey market for a terrestrial instrument with hardware requirements intended for rapid acquisition of coordinated data at millimeter accuracy (at the time the available technology was either too slow or set for centimeter accuracy). A further use for laser scanning was to avoid danger when

recording industrial accidents or contaminated areas.

The significance of this for cultural heritage was that this new technology could record surfaces with greater rapidity than conventional technologies such as total stations could. Where buildings or other historic structures were in danger of collapse, laser scanner operators no longer had to get close to them to produce detailed records.

Key to the development of laser scanning were communities freely exchanging and disseminating information. Three of the five main manufacturers of mid-range laser scanners have common research origins. These companies are Leica, which bought its rights from CyraX (Kacyra and Dimsdale's company); Riegl, whose founder was a former colleague of Kacyra's from before 1992 (hence, the Cyclone software works with scan data from both Leica and Riegl scanners); and Topcon, who cooperated with and then bought out Voxis, a company founded by Dimsdale in 2003.

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1. T. Kremen, B. Koska, and J. Pospíšil, "Verifying Terrestrial Laser Scanner Quality," *GIM Int'l*, vol. 21, no. 8, 2007, pp. 28–29.

Blender

Blender began in 1995 as a 3D toolkit for a Dutch animation studio called NeoGeo. The studio set up a subsidiary, Not a Number (NaN), to develop and market the program as a free cross-platform 3D creation suite. At that time, companies normally charged thousands of US dollars for such software. Profits from additional products and services made it possible to offer the program for free. Because the program was free and offered fast animation, demand for it spread to the wider computing public rather than just to wealthy corporations. The company failed owing to market realities and its limited capabilities at the time.

However, in 2002, Ton Roosendaal, an original NeoGeo cofounder, founded the Blender Foundation because of the user community's enthusiasm and commitment. The foundation has an official website (www.blender.org), a community website (www.blender.org/community/user-community), a wiki ([en.wikipedia.org/wiki/Blender_\(software\)](http://en.wikipedia.org/wiki/Blender_(software))), and a news website (www.blendernation.com).

open source environment for working with point clouds. We wanted to demonstrate that data captured by costly techniques doesn't have to be expensive to process. We also wanted to encourage greater synthesis and application of scan data by providing tools to process it.

Normally, Blender interprets each point in the cloud as a separate object because it works with absolute or fixed coordinates. We had to reverse this viewpoint so that Blender redefined each section of the scanned area and recognized it as one object with multiple points. The Blender extraction method retains the original relative positions of all point cloud data, while grouping it into manageable blocks.

Blender has a very useful feature set, but it isn't designed to work with point clouds' large data sets that laser scanning creates. Instead, the program works with distinctive geometric shapes such as polyhedra. We discovered a way around this problem by splitting the point cloud into more manageable sections. These were imported into Blender one by one, and they were converted into meshes of geometric shapes. Underneath these shaped meshes, the original points remain, should reprocessing or reinterpretation be required.

For more on Blender, see the related sidebar.

Processing the Scan Data

Importing the scan data into Blender takes five steps (see Figure 2):

1. Register all scan worlds using the scanner manufacturer's software—for example, Cyclone (Leica's scanner operating software) or RiSCAN (Rieg'l's scanner operating software). A scan world is an area captured by the scanner that is later combined with other areas captured, if required, to make up the final point cloud. To put scan worlds together, there must be overlap of an area in each one.
2. Segment the fully registered point cloud by using the reference plane function in the manufacturer's software tools menu. You can achieve the same process in other software such as AutoCAD using a DXF (Drawing Interchange Format) copy of the point cloud. Drape the reference plane over the point cloud. You can extract individual sections in the plan-view perspective as DXF files—each retaining all *x*, *y*, and *z* coordinates as in the original integrated modeling program (IMP) file.
3. Extract each section as a DXF file. Import the sections into Blender.
4. Open individual files in Blender and select as

many points as possible. Go to the bottom menu and use the join objects function.

5. Repeat the process on all files, and then link the objects together to reassemble the point cloud.

We used the points from the scans, photos, or other point data to align particular functionalities in Blender, such as mesh tools, polygons, and plane cubes. Basic Blender functions such as extrude, remove doubles, and face were sufficient for this modeling. However, lacing together vast numbers of points requires a suitable macro or script. Where relevant, we also used illustrations and photographs to make decisions, which also helped us recreate texture and internal parts such as machinery that had rusted away or been removed.

The process demonstrated that working with point data in an open source environment is possible without a plug-in or an added design feature for programs such as Blender. Familiar difficulties of modeling with large data sets, such as time and effort, still apply. Here, we've demonstrated that processing point data doesn't have to be expensive but does require an awareness of the available tools and lateral thinking.

The process isn't just technical. Once scan data, photo data, or any other digital data has been captured, it becomes static, unaltered by time, and representative of the moment in which an object or scene is captured. It's also representative of the processes and performance that went into its capture. As outlined in the concept of empirical provenance (which we discuss in the next section), the link between captured and processed data is ever present but might not always be apparent when data capture or interaction occurs. Working with

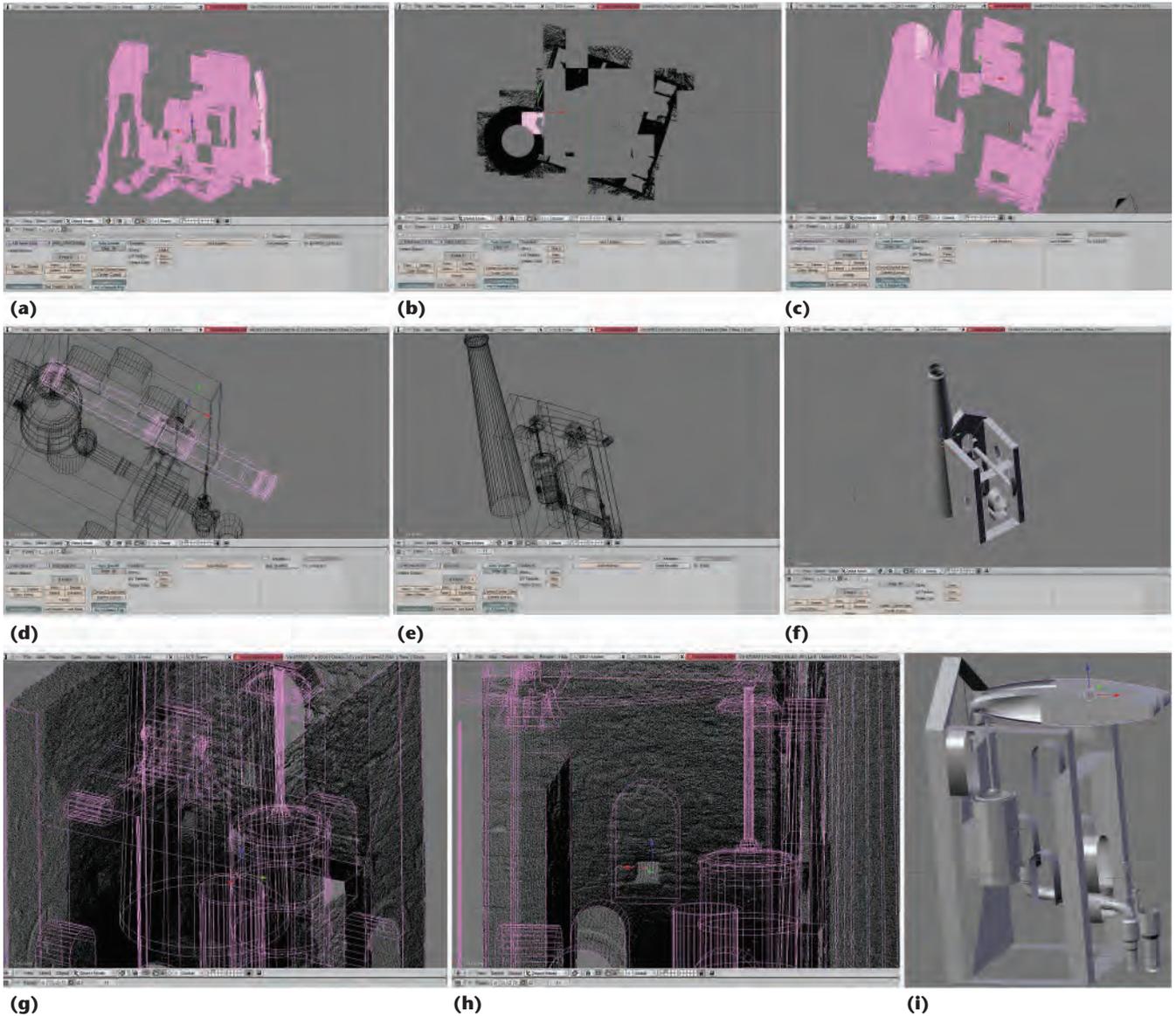


Figure 2. Stages of processing of point cloud data in blender. (a) Point cloud conversion in Blender. (b) Reconstructing a modified point cloud section using absolute coordinates. (c) A polyhedral frame for modeling. (d) Reconstructing the Wheel Engine House's inner workings. (e) A skeletal frame with the engine incorporated. (f) Reconstruction before adding the surface texture. (g) Using texture from point density to aid modeling. (h) Inner workings and external frame construction. (i) A layered process for model construction.

data sets involves further processing or interpretation that reflects the environment and conditions in which it's conducted. The tools and the person using them will always directly affect the results. In our case study, practicalities relating to the available processing power and the problems of working with large data sets were overriding factors determining our approach.

Long-Term Data Management

Eleven years after Stewart Brand's "Escaping the Digital Dark Age,"³ retrieval of information as recent as 10 years old is still, if not more, problematic. For example, you could view digital in-

formation's exponential growth as alarming or exciting. Recent research on predictability models for Internet growth and case studies, such as Guo-Qing Zhang's "Evolution of the Internet and Its Cores,"⁴ provide insight on the state of digital information, which doubles in size every 5.32 years. Digital survey tools, such as mid-range laser scanners, aren't detached from this situation.

