

3D Imaging in Cultural Heritage, The British Museum

Abstracts & Exhibitions

Keynote Talks

3D Imaging, Cultural Heritage and TV

Michael Scott

University of Warwick

This talk will examine how 3D laser scanning has been used recently in TV documentaries (and associated web based platforms). It will seek to outline what 3D imaging has successfully achieved, where it brings real added value in terms of programme and platform impact, and the potential roles it might play in the future.

Michael is an Associate Professor in Classics and Ancient History at the University of Warwick, a National Teaching Fellow, author of several books on ancient Greek and Roman society, and has written and presented a range of documentaries for National Geographic, History Channel, ITV and the BBC.

Exploring Egyptian Mummies: From CT Scans to 3D Visualisations

Daniel Antione

The British Museum

Over the past decade, mummies held in the British Museum collection have been the focus of new research using the latest scientific methods. In the past, the only way to analyse bodies such as these would have been to unwrap them, but the emergence of sophisticated non-invasive X-ray imaging techniques in the 1980s virtually eliminated the need to disturb their coverings. The investigation of mummies now makes use of the latest Dual Energy CT scanning and 3D visualisation technology, and this non-invasive approach that was employed to study six individuals who lived in ancient Egypt from about 900 BC to about AD 180.

Daniel Antoine is the British Museum's Curator of Physical Anthropology, with responsibility for the Museum's human remains. His areas of expertise include the scientific study of human remains, the anatomy of the human skeleton, ancient diseases and hard tissue biology. He is an Honorary Senior Research Associate at the Institute of Archaeology, University College London and the Secretary of the Institute for Bioarchaeology.

Discovering museum collections using 3D imaging techniques

Farah Ahmed & Alex Ball

The Natural History Museum

Natural History Collections, as a sub-set of Museum collections, face many of the same pressures as Cultural Heritage Collections. They represent a long-term record of humanity's efforts to collect, record and describe the natural world. The

NHM's collections (around 80 million specimens) include specimens from across the natural world, encompassing rocks, minerals, fossils, animals and plants as well as manuscripts, record books, maps, drawings and paintings. These include objects of great scientific or historical interest. Many of the specimens are unique, so our main motivation for much of our research is to apply non-destructive techniques, often in correlated combinations.

In this talk we aim to discuss multi-scale 3D data acquisition – how do we acquire accurate 3D models from objects as diverse as whale and dinosaur skeletons, insects and other invertebrates and even >400Mya micro-fossils? Where objects are extremely rare or precious, our studies may emphasise an understanding of the instrumental effect upon the sample. For example, the effect of micro-CT examination on the recovery of DNA from bones and tissue samples or measurement of the contamination rates of samples under examination by SEM and its application to NASA, ESA and JAXA sample return missions. As well as NHM samples, we are routinely asked to apply our expertise to materials in other Museum collections. This talk aims to provide examples for a variety of different projects to give some insight into the range of applications faced by our team on a daily basis.

Farah Ahmed is the Head of Imaging in the Imaging and Analysis Centre (IAC) at The Natural History Museum. Farah received a BSc in Biomaterials Engineering and a PhD in Biophysics from Queen Mary University of London. Farah studied the three-dimensional structure of pathological bone using Micro-CT during her time as a PhD researcher. Following a short research position at the school of Medicine and Dentistry at QMUL, she worked in a CT based consultancy. Farah currently manages the X-ray CT facility at the Natural History Museum in London and works on over 100 CT related projects a year across all science disciplines. Farah has held position of conference chair for Tomography for Scientific Advancement (ToScA) since 2013. She also holds a fellowship awarded in 2013 by the Software Sustainability Institute. Farah is heavily involved in outreach work and is interested in working closely with science and non-science groups to communicate NHM science to the public. Farah's main research interests lie in developing CT methodology for a broad range of applications including - meteorites, soft tissue, bone, biomaterials, medical devices, the mining sector and palaeontology.

Alex Ball is the Head of the Imaging and Analysis Centre at The Natural History Museum. Alex's PhD at Royal Holloway (University of London) dealt with an early application of computer-aided 3D-reconstruction based on serial-sectioned materials, combined with light microscopy, SEM and TEM. Alex has over 25 years' expertise in scanning and transmission electron microscopy (SEM, TEM), variable pressure SEM, non-destructive imaging and analysis, micro-CT and light and confocal microscopy. In his time at the Natural History museum he has founded and developed three separate laboratories to provide centralised light microscopy, micro-CT and 3D surface scanning facilities. Outside of the NHM, Alex is secretary to the Society of Electron Microscope Technology, a member of the Council of the Royal Microscopical Society and a member of the RMS' Electron Microscopy and Education and Outreach Committees.

Thursday, 9th November 2017

Session One

3D Reconstruction of Niniveh

Naphur van Apeldoorn¹, Boris Lenseigne¹, Pieter Jonker¹, Joris Dik¹ & Lucas Petit²

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Parts of the Southwest Palace of Sennacherib (≈ 700 BC), which were exhibited in Nineveh (Iraq), are now destroyed by the ongoing war in Iraq and Syria. The palace rooms used to be decorated with numerous reliefs, which illustrated the activities of Assyrian royals and their Gods. Luckily, digital pictures of the site are available thanks to an Italian expedition in 2002. Our goal is to physically reproduce the destroyed reliefs using this photo database. First photogrammetry was used to rebuild the global dimensions of the reliefs while details were reconstructed by combining a highly detailed depth map obtained from Shape from Luminance (SFL), together with a coarser Artificial Reconstruction. The final 3D models were used to produce full size reproductions by digital manufacturing.

The SFL algorithm was provided by QdepQ Systems BV. It uses illumination to extract the shape of objects from an image. The image is split into multi-scale components using locally adaptive filtering. An increase in scale leads to an increase in the level of details. Where at its lowest scale, it represents the illumination direction. Once combined, it is possible to produce an image with a global diffuse illumination from which a reconstruction is made from the shading information. Nevertheless this algorithm tends to produce over-detailed reconstructions and must be used in combination with a smoother artificial depth map. The latter makes use of the assumption that lines in the image correspond to changes in depth. Using line drawings produced by experts, the algorithm maps each line to the appropriate change in relief and produces a coarse elevation map. The two maps are fused together in a way that emphasizes coherent structures over rough random changes.

This approach was validated on one of the remaining reliefs of the palace, which is in possession of the National Museum of Antiquities in Leiden (RMO), the Netherlands. A laser 3D scan of the relief was made as a reference and compared to a reconstruction based on a 2D photo. This was used to fine tune the algorithm and validate the approach. We found that both the structure and the details could be reconstructed finely. Finally, close-up reconstructions of details and large scale reconstructions of whole reliefs were merged to produce the final 3D model.

The last step was to convert the digital reconstructions into physical objects. Reproductions were made using CNC milling of limestone, full colour sandstone 3D printing of Z corporation, and elevated printing provided by Océ. They will be exhibited together with handmade reproductions at the RMO in October this year. This shows that even when the original is lost, copies of ancient artefacts can be made from pictures only. We also learned that results are vastly dependent on the picture quality: extensive tuning was needed when using 15 years old photographs. However, this remains the only way when the originals are destroyed and only pictures are left.

The Must Farm Pile dwelling: An Integrated 3D Workflow and Analysis

Donald Horne

Cambridge Archaeological Unit

The Cambridge Archaeological Unit's 2015/16 excavation of the Must Farm pile dwelling is one of a handful of excavations systematically using Surface from Motion (SfM) as the recording strategy and (at the time of writing, to the author's knowledge) the only commercial investigation to do so.

Within the museum and built heritage sector of archaeology, three-dimensional recording technologies are now comfortable additions to the analytical toolset. Yet within excavation - an act destructive by its nature, where the need to have a more complete recording is more pertinent - 3D technologies are rarely used. When they are used, they tend towards the documentation of the most aesthetically exciting items with no systematic strategy in place. Furthermore, the models tend to be considered the product in themselves, foregoing the analytical potential the correct use of 3D recording could potentially yield.

Due to the 2006 evaluation, it was known from the outset that the excavation of Must Farm would have a complex of fragile timbers and a spatially intact syntax of an artefact assemblage. Upon excavation, Must Farm shattered our most wild expectations with the discovery of at least five Bronze Age structures and their contents preserved at an almost forensic level of preservation making it one of the most exciting excavations of 2015/16. With SfM and the workflow implemented at Must Farm 3-dimensional recording not only recorded stunning models but was the crucial in the site's progression. It aptly met the challenges of the increased complexity and had the versatility to easily flit between issues of scale. Allowing us to create detailed models of artefacts while still in situ, to the point of macro use wear on metal work and weave direction on fabric, while continuing to record the greater context with little initial extra effort. This methodology allowed the model's data to be utilised as the site continued adding the metadata as the wood and artefacts were lifted. While simultaneously creating easily disseminated models and capturing more ephemeral data, such as char patterns, and creating a more fulsome facsimile of this information.

With the post-excavation phase the data recorded via SfM and the nuance it brings continues to demonstrate 3D recording versatility: our artefactual syntax can be understood not only by location and number but by size and shape; supporting evidence of middening versus near in-situ items. 3-dimensional tool marks on wooden artefacts can be recoded and compared.

With such versatile visualisation and potential analytical use I hope this paper will demonstrate how 3-dimensional recording cannot just aid excavated archaeology but how, with some forethought and in the correct conditions, gain more data in less time; which is surely the gold standard for any new technology brought to archaeology.

***Virtual Roman Frontiers: 3D Visualisation and Innovative Technology
Applications for the Antonine Wall***

Lyn Wilson, Patricia Weeks, Alastair Rawlinson, Erik Dobat, Christof Fluegel and
Carsten Hermann
Historic Environment Scotland

Nearly 2000 years ago, the Antonine Wall was the most northerly frontier of the Roman Empire, stretching across central Scotland. Today it is part of the serial transnational Frontiers of the Roman Empire World Heritage Site (FREWHS). On the ground, the remaining archaeology is often not much more than faint traces of earthworks. There is however a rich assemblage of artefacts excavated from the Roman sites along the Wall. A principle challenge for the Antonine Wall is in presenting a coherent interpretation framework of sites spread across Scotland and artefacts housed in separate museum collections.

To improve interpretation and accessibility, we are collaboratively undertaking several digital heritage initiatives based on 3D imaging of archaeological sites and artefacts. This has included aerial LiDAR, terrestrial laser scanning, structured light scanning, digital photogrammetry (structure from motion) and motion capture technology. The culmination of the 3D digital documentation programme is the delivery and implementation of digital games, virtual reconstructions and virtual reality experiences.

An interactive mobile app is also being developed which incorporates location-based augmented reality to digitally repatriate artefacts to their excavation spots. It transports visitors back in time through virtually reconstructed fort and ancillary buildings, based on accurate 3D imaging data and archaeological evidence. Through our collaboration, the app will include 3D data and information on the Roman frontier in Bavaria in addition to the Antonine Wall. It will allow virtual visits from anywhere in the world, helping to reinforce the transnational nature of this World Heritage Site. The Advanced Limes app (ALApp) is available as a free download through the iOS and Google Play stores, and further interactive 3D content is being added over the next two years. Once the app is completed, the platform will then be shared for free with colleagues in other parts of the FREWHS to allow them to add their own content.

The use of 3D technologies is ideally suited to the challenges posed by the lack of extant archaeology, the disparate nature of the artefacts and the international nature of sites. This paper will examine the challenges faced in creation of the digital platforms and discuss the potential of existing and emerging digital technologies to make a positive impact for cultural heritage interpretation, understanding and accessibility.

Project funding comes from a variety of sources, including Creative Europe, Historic Environment Scotland, The Scottish Government (via the Scottish Ten Project), and Local Authority partners.

