FACTVM FOVNDATION

FOR DIGITAL TECHNOLOGY

IN PRESERVATION

2019

FACTVM FOVNDATION 2019

Factum Foundation
Volume III
2016 - 2019

Render of marble panels on the façade of the Basilica di San Marco in Venice recorded using photogrammetry.
Cover: detail from the *azulejos* of Casa de Pilatos.

FACTVM
FOVNDATION
for DIGITAL TECHNOLOGY
in PRESERVATION

"Because it connects the most advanced technology with the deepest care for the materiality, history and intricacies of works of art, Factum Arte occupies now a central place at the crossroads of all the issues concerning the restoration, conservation and politics of treasures spread in many different countries. What the Factum Arte team has managed to assemble allows for a set of skills impossible to find anywhere else to not only probe deeply into works so as to reproduce them, but also, to produce new works of art. Or rather, it has given to the words 'reproduce' and 'facsimile' a completely new sense and direction that has become synonymous with creation and innovation."

Bruno Latour, Philosopher and Historian of Science

2019
www.factumfoundation.org

Facsimiles of the two lamassu, recorded at the British Museum, were installed at the entrance to the student centre at the University of Mosul in 2019. These guardian spirits now serve as a protective force encouraging learning and the sharing of knowledge.

One of Antonio Canova's last monumental sculptures, a 3m-high equestrian statue, was broken up in 1969 during building works in the Museo Civico di Bassano del Grappa. Factum Foundation has digitally restored the statue in preparation for casting as a full-size bronze statue.

Originally painted on wood, Raphael's *Christ falling on the way to Calvary* was transferred to canvas in the early 19th century. Factum Foundation's re-creation travels both forwards and backwards in time, imagining what the painting would look like on a hard surface.

The facsimile of François Boucher's *Portrait of Madame de Pompadour* has allowed it to be displayed in a former context, Waddesdon Manor in Buckinghamshire, UK. The facsimile formed the centrepiece of a 2019 exhibition, "Madame de Pompadour in the frame".

The sacred cave of Kamukuwaká, a site of vital importance to the peoples of Xingu in Brazil, was vandalised in 2018. Factum Foundation recorded the cave in the days following the attack, and has worked with the Xingu to propose a digital restoration of the damaged sections.
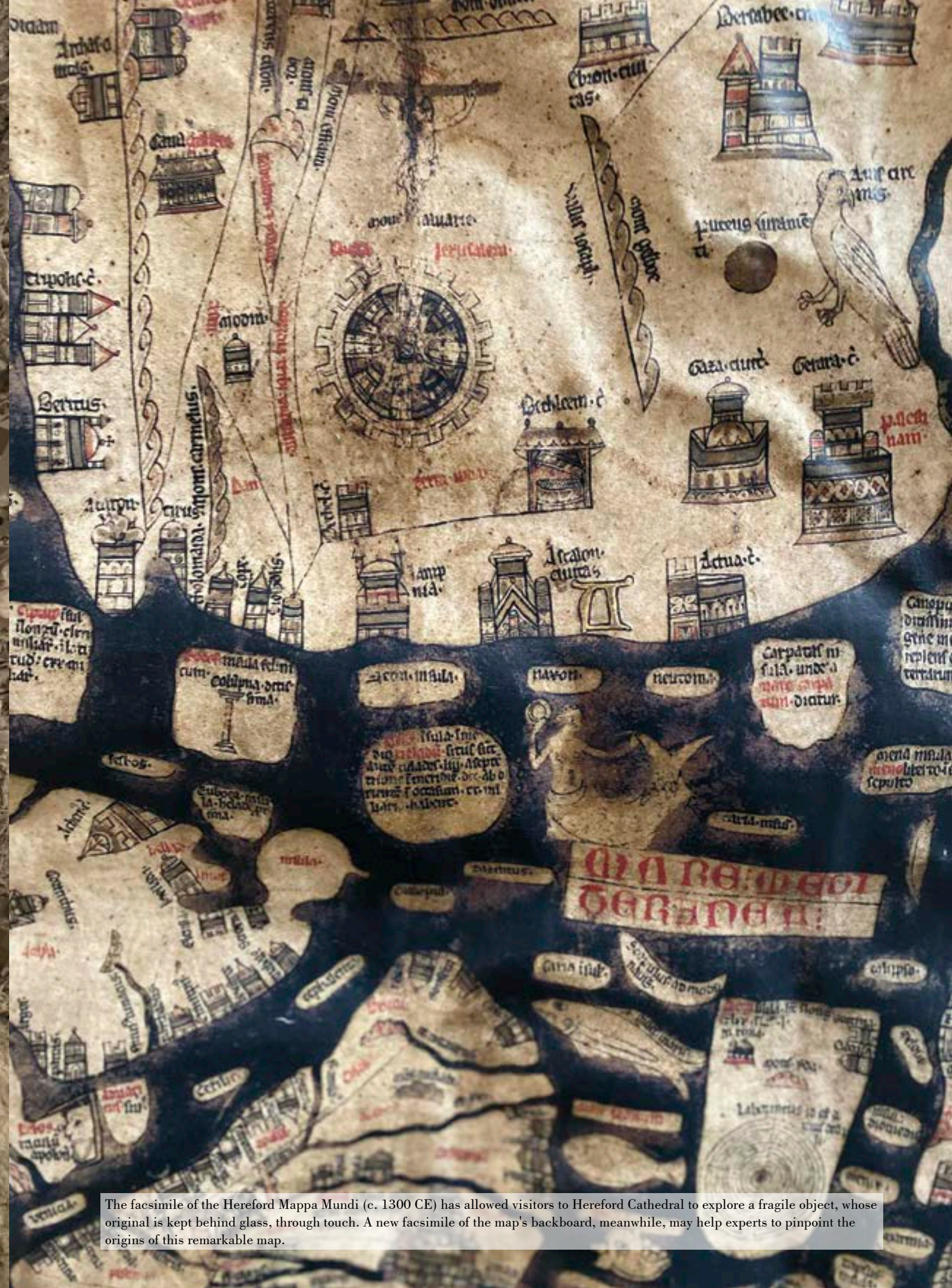
The facsimile of the Hereford Mappa Mundi (c. 1300 CE) has allowed visitors to Hereford Cathedral to explore a fragile object, whose original is kept behind glass, through touch. A new facsimile of the map's backboard, meanwhile, may help experts to pinpoint the origins of this remarkable map.