It's no coincidence that new methods of managing increased data production have emerged over the past 11 years. Each method gives a range of sustainable preservation strategies for all relevant data sets—providing guidance on what information to keep. Management strategies such as the CIDOC

Empirical provenance for mid-range laser scanning	Empirical provenance for modeling
■ Scanner model (including technical specifications)	■ Software used
■ Point or target registration	■ Steps undertaken to make changes
■ Software used	■ Any changes in file format
■ Scan position	■ Any changes in resolution
■ Scan direction	
■ Field notes (for example, environmental conditions)	
■ Photographs and videos of the recording process	
■ The resolution selected	
■ Original individual scans before decimation or any modification before combination with other scans and before overdraping	
■ Original photographic panorama before being overdraped on the scan	
■ Any conversions—for example, Cyclone and subsequent file format changes	

Figure 3. Checklists for establishing the empirical provenance for mid-range laser scanning and subsequent modeling.

Conceptual Reference Manual (CIDOC CRM), empirical provenance, Dublin Core Metadata Initiative (DCMI), and RecordIM (Recording, Documentation, and Information Management), whether intentional or otherwise, highlight the flexibility, dynamic flow, and organic characteristics of digital-data development and growth. Worryingly, they also reflect digital data's ephemeral nature and the difficulties in ensuring its long-term survival.

Empirical provenance (sometimes called empirical origin) is a solution for giving data sets a cultural memory; it originates in Immanuel Kant's *Critique of Pure Reason*. It concerns the need to establish where information comes from and how it was produced. This helps avoid misconceptions due to corruption of data sets caused by human error and misunderstanding. The role people play in creating digital data sets, along with processing and archiving, becomes easier to follow and understand.

Cultural Heritage Imaging (CHI)—a California non-profit corporation—has outlined key information for empirical-provenance records for camera-based techniques (see http://www.c-h-i.org/featured_projects/feat_pub_04.html), based on Mark Mudge and his colleagues' scheme.⁵ On the basis of CHI's outline, we've developed checklists for mid-range laser scanning and modeling (see Figure 3).

Open source and low-cost modeling are good ways to preserve data through accessible distribution in the same way that plain text and PDF files have assisted the flow of basic text and 2D images. Accessible distribution ensures many copies are available and that data will less likely be lost. However, wide distribution can lead to loss of data integrity, so it's important that the empirical provenance accompanies the data outlining its

creation. The process's relative simplicity makes it accessible to a wide audience, thus bridging the gap between specialists and nonspecialists. ❏

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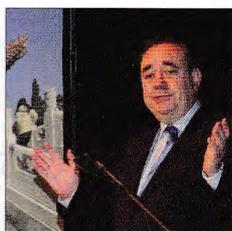
Selected CS articles and columns are also available for free at <http://ComputingNow.computer.org>.

Appendix B
Industry Publications



Surveying for geographical and spatial information in the 21st century

Scanning and
Scotland's First
Minister



It was all happening
up in the air at this
year's InterGeo



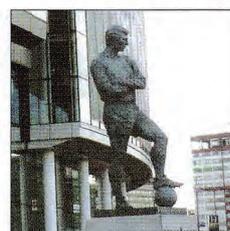
Talking to FIG's
President Teo
CheeHai



Twisting maps at
AGI's
GeoCommunity

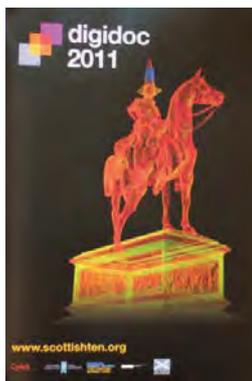


Investing in tough
times at Leica's
Wembley show



RICS

the mark of
property
professionalism
worldwide



Preserving the Past and Shaping the Future

By Adam P. Spring

Glasgow's Digital Documentation 2011 attracted some high profile players as well as political leaders, reports Adam P. Spring.

In September members of the heritage community from across the globe gathered in Glasgow at the Scottish Youth Theatre for Digital Documentation 2011. Established in 2009, the conference has continued to go from strength to strength, as well as showcasing the on-going digital preservation work conducted by a team brought together by **Doug Pritchard** (Glasgow School of Art) and **David Mitchell** (Historic Scotland). A current example is the impressive Scottish 10 project, infused by **Ben Kacyra** and **Mike Russell**.

Keynote by Scotland's First Minister

For **Alex Salmond**, DigiDoc 2011 was an example of how "it pays for a small country to think big". In a passionate and pragmatic speech Scotland's First Minister outlined his desire for the country to embrace its past in order to help shape its future. A process he felt strongly about - to the point where he "pulled rank" on former Culture Minister, **Mike Russell**, to keynote the event. Quite a catch for the organisers.

Salmond's speech set the tone for, and resonated throughout, the conference. As events unfolded it became clear ideas pertaining to national solidarity had a

positive and profound effect on the preservation of Scotland's cultural heritage. Overwhelmed by events, **Paul Bryan**, head of geospatial imaging for English Heritage, poignantly noted: "The understanding demonstrated by and support from First Minister Alex Salmond is an inspiration and an example that other organisations and governments need to learn from."

Indeed the open-minded approach adopted by the public sector in Scotland was refreshing and illuminating. In times when other parts of the UK are brushing heritage concerns to one side to satisfy increasingly unpopular political and economic agendas the message in Scotland was clear: thinking long term and seeing the bigger picture is the way to drive things forward.

International Collaboration

The amount of preservation work taking place in conjunction with other organisations, such as CyArk, on a worldwide scale further exemplified this. There was no sign of such collaborations slowing down, especially with a Scottish Ten project in Rani Ki Vav, India, scheduled for an October 4th start date. It was clear communication and implementation of Salmond's ideas continue to be achieved to maximum effect by DigiDocs organisers and supporters - Glasgow School of Art (GSA), Centre for Digital Documentation and Visualisation (CDDV), Glasgow City Council, Historic Scotland, CyArk and sponsors Leica Geosystems.

Ben Kacyra and CyArk

Alongside clear support from Scotland's governing party, the SNP, the influence of laser-scanning veteran **Ben Kacyra** loomed large at DigiDoc 2011. A forefather of commercial mid-range laser scanning, Kacyra has continued to address cultural heritage concerns since 2003 through CyArk - a California non profit corporation (501c3). In part a reaction to the destruction of the Bamiyan Buddhas in Afghanistan, CyArk was forged from a genuine desire to digitally preserve endangered heritage sites worldwide. Since 2007 an extension of this vision has been the ever increasing and evolving relationship with the Glasgow School of Art, the Centre for Digital Documentation and Visualisation and the Scottish Government. On a personal level there is also the direct connection between the land of the Scots and the Kacyra family; Ben's wife, Babara, has Scottish ancestry.



Above: Scotland's First Minister Alex Salmond gets the show underway.



Right: Plenty of networking time for delegates in between sessions.

The range of presentations supporting CyArk and its mission cemented Ben Kacyra's position as an inspirational figure with a clear vision. In fact the influence he seemed to wield was summed up in the closing speech by the non-profits director of projects and development, **Elizabeth Lee**. It was clear that Scottish Ten was integral to CyArk's goal of digitally preserving 500 of the world's key heritage sites over five years.

The Scottish Ten

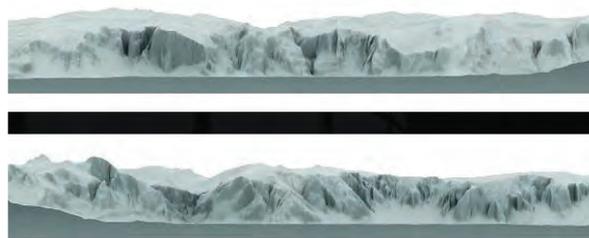
For David Mitchell (HS) and Doug Pritchard (GSA) Scottish Ten exemplifies the power of likeminded people coming together and working together. In their joint presentation the origins - along with ongoing and future work - of the project was outlined in vivid and visually stunning detail. A direct outcome from an introduction between former minister of culture Mike Russell and Ben Kacyra, Scottish Ten is cross branding Scotland's five UNESCO World Heritage Sites with five other such sites around the world. Supported by £1.3 million donated by Scotland's Government, the project has generated £3 million worth of press coverage already and has had a noticeable affect on tourism in Scotland. A large portion of Scottish Ten press came from the scanning of Mount Rushmore in 2010.

Presentations

DigiDoc's range of presentations exemplified a balance between public and private sector collaboration. The international range of speakers reiterated the close working relationship with CyArk who had advised on the presentation list. For instance phase-shift laser-scanning pioneer **Katsushi Ikeuchi** travelled all the way from Tokyo to present at the conference.

Over the two days the overarching message

Right: XRez Studio founder Greg Downing takes his enthusiasm for digital photography very seriously.



Right: CyArk's Elizabeth Lee gave a closing speech to the conference.



from all presenters was clear: it was the people driving the technology not the technology driving the people. This included **Brian Mathews** (Autodesk Lab's) showcasing free photogrammetry package Photofly; **Elmer Bol** of the soon to be acquired by Autodesk Alice Labs, demonstrating new features in Studio Clouds; **John Meneely**, the Queen's University Belfast geologist whose wife would not let him bring his Faro Focus3D to bed with him; and xRez Studio's **Greg Downing**, a man whose passion for computational photography led him from the mean streets of San Francisco to a business partnership catering

“... the project has generated £3 million worth of press coverage already and has had a noticeable affect on tourism in Scotland.”



SCOTTISH TEN is an international 3D scanning project to digitally document Scotland's five World Heritage Sites as well as five international ones.