Session Two

New Investigations and 3D Computed Tomography Reconstruction of the Antikythera Mechanism, using 3D X-ray CT Data and 3D CAD Software

David Higgon, Tony Freeth, Ashkan Pakzad, Tony Freeth, Francesco Iacoviello, Andrew Ramsey, Robert Speller, Jennifer Griffiths, Adam Gibson
University College London

The idea that the ancient Greek astronomical calculating machine, known as the Antikythera Mechanism, included prediction of planetary positions was first proposed by Albert Rehm in 1905. Through lack of data, he got everything mechanically wrong and little work was done for half a century when the idea was revived by Derek de Solla Price - though without concrete proposals. The work of Michael Wright transformed this area of research when he proposed a remarkable co-axial pointer system, driven by epicyclic gears, which displayed the positions of the planets in the Zodiac. Research by Tony Freeth & Alexander Jones, based on X-ray CT data gathered in 2005, then established beyond reasonable doubt that the Antikythera Mechanism did include an advanced planetarium. This research also dramatically simplified Wright's proposed gearing. A recent study of the Front Cover inscription of the Antikythera Mechanism, using the X-ray CT data, made the shock discovery of two planetary numbers, 462 and 442. These are planetary periods for Venus and Saturn and they have profound consequences for the design of the Antikythera planetarium. This paper explores the design implications of this new information, using 3D X-ray CT data and 3D CAD software.

The Antikythera Mechanism is a well-researched device dating to around 200BC. It is an ancient analogue computer, with at least 30 sets of gears, for predicting the positions of celestial objects and important dates in the ancient Greek calendar. An investigation of the object was carried out in 2005 at The National Archaeological Museum in Athens using high resolution microCT in an attempt to determine its internal structure and function. This investigation led to a much greater understanding of the mechanics of the device and the interpretation of its function. However, one particular data set did not reconstruct well, so that the resulting images appeared distorted, meaning that several of the inscriptions could not be fully deciphered.

This paper describes work that has taken place using the deficient data set. This data set was intended to provide the highest quality reconstructed image of the largest, and possibly most important, of the fragments of the device, fragment A. Unfortunately, problems which occurred during the image acquisition meant that the reconstructed images were blurred. Image analysis of the 2957 individual projections suggested that 25 projections were missing from the dataset. An alternative hypothesis, that the fragment slipped during imaging, was rejected. Three different strategies were used to correct for the missing projections. All showed substantial improvement over the original uncorrected image. The preferred method was to substitute blank projections where the original projections were missing. This led to visibly clearer images and most importantly, enhanced visualisation of the text.

Micro-CT reconstruction of a 16th century miniature carved boxwood tabernacle in the British Museum Waddesdon Bequest (WB.233) and an investigation into methods of its manufacture

Philip Fletcher¹, Dora Thornton²

¹University of Bath, ²British Museum

A 16th century boxwood miniature carved boxwood tabernacle (WB.233) was micro-CT scanned at the Natural History Museum (NHM) in preparation for its redisplay in the British Museum's new Waddesdon Bequest gallery. The tabernacle is made up of four sections which can be taken apart and opened to reveal minutely carved scenes telling the Christian story. Designed as an expensive devotional toy, the piece is closed and static when displayed. This makes it hard to understand its intricacy, playfulness and interactive design, or to connect with its making and meaning. A micro-CT scan of the object was carried out to allow the public to see a virtual reconstruction of the object opening on the small display screen adjacent to the object. Now we can reward close looking and create an emotional link with makers and first owners of this important collector's piece. Details of the virtual reconstruction of the object and methods of manufacture will be revealed through study of the CT model.

The Digital Pilgrim Project and the Object Resource Box

Amy Jeffs

University of Cambridge

This paper will consider how 3D modelling, complemented by other digital media, is helping curators transcend institutional boundaries. It will take as its case study the Digital Pilgrim Project's (<https://www.hoart.cam.ac.uk/research/the-digital-pilgrim-project>) work 3D modelling medieval pilgrim souvenirs and secular badges.

Pilgrim badges, like many other similar small, prolific object-types including Roman votive plaques or amulets, can be found in collections all over the UK. Sometimes these curatorially challenging collections contain just two or three objects, sometimes hundreds. As they nearly all have certain things in common, including manufacture technique, general function (worn on hats and bags), imagery and associations with themes of travel and devotion, they benefit from being viewed closely and collectively.

After a short overview of the project, I will turn to the issue of exchange; namely, that much can be gained from freely sharing digital resources between institutions as interpretive tools. We will make available the 3D models we have created, alongside GIS maps showing their archaeological distribution and footage of manufacture and associated sites to be displayed by any museum or used by curators as a way-in to the object type and as a foundation for more collection-specific interpretations. Communicating the availability of these media will perhaps be our greatest challenge.

For us, open access is possible because the digital media we are creating are a collateral consequence of a University-based research project and due to the values of an external funding body. There are many more like us. This paper will argue that open access could lead to efficient exchange of display resources, if given the right support. What is needed is a centralised website, perhaps with a name like the Object Resource Box (ORB). It would function like Wikipedia but for cultural heritage objects. Downloadable digital media produced as a result of research projects, including 3D models, animations, short films could be uploaded by anyone and

indexed according to object type. The producers could be credited and their projects advertised and users would be free to embed, download and display.

The paper will close with an invitation for delegates to consider the viability of this resource and, perhaps, even to implement its creation, using the Digital Pilgrim resources as an initial prototype.

Session Three

Whale of a Project: How to Scan the World's Largest Animal

Kate Burton

Natural History Museum

This paper will be a brief discussion into how the task of 3D surface scanning the entirety of a disarticulated blue whale skeleton was completed. This involves using a combination of laser and structured light scanners which are mounted and hand-held. First it involves capturing the images in real time. These machines are accurate to research-quality levels and are able to produce details down to the micron level. The next stage is when the data is cleaned up. At this point, extraneous data points like the props used to hold up the object are deleted. The last stage for 3D modelling is the transformation of raw data points into a polygonal mesh that can be used for a large variety of purposes. Once in mesh form, the object is again inspected for any missed or bad data, then is polished up and ready for distribution. I will discuss what worked, what did not work, and plans for the future.

Confocal microscopy applied to natural history specimens

Tomasz Goral

Natural History Museum

Confocal laser scanning microscopy is a well-established optical technique allowing for 3D visualisation of fluorescent specimens with a resolution limit close to the diffraction of light. Thanks to the availability of a wide range of fluorescent dyes and selective staining, using antibodies, the technique is commonly used in life sciences as a powerful tool in studying different biological processes, often at the level of single molecules. However, this type of approach is often not applicable for specimens which are preserved e.g. in historical slide collections, embedded in amber or are fossilised and cannot be exposed to any form of selective staining or other form of destructive treatment. This usually narrows down the number of microscopy techniques that can be used to study such specimens to traditional light microscopy or scanning electron microscopy. However, these techniques have their own limitations and cannot reveal fully three dimensional structures within such barely accessible samples. But can confocal microscopy be of any help? The answer is positive and it is due to the fact that many natural history specimens exhibit strong inherent autofluorescence which can serve as an excellent source of emitted photons for confocal microscopy visualisations. In this study we employed laser scanning confocal microscopy for the first time to visualise 3D interactions of fossilised fungi, plants and arthropods embedded in thin sections of the Rhynie Chert deposit. Our results demonstrate that some autofluorescence signal is still retained in this complex material and it can successfully provide new insights into the 3D morphology of the various groups found in Rhynie Chert.

3D Documentation of Rock Art in Megalithic Structures in Brittany (France) and its Application as an Aid to Curators

Valentin Grimaud, Serge Cassen

Université de Nantes

In the Carnac area (South Brittany, France) many megalithic structures were built during the Neolithic period, some of which are extraordinary in the way they present examples of rock art. Sadly, climatic changes, previous restoration and mass tourism are not providing the best conditions to conserve the monuments and their treasures in the long term. Curators then face a huge challenge.

We are working on a project which aims at documenting and understanding rock art. We are also contextualizing sections of rock art in-situ in their Neolithic context, and when possible in their landscape. Creating these representations is time consuming and we consider therefore that more than one objective should be targeted. More precisely, 3D models should be considered useful to understand, communicate and conserve these objects or rock art. This last topic will be presented hereafter.

In order to help curators, we have established a protocol and developed some tools in order to facilitate their work. Thanks to 3D representation, we can accumulate data about what we can observe today. For this reason, we consider high resolution 3D data as one part of the documentation, and not as the end. Lightweight models receive a set of textures – each one is a level of information. To achieve this goal, we need to detail all the information we can produce and structure it through clear organization. We also need to make it accessible through time and to people who are not familiar with 3D software. We have therefore developed with the consortium 3D SHS two tools for this purpose: one to archive 3D models, the other one to diffuse them through an application with some basic functionalities. The first one is built upon a lightweight schema compatible with high standard of CINES (a French institute working on archiving data). The second one consists on adding new functionalities to the software OpenSpace3D in order to facilitate the construction of virtual environments and the interaction with them. Possibly the most interesting part is the ability to interact with 3D models through various devices like LeapMotion, HTC Vive, and others.

As a result, the data can now be structured, will be compatible with some types of data mining, be easy to consult for non-3D specialists, and in future recording could be compared to the previous data because it will be accessible. Alongside the detailed recording of the rock art this will be of great benefit for curators in protecting these sites for the future.

UAV Photogrammetry Potential for the Recording of Fragile Fossils: A Preliminary Assessment

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Advances in cost-effective three-dimensional model creation have pioneered methodological approaches to analysing fossilised remains. In an attempt to preserve and conserve fragile fossils numerous palaeoanthropological studies utilise three-dimensional models that can be assessed extensively post-excavation. Highly exposed and erodible sites where fossil extraction can be difficult often necessitates

the need to record fossils in situ. Fossilised footprint localities are a prime example. In this study we attempt to identify the best practice for recording fossils in situ. We test the applicability of using unmanned aerial vehicles (UAV) as a non-destructive and non-invasive method to record a selection of experimentally generated footprints as a proxy for fragile fossils. We hypothesize that the use of a DSLR camera attached to a UAV will produce higher resolution images and models with greater point cloud density than that of data collected from an action camera (we tested the use of a GoPro), although this will come at the expense of a reduced flight time due to greater payload that may prove problematic for recording large-scale fossil sites.

Eight flights were designed with four flight paths. The UAV was flown at 3-5 metres high, then at 1-3 metres high following a specific flight path (a circular path, a raster, an arched path and a linear path). Each flight was completed twice, once with a GoPro and then a DSLR. Each path was then repeated using a handheld GoPro and DSLR. Three-dimensional models were created using photogrammetry in Pix4D. Unfortunately DSLR data from the flights produced poor photograph overlap, resulting in many of the models failing to calibrate despite high resolution images.

Results indicate that GoPro data produces low point-cloud density compared to data collected from a DSLR in both handheld and flight capture. We tested for any statistically significant changes in shape/size per model using geometric morphometric techniques to identify the optimal flight path for accurate model capture. Analyses were computed in Morpho and Geomorph, R packages. Results demonstrate that regardless of payload there were significant changes in shape/size for flight data compared to handheld data. Choice of flight path significantly affected shape/size, highlighting the least optimal paths. GoPro data consistently produced incorrect model dimensions, regardless of recording method. This may be the result of a wide lens distorting mesh optimisation.

Further flights were designed to incorporate the applicability of using stills from a GoPro and video from a DSLR. Results were more promising: data from GoPro stills did not exhibit any significant changes in shape or size, with no distortion of models identified. DSLR video capture produces greater calibrated models and model accuracy. However, both of these methods come at the expense of reduced point cloud density.

Preliminary results have demonstrated that a non-invasive UAV can be used to record in situ fossils. However, only DSLR video or GoPro still capture should be used. If models are required to be high resolution then it is advised to use a handheld DSLR following a specific flight path. Further experiments refining flight optimisation are required.

Session Four

How Practical Can It Be? Photogrammetry and 3D Modelling in the Documentation and Conservation of Cultural Heritage

Ana Patrícia Monteiro
CITAR/EAUCP, Porto

There is concrete proof that digital techniques, such as photogrammetry and 3D modelling, have been taking a very useful role in heritage documentation. Nevertheless, art conservators often have limited time and resources to explore the potential of digital tools. As such, we intended to test the practical applications these tools allow during a conservation intervention.