The **FACTUM FOUNDATION FOR DIGITAL TECHNOLOGY IN PRESERVATION** is a not-for-profit organisation, founded in 2009 in Madrid. It works alongside its sister company, Factum Arte: a multi-disciplinary workshop in Madrid dedicated to digital mediation in contemporary art and the production of facsimiles.

The Foundation was established to demonstrate the importance of documenting, monitoring, studying, recreating and disseminating the world's cultural heritage through the rigorous development of high-resolution recording and rematerialisation techniques.

Factum Foundation's aims were recorded at the time of its formation – they remain the same today:

- Use non-contact recording methods to document cultural heritage sites and objects to the highest possible standards.
- Change attitudes towards the digital recording of cultural heritage, encouraging the creation of permanent and accessible public records of important objects and artworks.
- Develop new recording and display technologies, and new uses for existing technologies.
- Create practical, secure archiving and display systems for high-resolution data.
- Create facsimiles of recorded objects – copies so accurate that the naked eye cannot tell them apart from the original – and use these facsimiles to do things which the originals cannot: to allow fragile objects to travel, fragmented objects to be reassembled, and untouchable objects to be touched.
- Develop new techniques of digital conservation and restoration, expanding the range of possibilities open to curators and conservators by allowing objects to be restored in the virtual realm.
- Share recording skills and technologies as widely as possible. The Foundation has set up training courses and centers in locations from Egypt to Dagestan to create local experts in digital preservation who are able to record their own cultural heritage.
- Make digital records of works of art accessible to the widest possible public through the Creative Commons model.
- Develop exhibitions that allow audiences to understand the dynamic nature of objects, using digital models and physical facsimiles to challenge the idea that an object in its current state – perhaps restored, damaged, and enhanced over a period of centuries – is the only key to understanding and appreciating that object.
- Play an active role in the international effort to develop shared principles for the digital recording, archiving, and dissemination of cultural heritage.
- Leave to future generations an archive of raw, unmanipulated data which they can analyse according to their own questions and perspectives and using their own technologies, allowing them to inherit the past in a condition in which they can study it in-depth and emotionally engage with it.

Table of Contents

Factum Foundation using CNC-milling machines to engrave the contours and coastlines of Al-Idrisi's world map on silver.

Introduction

"That immaculate eye for detail is typical of the work of Factum Arte, a Madrid-based studio whose combination of digital analysis with assiduous craft is transforming the way we see art. I have been watching their work develop for nearly a decade. I am now convinced it is the most important thing happening in 21ˢᵗ-century art – because it can quite literally save civilisation."

Jonathan Jones The Guardian - February 2017

Since 2009, the Foundation has grown organically through a clear philosophy, focused actions, determination and hard work. As a not-for-profit our vision and determination has been that the preservation and sharing of cultural heritage will lead to new understandings. This is the third Factum Foundation book and it celebrates the first ten years of the Foundation.

Objects are dynamic: over the course of months or millennia they change, both in physical composition and in the meanings attributed to them. The western museological tradition has historically shown respect for objects (and sought to protect them) by removing them from their original context and keeping them in a fixed state through physical interventions, whether involving the injection of protective chemicals or the careful application of fresh layers of pigment. But there are also non-contact approaches to conservation and restoration, and these form the core of Factum Foundation's work, which revolves around the creation of definitive recordings of objects at particular stages in their trajectories. The Al-Qatt wall paintings from Saudi Arabia (see page 103) have already changed dramatically since their recording and some have disappeared. While their loss is deeply regrettable, to seek to fossilise these paintings in a single, historic state would have been an inappropriate way of responding to a dynamic and changing tradition that is slowly dying.