The five-year project uses cutting edge technology to

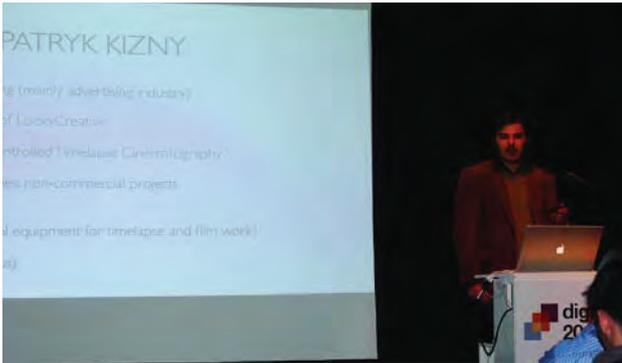
create exceptionally accurate digital models of Scotland's five UNESCO designated World Heritage Sites and five international ones, including the iconic Mount Rushmore Presidents in South Dakota, USA. The primary aims of the project are to:

- record important historical sites for the benefit of future generations in Scotland and overseas.
- share and disseminate Scottish technical expertise and foster international collaboration.
- provide digital media to site managers to better care for the heritage resource.
- recognise international Scottish cultural connections.

Led by Historic Scotland, Scotland's heritage agency, and its partner Glasgow School of Art, under their collaborative venture 'The Centre for Digital Documentation and Visualisation LLP', the Scottish Ten project will create digital documentation of the sites for future development of world class and innovative research, education and management. For more see, www.scottishten.org



Erwin Christofori, left, laser scanning with a bullet-proof vest.



Back to Aristotle's five senses: Patryk Kizny (left) of Looky Creative presented a film to provoke feelings and experiences.

for the SFX needs of the west coast film industry. In fact there was even a **Dr Strange-Walker** bicycling his Leica HDS 6100 scanner around the caves of Nottingham.

“... a mixture of rich and thought provoking visuals and sounds to provoke feelings and experiences integral to a sense of place...”

Digital Documentation Project, Transylvania

Though sleeping arrangements were not specified, another happy Faro Focus3D customer was EKG Baukultur. The Berlin and Vienna based duo **Mathias Ganspöck** and **Jan Kanngiesser** have been taking a multi-sensory approach to heritage documentation since 2005. Through the utilisation of social networking sites like Facebook the pair continue to take an active approach in trying to record heritage sites under threat. The Digital Documentation Project, Transylvania is a current example and aims to preserve areas of Rosia Montana in Romania from destruction caused by gold mining activities in the area. Archiving of data generated by such noble endeavours will hopefully be made easier by the advent of E57 - the first ubiquitous mid-

range TLS data format outlined by **Gene Roe** in his presentation on data standards.

Learning from Experience

Long time CyArk collaborator and Stuttgart based laser-scanning icon **Erwin Christofori** gave another presentation that reaffirmed his modesty and brilliance. He gave examples of Iraq, where a bullet-proof vest is mandatory, to some of the oldest evidence for cultural civilisation from Turkey. His talk was consistent through the evident excitement it generated. Modelling reality is not a problem for Christofori und Partners.

In a similar vein, Professor **Giovanni Pancani** and **Graziella Del Duca** of the University of Florence brought several threads of the conference together. Revisiting work they had demonstrated at Leica's 2010 HDS user group, photogrammetry influenced work flows and a Leica HDS 6100 were used to record and accurately represent ornate building interiors (see *Geomatics World* Jan / Feb 2011). The pair certainly brought new meaning to what could be called an "Italian job".

Experiential Processes

The visual and audio work of **Patryk Kizny** (Looky Creative, Poland) and **Seb Jouan** (Arup Acoustics Scotland) separately both achieved what it means to survey, along with the processes involved. At a time when survey is largely seen as a quantitative process, i.e. primarily concerned with metric information or at the most texture orientated in terms of the qualitative, Patryk and Seb brought things back to Aristotle's concept of the five senses.

Patryk's short film *The Chapel* (viewable at Vimeo) used a mixture of rich and thought provoking visuals and sounds to provoke feelings and experiences integral to a sense of place, in this case a building. Using more measurement based sound techniques and equipment, such as 3D microphones, Seb's worked provided the quantitative example required to cement the points visual art raises like *The Chapel*. For Patryk and Seb the world is as much about soundscapes and capturing the experience of a moment visually as it is integrating human sensory processes with those of their technology based counterparts. Imagine a world where a BIM can smell funny.

Conclusion

Digidoc 2011 was a credit to all involved. From the early bird data standards meeting (September 20th) organised by **James Hepher**, to the Wednesday evening céilidh at the Centre for Contemporary Arts, the conference reiterated that the digital heritage community is an enthusiastic and friendly (quite possibly alcoholic) group of people. By all accounts the Glasgow based event was engaging from start to finish. A great deal of praise was given to **Dorothy Hoskins** (Historic Scotland) and the event management committee by the end note.



The Lewis Chessmen: rapid prototyping from point cloud data

Discovered in 1831, the 12th century Lewis Chessmen comprise 78 pieces carved in Walrus ivory.

Another facet of data interpretation on display at Digital Documentation was rapid prototyping. Low temperature burning plastic (mixed with powder to give a matt finish) was used to recreate the Chessmen on a 3D printer. Such printers can be self replicating also. For more visit reprap.org.

GEO Informatics

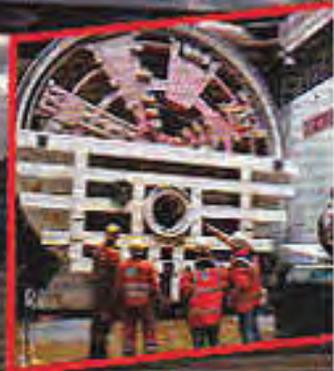
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Volume 15



- Racurs Conference ● Gatewing ● Migration to ArcGIS Server 10.1
- Real-time construction monitoring with GIS ● Pleiades-1A satellite imagery

CMedia

From capture to marketplace in a few easy clicks

The Third Industrial Revolution

This article examines the Third Industrial Revolution. Used to describe a major paradigm shift in product design and manufacture, it is impacting on the way information is gathered and used also. Smart technology applications like Theodolite Droid, open sourced hardware, crowd funding, non-linear workflows and affordable camera solutions like Hedcam are discussed. Digital designs made on everyday mobile devices can be transformed into real life usable or ornamental products. The Cornwall and West Devon Mining Landscapes World Heritage Site was used to generate examples.

By Adam P. Spring



Figure 1: Even with distortion caused by field of view, it is possible to use products like Hedcam to generate 3D data



Figure 2: Processing stills from Hedcam in software like 123D Catch will contain evidence of the 135 degree view of the lens

The Third Industrial Revolution

The Third Industrial Revolution is a concept first outlined by the American Economist Jeremy Rifkin. It is currently used to describe the way digital technologies are affecting design and manufacture processes. It is deemed the 'Third' because it is seen to follow the factory based model that came out of Victorian Britain and the assembly line approach to manufacture championed by Henry Ford. Wired editor in chief and joint owner of diydrones.com Chris Anderson cites Thingiverse.com - a website where predominately Trimble SketchUp drawn designs are readily downloadable for 3D printing - as the example of the Third Industrial Revolution in action.

Internet of things

It is no coincidence the Internet of Things, and later the Thingiverse, have become popular terms used to explain such phenomena. By presenting humans and objects as independent agents in the distribution and communication of knowledge, the idea sits well with products designed for general media consumption. The role of the smartphone or tablet in the collection of spatial information - as well as the relationship between the user and the technology - is well defined at an application stage. So too is the data narrative, which documents information collection as a process.

Theodolite Pro and Droid

Such mobile technologies as the iPad have indeed made general audiences more familiar with spatial information. The Application Programming Interface - more commonly known as the app - allows the user to access the different functionalities of a smartphone or tablet. App's like Hunter Theodolite Pro for iOS or Theodolite Droid for Android even go so far as to turn them into effective and versatile prospection tools.

Theodolite Pro and Droid access the inbuilt camera, GPS and motion orientation technology of a smartphone or tablet - turning them into an all in one inclinometer, optical rangefinder and GPS receiver. Accuracies obtained from the inbuilt GPS of most mobile devices are between 1.5 to 3 meters depending on location and satellite fix. As Theodolite Pro developer Dr. Craig Hunter points out, using an iPad or iPhone as an optical rangefinder can: 'On a tripod, with a clear view of the target, generally give range to within 2% or so.' To ensure the latter, capture should include orthographic shots of an object or surface.

Linear and non-linear workflows

A key thing to note about the app market is the way it presents a shifting trend in the way technology is used to collect and interact with

information. Smartphone and tablet use is centred around the solution provided as opposed to processor power - something that has been a staple part of most digital workflows since the meteoric rise of the personal computer in the late 1990s. A progression from the client server to the cloud, this has ironically taken data processing back to an approach reminiscent of mainframe computing. A ubiquitous form of terminal based computing through smart technology has become en vogue and multidimensional workflows part of everyday life.

Specialist applications

The same can be said for specialist applications where the flow of information no longer has a clearly defined beginning or end point. Paradigm changing activities like crowd-sourced data logging through geo tagging - even design and manufacture apps - are increasingly explained through guru compliant terms like the Internet of Thing and a Third Industrial Revolution. Terms ambiguous enough to bring order, or give ownership to, activities that are otherwise tangible and in a constant state of change. With a watchful eye gazing over companies like Google and Apple, even large precision measurement companies like Hexagon AB are advocating the only restrictions now placed on digital information come from the user themselves. Though consumer products like the tablet did not lead to the development of the non-linear workflow they have made them difficult to ignore.



Applications like Theodolite Droid access the inbuilt GPS, camera and motion sensor in handheld devices to gather spatial information

Open source hardware

Further optimization of applications can occur through open sourced hardware. Such hardware promotes the use of digital devices through physically mobile hardware. An example that continues to gain momentum in

spatial sectors is the unmanned vehicle. UAV and drone projects like diydrones.com and mikrokoetter.de have matured and are making aerial photo and video capture easier, cheaper and achievable by one person in the field. There is even the Arduino driven Arducopter,

which married the UAV and open hardware movement to create what is essentially a flying robot. UAVs can be used to generate photo based Digital Terrain Models or videos that represent the experiential - the sights, sounds and sense of a place. Even additive



The Rhino Slider is ideal for stereo image capture and can be extended to any length

printing a landscape, building model, artefact or the UAV itself has become affordable to casual users.