This premise arose during a master's degree dissertation, with theoretical and practical components, in a similar context to most interventions. The object of study in question was a 17th century Portuguese altarpiece (retable). Concerning the supra-cited techniques, they were used in different contexts for this research.

Photogrammetry was used to complement the existing photographic documentation. This process consisted in the use of several photographs of the piece in question, from different points of view, which were then processed using 123D Catch (Autodesk), now updated and renamed (Remake). The resulting model was animated using Blender (v2.8) to demonstrate aesthetic elements of the altarpiece and finally exported as a *.mov* file. An additional *.obj* file was also extracted to allow for compatibility with alternative software.

On the other hand, 3D modelling was used to demonstrate the construction process of the altarpiece, and to complement previously found descriptions and sketches of the retable. For this we used Autodesk Maya to build the early stages of the virtual model and, later on, Blender (v2.8) was used to for additional modelling. The resulting animation facilitates the comprehension of the altarpiece's constructive system by separating the different pieces that form the retable.

Results show, that these two methods allow the improvement of heritage documentation, and facilitate the overall comprehension and education of art. These, however, require time, dedication and access to equipment. The video animations enhanced the written dissertation and proved that these digital tools present good results, even with limited resources and conditions.

Although these applications are valuable in the field of restoration and conservation, further practices can be researched, improved, and implemented. Examples include: digital reconstruction, virtual restorations, representation of no longer existing architectural heritage, 3D printing of missing elements, or even artistic evolution of other forms of art.

To conclude, art conservators have a unique vision on the technical aspects of cultural heritage. They understand profoundly how to document and to save invaluable knowledge for future generations. Nevertheless, their abilities and time are limited to dedicate fully their attention to every aspect concerning heritage documentation. Digital tools, however, present viable and palpable ways to explore and develop more appealing approaches to guaranteeing the safe-keep of art in this modern digital era. Art history books can now be transformed into more interactive and educational digital mediums that appeal to every generation and help better to understand the importance of preserving art, as a part of our cultural heritage.

Integrating Multispectral Imaging, Reflectance Transformation Imaging (RTI) and Photogrammetry for Archaeological Objects

Emily B. Frank, Sebastian Heath, Chantal Stein
New York University

This project utilizes a 3D-model built with photogrammetry as scaffolding for the combined display and analysis of other types of imaging data, such as Reflectance Transformation Imaging (RTI), and broadband Multispectral Imaging (MSI).

Photogrammetry, RTI, and broadband MSI are well-established imaging techniques widely used by cultural heritage professionals. These techniques have seen rapid adoption by archaeologists and conservators working together in the field. While recognizing that no technique produces a perfect or undistorted representation, the data that this project integrates complement each other very effectively and result in high-resolution and visually expressive renderings that emphasize physical shape, surface variability, and spectral properties. Combining techniques facilitates very detailed study and visualization of an artifact that both highlights otherwise invisible features and can effectively communicate these aspects to scholars and the general public without requiring direct inspection or handling of the object.

Three-dimensional models were built of a stone object from Sardis, Turkey and an Egyptian painted wood object using Agisoft Photoscan Pro. RTIs were created of the worked surfaces on each using the RTIBuilder 2.0.2 available from Cultural Heritage Imaging (CHI). MSI images were processed with the add-in for nip2, the graphical interface of the free processing system VIPS, developed as part of the CHARISMA project, available from the British Museum. So-called “connection images” were used to integrate and align the data sets. These evenly lit images, taken with the same camera position and parameters as the auxiliary data sets, are included in the set of images used to build the 3D model with photogrammetry. The data sets were combined and visualized using Blender, an open-source 3D graphics and animation software.

We stress that this project uses software, equipment, and methods that are readily accessible to conservators and archaeologists in museum photo studios and in the field. We have also established a workflow for combining potentially any source of imagery. This technique shows promise for many applications where advanced visualization can contribute to analysis and conservation, particularly in situations where ongoing contact with the object is limited or ill advised. In summary, the successful combination of RTI, MSI, and photogrammetry data sets results in 3D models that support compelling interactive visualization and analysis of archaeological materials.

Co-Production in 3D Imaging

Eilish Clohessy
Derby Silk Mill Museum

At Derby Museums, co-production is embedded in everything we do. We work with our communities to develop and deliver meaningful experiences in our museums, from making museum furniture to building exhibitions and experimenting with new technologies. Co-production has formed a fundamental element of the 3D imaging programme at Derby Museums, with our communities consistently contributing to the development of our practice since the beginning of the project.

By co-producing, we are learning from each other; exchanging ideas, knowledge and expertise; sharing knowledge and building our communities. This paper will explore how Derby Museums and contributors to the 3D scanning programme have benefitted equally from the embedding of co-production principles into the project. This has included facilitating public 3D scanning sessions using professional scanning equipment both inside and outside the museum, to using free applications to create 3D content with school and college groups. We have been working with a number of volunteers to increase the amount of objects being scanned, providing training where necessary and helping to develop new skills, while working alongside volunteers with previous experience with 3D imaging processes has enabled us to improve our knowledge, skills and expectations for the project.

As a Trust, Derby Museums is undergoing significant change, from moving to Trust status in 2012 to the current redevelopment of Derby Silk Mill into a museum of making. As part of this redevelopment, we're exploring new ways of interpreting our collection. 3D imaging has provided us with a way of seeing objects in a new light, a process that has significantly benefitted from involving our community in the project through the process of co-production. This project forms a key part of our overall plan to make 100% of the collections in the new museum accessible. Co-production has not only aided this process, it has provided some amazing and inspiring insights into our collection which would not have occurred without input from the people who have engaged with this project.

See-Through Museum Project: A Complete Imaging Pipeline for Cultural and Natural Heritage

A. Kostenko, R. van Liere, K.J. Batenburg
University of Amsterdam

The See-Through Museum Project was launched in May of 2016 with an idea of bringing together researchers with an expertise in advanced x-ray tomography, structured light scanning and data analysis with conservators and restorers of several prominent Dutch and Chinese museums. The ultimate aim of the project is to create an integrated data acquisition, visualization and analysis pipeline allowing collection of the most relevant 3D data for a wide range of heritage artifacts.

We believe that the state-of-the-art imaging technologies will in the near future enable museums to have comprehensive digitized collections. These virtual collections will be accessible by audiences remarkably wider than an audience of a typical modern museum. Besides that, the abundance of imaging data will allow solving numerous research questions related to artifact design and conservation. However, currently, such a breakthrough is constrained by technical challenges in the 3D scanning process, which we address in our work.

Our focus lies within the field of tomographic methods (x-ray, neutron or visible light), as they allow to acquire a true 3D representation of an artifact. Some challenges of applying tomography to museum artifacts are related to their great variability. Variability of material composition makes it hard to choose optimal acquisition settings and often leads to errors in reconstructed images. Variability of sizes and form factors sometimes makes the scanning process unfeasible. On the other hand, combination of the data produced by different imaging modalities and analysis of that data require expert knowledge of a technical scientist and can often not be done by a cultural heritage expert.

We would like to present a number of showcases where we were able to find solutions to some of the challenges mentioned above. These showcases include

imaging and data analysis of samples of Burgess Shale fossils, Chinese carved ivory balls, pottery, Dutch shipwreck textiles and dendrochronology of wooden specimens. In each case, we have optimized the imaging conditions, algorithms used for tomographic reconstruction and developed tools that allow for quantitative data analysis. We hope, that ultimately this work will result in an integrated imaging pipeline that will cover the whole process of digitization of heritage artifacts, starting from optimization of raw data acquisition to analysis and visualization.

Session Five: Pecha Kucha

Illegible Forever or Virtually Retrievable? The Possibilities of 3D Tools on Hard-to-Read Inscriptions

Miguel Carrero-Pazos, David Espinosa-Espinosa
University of Santiago de Compostela

The expansion of Computer Science throughout the Humanities has contributed to the application of new methodological approaches in multitude branches of historical knowledge. One of them has been the reconstruction and virtual representation (3D) of archaeological sites and other cultural remains. This is particularly clear in epigraphic studies, where 3D modelling has encouraged a raise in the documentation and diffusion processes, using digital platforms such as Sketchfab. However, there is an important lack of studies which seek for the use of 3D methods to improve the epigraphic analysis and the reading of the texts.

In Galicia (NW of Iberian Peninsula), scholars such as G. Pereira Menaut or A. Rodríguez Colmenero have systematized the currently known Latin inscriptions with great effort. In this region, it is common that Latin inscriptions were carved in granite stones, and the problems regarding their conservation are extremely usual. In this respect, a large number is in a poor state of preservation which makes them very hard-to-read. This fact has prompted the use of different recording methods, in order to get an approximate picture of the rock surface. That is the case, for instance, of works centered on the use of series of photographs with ranking light or others which make rubbings by frottage technique. However, these techniques do not actually resolve reading problems, in some cases letters that can change the meaning of the whole inscription and in other, allegedly illegible texts.

In this context, the use of 3D methods for the epigraphic text restitution has great potential. In this way, Structure from Motion technique and open source software offer many possibilities for Roman Epigraphy, especially in the case of hard-to-read inscriptions. Therefore, this proposal aims to show how 3D modelling can contribute to read “illegible inscriptions” and resolve some transcription problems. To do this, we will present different case-studies of Latin inscriptions from the ancient Gallaecia. Starting from the 3D model creation by dense photogrammetry, we apply post-processing techniques to better read extremely eroded inscriptions. The application of these new techniques in future works will allow us to complete and improve the current collection of Latin inscriptions from Galicia, and to achieve a deeper knowledge of the relevance that this region played under the Roman Empire.

Visualising the Operation of a 15th/16th-Century Pottery Kiln at Newport, Pembrokeshire, UK

David Dawson, Oliver Kent and Bill Stebbing*

*Scan to Plan

The remains of pottery kilns have been collected by museums (eg the Clarendon Palace tile kiln at the British Museum). Exhibiting them has been a challenge.

In 2017 a team completed the project to excavate, record and evaluate on behalf of Cadw and the Newport Memorial Hall Committee a remarkably well-preserved pottery kiln under the stage of the hall. This work was preliminary to making the kiln accessible for public study and enjoyment through a Heritage Lottery Funded scheme. The project has confirmed that the kiln is of great significance being a precursor of the 19th-century kiln from the Ewenny Pottery reconstructed and on public display at St Fagans National Museum of History near Cardiff.

The use of laser scanning has become a relative commonplace as a technique in providing a record of great accuracy of an artifact in its topographical context. For the Newport project, its use to provide a 3D record to be subjected to further interrogation and as a source of analytical images to publication and asset management standard has been exploited to the full for the Newport project. The paper shows how such images – cross-sections, plans and elevation – incorporating data of parts difficult to otherwise access let alone measure – enhance visual understanding of the structure.

This data set provides the foundation for the further interpretation of this particular kiln within the context of what is known of the development of kiln technology in Britain in the last 2000 years. Point-cloud data was combined with simple animated graphics, informed by the results of over 40 years research by the Bickley Ceramics Project into the operation of this kind of simple updraught kiln. This included the reconstruction and operation of kilns based on archaeologically recorded examples from Barnstaple (17th century) and Donyatt site 13 (18th century). The two aims were first to provide an academic interpretation of the kiln for peer-reviewed publication but the second was for the project the important aim to provide a straightforward presentation of the kiln, its operation and its significance to the local community. At a simple level, the remains of the structure of the kiln can only be appreciated using 3-D imaging. At a further level it is essential to explain what the structure would have looked like, how it worked and how it fitted within a pottery-making complex and what its products were used for. The accurate record of the structure and its products and well-researched practical experience of using similar kilns were essential to the success of achieving these aims.

The paper describes how by working with the local project team solutions were found and how they were developed to meet specified objectives.