Not all data is equal. The quality of Factum's digital recordings of the surfaces of objects aims to capture the specific character and details of a surface that will reveal unseen details about their production or biography. We record with a degree of precision which allows the viewer to examine the objects closely and using different metrics, make meaningful comparecence between the data and the object. While images on a computer screen cannot possess the "real" materiality of the original object, they have an insistent presence of their own, allowing objects to speak in new ways, and viewers – whether museum conservators or the interested public – to look with new eyes. To explore the surface of Powhatan's Mantle on Factum's web-based viewer is a different, but arguably equally satisfying, experience to looking at the original behind glass in the Ashmolean Museum. The quality of Factum Foundation's recordings offers a direct riposte to those who believe that digital formats are by nature impoverising; they require, and allow, a new digital connoisseurship.

We believe that it is vital to have shared standards for digital copies, and in 2017 Factum Foundation played a significant role in instigating the ReACH initiative, which was launched at UNESCO in May of that year. ReACH resulted in a collectively agreed international declaration that recognises the value of digital recordings for cultural heritage. It aimed to define best practice concerning the production, storage, and dissemination of digital and physical reproductions. It was signed by 20 major museums and foundations.

A second forward-looking initiative was the launch in October 2018 of ARCHiVe, the centre for Analysis and Recording of Cultural Heritage in Venice, a joint venture of Factum Foundation with the Fondazione Giorgio Cini and the Digital Humanities Lab of the École Polytechnique Fédérale de Lausanne, with the Helen Hamlyn Trust as founding supporter. ARCHiVe aims to become a leading centre for the creation of hardware and software for recording, processing, archiving, sharing, and analysing cultural heritage. It follows the ReACH declaration in emphasising the need to share data, technologies, and skills as widely as possible, particularly with those who have traditionally been left out of the global cultural heritage industry. One of the biggest challenges faced by ARCHiVe, and by Factum Foundation, is the question of the long-term storage of data, and we are continually working on creative solutions to ensure the survival of these records for future generations.

Factum Foundation also makes facsimiles of the objects it records. When we use the term facsimile, we refer to an object which uses all available objective means to replicate the original. The colour will be the same as that of the original in the same lighting conditions, and the dimensions will correspond precisely, not only in terms of the size of the canvas but down to the precise surface relief of rough stone or the marks of a paint brush. When displayed alongside the original, the facsimile should look indistinguishable to the human eye. In making these objects, we use a combination of the latest rematerialisation technologies with traditional skills such as gilding and surface patination, employing highly skilled digital artisans alongside those working with long-established craft skills.

In its early years, Factum was often asked whether it was involved in the business of producing fakes, and the question of how exactly our work sits in dialogue with its original is one with which we are continually engaged. It is perhaps worth emphasising, first of all, that the contemporary obsession with originality in art is not a historical constant. In many times and places, the ability to make a high quality copy of an artwork has been held in the highest esteem. Museums across Europe and America, for instance, are now regretting the wholesale dismantling of their cast courts, collections of copies designed to be copied in turn, which once formed the bedrock of their countries' art education systems. The creation of any kind of record – even the taking of a single photograph – involves subjective decision making, and we believe that the decisions involved in creating physical, 3D reproductions of objects lead to a deeper understanding of how objects work; when concepts are divorced from physical decision-making they tend to dissolve.

Factum Foundation has only begun to explore the possibilities opened up by its recordings and facsimiles, but it is already abundantly clear that facsimiles are creating new forms of sharing that allow fragile objects to travel to new audiences. They can facilitate the reassembly of fragmented objects and collections. They can also allow objects to be touched and accessed for a range of different reasons. Factum Foundation has found the support to rematerialise the Bakor monoliths of southeast Nigeria, and helped to curate a travelling exhibition of these significant cultural artefacts, many of them removed from the country since the Biafran conflict. These monoliths are now in museums and private collections around the world.

Digital technology also creates the possibility of going beyond the original object in its current state. Using a variety of techniques, it is possible to conduct digital restoration of an object without intrusive interventions to the object itself. In the case of Canova's horse, broken up in 1969 during building work to the museum in which it was housed, digital reconstructive methods allow the broken fragments to be modelled as a coherent whole, then cast in bronze. But unlike conventional restoration methods, digital restoration does not conceal the trauma which forms a vital part of the history of the original horse, instead allowing the co-existence of alternative versions of a single object.

In some instances, Factum has gone even further, using a combination of digital and physical materialisation as the base materials for creativity and for the transformation of objective reality, exploring the history of objects in ways which enhance and problematise our understanding of the originals. Raphael's *Lo Spasimo*, an oil painting on wood, removed from the boards by 19th century restorers in France and reassembled as a painting on canvas. Factum's re-creation of it explores what the image might have looked like on a hard surface; the result is not a facsimile of the original, and not a substitute, but a new object in its own right, which in some ways may offer a more authentic experience of Raphael's painting than the "original", now in the Museo Nacional del Prado.

Finally those who do the recordings are as important as what is recorded. The two are in fact intimately connected. If the tools for recording cultural heritage stay in the hands of European and American museums and universities, existing structures of cultural and visual imperialism will only be perpetuated. Factum Foundation is immensely proud to announce that as of February 2019, our long-running project in Luxor, the Theban Necropolis Preservation Initiative, is now in the hands of an entirely Egyptian team. Another successful training and collaboration initiative is ongoing in Dagestan. In the years ahead, and particularly in the context of current lively debate around the repatriation of objects to previously colonised parts of the world, such dialogue and exchange of knowledge will be vital to all of us, providing new opportunities for both colonising and colonised countries of the past.