Unmanned vehicles

Unmanned vehicles have widely been associated with the capture of aerial photographs and video in recent times. It is important to note, however, that unmanned data capture is not solely the preserve of the UAV or drone. Applications extend to underwater photogrammetry using Autonomous Underwater Vehicles (AUVs), for instance, or computer vision inspired laser scanning solutions, such as that offered by Pittsburgh based company Allpoint Systems. It is a shift in design and manufacture practices - the Third Industrial Revolution - that have made the UAV the most accessible unmanned vehicle to date.

Crowd sourced innovation

Crowdsourcing is driving a range of open sourced hardware. Even the crowdfunding site Kickstarter is changing the way products are developed. Described in the New York Times as the peoples National Endowment for the Arts, it is having a noticeable, impact on cultures based around innovation and the production of ideas. A prime example is the Washington based company Rhino Camera Gear who used Kickstarter to develop the Slider tripod system.

The Rhino Slider

The Rhino Slider is a tripod designed for shooting motion video. Intended for movie makers using DSLR cameras, its intuitive design makes it an ideal tool for stereo pair image capture also. Much like UAVs, it can be used in conjunction with any camera system, tablet or smartphone. In fact, it would even be well placed alongside a gigapan. Include an app like Theodolite Pro or a GPS attachment for a camera (Canon and Nikon now produce their own) into a Slider assisted workflow and a quick, effective way to take georeferenced stereo photographs is created.

Shifting design and manufacture culture

Finally, there is a further significant element to the Third Industrial Revolution, which is that the design and manufacture of a product does not have to occur in the same place. These processes can happen anywhere and independent to one another. In fact it is this - combined with the connectivity made possible by digital technologies - that is seen to have driven costs of manufacture down as well as liberate processes from the factory as a physical entity. Even 3D printing can be achieved in numerous ways. For instance, the University of Bath created reprop.org - a project used to design and develop open source 3D printers that are self-replicating and affordable to a mass market. Point and click solutions like shapeways.com even offer a mail order approach to rapid prototyping. The only decision the user need make is whether they want to know how 3D printing works.

123D example

Offered by Autodesk for free, the 123D software range is the most apparent example of the Third Industrial Revolution currently in play in the spatial sector. Following Rifkin's line of thinking, the 123D toolbox can be used to print out parts for a UAV that, once assem-

bled, can be operated by a tablet through open sourced software like phonedrone. A smartphone can be mounted to the UAV too - serving as a sensor used to collect photographs, video and GNSS data. Any images generated can then be processed in 123D Catch and the data sent off for 3D printing. This is achievable for under USD \$1000. In the examples outlined a Hedcam video camera - a waterproof system designed for extreme sports enthusiasts - has been used for data capture.

Summary

The changing face of production and manufacture processes continues to impact on the geospatial sector, making the Third Industrial Revolution a reality. The development of apps, especially free or low cost apps for mobile devices, along with open sourced hardware is making digital capture and modelling easier and cheaper. Crowdsourced funding and distribution models are taking 3D image capture into new territory by enabling an individual with an idea turn it into a reality. The final element is that rapid prototyping can readily turn these digital products into hard copy in a range of materials from plastics to metals to wood - anywhere in the world where they are required at low cost and without international transport costs.

Aerial mapping using a UAV, a digital SLR camera and Adam Technology 3DM Analyst
www.youtube.com/watch?v=8BqAr3ap3WU&feature=g-all-u

Automated laser scanning using Allpoint Systems Scan-time solution:
www.youtube.com/watch?v=rDZUGlQsHo

Using a smartphone on a UAV:
www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XXXIX-B4/349/2012/isprsarchives-XXXIX-B4-349-2012.pdf

The Vampire UAV designed in Trimble SketchUp and available at Thingiverse.com:
www.youtube.com/watch?v=DLrN-HrLtUS

Open sourced hardware Arduino: www.arduino.cc

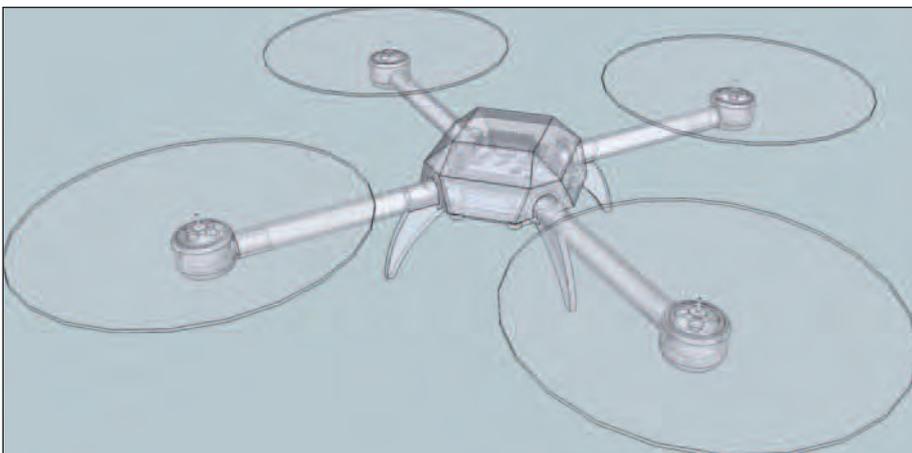
Using the Arduino to create a flying robot:
<http://code.google.com/p/arducopter>

Parrot designed drone that can be operated using a smartphone or tablet:
<http://ardrone2.parrot.com>

Phonedrone open source UAV operating application:
www.youtube.com/watch?v=qdZokmVdrc

The Rhino Slider has great potential in stereo pair capture:
<http://rhinocameragear.com>

Lightweight, durable video cameras, such as GoPro and Hedcam, continue to play an increased role in 3D image capture and DTM production: www.hedcamz.com



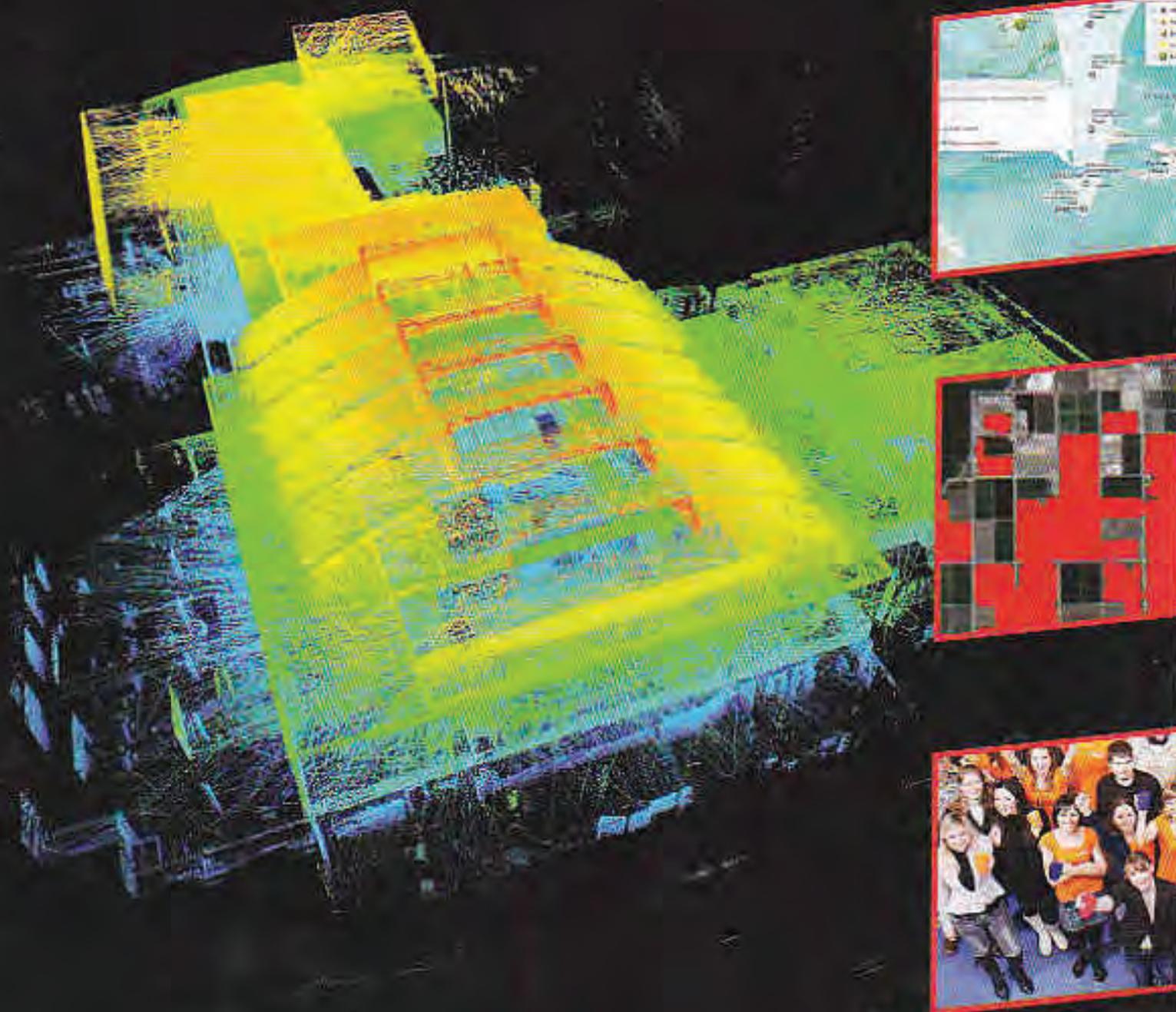
The Vampire UAV was designed in Trimble SketchUp and can be downloaded for printing from Thingiverse.com

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- Mobile Mapping going Underground
- Big Data Analysis and Location
- gvSIG and Quantum GIS
- Is the Tablet an Enabling Technology?

CMedia
CONCEPTS
MEDIA
AND
INFORMATION

From Survey Projects to Media Applications

Is the Tablet an Enabling Technology?