Neutron Tomography of 'Pattern-Welded' Swords from the Viking Age

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ISIS Neutron and Muon Source, STFC Rutherford Appleton Laboratory

Scientific investigations and archaeometric studies have played a major role in the field of archaeology, especially with regard to materials transformed through human activity. Until recently, metal artefacts have been mainly studied through standard analytical techniques like metallography and Scanning Electron Microscopy (SEM), which required the samples to be taken from the artefact and provided only punctual information. On the contrary, neutron techniques allow measuring bulk properties in a non-invasive way.

Scandinavians from the Viking Age (800–1050 AD) were famous for being brave seafarers and explorers, and their weapons represented an indispensable tool in their travels. Sword from the Viking age often showed 'pattern-welding', made by welding together thin strips of iron and steel that were twisted and forged in various ways, producing a decorative pattern on the surface. Such a process introduces a differentiated distribution of the steel related phases (ferrite, cementite and slag inclusions) in the different parts of the blade.

In this work we present a neutron imaging study of three sword blades from the Viking age belonging to the National Museum of Denmark. In particular, white beam and energy selective neutron tomography have been applied, in order to study the morphology of the blades, detect information on the forging techniques, and map the distribution of steel related phases in such composite 'pattern-welded' structure. The measurements have been carried out at the ANTARES beamline at FRM II (Garching, DE).

Preserving and protecting Ancient Pueblo heritage and landscapes: 3D scanning in the canyons of the Mesa Verde region, Colorado, USA

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Since 2011 the Sand Canyon-Castle Rock Community Archaeological Project, the first Polish archaeological project in the US, is being conducted in the Mesa Verde region of southwestern Colorado. The project focuses on analysis and reconstruction of the settlement structure and socio-cultural changes that took place in a community of around forty small Pueblo culture sites dated to the thirteenth century A.D. in Sand Canyon, East Rock Creek Canyon and Graveyard Canyon. These canyons are part of the legally protected area of Canyons of the Ancients National Monument located in the heart of the Mesa Verde region of southwestern Colorado and southeastern Utah that is well known to scientists and many tourists because of the famous Pueblo Indian cliff dwellings and towns located within the alcoves and shelters of the sandstone canyons.

During the four seasons of the project we also used modern techniques of documentation, such as photogrammetry for six sites, and laser scanning that was conducted during two seasons at eleven sites, mainly dwellings located in cliff alcoves and free-standing towers. In addition to the architecture, we have documented rock art, both petroglyphs and paintings, including Ancient Pueblo rock art from the third to fifth century A.D. showing shamans and warriors and later Pueblo petroglyphs connected with astronomical observations as well as historic

Indian petroglyphs, mainly Navajos and Ute, depicting fighting warriors and hunting scenes with buffalo and deer.

Registered data has been used to generate accurate 2D documentation including profiles, projections, architectural details and 3D models. The equipment for scanning included Faro Focus 3D scanner. Its great value is speed of work, small size and weight, that makes it well adapted in difficult terrain. Generated 3D models have been used to interpret details by varying the position of the light so that you can isolate the dimly visible details. Another element is the virtual 3D models that are used in the game engine for free presentation as well as multimedia information that is contained in the research, and generated documentation. A point cloud was used to generate geospatial and architectural data, including contour maps, a Digital Elevation Model that encompasses the sites and its closest surroundings, and classic drawing documentation.

3D Reconstruction in an Illumination Dome

Lindsay MacDonald, Stuart Robson, Mona Hess
UCL

The illumination dome at UCL enables sets of images of an object to be captured from a fixed zenithal camera position, with illumination from 64 flash lights at known coordinate positions on the hemisphere [1]. The image sets acquired by this device are used primarily for visualisation of cultural heritage objects by the polynomial texture mapping (PTM) technique [2], but they have also proved to be viable for estimation of the angular reflectance distribution function of the surface [3]. The problem with 3D reconstruction from a single camera position, is that, although high quality surface normals may be extracted, there is insufficient information to determine the scaling factor for the height, and low spatial frequencies are not accurately represented, leading to warping and distortion of the resulting surface. Additional information is always needed [4].

For the 3D digitisation of objects in museum collections, multi-view photogrammetry with dense reconstruction may be employed to generate a point cloud, although the technique often produces noisy results with missing regions ('holes'). Usually the camera is moved to multiple positions around a fixed object, capturing a set of images from many angles of azimuth and elevation. The present study investigates whether an accurate 3D representation can be obtained by tilting and rotating the object systematically within the field of view of the fixed camera, inside the illumination dome. For a test object we selected a small ceramic item from the Late Period in Ancient Egypt, c.664-332 BC. This was previously 3D scanned using an Arius Rover laser scanner, and is featured in the 3D Petrie online gallery [5].

Three image sets were taken by a Nikon D200 camera with a 105mm macro lens, mounted on the dome:

- (1) 34 images of a small photogrammetric object with retroreflective targets, which was rotated to 8 azimuthal angles and tilted to 4 angles of elevation, illuminated by 12 flash lights in the dome;
- (2) 34 images of the test object, rotated and tilted in a similar sequence;
- (3) 64 images of the test object in a fixed horizontal position at the centre of field, illuminated successively by each of the 64 dome flash lights (standard PTM image capture procedure).

The images from the first set were processed by the Vision Measurement System (VMS) software to determine the parameters of the lens distortion model. The

second processing step required the creation of masks to isolate the test object from background, then Agisoft Photoscan software was applied to produce a 3D point cloud. The third image set was processed by the 'bounded regression' technique to extract the albedo and surface normals at full image resolution. The high spatial frequencies of the surface normals were combined with the low spatial frequencies of a digital elevation model (DEM) derived from the 3D point cloud to produce a 3D representation having the high spatial resolution of the photometric processing together with the geometric accuracy of the photogrammetric processing. The results were compared with the point cloud of the object previously obtained from the 3D laser scanner. The research question was how few images (taking subsets of the images from the second and third sets) were sufficient to give an accurate reconstruction. We suggest that in future, with automation of the capture and image processing stages, this method could provide an effective means of 3D digitisation of museum collections.

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Combining scan technologies to solve complex imaging problems

Amy Scott-Murray
Natural History Museum

NHM's collections include six Great Auk eggs. They are blown eggshells with the interiors removed. The Great Auk is extinct and very few shells exist in collections, meaning that our specimens are rare, valuable, fragile and scientifically irreplaceable. An ongoing research project aims to micro-CT scan three of our eggs, to study the micro structure of the shell construction. In order to do this, the eggs must be held securely within the CT scanner at exact angles and locations. The exact same nine locations on each egg must be scanned, in order to yield comparable data points.

We solved this problem by using structured light scanning and 3D printing to construct custom outer jackets for each egg, and a system of interchangeable frames that hold the eggs and jackets in the correct places in the scanner. We also surface

scanned the inside of our micro-CT scanner and used this data to simulate the movement of the eggs and mounts inside. This allows optimal orientation with the beam and ensures no collisions with internal parts. This system can be adapted to the scanning of precise points on any eggshell, and is an interesting case study in the combination use of diverse technologies.

Friday, 10th November 2017

Session One

A Victorian Explorer and the ancient Maya in 3D: The Google Maya Project at the British Museum

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¹British Museum, ²UCL

The British Museum has partnered with Google to use digital technologies to develop new ways to engage the world with Alfred Maudslay's collections and explore what they reveal about the ancient Maya. Maudslay travelled through Central America and Mexico in the 1880s and used state-of-the-art 19th century technology (mould-making, plaster casts, and dry-plate photography) to preserve the image of Maya sites and texts for the future. The BM owns the most complete collection of these casts (nearly 500), as well as many of his original plaster moulds and paper squeezes, his photographs (about 800 glass plate negatives), and his field notebooks and sketches. These objects are a treasure trove for research of the ancient Maya, the history of discovery and exploration in Central America, and a fascinating story for the general public.

One part of this multi-level project focuses on the casts currently stored at Blythe House. Using structured light 3D scanning with the medium-resolution Artec EVA scanner we are in the process of scanning the casts and recreating the monuments from different Maya sites. Many of the monuments documented by Maudslay contain details that have since eroded or have been destroyed, so that accessible models of the casts and photos will make an impact on the fast-developing field of Maya epigraphy and help the understanding and interpretation of Maya hieroglyphic writing.

Considering the fascination with the ancient Maya and exciting stories of early exploration, the 3D models and a planned 360° video animating and exploring one of the monuments in detail will appeal to an interested public of all ages. A first glimpse of the success of the educational use of AR/VR are the school visits with our Google Expedition to the Guatemalan site of Quirigua.

A dedicated space within the Google Cultural Institute on the web with videos, short online exhibits, links to the repositories and catalogue, and general information about the ancient Maya at the British Museum will act as a portal showcasing one of the exciting ways that digital technology can transport us back in time.

Education and Professional Development for New Cross-Disciplinary Roles in 3D Imaging and Digital Heritage Technologies in Europe

Mona Hess

UCL

As cultural sector practice becomes increasingly dependent on digital technologies for the production, display, and dissemination of our cultural heritage, it is important that those working in the sector understand the basic scientific principles underpinning these technologies and the neighbouring disciplines such as museum studies and conservation. The understanding of issues in cultural heritage preservation and digital heritage begins in the education of the future stakeholders and the innovative integration of digital technologies and transferable skills into the curriculum.

While some years ago documentation, heritage recording and scientific imaging and measurement in 3D were still quite separate topics, the emerging discipline of 3D digital imaging for cultural heritage and digital heritage technologies is becoming increasingly adopted by the heritage community. Digital heritage is now facing challenges, and experiencing support, from heritage studies and 3D metrology and imaging sciences. New roles, such as 'digital curator' are emerging, and will complement existing roles at heritage institutions. New research aims for digital documentation in cultural heritage are a symbiotic relationship between diverse disciplines, but at the same time stand within a tradition of heritage documentation. The development and valorisation, i.e. the creation of valuable assets, of digital heritage documentation is a collaboration of many: conservators, curators, exhibition designers, physicists, surveyors, engineers, architects, archivists, software developers and computer scientists. They all have their role in creating a usable, detailed digital surrogate of a heritage object or building.

Therefore, the education and learning opportunities for new cross-disciplinary roles will be necessary in museums and heritage institutions in order to meet the new demands for 3D image production towards open data repositories for education and research. The integration of expertise of heritage professionals in the 3D imaging programmes in cultural heritage institutions is paramount.

This presentation will give an overview on the current offer of academic study as main course or elective courses that will educate the next generation of stakeholders in our heritage institutions, museums and public bodies for the preservation of our heritage. Current opportunities for Continued Professional Development (CPD) and other ongoing courses for in-house capacity building for heritage and museum institutions shall be explored. Case studies will be given from the United Kingdom and Germany.

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All-Round Experience: Using Gesture-Controlled Multi-Sensory Technology to Unlock Museums for a Learning Disabled Audience

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ARCHES (Accessible Resources for Cultural Heritage EcoSystems) is a Horizon 2020 funded project with partners in Heritage and Technology across Europe. The project, situated in three European nations, uses an innovative participatory research approach to understand and address issues in cultural access within museums. The London group of researcher-participants worked with one of the technical partners, VRVis, to help develop a gesture-controlled multi-sensory technology to access heritage artefacts and resources.

Multi-sensory displays have become an established access option for blind and visually impaired museum audiences. Until now, the benefits of these for learning disabled audiences have not been widely examined. This is also the case regarding newer, technological, manifestations of these forms such as interactive audio guides and augmented reality applications.¹ However, the affordances of gesture-controlled audio-visual guides have great potential for visitors' enjoyment, learning and comprehension. The paper describes a working prototype of this technology, the design decisions and results of several evaluation studies with learning disabled participants.

A significant feature of this technology, particularly for those with learning disabilities, is that its affordances enable visitors to independently navigate an object and display, potentially for the first time. By delivering the content in different ways at the same time (for example visually, aurally and by touch) a multi-sensory experience is created. This maximises the opportunity to understand the artefact and its context, whilst making the most of the visitor's abilities, senses and learning preferences.