Objects are some of the most articulate ambassadors of their time and place. The most important task of Factum Foundation is to amplify their voices.
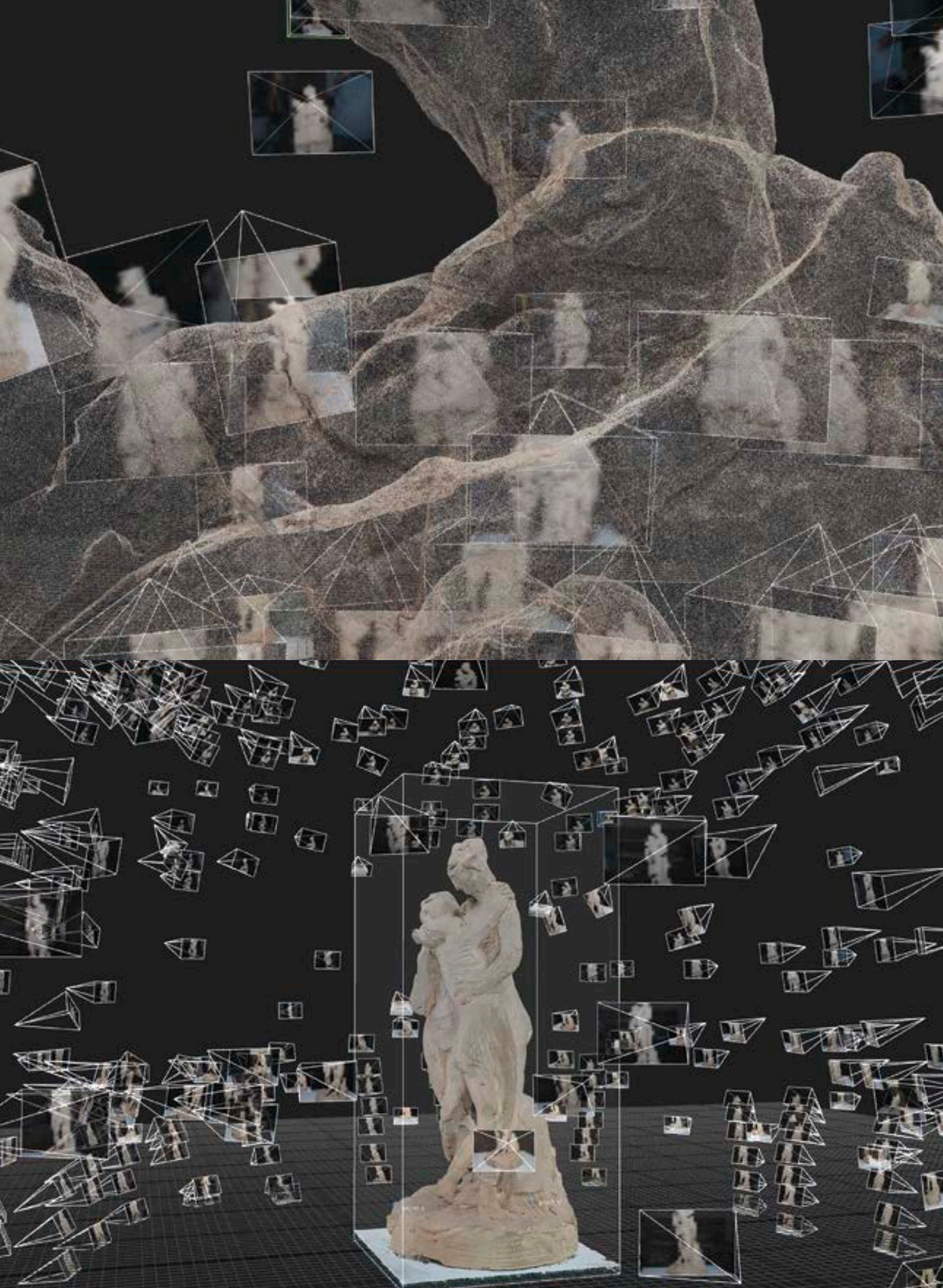
TECHNOLOGY

"Bringing together these strands – technical, human, aesthetic – combined with fanatical attention to detail has secured Factum's reputation."

Matthew Sturgis
Patek Philippe - October 2017

TECHNOLOGY

At the core of most of Factum Foundation's technologies lie the principles of mapping. Just as cartographers measure the distance between points on the surface of the world, LiDAR and photogrammetry calculate the distance between points on the surface of an object or a building and reconstitute the solid mass of the thing itself as an ephemeral cloud of points. But where cartography takes a landscape and reduces it to the size of a piece of paper, Factum takes the piece of paper and uses mapping technologies to chart the 'landscape' of its surface, revealing crevices and complexities invisible to the naked eye.