The tablet computer is a versatile device that continues to make an impact in many professional sectors – survey markets included. This article focuses on the latter and examines the various ways in which consumer products like tablets are being used in spatial information workflows. Initially proposed as a learning aid for children by Alan Kay in 1968, its development actually came about due to the growing number of uses for mobile phones and a more considered approach to the integration of technologies across consumer product lines. Examples were generated using a Google Nexus 10 and free applications.

By Adam Spring

The number of sensors included in products like tablet computers, along with the accuracy at which data can be collected, continue to increase. Companies like Broadcom, for instance, have produced a GNSS chip for consumer technologies - the BCM4752 – 10x more accurate than its predecessors. Given the role such devices continue to play in spatial information workflows this article explores smart technologies and their use as tools on and off site.

The iPad

The launch of the iPad kick started the tablet market in 2010. A driving force of development for both Apple and Android – who had been working on their OS system around a similar timeframe -was the integration of existing technology into emerging consumer products. Based on ideas considered by Alan Kay in 1968 the iPad and other tablets represented a slight departure from the vision he would outline later in A Personal Computer for Children of All Ages. Released after the iPod Touch, the iPad was the third Apple product to feature the iOS operating system designed for the iPhone.



Geo Cam turns a tablet into a Theodolite

An active learning tool

The concept for the “Dynabook” was explored in more detail in a paper written by Alan Kay in 1972. Described as an active learning tool

for children its design was somewhere between a laptop and a tablet, though the latter was more in line with his ideas. Thirty eight years later, the development of a lucrative mobile

phone market and the miniaturisation of technologies like touch screens made tablet computers a viable product to bring to market. By that time Kay's ideas had made their way into precision measurement marketplaces too. For instance, a quote often used by the President of Hexagon Geosystems, Juergen Dold, actually came from Kay (see *Geomatics World*, January/February 2011: pp. 32-34): 'The best way to predict the future is to invent it!'

Enabling technology

Whether used on its own or in line with other solutions the tablet has become an enabling technology - an innovation that brings dynamic change to a workflow or user community. The emergence of hybrid 'laplets' like the Microsoft Surface Pro on the one hand and Linux based operating systems like Tizen on the other continue to broaden the concept of the tablet.

In fact, the developers of Tizen are currently looking at technology integration. Firstly, they are integrating technologies centred on ubiquitous platforms like the markup language HTML5, which provides the instructions for how text and media are displayed. Designed to accommodate for other developments like cloud computing and an increased shared experience through the Web, HTML5 is looking to standardise the way information is presented to browsers.

Secondly, Tizen is able to integrate itself through hardware. Companies like Samsung are looking to include it in devices like TVs as well as tablets and mobile phones. The applications or "apps" that continue to be shaped by such processes unlock the potential of the increased number of sensors incorporated into hardware. There are even free system diagnostics tools like Sensor Kinetics that give direct access to the sensors inside a device, as discussed later in this article.

Combined technologies

Bringing together components, such as GNSS chips and motion sensors, into one affordable system has led to intuitive developments like the app. It is the app that makes the tablet more than a tool for 'old' media consumption, such as books, and gives users an opportunity to be creators. They provide a level of accessibility to and interaction with hardware that is reminiscent of the Homebrew computer movement of the 1970s. Such movements were integral to the personal computing revolution, as well as the consumer markets created off the back of it.



Alan Kay imagined the Dynabook as a cross between a laptop and tablet in 1972



ImageMeter takes the x and y coordinates in a photograph and uses them for vector modelling



Hotspotting means you can find an internet connection anywhere on the map

Flexible user interfaces

Such developments have created flexible user interfaces, which take into account the advantages and limitations of using consumer products for tasks otherwise specialist in nature. For instance, there is an active learning experience for general users working with apps like Geo Cam and ImageMeter. In order to use the information collected to its fullest, they are encouraged to understand basic principles of survey like triangulation or that photographs contain x, y coordinates and can make vector modelling more accessible and easier. The iOS app Hunter Theodolite Pro even provides easy to follow instructions that outline basic principles of survey. The apps created to permit wide scale flexibility at application stages turn tablets into a digital prospection tool - one that can be used

in most workflows to perform numerous tasks. The Google Nexus 10, for instance, is pre-packaged with its own suit of tools that are designed with spatial information sharing in mind. This is to the point where the photo and video interface allows for longitude and latitude information to be added to file property tags. Otherwise separate entities like Google Earth, Google + and Photo Sphere are clearly interlinked and can be used to augment and share experiences with anyone around the world even before the first app is downloaded. Google's strategy includes the experiential side of mapping - it accommodates for what Aristotle saw as the five senses of vision, sound, touch, smell and taste. Much like the AutoCAD WS app where plan drawing can be infused with videos, images or commentary, social media like Facebook can feed into free GIS systems like Google Earth too. Information flows that otherwise seem set apart from one another in analogue workflows fit seamlessly together through digital media and easy to use devices like the tablet.

Hexagon 2012

At the Hexagon 2012 conference tablets and smartphones were used to explore the social interactions of its user community. Apps formed part of the social experience and reinforced ideas pertaining to non-linear workflows. Attendees were given the opportunity to build their own event using the Hexagon 2012 app while QR coded name tags promoted networking opportunities and peer to peer learning (see *Geomatics World*, July/August 2012 : pp. 26-28). For the same devices used to do this a photo dehazing app for iPhone and iPad was introduced too. Derived from Geomeia based technology this example was described by the President and CEO of Hexagon AB, Ola Rollen, as a product born out of specific applications that is now being used in everyday life.

Free applications

The free Android apps selected have been chosen as examples that feed into different aspects of documenting a scene digitally. Included are apps designed for connectivity to the Web, surface mapping, 3D imaging workflows and augmented reality.

ImageMeter

ImageMeter was designed as an easy to use vector modelling tool by the Technical University of Eindhoven based programmer Dr Dirk Farin. The app lets users add horizontal and vertical values to x and y pixels. Once a reference plane has been created dimen-



Photo Sphere creates 360° panoramas that can be used in Street View and Google +

sions and angles can then be placed in the scene automatically. Thus making plan drawings and scene analysis much easier. Greater accuracies can be achieved by importing high resolution images into ImageMeter.

TopoPLANNER

Developed by Certainty 3D, TopoPLANNER uses Bing, Yahoo and Google maps to help users plan mid-range laser scanning workflows. Primarily for tripod based scanning units the Florida based company also designed TopoTRANSMISSION for mobile mapping systems. TopoPLANNER is particularly useful for projects carried out in built up urban areas.

The Reader AR

The Reader AR is available for iOS and Android. It was developed for the phase shift laser scanner manufacturer Zoller and Froehlich by the Italian company G-maps. An augmented reality viewer, the app demonstrates the way in which tablet and smartphone technologies can be used as an alternative media for viewing 3D models. Similar to the US company Zebra Imaging - who turn point clouds or meshes into holograms - G-maps is using augmented reality to give data an added sense of dimensionality. Something still overlooked in workflows where a reduction to 2D is required.

Meshlab

Meshlab is an open sourced 3D modelling package that stemmed from a course assignment at the University of Pisa in 2005. Ideal for small 3D imaging data sets and decimated point clouds in terms of larger files, it has been repackaged for iOS and Android systems as a free viewer. The viewer can be used to support work flows derived from the com-

plete package which is available as a free download also.

The easy to use app is deceptively versatile - especially in markets currently driven by the Internet of Things and Third Industrial Revolution. With the desktop versions of Meshlab supporting export formats for 3D pdf, rapid prototyping and standard CAD formats like .dxf the app can be used as a simple and effective way of showing off point clouds, as well as flat and meshed surfaces. The interactive light functionality accentuates this further.

3D Camera

Though current 3D capture apps for Android and iOS have some way to go to be of value in professional workflows, ease of use and the ubiquitous nature of the product make 3D Camera a useful tool for teaching basic principles like projective geometry. One of the better depth camera apps available 3D camera uses stereo pair images to generate the missing z coordinate from standard photos. This z axis can be turned off or extended in the viewer, which enables users to share results through Picasa too. Photos can be imported or taken by the device running 3D Camera. The app does, however, require an internet connection to process results through its servers.

AutoCAD WS and AndCAD

Both these apps can be used to work with CAD files. An extension of its desktop equivalent AutoCAD WS enables users to work with 2D and 3D files anywhere as well as incorporate social media functions designed to provide commentary and feedback. AndCAD is a standalone CAD package that retains functionality in its demo version at the expense of not being able to save data.

Sensor Kinectics

Sensor Kinectics lets users monitor all sensors inside an Android device. This includes GPS, accelerometer, gyroscope, proximity sensor, digital compass, magnetometer and barometer. With a series of help files it also provides information that encourages users to perform their own tests, as well as turn sensors off and on.

Hotspotting

Hotspotting is an app that scans for free wifi all over the world. With a growing community and database, users are encouraged to share new finds in order to make Hotspotting self-sustaining.

Photo Sphere

Google's Photo Sphere falls somewhere between the idea of an Internet of Things and augmented reality mapping. In the same way PTgui can be used to generate 360° panoramas, Photo Sphere gives users the opportunity to add their own Street View to Google Earth and Maps. Google + and Hang Out members can geotag these panoramas (this includes an external camera workflow for Nexus devices). Another advantage of using Nexus running Android 4.2 is the camera operating software. It is easy to use and is designed to optimise what can be achieved with the internal camera.