Previously traditional tactile drawings and reliefs have excluded learning disabled audiences from independent exploration due to the profound 'interpretation gap'. We describe the development of an interactive audio-visual guide designed to bridge this gap. This type of multi-sensory system has the potential to transform the museum experience for those with learning disabilities, a previously excluded group, and allow museums to create new experiences for a new audience.

This paper presents an example of a gesture-controlled interactive audio-visual guide (IAG). It uses low-cost depth cameras operating directly on relief surfaces to produce an interactive, multi-sensory experience, with location-dependent verbal, captioned and image-supported descriptions as the artefact is explored by the visitor. The participant-led research method of our studies produced a unique pathway, depth of result and new, significant and innovative developments in the system itself. We will demonstrate the potential that such a system offers both visitor and museum. Finally, we will speak about the future and predicted developments in the IAG system and related technologies, looking at the potential for incorporating innovations in virtual reality, displaying 3D projections onscreen, and accessing x-ray CT scans. The design and theory behind the system offers a firm foundation for many evolutions and additions to come. The untapped potential of this system reflects that of its

¹ Sheehy, K., Ferguson, R., & Clough, G. (2014). *Augmented education: bringing real and virtual learning together*. Springer.

primary audience, which it might most enfranchise: we have yet to discover the true scope of what learning disabled visitors can bring museums but, in this technology, we have the opportunity to begin to find out.

Session Two

Neutron Imaging – A Non-Destructive Testing Method Providing an Alternative Perspective to Cultural Heritage Objects

David Mannes, Eberhard Lehmann

Paul Scherrer Institute

Neutron imaging is applied as tool for non-destructive investigations alternatively or complementarily to the more common X-ray methods. While both methods work along similar principles, i.e. the transmission measurement of radiation, the resulting images vary significantly. This is due to different interaction behavior of the radiation with matter, which entails completely different contrasts. Unlike X-rays, neutrons can penetrate thicker layers of metal (lead is for example almost transparent) while they show a high sensitivity for some light elements such as hydrogen and thus providing a high contrast for organic materials. Neutron imaging can hence be seen as complementary method to X-ray imaging.

This complementarity is especially valuable, when examining metallic or metal containing objects. Such objects can be rather challenging, when using X-ray as the heavily absorbing regions can lead to (starvation) artefacts in the reconstructed data sets; increasing the X-ray energy will not necessarily yield a satisfying result either, as there would only be scarce contrast for light elements left. Neutron tomography can overcome such problems as it provides even good contrast for hydrogenous (e.g. organic) material within metallic objects. One example for such an investigation is the neutron tomography of a lead sculpture by P. Gargallo from the “Museu Nacional d’Art de Catalunya” (MNAC) [1]. The sculpture consists of lead sheets fixed upon a wooden core; the lead sheets show corrosion (basic lead carbonate) on the inside, threatening the integrity of the object. Neutron tomography allowed for a non-destructive evaluation of the condition of the sculpture mapping all areas affected by the corrosion, hence yielding a base for conservation and restauration works. Another example are leaden cannonballs from the battle of Bosworth; interestingly the cannonballs consist not of solid lead, but feature iron cores showing different geometries (e.g. cubes or rings) [2]. For certain objects and questions it can be beneficial to use a combination of neutron and X-ray tomography. This will be presented on two examples: a combined neutron/X-ray tomography investigation of a short sword found in lake Zug (CH) [3] and a multimodal to assess the impact of conservation treatments on archaeological iron findings.

With this presentation, we will give an overview on the broad spectrum of cultural heritage topics, which can be studied using neutron imaging highlighting the method’s opportunities and limitations for such investigations. This will be exemplarily shown on investigations carried out at the neutron imaging facilities at the Paul Scherrer Institut, Villigen (CH). The results should encourage potential users of neutron imaging to perform trials at our beam lines and to understand the potential for future dedicated studies.

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Revealing the Secrets of an Umbrian Madonna and Child at National Museums Scotland

Diana de Bellaigue, Lore Troalen, Xavier Dectot
National Museums Scotland

In 2013, a rare Umbrian Trecento sculpture of a Madonna and Child was identified for permanent re-display at National Museums Scotland (NMS). It is the only known Trecento Umbrian sculpture in a British public collection, the only piece linked to the Master of the Gualino St Catherine outside of Italy, and the first of the Gualino group of eleven to be subjected to full technical examination and conservation. Key to the success of the study was the use of a non-invasive 3D & 2D imaging techniques to support analysis, conservation and dissemination of the results.

Study under ambient and ultra-violet light was conducted to assess the nature of the object's surface. 2D and 3D CT X-Radiography were undertaken to assess the internal structure and condition. Stratigraphic paint analysis was carried out using mounted cross-sections dry polished to allow for analysis using optical microscopy and scanning electron microscopy (SEM) with energy-dispersive X-ray microanalysis (EDS). Wood identification and dating were undertaken using SEM imaging and radio carbon dating.

CT imaging informed our understanding of manufacture and condition as well as influencing conservation treatment decisions. The number of the timbers, the fixing methods, and the positioning of the bole were revealed. This information was used to test art historical theories about the carving technique: the data showed the skill with which the Master had exploited the girth of the tree to produce the majority of the carving minimising the need for additions.

When assessing condition, CT images enabled us to see the extent of insect damage, and to explain other areas of surface repair, for example on the Christ Child's head where radial cracking, invisible to the naked eye was found. During the conservation of the sculpture modern additions, notably the fingers on the Christ Child's hand could be removed with precision by using the CT images as a guide.

Following analysis and treatment, a 3D digital image was created using an Artec MHT structured light scanner. This will be used to create a series of digital colour models of the statue based on the results of stratigraphic paint analysis. With the combination of CT data revealing the 'interior', and structured light scanner modelling the surface, we will take the viewer back to the assembly and carving of the wood, next to a view of the original paint scheme and then through subsequent repaints up to the present day. As the surface preservation of the sculpture is poor, this will open the door to a deeper understanding of the sculpture for the general public as well as making accessible technical academic research findings.

Today we have a full technical profile for one of the objects in the Gualino group allowing for empirical rather than solely stylistic comparison. This will help students

of the Master of Gualino specifically but also add to our understanding of Trecento polychrome wood carving more generally. 2D and 3D imaging techniques enabled a fuller appreciation of the sculpture and will, in the future, facilitate the sharing of this knowledge.

3D Imaging with Neutrons – Delivering Information beyond X-rays

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Thermal and fast neutrons generated at research reactors or spallation sources can penetrate most metals while delivering high contrast for many light elements, which is often the opposite behavior of X-rays. Hydrogen, i.e. organic materials, can be detected even in lead enclosures. Neighboring elements, even isotopes of the same element, may deliver very different contrast.

X-ray methods are always first choice for easy application and availability, but neutron methods are great tools where X-rays fail, not only in cultural heritage. Neutron Imaging has been used with great success for computed tomography on fossils embedded in red beds, i.e. iron containing materials that are impenetrable for X-rays.

Fossilized teeth can be classified according to the interface between enamel and dentine, but only some specimen can be examined with X-rays or synchrotron radiation, while others deliver no contrast at all, because some – yet undetermined – mineral exchange has happened in the soil embedding the fossil. Neutron imaging still delivers large contrast. Fossilized bones in chalk rock or conglomerates like Breccia deliver very little contrast to the surrounding material for X-rays, while they can be easily distinguished using neutrons. Hollow metal statues or relics may be examined for enclosed organic materials like cloth, bones or wooden supports. The talk will give an overview about cultural heritage examinations with neutron imaging at the FRM II reactor of Heinz Maier-Leibnitz Zentrum in Garching, Germany, and partner institutes.

A 3D understanding of the varnish layers in Rembrandt's Marten and Oopjen

Katrien Keune¹, Petria Noble¹, Gwen Tauber¹, Susan Smelt¹, Esther Van Dijn¹, Michel Menu², Elizabeth Ravaud², Gilles Bastian², Witold Nowik², Silvia Prati³, Giorgia Scitutto³, Rocco Mazzeo³, Aldo Roda³, Mitra Almasian⁴, Leah Wilk⁴, Maurice Aalders⁴, Henk van Keulen⁵

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In early 2016, France and The Netherlands bought two monumental pendant paintings by Rembrandt van Rijn: 'Portrait of Marten Soolmans' and 'Portrait of Oopjen Coppit' (1634), oil on canvas, 209.6 x 135 cm and 209.5 x 135 cm, respectively. The paintings are currently being researched and treated in the conservation studio of the Rijksmuseum, The Netherlands. Prior to treatment an extensive investigation into the composition and build-up of the varnish layers on the paintings was carried out by the C2RMF and Rijksmuseum. The obtained knowledge is crucial to optimize the conservation treatment and to support the decision-making process.

Bulk analysis of the varnish layers with GCMS (C2RMF/ RCE) provided information about the sum of all components present and could not be correlated to particular varnish layers. Results are also complicated by the presence of wax-resin linings. As the paintings have always been together it is logical to assume that the portraits were treated at the same in the past. However, cross-section analyses show otherwise, as the build-up of the varnish layers differs between *Marten* and *Oopjen*. For *Marten*, light microscopy, imaging ATR-FTIR and SEM/EDX (Rijksmuseum) reveal a build-up of 1-3 layers of a natural (oil-)resin varnish on top of remnants of a proteinaceous layer with a lead-rich crust. The build-up of the varnish layers in *Oopjen* is more complex and contains a thick egg-white varnish with vertical cracks that are filled with an old resin holding many, tiny lead-containing crystals. The egg white was identified with Chemiluminescent Immunochemical imaging on the paint cross-section (University Bologna). Underneath the egg-white layer, remnants of a proteinaceous layer with a lead-rich crust similar to that in the portrait of *Marten* are visible. Investigation into the treatment history in 2016 established that the most recent treatments in the 1950s were executed a few years apart, by different hands, and in different locations. The portrait of *Marten* was restored in New York between 1952-53 by William Suhr, and the portrait of *Oopjen* by Henricus Mertens in the Rijksmuseum in 1956, just prior to the Rembrandt exhibition of that year. This explains the differences in composition and build-up of the varnish layers between *Marten* and *Oopjen*. The remnants of the proteinaceous layer with lead-rich crusts are found in both paintings. The thick egg-white varnish on *Oopjen* was apparently left on the painting during its restoration in 1956.

Having established the composition and build-up of the varnishes, optical coherence tomography (OCT) (Academic Medical Center, Amsterdam), center wavelength 1060 nm, has been applied to study the distribution of these layers over the surface of the paintings. From various areas in both paintings, small squares (10x10mm) were scanned showing variations in the thicknesses of the resin layers. Interestingly, in the dark brown remains of varnish in the depths of the impasto, for instance in the rosette on the left shoe of *Marten*, at least six varnish layers could be distinguished with OCT pointing to numerous restoration/varnishing campaigns. For the portrait of *Oopjen* it is important to understand if the egg-white varnish is only present as remnants in localized areas or, whether it is present over the whole painting. As it is difficult to unequivocally identify the egg white-layer using OCT alone, a combination of OCT and high resolution UV imaging will be explored to address this question. In addition, OCT has also been used to evaluate cleaning tests, before, during and after reduction of the varnishes.

The obtained knowledge and insights into the 3D distribution of the (remnants of) varnish layers, has been crucial in the decisions involved in the conservation treatment. Moreover, the conservators now know better the nature of the materials that they wish to remove and are able to efficiently tailor the methods required to carry out the various steps of the treatment.

Computed tomography for the study of large artworks and archaeological materials by means of a customised instrumentation

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X-ray imaging allow to “see” the inner and hidden parts of artworks and archaeological materials in an absolutely non-invasive way. Among them radiography is often enough to understand the distribution of different materials, the

techniques used by artists or to have some hints about the state of preservation; this is especially true for paintings or other thin artworks. For more complex artworks or when the radiographic projection is not clear enough, tomography (CT) is required to visualise the entire 3D volume of the analysed artwork or archaeological finding. In fact, even if it is more time-consuming than radiography, CT is a very powerful tool and it allows revealing and precisely localising hidden features, measuring the dimensions of inaccessible parts, evaluating the state of preservation, discovering previous restoration interventions.