One of Factum's greatest strengths is that we treat technology as an art as well as a science. We see digital and traditional technologies as part of a bigger picture, meaningless when detached from the social, cultural, and artistic uses to which we put them. From processing data to making facsimiles, we conduct as many processes as possible under one roof, allowing us constantly to re-evaluate the connections between different technologies and different parts of the fabrication process. We are always innovating, designing new hardware, new software, and new techniques to meet the needs of specific projects. The Lucida 3D Scanner, designed for Factum Arte by Manuel Franquelo in 2007, has completely transformed the scanning of paintings and relief surfaces, while the formal methodology which we have developed for photogrammetry allows us to create 3D models which are accurate to 100μm. We are highly flexible in our use of technology, and experts in combining datasets: we often use two or more methods to record objects, and are able to merge the data in such a way as to combine the advantages of each. Our use of technologies is also a two-way conversation. On the one hand, reproduction and recording technologies are defined by the uses to which we put them, but on the other, the affordances and limitations of these technologies inspire us to acts of engagement with the material world which would never have occurred without them.

As well as merging different datasets, Factum is continually exploring ways of integrating new and digital technologies with traditional arts: gilding a 3D printed frame, for example, or using traditional restoration techniques and materials to finish the surface of Seti's sarcophagus. Although our facsimiles prioritise the visual, we also seek to explore the physical materiality of the original objects and the relationship between historic and modern production techniques. Just as the software visualises the surface of an object as a point cloud, so Canova's pantographs in the late 18th and the Cheverton machine in the early 19th century organised the reproduction of statues around a series of fixed points. We should not feel that we are regressing when we explore old technologies such as these, and in projects like John Baptist Jackson's Woodblocks or Raphael's *Lo Spasimo*, the confrontation engineered between old and new allows profound reflection on how different materials can be manipulated to bring about similar results – as well as of the limits of such manipulation.

Factum Foundation does not copyright its technologies, and does not seek to monopolise a market for their construction and repair. Our scanners are made using parts which so far as possible are readily available on the market or which can be designed and output using CAD technology and 3D printer, lathe or routing machine. It is of vital importance to us that they are fit for long-term purpose in contexts such as the Valley of the Kings in Egypt or rural Dagestan. A manual laying out our methodology for photogrammetry will be published in the near future, and will be downloadable for free from our website. But while we are able to share our own technologies and skills, the challenge remains to find ways for colleagues in places with fewer digital resources and less developed infrastructure to access software, which is often expensive and requires significant processing power and internet access. It will take inspired foresight on the part of companies who make the software to make these tools accessible.

Opposite page (clockwise from top): screenshots of a point-cloud model made using photogrammetry, showing the positions of the camera during shooting, stitching together photos in order to standardise colour across a painting; vectorising al-Idrisi's map; using the Lucida 3D Scanner to record the Tomb of Seti I; inking CNC-routed plates in preparation for traditional print-making; printing colour onto a low-relief surface during the making of a facsimile.
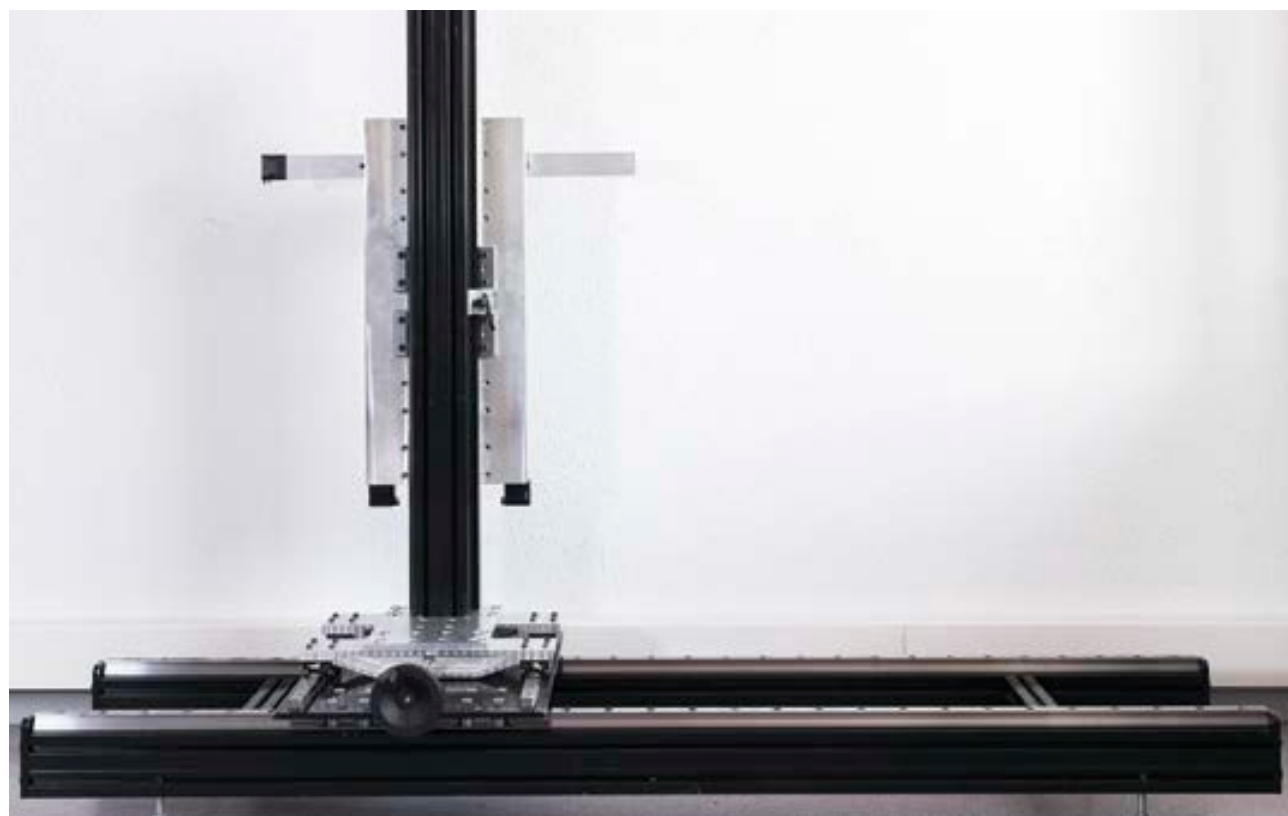
Lucida 3D Scanner