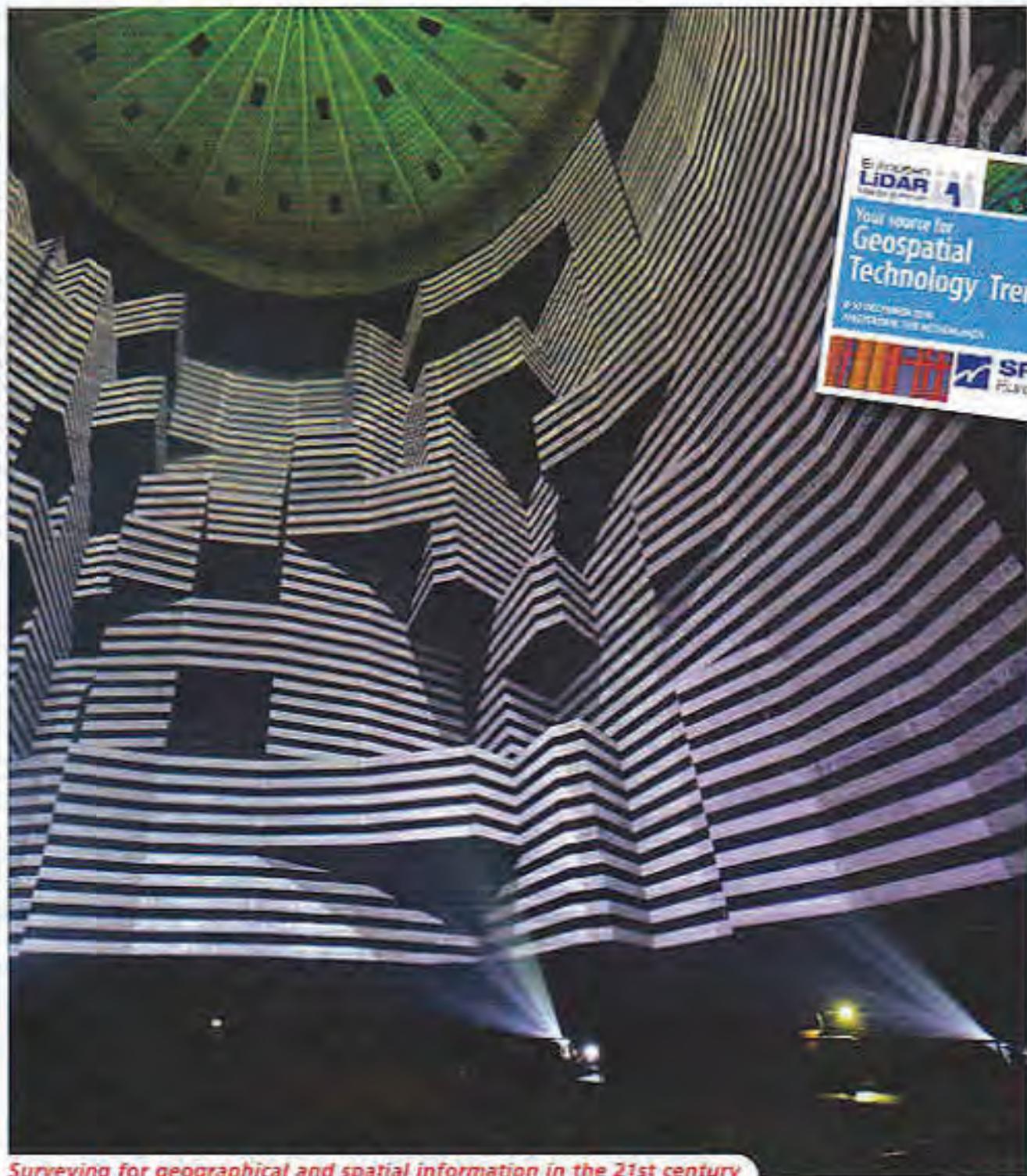
Geo Cam and Theodolite Droid

Geo Cam and Theodolite Droid turn Android devices into a Theodolite by using the sensors available (see Geoinformatics 7, Vol. 15: pp. 32-34). Similar in function and design both apps can be used as range finders, GNSS loggers and to perform functions like elevation measurement and landscape mapping. Geo Cam can be used in North America and the NAFTA region, while Theodolite Droid can be used in Europe and surrounding countries.

Conclusion

It is impossible to separate out the discussion of tablet computers from that of mobile phone technologies. The size of the tablet, however, is what separates it out in terms of application and use. Based on an ancient format - i.e. the book - it has stood the test of time because it is the right size for human interaction and engagement. Whilst the tablet itself has gone and will continue to go through a series of iterations and changes, its role as a receptacle and communicator of knowledge will not.

For more information, have a look at:
www.broadcam.com/products/features/GNSS.php



Surveying for geographical and spatial information in the 21st century

Is Revit now the de facto standard for BIM?

A standard for Discrete Global Grid Systems

Going for gold at HxGN Live 2014 in Las Vegas

A new tool for locating underground utilities

PPP aboard ships could improve satellite altimetry



HxGN Live 2014: workflow infuses services and solutions

HxGN Live was held in Las Vegas in June for a third consecutive year. It was where everything came together for Hexagon AB. Synergy, BIM and consumer-driven stories were just some of the themes explored by the 3500 people who attended in the vast MGM Grand hotel. And Leica Geosystems is a focal point that continues to bring everything together for its Swedish parent, observes our reporter **Adam P. Spring**.

This year's HxGN Live was another milestone event for Hexagon as a company. It was as significant as its first conference back in 2011 in Orlando, Florida. Seamless integration between Intergraph and Hexagon - rival service and solution providers until Q4 2010 - had become second nature for all Hexagon employees. Numbers for the high definition survey (HDS) sessions were also at a record high of 800 attendees. This figure was up by 100 people from the 700 users that attended in 2013. HxGN Live in Hong Kong was announced for November 18th-20th, 2015.

Point cloud a standard for BIM and CIM

The Leica Geosystems training day showed that scanning based solutions continue to evolve. For example, sessions for hybrid systems like the Nova MS50, the multi station instrument that combines total station technology with GNSS and scanning, took place for the first time. Interactions between users and seasoned HDS trainers like **Guy Cutting** also indicated the point cloud was now an industry standard. This was especially the case in emerging application markets like Building Information Modelling (BIM) and Civil Information Modelling (CIM).

Scan to BIM

Joshua Rayburn, an HDS manager for part of the NAFTA region, presented scan to BIM using a Leica P15 laser scanner. This hands-on session began with scans collected in the training room. Point cloud information was then used to demonstrate a scan to BIM workflow, where data was processed in Cyclone and Cloudworx for AutoCAD. Decision making processes were being informed by as-

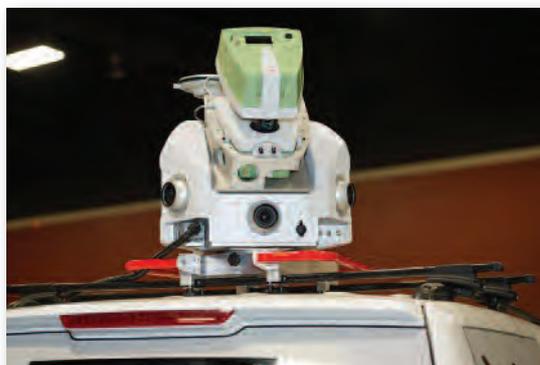
built information derived from point cloud data - real world conditions for a building or structure. Navigating between what Hexagon viewed as the digital world and real world is what makes BIM a powerful project management strategy. Information use now goes beyond standalone 2D plan drawings.

Overall, the HDS training sessions highlighted that P15 and P20 scanner solutions guarantee high resolution data collection at industry leading speeds. Sessions like Rayburn's lay the foundation for numerous Cyclone related announcements made at HxGN Live 2014. Like Intergraph Imagine software (which used to fall under Security Government and Infrastructure - S,G&I), this included the use of solutions provided by Australian company Euclidean. Their technology has been integrated into several cloud based viewers and was demonstrated at the conference in order to show how to manage large datasets. HDS hardware and software solutions therefore continue to meet the demands of Hexagon's worldwide user community.

The keynotes

The opening keynote was entitled *The Disruptive Power of Transformation*. Hexagon has reshaped itself around information and communication technologies (ICT). This was achieved via its Smart Content Program (SCP) and GeoCaaS service. Outlined by president and CEO Ola Rollén, SCP was part of a business model "moving from product centric to workflow solutions." It also set the tone for a genuinely Live event based around intelligent and autonomous systems, a move away from technology isolation in favour of technology convergence and more efficient design and manufacture processes. Information capture and distribution lifecycles were also explored in the days that followed.

Right: The Pegasus Two combines several Hexagon solutions in order to create a mobile mapping add-on for vehicles.



Right: The T2 is a portable cart based laser scanning solution that continues to evolve around infrastructure based applications.



Geosystems, Geospatial and Metrology

Jurgen Dold, president of Hexagon Geosystems, discussed market growth and data integration in his Leica Geosystems keynote. Whether it was investment in the mining sector or emerging unmanned aerial vehicle (UAV) applications, Dold confidently voiced his approach to change: "We need to create places where multiple datasets are coming together from multiple data providers. So, we can then take those and create information layers - to create this information for more and more users."

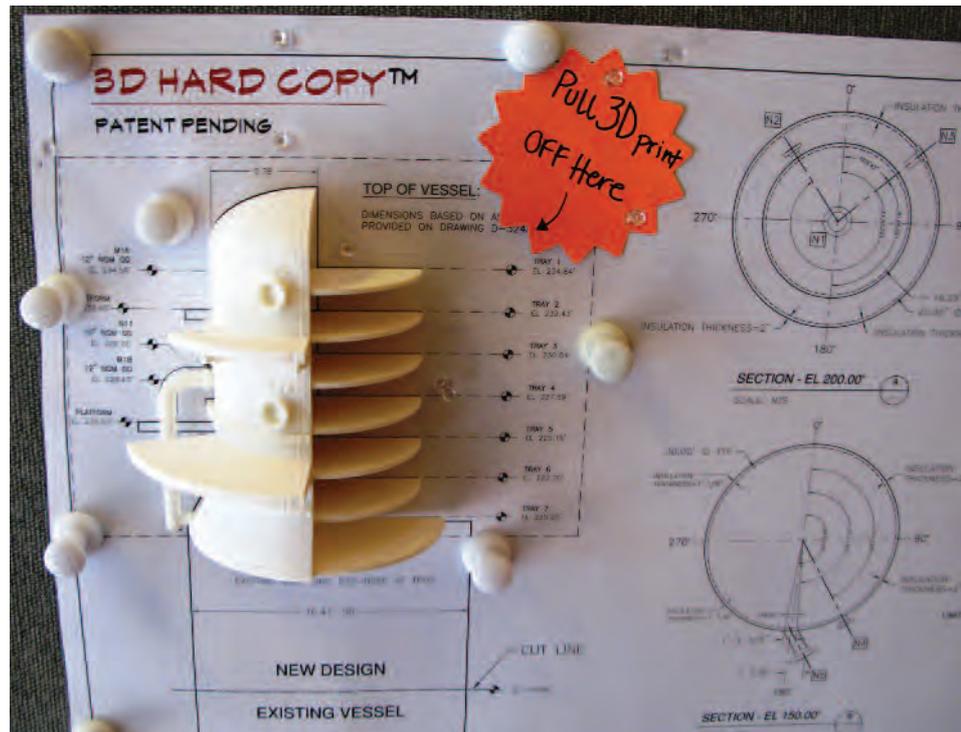
It was also the first time **Mladen Stojic** had attended HxGN Live as president of Hexagon Geospatial. Intergraph's geospatial portfolio had been rebranded at the end of 2013, and a new branch of the Hexagon family was created. In his inaugural keynote, Stojic demonstrated why he was the person to shape its future: "Our goal is to transform the industry and, ultimately, transform the geospatial economy associated with capturing content, producing content, providing content as a service and using that content in solutions."