During the neu_ART project [Re et al, 2012] a CT scanner has been designed, developed and installed at the Centro Conservazione e Restauro “La Venaria Reale”. Its features were chosen to guarantee a high flexibility in terms of both materials and dimensions of the analysable objects, allowing the computed tomography of voluminous objects up to 2.5 m in height and 2 m in width.

During these years, many artworks and archaeological findings have been analysed by means of CT using this apparatus. In this contribution, a review of some of the most interesting results obtained with this instrument will be presented, highlighting the versatility in analysing both wooden and metal artefacts, ranging from tenths of centimetres to some metres [Re et al, 2014; Re et al, 2015, Re et al, 2016].

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A Standard for 3D Computed Tomography of Musical Instruments – the MUSICES-Project

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The MUSICES-project is funded by the German Research Association (Deutsche Forschungsgemeinschaft, DFG) and develops since 2014 a standard for X-ray Computed Tomography (CT) imaging of historical musical instruments. MUSICES is a cooperation of the Germanisches Nationalmuseum, Nuremberg and the Development Center for X-ray Technology (EZRT) of the Fraunhofer-Institute for Integrated Circuits (IIS) in Fürth.

A main task of MUSICES is the device-independent description of technical parameters for 3-D CT imaging of musical instruments, which occur in different sizes and consist of various materials and material combinations. Another objective is the specification of a sustainable metadata model, in order to make all measurements replicable, comparable and accessible. The required spatial resolution in terms of a minimum voxel size is defined in a way to allow investigations such as exact geometrical measurements at otherwise inaccessible parts and dendrochronological

dating, or further processing of the volume data sets like the derivation of surface models and of input data for acoustical analysis or 3-D printing.

During three years 105 different musical instruments were scanned using various types of X-ray-CT-systems and scan parameters as well as different algorithms for reconstruction. The final results of the project will be presented in the talk. The chosen instruments represent a wide range of issues, specific questions and tasks for using CT for musical instruments. The scanned objects include several stringed instruments from a kit violin to an entire double bass, brass instruments from single mouthpieces to a bass tube, small and big keyboard instruments, various wind instruments such as recorders, crumhorns, cornettos, clarinets etc. and ethnological objects.

Musical instruments mostly consist of a combination of various materials like wood, metal, ivory, clay, glass etc. with highly differing densities. This is a challenge for X-ray-imaging due to the variation of attenuation parameters in one object. During the project the imaging quality for such objects was enhanced using i.a. virtual twin CT acquisition and dual-energy CT. Thus, the results of MUSICES are easily transferable to other fields, where a non-destructive fully three-dimensional volume digitization of objects containing multiple materials is required.

The lecture presents various examples of all measurements and information regarding the practical conditions of scanning. Further, the chances, but also the challenges of this technique are discussed in detail. The examination workflow contains best practice reports concerning transport and climatic conditions as well as advices for a multifunctional mounting system for objects with strongly varying geometrical shapes. A recommendation on data processing, handling and storage is also described. A freely accessible database containing all information about the objects and technical X-ray-parameters is presented as well as a solution for making big data sets easily accessible: A web-based viewing software (developed by the Fraunhofer EZRT) provides means for visualization of large data volumes via the internet, additionally featuring tools like clipping and measuring.

Lift the Veil off the Block Samples from the Warcq Chariot Burial (Ardennes, France): CT-Scan, Photogrammetry, 3D printing and Mixed Reality

Nicolas T., Gagne R., Tavernier C., Millet E., Bernadet R., Arnaldi B. and Gouranton V.
L'Institut National de Recherches Archéologiques Préventives

Archaeological artefacts and the sediments that contain them constitute the sometimes tenuous evidence that requires analysis, preservation and showcased. Different methods of digital analysis that provide non destructive solutions to preserve, analyse and showcase archaeological heritage have been developed over recent years. However these techniques are often restricted to the visible surface of the objects, monuments or sites.

The techniques used in medical imaging are more and more frequently used in archaeology as they give non destructive access to the artefacts' internal and often fragile structure. This use is mostly limited to a simple visualisation. The information obtained by CT-scan is transcribed in a visual manner and its inherent detail can be used much more widely in the domain of the latest 3D technologies such as virtual reality, augmented reality, multimodal interactions and additive manufacturing. In combining these medical imaging techniques, it becomes possible to identify and scientifically analyse by efficient and non destructive methods non visible objects, to assess their fragility and their state of preservation. It is also possible to assess the

restoration of a corroded artefact, to visualise, to analyse and to physically manipulate an inaccessible or fragile object (CT, 3D printing) and to observe the context of our hidden archaeological heritage (virtual reality, augmented reality or mixed, 3D). The development of digital technologies will hopefully lead to a democratisation of this type of analysis.

We will illustrate our approach using the study of several artefacts from the recent excavation of the Warcq chariot burial (Ardennes, France).

We will present two types of physical interaction with inaccessible objects the first is based on a transparent 3D printing of a horse's cranium and the second is a more tangible interaction that combines 3D printing and virtual reality. We will highlight how this method can be integrated into the archaeological process whilst comparing it to existing methods. Its relevance and future research perspectives will also be discussed, in particular within the context of preventive archaeology.

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Post-Mortem Practices in the Mesolithic of Brittany : A Multi-Modal Digital Approach

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Centre de Recherche en Archéologie, Archéosciences, Histoire

The oldest human bone of Brittany was dug up from the mesolithic shell midden of Beg-er-Vil in Quiberon and dated about Ca 8200 years. The low acid soils of these dump area represent exceptional sedimentary conditions. For these reasons, but also because these bones have a very particular patrimonial and symbolic value, their study goes altogether with concerns of conservation and museographic presentation. The clavicle is constituted of two pieces discovered separately at a one meter distance from each other. The two pieces match, so it can be assemble in a single fragment of approximately 7 centimeters. Cut-marks are clearly visible on the surface of these bones. They are bound to post-mortem processing, realized on fresh bone in order to remove the integuments, which it is necessary to better qualify. The clavicle was studied through a process that combines advanced 3D image acquisition, 3D processing (Fig 1.), and 3D printing with the goal to provide relevant support for the experts involved in the work.

The bones were first scanned with a CT scan, and digitized with photogrammetry in order to get a high quality textured model. The CT scan appeared to be insufficient for a detailed analysis; the study was thus completed with a μ CT providing a very accurate 3D model of the bone. Several 3D-printed copies of the collarbone were produced in order to constitute tangible support easy to annotate for sharing between the experts involved in the study.

The 3D models generated from μ CT and photogrammetry, were combined to provide an accurate and detailed 3D model. This model was used to study desquamation and the different cut marks, including their angle of attack. These cut marks were also studied with traditional binoculars and digital microscopy. This last technique allowed characterizing their type, revealing a probable meat cutting process with a flint tool.

This work of crossed analyses allows us to document a fundamental patrimonial piece, and to ensure its preservation. Copies are also available for the regional museums.

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SfM Modelling at Amara West

Neal Spencer
British Museum

The British Museum research project at Amara West, a colonial pharaonic town in Upper Nubia (Sudan), has integrated the use of Structure from Motion (photogrammetry) 3D modelling within the project. Challenges in terms of import restrictions, site access, climate and budget have informed the selection of methodology, which has resulted in the creation of a research tool for post-excavation use, and public outputs.

On Friction & Movement. 3D-Metamodeling Christopher Polhem's Mechanical Alphabet

Pelle Snickars
Umea University

According to the Swedish scientist Christopher Polhem (1661-1751) *mechanics* was the foundation of all knowledge. As a pre-industrial inventor working during the early 1700s, he sincerely believed that *physical models* were always superior to drawings and abstract representations. As a consequence, he designed a so called *mechanical alphabet*—some 80 small wooden models with moving parts, crafted with the pedagogical purpose to illustrate different mechanical principles like the lever, the wheel or the screw. These models were originally displayed at the Royal Model Chamber in Stockholm from the 1750s and onwards.

Within the ongoing Swedish research project “Digital Models”, we have worked with 3D modeling and 3D imaging Polhem’s mechanical alphabet in different ways. One major difficulty in rendering these models based on “technical rigor in digital heritage visualisation”—to quote the London Charter on computer-based visualisation of heritage—has been *model movement*. A 3D version of a model can be moved around, but moving parts cannot be rendered in 3D scans. Hence we have also tried to work with animations and virtualisations as representational modes. Regarding animations, movement can be rendered—but not interaction. In addition, computer code can make, say, a cogwheel run completely smooth. In one of Polhem’s original models, however, the cogwheel caused a lot of *friction*; the model was built by wood after all. Hence, the issue of how to *interpret* friction in 3D imaging became notoriously difficult for us. Through the usage of HTC Vive glasses—and the software Unity—we have also metamodeled how the Royal Swedish Model Chamber looked like around 1750, and inserted our scanned, photographed or animated models in VR. Essentially, the idea has been to examine different forms of interactivity, movement and friction by including a number of Polhem’s models in the virtual model environment—with a possibility to re-envision the pedagogical quality of these models in a strict digital setting.

Using a Modified Camera for Integrated Spectral and 3D Imaging to Monitor Cultural Heritage Objects

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Heritage professionals are using high-resolution consumer digital cameras for visible light 2D and 3D cultural heritage documentation. Consumer digital cameras paired with computational approaches including Structure from Motion, Multi-View Stereo and Bundle Adjustment can provide heritage professionals with an automated,

flexible, accurate, and accessible 3D reconstruction workflow. Silicon sensors, at the heart of consumer digital cameras, are inherently sensitive to near ultraviolet and near infrared radiation but are optimized for colour photography by incorporating an infrared blocking filter and a colour filter [Bayer] array on the sensor. By removing these filters, the cameras can provide capabilities for spectral imaging while retaining the same user-friendly properties and interfaces to a wide range of photographic accessories and software. The end result is a less expensive, high-resolution option for 2D and 3D spectral imaging of cultural heritage objects.

As modified cameras become more widely used for conservation documentation, it is important to understand how these devices can be used as quantifiable scientific tools to record and monitor our heritage objects. This research investigates the use of a modified consumer digital camera as a tool for spectral-3D imaging. The work is founded on characterising the modified camera to understand how the modification impacts the resulting imagery and 3D reconstruction. This paper will report on research to characterise the modified and unmodified cameras by assessing the 2D image quality, measuring spectral response, and reporting on an initial evaluation of 3D reconstruction performance. The 2D image quality assessment used the Digital Imaging Conformance Evaluation as part of the Federal Agencies Digitization Guidelines Initiative technical guidelines whilst the spectral response will be measured using narrow bandpass filters. 3D reconstructions of a test object, a wooden vase, will be processed using Agisoft Photoscan and compared at a sub-mm level measuring mean distances and local deviations between 3D models.

Results suggest that the modification does not significantly impact the image quality or performance of the camera, but does increase the spatial resolution. Measuring the spectral response quantifies the system as a scientific device for more accurate measurements and provides indications of wavelengths and ranges that could provide improved response based on sensitivity. Comparisons of the 3D models produced from the unmodified and modified camera provide similar 3D reconstructions.

The modification of a consumer digital camera can provide a less expensive, high-resolution option for 2D and 3D spectral imaging, while the characterisation of the modified camera provides a better understanding of the device as a scientific tool. When used together spectral and 3D imaging techniques provide complementary information that is able to better record changes in material, dimension, surface geometry and visual appearance. This research is a part of an investigation of the use of a modified camera for integrated spectral and 3D imaging for monitoring cultural heritage objects.