The Lucida 3D Scanner is a system developed at Factum for the recording of low relief surfaces such as paintings or bas-reliefs. It is a non-contact scanner which works at close range, capturing surface texture at high-resolution. It was designed and built by the artist and engineer Manuel Franquelo at Factum Arte with logistical support from Factum Foundation. The in-house development of the Lucida was a response to the growing needs of both Factum Foundation and Factum Arte for high-resolution surface data of paintings, as well as for ongoing recording projects in the tombs of the Valley of the Kings, Luxor.

Surface relief and texture represent a growing area of interest in heritage conservation. They are useful when studying a work of art, as well as for monitoring changes to the surface through time or as result of restoration processes. High-resolution relief data can also be used in conjunction with colour data from panoramic photography to 'rematerialise' an object as a facsimile of the original, or to visualise it in diverse forms – from projections to layered digital browsers that can be accessed online.

However, whereas most commercial 3D scanning technologies find dark colours and glossy surfaces problematic, the Lucida is unique in that it records the surface texture of low-relief objects without being affected by their colour or material properties – the texture of a gold object will be recorded to the same degree of accuracy as that of a marble relief.

The Lucida is movable and easy to operate, producing high-resolution data with close correspondence to the original surface. It has been used to record paintings and other objects at institutions such as the National Gallery (London), the Museo Nacional del Prado (Madrid), the Musée du Louvre (Paris), and the Tretyakov Gallery (Moscow). Projects realised with the Lucida 3D Scanner have been shown at the Fondazione Cini (Venice), Strawberry Hill House (London) and the Antikenmuseum Basel, amongst others.

The Lucida 3D Scanner recording the *azulejos* of Casa de Pilatos in Seville.

Opposite page: recording the surface of the *Black Square*, 1915; Lucida 3D Scanner.

Data from recordings of tiles in the Casa de Pilatos, Seville. From left to right: colour, 3D data, colour + 3D.

The first step of the photogrammetry process is to photograph an object from hundreds of different angles, capturing every detail of its surface contours and texture.

Screenshots from RealityCapture, the software used to convert the hundreds of photos taken during a photogrammetry recording session into 3D models. This image shows the model in the middle surrounded by triangles representing the camera positions used during shooting.
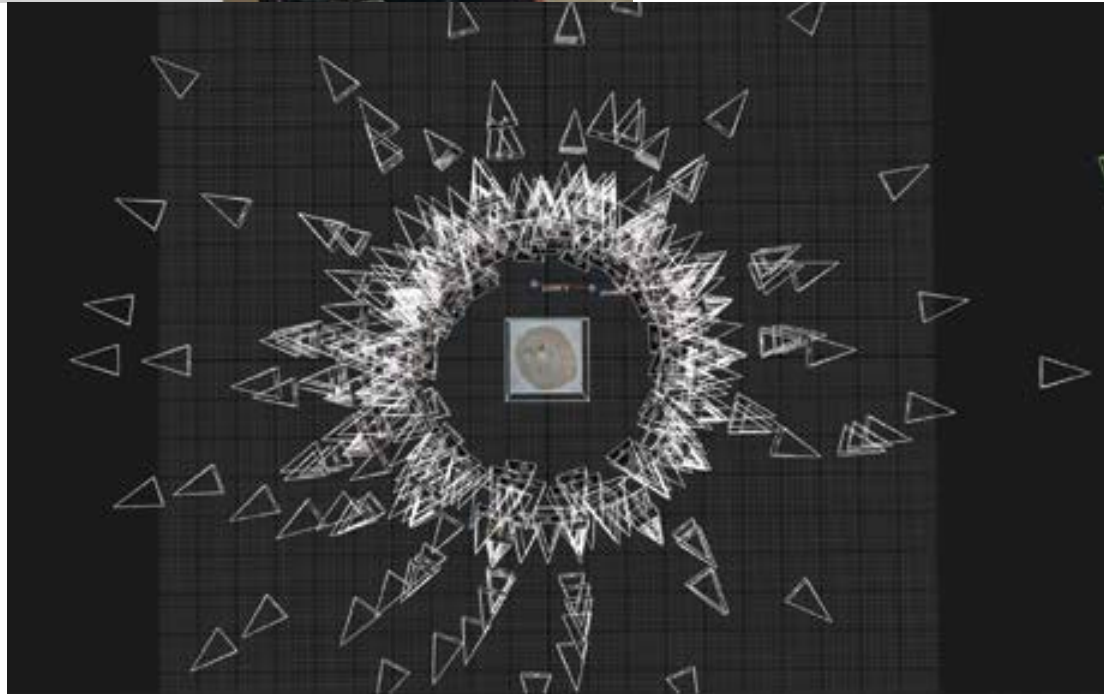
The apex of each square pyramid is the point from which the photo was taken. The base shows the image, which is different for every pyramid/shooting position.