Transforming industry was also at the heart of the Hexagon Metrology keynote. **Norbert Hanke's** team were ahead of the curve in a sector where quality control and production lifecycle are primary considerations. **Ken Woodbine**, PC-DMIS developer, used the metrology management system (MMS) - a collaboration between Hexagon Metrology and Intergraph - to discuss integrated data. He explained how MMS continues to expand the concept of product lifecycle management (PLM) in the metrology world: "It aligns with several current software megatrends like big data, cloud computing and the Internet of Things."

Nova MS50

Last year the Nova MS50 MultiStation was heralded in via a champagne reception in the Leica Geosystems keynote. One year later, numerous presentations highlighted why its Heerbrugg design team felt a great sense of pride toward their creation. In the HDS sessions, for example, **Sean Douthett** of David Evans and Associates showed how MS50 data could be integrated with ScanStation C10, P20 and HDS 6000 point cloud information. The range at which data could be collected was a notable consideration for Douthett as an MS50 user. High resolution data capture over 150 metres was a key selling point in scan-data fuelled social circles.

Hans Moller, lead surveyor at Bechtel Oil, Gas, & Chemicals, also discussed the advantages of an MS50 based workflow. Set in Australia, the story he told was driven by point cloud data for industrial sized containers from the Curtis Island natural gas processing facility. The MS50 provided high quality data as both a total station and laser scanner.



Results for site monitoring activities and various surface analysis tests were particularly impressive.

The variety of applications outlined in Douthett's and Moller's presentations teased out an important point about the Nova MS50. It had become a powerful gateway technology for users who might be unfamiliar with laser scanning. It had, no doubt, opened doors for the Leica Geosystems HDS brand since its release - such as applications where users may otherwise be resistant to change.

Market growth

User diversity and an increased number of first time attendees demonstrated that interests in geospatial information were growing. In order to capitalise on it, **Ola Rollén** likened the approach Hexagon was taking to the Apple iTunes model. His Content as a Service (CaaS) strategy took advantage of data integration, market consolidation and the long-term value of what he sees as actionable information. In other words, the non-linear workflow was here to stay.

Customer feedback on architectural, engineering and construction (AEC) work in the US revealed that the NAFTA region was in full economic recovery. The amount of work Hexagon users were getting in comparison to previous years was certainly a shopfloor indicator. Texas based companies like Lanmar Services had, as its CTO **Larry Kleinkemper** put it, "never been busier." BIM and CIM were reshaping the way spatial information was being used in the "new world". Clients were also having more of a say in decision making processes.

The power of BIM

Leica Geosystems was well placed within

Above: Low cost 3D printing can now be used as part of a BIM workflow to help inform AEC based design processes (Photograph Courtesy of **Remco Takken**)

"It had become a powerful gateway technology for users who might be unfamiliar with laser scanning."



Above: The Golden Nugget in Downtown Las Vegas is one of 20 places in the world that has a Gold to Go machine.

Hexagon to reap the benefits of BIM related applications. The HDS brand had clearly matured, and the idea of 2D plan drawings as the baseline dataset had clearly become a thing of the past. For example, scan to BIM could be used to describe how as-built conditions were documented through a point cloud. This had also translated over into the work environments of Intergraph Process, Power and Marine (P,P&M) users. Hence, the rise of the term CIM, civil information management.

Data integration was also promoted in BIM work cycles through integrated project delivery (IPD), which helps utilise the talents of all project team members to obtain the best results possible. **Cathi Hayes**, BIM manager at Leica Geosystems, reiterated this throughout her "Field Trip" sessions - even pointing out that BIM and IPD are intricately linked to one another. Market and user outcomes seemed limitless to anyone sitting in the Hayes sessions held in 2014.

Synergy

Synergy between all parts of the Hexagon family was discussed throughout HxGN Live 2014. **Jack Ickes**, President of the geospatial solutions division at Leica Geosystems, demonstrated how a ScanStation P20 scanner was combined with acquired solutions like GeoCue. This created the Pegasus Two, a powerful mapping solution new to the Leica portfolio. A cart-based system was also showcased. Called the T2 (that title is bound to send a frisson through old hands and lovers of the ubiquitous Wild T2 theodolite, which sold 90,000 over 70 years for Wild, Leica's predecessor company), it includes a Velodyne sensor. Future developments based around the growing relationship between P,P&M and Leica Geosystems were hinted at too.

Mining

Hexagon has repositioned itself within the mining industry over the last year. Design, exploration and operation are the key components of its onsite workflow. Its mining software and fleet management markets have been merged in order to make Hexagon the number one services and solutions provider in the mining sector. In other words, MineSight, Leica Mining, SAFEmine and Devex were brought together in order to "leap frog" the competition. In the Leica Geosystems keynote entitled *Dirt, Diamonds and Data*, president of Hexagon Mining, **Guilherme Bastos** outline his 360 plan for the future: " We cover mine surveying, mine planning and scheduling, real-time management for open pit and underground mines, process automation, 3D visualisation and safety."

Mining infrastructure and asset management are set to have a noticeable impact on future streams of income for Hexagon. Acquisition of the UAV company Aibotix (an ideal solution for data capture in open pit mine mapping), complimented motion extraction based solutions like SAFEmine. This all-in-one traffic safety and collision avoidance solution was already being used on the ground to make open mine environments safer.

Gold to go

The Golden Nugget casino is located in downtown Las Vegas. It is the largest casino on Fremont Street and has featured in films like *Diamonds Are Forever*. In 2011, a new chapter was added to its history when a Gold to go vending machine was installed in its Gold Tower Lobby. Prices are updated every ten minutes and 24 carat gold bars are sold in 1, 5 and 10 gram sizes. Boxes of gold coins can also be purchased.

Las Vegas is one of 20 locations where Gold to go vending machines can be found. They are also in other parts of North America, the Middle East and Europe. For example, Westfield Shopping Centre in West London had a Gold to go machine installed in 2011. The business aspiration of Germany based TG-Gold-Markt is to have 500 Gold to go machines in operation around the world.