Old Casts in a New Light: 19th Century Plaster Casts of Classic Maya Artefacts as Cultural Heritage and Efforts for their Digital Preservation and Analysis

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The only partially deciphered Maya hieroglyphic script and language constitute the focus of the long-term research project "Text Database and Dictionary of Classic Mayan" (2014-2028), carried out cooperatively by the Bonn University and the Göttingen State and University Library. Our goal is to compile a text database and, on this basis, a dictionary of Classic Mayan, the language of the Classic Maya civilization (A.D. 250 to 950). The project is co-operating with Dr. Hubert Mara of Heidelberg University and uses a *Breuckmann smartSCAN C5* structured-light scanner for high-resolution and three-dimensional documentation of hieroglyphic artefacts. Since two

years the digital documentation of late 19th century plaster replicas of Maya monuments has become a focus of our work in various collections (e.g. Cambridge, Berlin, Basel). Because important hieroglyphic and pictorial information have survived intact on plaster replicas these now represent the best surviving record of the original and thus their documentary significance is immense to Maya epigraphic research. One example that we will discuss is the hieroglyphic stairway from of Palenque. Many portions on that epigraphic document survive only on the late 19th century plaster cast presently stored in the British Museum while the original has severely deteriorated since its discovery. Since 2016 we have been collaborating with the Museum of Archaeology and Anthropology in Cambridge. It stores 63 replicas of Maya monuments from Quirigua, Copan, Yaxchilan and other major archaeological sites that were manufactured *in situ* by the British explorer Alfred P. Maudslay in the late 19th century. In this period of research the production of paper squeeze-moulds and the casting in plaster was a popular method in the archaeological record, study and display of ancient and newly discovered sculptures. Maudslay obtained hundreds of casts of Maya monuments with many of them being stored in the British Museum since the 1920s. Maudslay also copied the more important pieces of his casts and sent them to various museums in the UK, France and the United States.

A glance at the research history exhibits that an adequate documentation and publication of these unique sources have not yet been carried out. In cooperation with Heidelberg University we have thusly set the task of documenting these long neglected source materials for its project database using a high-resolution 3D fringe projection scanner. Such precise 3D records i.e. 3D models allow the application of novel visualization techniques of the Maya glyphs emphasizing their topographic and geometric properties. With robust filter algorithms like the Multi-Scale Integral Invariants (MSII) finest details of the text and image can be rendered on the computer screen improving their readability. These new means of digital autopsies complements the difficult analysis during field conditions leading to an optimal transliteration. Especially for faint or faded (medieval) inscriptions the MSII filter could reveal additional characters as well as tool marks and other paleographic evidence. As our contact-free 3D scanner additionally acquires the color of the surface we can provide multi layer images for further means for thorough studies without use of the original.

Poster Presentations

The Empty Niche

Jim Walsh
Conway Hall

In 1929 Conway Hall was unveiled with a niche in the foyer, this niche was designed to display a revered piece of artwork; a bronze bust of Dr Moncure Conway, celebrated writer, abolitionist and free thinker, for whom the building was named. However, in the buildings eighty-plus year history the bust was never displayed in Conway Hall, or even mentioned in their archives.

Following a period of research, we discovered that two other busts, made from the same mould, were in two different places in the United States. At that moment we decided to make a documentary about our missing bust and also get a 3D print version of the bust made and installed in the empty niche of our foyer at Conway Hall.

The documentary is presented by Ginny Smith, who regularly presents shows for The Naked Scientists on BBC Radio 5 Live and BBC Radio Cambridgeshire. Trunkman Productions produced and directed The Empty Niche. Research was carried out by the team at Conway Hall, staff and Trustees. The 3D print was made by iMakr on Clerkenwell Road and has now been installed.

Conway Hall Ethical Society is the longest running freethought society in the world, dating back to 1793. Conway Hall itself opened in 1929. The Hall now hosts a wide variety of lectures, classes, performances, community and social events. It is renowned as a hub for free speech and independent thought. It's library holds the Ethical Society's collection, which is the largest and most comprehensive Humanist Research resource of its kind in the United Kingdom.

Intelligent robotronics: 3D Imaging Technology for Restoration of Tangible and Intangible Cultural Heritage

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Our work aims to create new tools for the study and teaching of history of art, science and technology using innovative so-far developed 3D software-hardware technologies and to apply them to recreate the look of underwater archaeological finds, famous sculptures and buildings, for the synthesis of three-dimensional objects from drawings and pictures, including to detect errors in structures. Starting from the 3D imaging models is also possible to build realistic scaled physical models of artistic works, monuments and buildings by means of suitable 3D printers. Research in the field of archaeology is conducted in cooperation with the Zadar University in Croatia and the Bologna Academy of Sciences. Using the same tools to generate mathematical models on the virtual holographic screens, it is planned to prepare materials on the history of science and technology - intertwined scientific schools of Russia, developed by celebrated academics of Russian Academy of sciences and Accademia delle Scienze dell'Istituto di Bologna, such as M. V. Lomonosov and P. L. Tchebyshev, and also RAS academicians, M. V. Keldysh and D. E. Okhotsimsky, who opened the era of space exploration, ballistic calculations and intelligent robotics.

The project was initiated within the framework of the Austrian-Russian scientific school "Intellectual robotronica" (KIAM RAS, Russian state humanitarian University, Vienna University of technology) and the International laboratory "Sensorika", partly funded by RFBR Grants 16-07-01264, 16-07-00811, 16-07-00935.

True Colours: 3D Printed mass-coloured replicas of polychromed medieval sculpture as a conservative tool

Marjan Debaene

M – Museum Leuven

Up till recently, replicas of medieval polychromed sculpture were mostly made by casting the object in plaster or plastic and painting it afterwards. To achieve a satisfying result, the cost of this type of polychromed cast can rise heavily. Moreover, casting is an invasive method that can harm the sculptures or their polychromy layers in the process. 3D printing has been used before to make replicas of various heritage objects, but these are mostly printed in a monochrome plastic or in unrepresentative colours. This gives the replicas a very 'fake' feel to them. M Museum Leuven has been researching the possibility of using 3D printing as a method to produce a satisfactory mass-coloured replica of a polychrome sculpture. This method is far less invasive than casting the object as you have only to 3D scan the object. By choosing a mass-coloured printing technique we can eliminate the pricy paint job afterwards. This method could be used to produce replicas of sculptures that are now still in situ in a religious building and have to be replaced by a copy because of safety or conservation reasons due to anti-theft issues or climatological problems threatening the object to such an extent that the best option is to keep the original in a museum and replace it in situ with a replica. For far too often however, museums have in the past collected devotional objects from churches and abbeys without doing something in return for these communities. Yes, the object was conserved for eternity in the museum but the community was left emptyhanded and lost its devotional sculptures.

This project wants to develop a tool that can help museums be of service to the religious communities that still keep medieval devotional sculpture, but who have often many financial issues to keep objects safe. By 3D printing a mass-coloured replica, the object is safeguarded and the religious community still has a copy of its devotional object in situ. Of course, it should always be possible to return the original object temporarily for special occasions such as processions and special liturgical celebrations, or even definitely when safety problems have been dealt with. M Museum has partnered up with Leuven based 3D printing pioneer Materialise to produce a test case. A 15th century Virgin with child from the Church of Our Lady in Haasrode (Belgium) has been 3D scanned and printed. This paper presents the results of this testcase but does not shy away from the pitfalls of this replicating method and stresses the importance of setting the right criteria and covering bases beforehand. For instance, achieving the correct printed colours has proven to be quite difficult. Also, the choice of the right print ink is crucial to achieving a good result. Equally important issues to work out in advance are financial repercussions (and needs of funding to broaden the project) and last but definitely not least the willingness of a community to worship a replica rather than an original medieval sculpture.

High resolution monitoring of historical surfaces by using Shearography and Structured Light Scanning

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For the analysis and monitoring of endangered historical surfaces at the 14th century choir screen paintings in Cologne Cathedral a novel combination of two non-destructive testing methods - NDTs (Shearography and Structured Light Scanning) is to be presented.

Shearography is a laser-optic micrometry technique in which light serves as benchmark for the determination of surface-topographical changes. In a controlled double-exposure process with shifted ("sheared") images on the same spot, surface measurements are compared after a short stimulation using vacuum, sound waves or temperature. The degree of deformation or dilatation of the underlying materials or layers, which is visualized by interferometric methods, is determined. In the case of the choir screen paintings, a thermal stimulation of a maximum of 2 K was performed. Shearography can be used to detect cracks, cavities or material differences.

By means of high-sensitivity Structured Light Scanning, the surface topography was additionally captured three-dimensionally in a high-resolution. By repeatedly measuring and subsequently superimposing the surface reliefs, changes such as movements, application or loss of material can be accurately recorded and visualized.

The choir screen paintings in Cologne Cathedral are considered fragile and endangered. Problems arise from old treatments and the hygroscopic preservatives applied in the 20th century. In particular as damaging processes are inevitable due to the climatic situation in the cathedral with a relative humidity of above rh 60% and with frequent changes in humidity or temperature.

The complementary application of shearography, structured light scanning and photo documentation for the monitoring of endangered paintings showed unexpectedly good results. Not only analyses of the overall condition of the objects by using these technologies can be made up but also surfaces which were chemically treated or consolidated up to depths of approx. 4 mm can be monitored in high-resolution.

Neutron tomography on IMAT

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STFC Rutherford Appleton Laboratory Harwell

A new neutron tomography and diffraction facility has recently been taken into operation at the accelerator-based neutron spallation source ISIS at the Rutherford Appleton Laboratory at Harwell. Neutron radiography and tomography can be used for a non-invasive 3D visualisation of inner components and structures of many common heritage science materials. The high penetration power of neutron allows assessing the preservation state of an object; organic material inside metal structures can be made visible, and distributions of hydrogenous materials can be determined. Selected regions of interested can be additionally characterised by time-of-flight neutron diffraction, for studying the material compositions and crystalline structures. Objects irradiated with neutrons become temporarily radio-activated; the storage time is usually in the order of days.

3D imaging for unfolding folded papyri

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One of our best sources for information about the culture of our predecessors are their writings. Some of these writings are hidden in rolled, folded or crumpled documents. Due to recent improvements with respect to sensitivity and resolution, a few spectacular disclosures of hidden texts were already possible by x-ray tomography on scrolls.

In the case of papyri in ancient Egypt there are numerous objects known as folded papyri, sometimes even sealed, where the technique of folding was different for different purposes. To find the proper procedure for virtually inverting the folding of such packages, 3D imaging is extremely valuable. When the folding type is unknown and cannot be determined by visual inspection, 3D imaging provides the tool to find how to start the procedure and continue with following stages. We have demonstrated the procedure and tested algorithms on a mockup sample folded according to the “magic fold”, which was written with highly absorbing metal containing ink for optimal tomography conditions. Applications to papyrus packages from ancient Egypt and further perspectives will be discussed.

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Old Russian jewelries studies by means of neutron imaging method

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A neutron radiography and tomography facility have been developed recently at the IBR-2 high flux pulsed reactor. The IBR-2 high flux pulsed reactor is one of the most powerful pulsed neutron sources in the world with the average power 2 MW, power per neutron pulse 1850 MW and neutron flux in pulse of 5×10^{15} n/cm²/s. The neutron radiography and tomography facility is placed on the 14th beamline of the IBR-2 high flux pulsed reactor. As scintillation screen, the ⁶LiF/⁶ZnS scintillator of 0.2 mm thickness is used. The light is reflected out of the beam by a mirror and focused on CCD chip by an optical lens Nikon 50 mm 1:1.4D AF-Nikkor. The sample manipulator system is based on HUBER goniometer with x-, y- translation and z-rotation stages. The minimal rotational step is 0.02 deg. The imaging data are subtracted by the dark current image and are divided to the incident neutron beam by means of an ImageJ software. The tomographic reconstruction is performed by a H-PITRE program. The VGStudio MAX 2.2 software of Volume Graphics (Heidelberg, Germany) is used for the visualization and analysis of reconstructed 3D data. The evaluated spatial resolution for the field-of-view 20x20 cm² is about 300 μm. The tomography experiments have been performed with rotation step of 0.5o and total number of measured projections was 360. The exposure time for one projection was 10 s and resulting measurements lasted for 4 h.