Photogrammetry

Photogrammetry is a 3D recording technique that employs 2D images to extract information about the geometry of an object or surface. It involves taking hundreds of photographs of an object from many different angles and processing them using specialised software that works by identifying and 'extracting' thousands of common features to create a 'point cloud' – a dataset made up of millions of points located in 3D space. During post-processing the points are triangulated (connected to one another by lines) and conjoined with flat planes to produce a 3D model – a 'geometric mesh' composed of vertices, lines and flat planes. The model can be output digitally for study, or in physical formats via 3D printing or CNC machining.

Photogrammetry is fundamentally democratic: it can be done by anyone with a phone camera and access to free photogrammetry software. However, in order to produce the kind of high-resolution 3D models that accurately capture the geometry and surface detail of an object - under ideal conditions with resolutions of up to 100 microns - a high level of skill and professional hardware and software are required for both data recording and data processing.

Factum Foundation currently employs close-range photogrammetry – sometimes combined with structured-light or LiDAR data – to produce geometrically precise, but also highly detailed, 3D models of artworks. The technique has a number of advantages, including the possibility of recording colour information at the same time as 3D data. Photogrammetry is also inherently portable – in most cases the equipment (camera, tripod, flashes) can fit into a small camera bag, making it a particularly useful tool for recording at remote sites.

Photographs and a render of a terracotta maquette of the *Three Graces* by Antonio Canova. The camera moves round the object, capturing it from multiple angles.

Hundreds of photographs are needed to construct a high-resolution 3D model.

The blue lines between pyramids show where the software has identified shared points between one photo and another.

The green and orange lines between these four photos show the shared points which the software recognises between the images. In this case there are hundreds of points of contact, allowing for rematerialisation at high resolution.
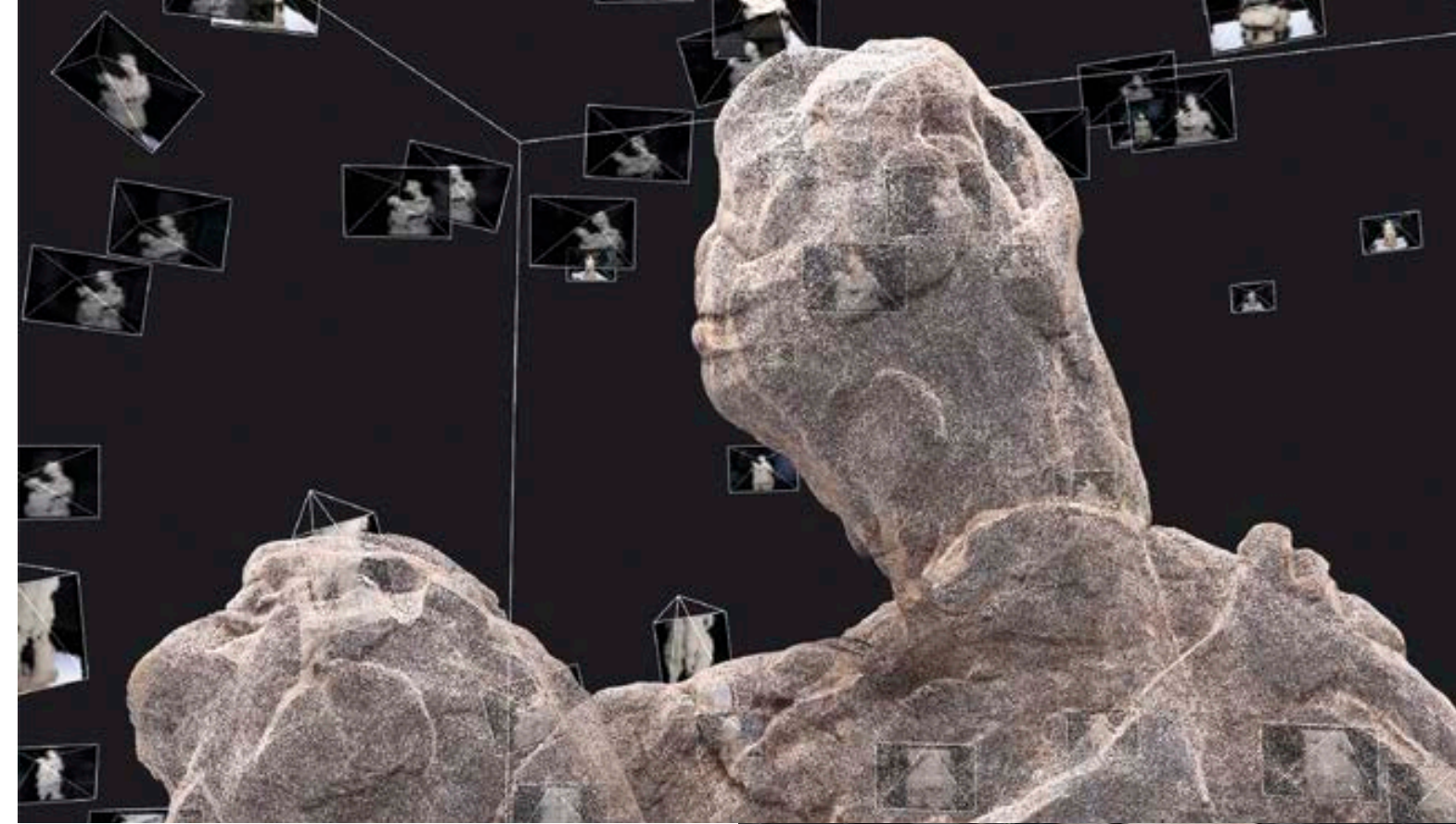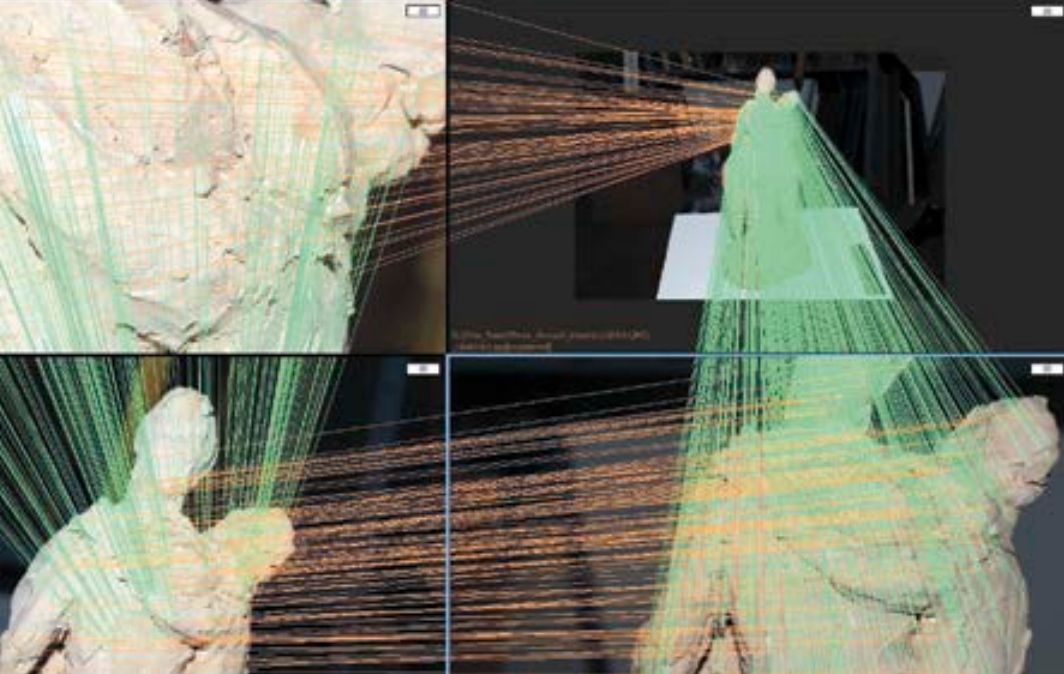
A zoomed-in image shows that the model is in fact a point-cloud, made up of millions of separate points.