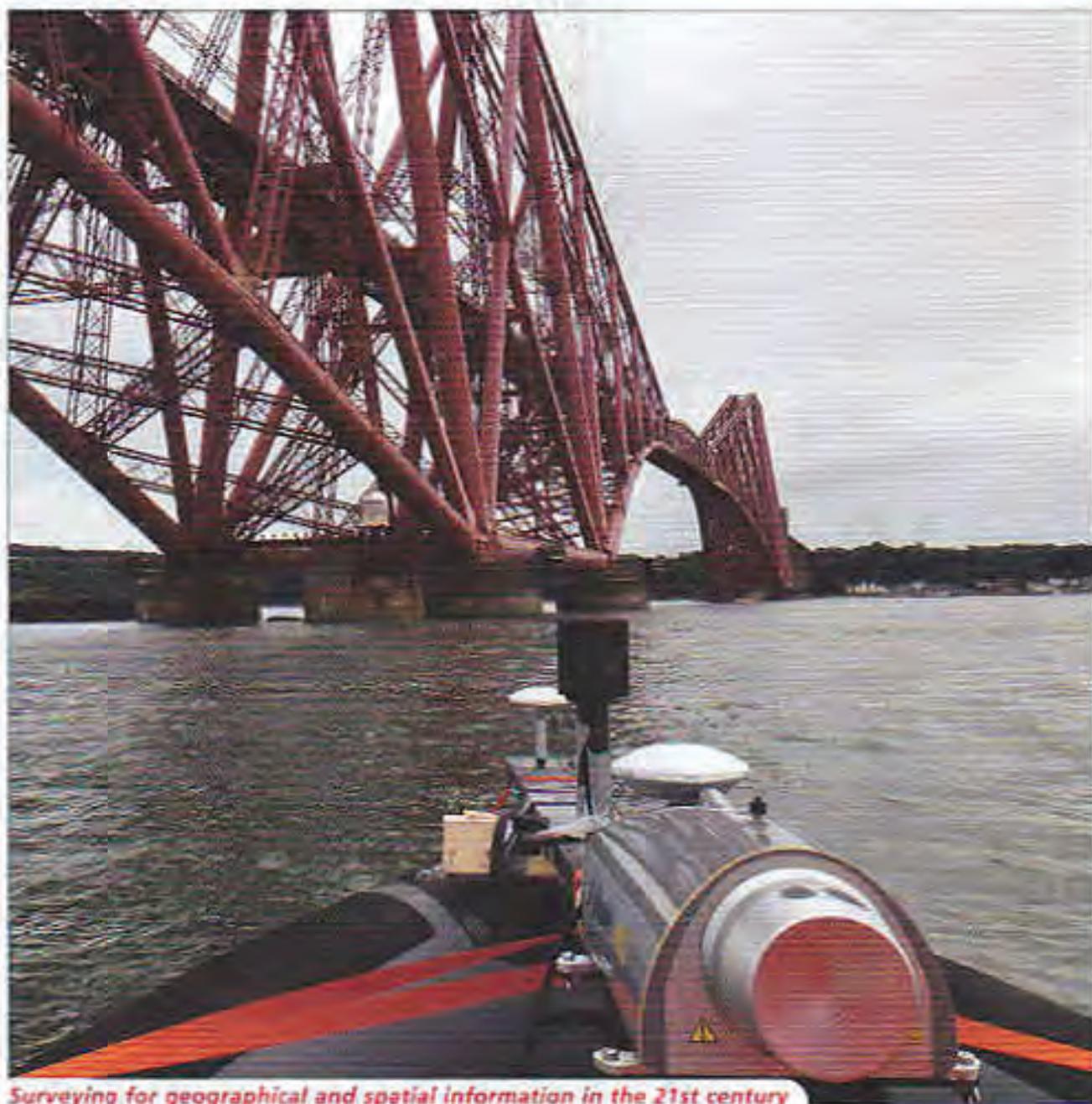
Summary

Hexagon AB was pragmatically transparent about its immediate and long-term goals at HxGN Live 2014. The mantra of a world shaped by an evolving information flow, which had been presented to its customers, was now a fundamental part of its day-to-day business operations. Divisions like P,P&M - outlined as having sizeable growth potential in the capital markets day presentation - provided insight into what to expect at the next HxGN Live event. User stories will not only be told in Las Vegas in 2015. They will also be presented in Hong Kong.

About the author



Adam P. Spring is a consultant and visiting lecturer in Applied Technologies and Reality Capture in the Department of Archaeology, University of Plymouth. He has featured in numerous academic and research publications. In addition to reselling 3DM Analyst, he has been a consultant for Autodesk and Leica Geosystems. For more information, visit <http://remotely-interested.com/>. You can follow Adam on Twitter at [@ThatInterested](https://twitter.com/ThatInterested)



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REAL opportunities ahead for geomatics

San Francisco gets REAL for GW's Californian reporter



Forth bridges scanned from land and water



QS colleagues are waking up to what BIM has to offer



Brilliant challenge for onshore hydrographic survey



Buying a laser scanner. Can these journals help?





Laser Scanners and the market in 2015

For surveyors, the purchase of a laser scanner is likely to be one of the costliest single equipment purchases they make. **Adam P. Spring** offers some timely advice and guidance for the decision making process.



• *Adam P. Spring is a consultant and visiting lecturer in Applied Technologies and Reality Capture in the Department of Archaeology, University of Plymouth. He has featured in numerous academic and research publications. In addition to reselling 3DM Analyst, he has been a consultant for Autodesk and Leica Geosystems. For more information, visit <http://remotely-interested.com/>*

Demand still continues to grow for the types of laser scanner most *GW* readers are familiar with. In recent years, depth imaging via gaming sensors and mobile devices has also started to take related markets in a new direction. For example, Trimble linked Google's Project Tango to SketchUp almost immediately after the technology was announced. There are even videos of former Mensi alumni, **Omar Soubra**, using a Tango tablet for BIM applications. The gap between consumer, prosumer and professional markets continues to shrink and to blur.

This article is not just a reaction to such developments. It stems from firstly being a long time user or earlier adopter of commercial laser scanning and secondly, recent experiences of buying a laser scanner. Despite ongoing refinement, laser scanning remains a best-fit solution. There is no one tool that can do every job. In fact, finding a best-fit solution can be a daunting task. This is especially the case when trying to be an agnostic consumer. Someone who looks beyond particular brands, who has a deep understanding of the solutions available. The one ubiquitous statement that can be made about laser scanning is that it remains an application-driven technology.

Specifications

It is interesting to note that **Jerry Dimsdale**, co-founder and CTO of Cyra Technologies, openly stated that a need for a standard in specifications for laser scanning is still required. Writing in *LIDAR news*, September 2014 he likened conditions to those of the formative years in the United States: "In this regard, we are currently living in the Wild West, it is not healthy, and I don't believe it can continue." Jerry also gave a presentation at SPAR International 2015 - *Performance Evaluation of 3D Capture Systems, Driven by Project Demand*.

In one respect, the problem that Jerry identified lies in the packaging. Though marketed alongside traditional survey tools, laser scanners are not the same as a total positioning station (TPS). They are designed and built to document surfaces or a scene as opposed to a specific point. This is often made difficult in specification documents where laser scanners are categorised in similar context to TPS. In reality, laser scanners are range cameras that collect information based on known variables related to the camera model in place. This is discussed in more detail in the *Journal of Archaeological Science* article

Developing a low cost 3D imaging solution for inscribed stone surface analysis.

Data flow

The relationship between application, workflow and services and solutions used on a day-by-day basis are fundamental to which scanner you buy. Another thing to consider is how you are entering into the market. If you are new to laser scanning, customer support will be as important as the price point of the sensor being acquired. It can ultimately determine whether bringing laser scanning into your day-to-day business activities is a success or failure. Peer-to-peer learning through user communities already in place is also an invaluable resource.

Industrial example

Industrial plant applications will be used to present some variables to consider when buying a laser scanner. They present environments that contain multiple depths of field in terms of object relationships and varying surface reflectance. For example, black piping or white piping will give different signal returns for objects of the same shape and size. In terms of deliverable, safety is usually paramount to any activities taking place in these engineering environments. **Matthew Craig**, Business Development Manager for LFM Software Ltd., conducted an interesting comparative study of four different laser scanners used in a plant environment in 2014.

Every pipe, fitting or bolt has a known and measurable value as an asset. They translate over into a laser-scanning workflow through the time it takes to document a site, the guaranteed accuracy and resolution at which that scene can be documented and the range at which data can be collected. The end deliverable and data-processing workflow should always be considered before work takes place on site.

Data Cycle

In this instance, the data cycle is based around CAD. Not just 2D CAD but potentially multi-dimensional CAD. This means that point-cloud friendly packages like LFM and EdgeWise would be well placed alongside standards like AutoCAD Plant 3D and Bentley AutoPLANT. In fact, LFM is a good gateway solution to include in a workflow for anyone looking to make the transition to point-cloud based design in plant-driven industries in 2015.



Above: Topics discussed in this article are expanded in two articles. The first appeared in the *Journal of Archaeological Science*, December 2014. The second in the *Institute of Electrical and Electronics Engineers* publication *Computer*, February 2015.

Autodesk ReCap, CloudCompare and Leica Geosystems Cyclone are also complementary solutions in terms of point-cloud registration.

Multiple laser-scanning options could be used on site in the context of industrial plant applications as well. For example, there would be advantages in combining systems at the more affordable end of the spectrum, such as the Topcon GLS 2000 and FARO Focus3D X Series. This option relates to range and combined quality of data captured - especially when buying on a budget. There are also advantages to using all-in-one options like those offered by Leica Geosystems. Since they were acquired by Hexagon in 2005, Leica's solutions have become integrated across the company portfolio. This means information from hybrid systems like the Leica Nova MS 50 TPS total station and scanners like the Leica P40 are designed to work with as many Hexagon products as possible.

There is also Zoller and Froehlich (Z+F). They created the first all-in-one scanner via the 5006 in 2006 (scanner, battery and computer) while they incorporated full HDR photography in their 5010C scanner in 2012. Z+F offer manufacturer packaged thermal imaging for terrestrial laser scanning point cloud data via the T-CAM and low light shooting capabilities for "overdrape" photography through the SmartLight. Z+F also announced Blue Workflow for better registration via LaserControl Scout and the 5010 X at SPAR International 2015.

Austria based Reigl are another standard bearer, especially in mobile, airborne and longer range applications.

Market influence

Terrestrial laser scanners have been driven by commercial development cycles since a market was created around them in the late 1990s. The need for better standards is a by-product of these market building processes to an

extent. Desires by the manufacturers need to be separated out from the need for better comparable standards between them. There is a difference; and the long-term evolution of associated markets depends on it. Included in this is the need for greater interaction between the service and solution developers across the different brands.

The need for improved specifications in laser scanning feeds into broader trends currently taking shape in 3D imaging communities as a whole. Laser scanning is not an island in this instance - no one is to blame. For example, in 2015 there remains a difference between creating a 3D image and documenting a scene based on known variables. Structure from motion-based packages, which are frequently referred to as photogrammetry, offer a prime example of terminological issues in other parts of the geospatial sector. For a more detailed discussion of this go to the IEEE *Computer* article *Creating Substance from a Cloud: Low-Cost Product Generation*.

Summary

Where and how you enter the marketplace is ultimately what should determine which laser scanner to buy in 2015. Choices continue to grow in the laser scanning space, with new developers coming on the scene as each year passes. Which scanner you acquire is much more than just a technical question at this time. It is, in some ways, a highly sociological decision as well. For example, it never hurts to reach out to your contact base to get advice. Laser scanner users are a social group of people, who 9 times out of 10 will go out of their way to help you if they can.

The scanners mentioned in this article have nothing to do with brand preference on the author's part. It is just how they fit into the topic discussed. That said, the author does agree with Jerry Dimsdale that better standards for laser scanning do need to be in place. This includes improvements and a clear direction for file formats like E 57. After all, the main reason MIDI is still the file standard in the music industry is because manufacturers came together to make sure it worked.

- For more information on which scanner to buy turn to *Engineering Surveying Showcase 2015 issue No 1* from PV Publications. If you are an RICS member you are entitled to a free copy. Just email your details together with your RICS membership number to admin@pvpubs.demon.co.uk. If you are already a subscriber to GW you should have received a copy. If not, please call **+44(0)01438 352617**. For those who are not regular subscribers, we would be delighted to offer you a free digital subscription but that does not gain access to our decade and more of back issue archives. You need to subscribe. Go to: <http://www.pvpubs.com/GeomaticsWorld/Subscribe>

“The need for improved specifications in laser scanning feeds into broader trends currently taking shape in 3D imaging communities.”