Items of jewelry art of Old Russian time from ancient Russian city Tver were studied with use of this method. All the jewelry was made of silver and was greatly damaged by fire. All traces of gilding and blackening disappeared under temperature effects and also, those parts of jewelry which were connected by soldering were deformed. The Old Russian bracelet, heavily damaged by fire, and the kolt were studied by means of neutron tomography. We succeed to restore parts of gilding and blackening on a bracelet, what would be impossible by standard means of research (Fig. 1). Now we can say that a bracelet from Tver belongs to Kievan Old Russian jewelry school, which traditions ascended to the Byzantine Empire. Analogues of such bracelets can be seen in the museums of Moscow Kremlin, in the Historical and the Russian museums. Data obtained for a kolt (Fig. 2) is a great interest of restorers and researchers: we succeed to learn about the technique of connection of its separate details, and to reconstruct the number of separate elements used for its making (there are more than 50). Moreover, parts with different elemental composition were detected, allowing us to reconstruct the process of soldering of granules and filigree on the surface of a kolt. Undoubtedly, the data obtained not only allows optimizing the process of restoration of these items, but also provides us with new knowledge of the Old Russian technique of jewelry making and has a big exposition interest as well.

Post-Processing for 3D-Computed Tomography Data of Musical Instruments

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Industrial 3D-computed tomography (CT) has been established as a powerful method for non-destructive examination of objects of cultural heritage in restoration and conservation science. Spatial resolutions of less than 100 μm can be achieved which is high enough to conduct numerous further research utilizations and exact measurements of otherwise inaccessible parts. High resolution CT thus has numerous advantages compared to 3D surface scanning or medical CT methods, but also presents a lot of challenges. One of these is the required high-performance computational resources to process the achieved amount of data: Scanning of an entire violin in a spatial resolution of 100 μm yields a reconstruction consisting of up to 8000 single images with 16 bit resolution. The entire data set thus can have an overall cumulative size of more than 60 GB. Another challenge is the need of expertise to be capable of handling the data in order to extract available information. This contribution presents approaches to post-processing of recorded CT data in order to make the obtained information accessible for further research.

The MUSICES-project is developing a standard for computed tomography for musical instruments [Kirsch et al., 2017]. The technical settings and important steps for the storage of meta-data as well as advice for mounting and transport are part of the research, but no further processing of the collected data is considered. In addition to this fundamental research, workflows for the following possible applications based on CT data are presented using open source data formats and software:

- Segmentation and classification of homogeneous sub-volumes, utilizing software for medical image analysis, leads to a massive reduction of data. Handling, therefore, is simplified and individual sections can be extracted and stored in databases for specific research tasks [Yushkevich et al., 2006].
- Extracted ISO-surfaces can be used for rapid prototyping and the reproduction of whole instruments or missing parts for restoration purposes. Manufacture may be obtained by additive- (3D printing) or subtractive methods (CNC milling) [Savan et al., 2014].

- Sub-volume data can be utilized for physical modelling (FEM), thus allowing for evaluation of the vibroacoustic behaviour of instruments, even in non-playable condition. With regard to conservation issues physical modelling can also provide insights into the structural behaviour of displayed instruments under long term mechanical loading [Konopka, 2016].
- Measurements in any part of the object with high precision are possible.
- Dendrochronological dating can be performed on cross sections of wooden sub-structures.

The proposed methods are exemplarily applied to data of several objects scanned during the MUSICES project. Single wooden instrument parts are segmented, modelled, analysed and reproduced by CNC milling of wood and 3D printing of wood-polyester composites.

The presented results show straightforward and inexpensive ways to handle and process CT data of musical instruments, which are easily transferable to a wide range of objects of cultural heritage with various requirements with regard to conservation, restoration or technological issues.

References

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The Use of Micro-computed Tomography in Cultural Heritage

Belen Notario

Centro Nacional de Investigación sobre la Evolución Humana (CENIEH)

One of the current problems within the historical, archaeological, and cultural heritage is to update the guidelines, methods, criteria, and technologies that should be used in interventions on the objects of cultural property. Traditionally the studies of the archaeological materials have been carried out directly on the original piece, which has supposed an excess of manipulation of the same one.

Also, it was also a common practice for researchers to sacrifice some pieces (even single) for the elaboration of complete sections, in order to know in depth the materials. All this problems needed the emergence of new analytical technologies to avoid these problems. X-ray computed tomography emerges as a powerful method in the study, for instance, of archaeological objects allowing to make a virtual study of the complete morphology (both internal and external) of the piece, and to minimize excessive manipulation of the original. The use of this technique in the field of cultural heritage is very useful, since it is a non-destructive method that does not damage the sample in the process of analysis and measurement. Furthermore, once the 3D reconstruction is obtained, anyone can work on the piece and analyze all the parameters they want from all over the world. Likewise, this method is also useful for restorers allowing them to know how much they have to remove the residues present in the piece.

In this work, different archeological samples and problems related to the field of cultural heritage have been studied with the use of an X-ray micro-computed tomographer. The results obtained, that will be shown in the presentation, are very promising, which makes CT scanning a very useful tool with a favorable future in the field of cultural heritage.

A Matter of Scales - 3D multiscale applications in research and conservation of cultural heritage

C. Boust, C. Hochart, A. Maigret, A. N. Mélard
Centre de recherche et de restauration des musées de France (C2RMF)

The 3D techniques evolving since more than half a century offer today a wide range of devices. Some photo based 3D techniques are accessible to everybody, others require costly and complex scanners.

The non-contact scanning makes the 3D imagery particularly interesting for application in Cultural heritage.

The large offer of scanners leads to the problem of the choice of the accurate technique according to the questioning of researchers, restaurateurs, curators and other professionals in cultural heritage.

Capturing the Cultural Heritage of East Africa

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In the summer of 2017, a workshop was convened on the Indian Ocean island of Zanzibar, to explore solutions for the recording and protection of the Cultural Heritage of East Africa. Supported by the Global Challenges Research Fund, the three-day event brought together key heritage practitioners from Tanzania, Kenya, Rwanda, Somalia, Ethiopia, Uganda, Mozambique, Comoros and Mauritius, UK and Australia.

The Crisis in Eastern Africa for Cultural Heritage: Development, Population & Migration

Rapid development across the region is taking place. Funded through sovereign wealth funds and private investments from China and the Gulf, these plans avoid many of the accepted environmental and heritage impact assessments and have little regard for the protection or recording of cultural heritage. These developments will transform the African landscape and its cultures over the next 20 years. While it is largely impossible to divert these huge schemes, it is possible to mitigate their effects through the acquisition of information, digital preservation, community engagement, skills and capacity building.

The workshop addressed this emergency by bringing together: 1) those working in cultural heritage protection and conservation in the region; 2) experts in the latest rapid data acquisition digital methodologies, (including terrestrial and airborne laser scanning, aerial UAV photogrammetry, and open source software platforms); 3) specialists in international relations; 4) a design activist, an empathetic story-teller and an experimental archaeologist. The workshop addressed the particular issues of working in Sub-Saharan Africa and the practical limitations to these high specification rapid-recording digital approaches.

Integrated Digital Recording Solutions?

African Heritage is a fragile blend of intangible and tangible heritage. The region is the cradle of humankind, with a history of humanity that extends to at least 3 million years. Much of the heritage is unknown, under researched, and inaccessible. Radical solutions are needed to protect, conserve and to help preserve unique cultural identities, and digital solutions are one technique we were keen to explore.

This poster focuses on the digital elements of our workshop, in which we tested a range of remote sensing devices in the field, to demonstrate and assess their application within an African context. Zanzibar has a rich cultural heritage, from Holocene caves, to Swahili port-cities and Omani Arab palaces. There is also strong intangible heritage including boat building, basket weaving and textile production. Using terrestrial laser scanning we digitally captured a fully georeferenced model of the inside of Mwanampambe cave as well as Kidichi palace and a range of other aspects of cultural heritage. There is known evidence of human occupation of the site from 4000 BP, to its present use as a spirit cave. UAV survey provided an orthomosaic map of the cave in its landscape, while GPR provided a detailed model of the cave deposits. The same combination of techniques were applied to the Kidichi Palace and Baths which were built by Sayyid Said in the 1840's for his new Persian wife. The inside of the baths has elaborate stucco decoration with Arabic inscriptions and images of paradise. Using a drone and terrestrial laser scanner, we were able to model the exterior and interior of the Persian Baths, which has permitted the decoration to be studied in detail for the first time.

Exhibitions

Bill Harvey Associates

<http://www.billharveyassociates.com/>

Bill Harvey Associates are world experts on masonry arch and tunnel behaviour and author of the Archie-M software package for analysis of masonry arch bridges. We have produced customised analytical tools, specialist viewers on Unity, for building useful models for Civil Engineering Heritage studies usually to extremely short timescales. Through them we have demonstrated the resilience of existing infrastructure to unusual forces and movements, resulting in major cost and programme savings.

Exhibitor: Hamish (David) Harvey
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+44 1392 796640
Twitter: @hamishharvey

CYREAL

www.cyreal.com

CYREAL have developed a 3D digitisation platform for the Cultural Heritage Sector. Our goal is the production and management of low cost, high quality 3D models for use within archives as well as augmented or mixed reality applications. We are a 3D digitisation company based in London England, with skills spanning the IT and photographic industries, our services will be available globally from Q3 2017.

Exhibitor: Donald Cousins
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Museum in a Box

<http://www.museuminabox.org/>

Museum in a Box puts museum collections and expert knowledge into your hands, wherever you are in the world. We're building an innovative update on the old idea of a museum handling collection, where low-value objects are rented by schools for a short time. We're adding 3D prints, postcards, near-field communication (NFC) technology, and Raspberry Pi to connect museum objects to the web, and radically increase outreach and engagement for museums.

Exhibitor: Charles Cattel-Killick
charlie@museuminabox.org
Twitter: @_museuminabox

Sketchfab

<https://sketchfab.com/>

With a community of over one million creators, we are the world's largest platform to publish, share, and discover 3D content on web, mobile, AR, and VR. It provides a viewer based on the WebGL and WebVR technologies that allows to display 3D

models on the web, to be viewed on any mobile browser, desktop browser or Virtual Reality headset. Sketchfab provides online and mobile community portals, where visitors can browse, rate and download public user generated 3D models.

Exhibitor: Thomas Flynn
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Soluis

<http://www.soluis.com/heritage/>

The Soluis Group incorporates several operating divisions that offer a range of best-in-class visual presentation and stakeholder engagement solutions. Founded in 2000, Soluis have established a reputation for flexibility, innovation and quality in delivering exceptional service that helps our clients to connect more effectively with clients, project partners and communities. The team at Soluis has over 14 years of experience in presenting heritage architecture through CGI visuals and animation. As a business with a great many staff members whose skills were honed as part of architecture degrees, we have an informed and nuanced understanding of both our subject matter and method in representing heritage content.

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ThinkSee3D

<https://www.thinksee3d.com/>

Digital and physical 3D making services for science, culture, education, ecology, design, art and research. Services include: 3D scanning using photogrammetry, structured light scanning for natural and cultural heritage projects; 3D print to mould to cast services for wider material choices or replicas for museum retail; object, model and specimen creation/replication service using a variety of methods including full colour photo-textured 3D printing in gypsum/acrylic to simulate and replicate bone, ceramic, aged-metal and stone.

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Photogrammetry Workshop

Thursday, 9th November

14:00-15:00

**Sackler Room, Clore Centre
(next to BP Lecture Theatre)**

Thomas Flynn, Cultural Heritage Lead at Sketchfab (<https://sketchfab.com/>) & *Alec Ward*, Development Officer for Digital & Communications at the Museum of London (<https://www.museumoflondon.org.uk>)

A presentation workshop demonstrating the process of making 3D models of museum objects using photogrammetry, and uploading/curating that model on the online 3D hosting platform Sketchfab. The workshop will go through the steps of taking the photos of an object, using specialist photogrammetry software to make a 3D model and uploading the model onto Sketchfab. Online 'action packs' will be available for people interested in trying the process out (workflow doc, links to software options, a 'best practice' guide for online 3D).