The recording is at a high enough resolution that even the finest marks made by the hand of the sculptor are reproduced.

To construct a printable model, each point is joined to the nearest two points to construct a triangle, and the space between them is filled to create an opaque plane. When zoomed in, the surface of a model is seen to be made up of millions of triangles.
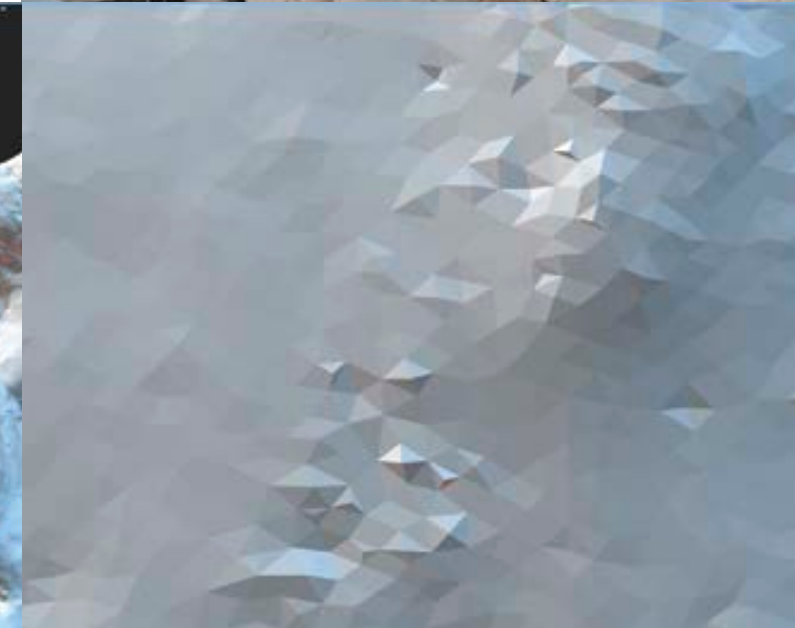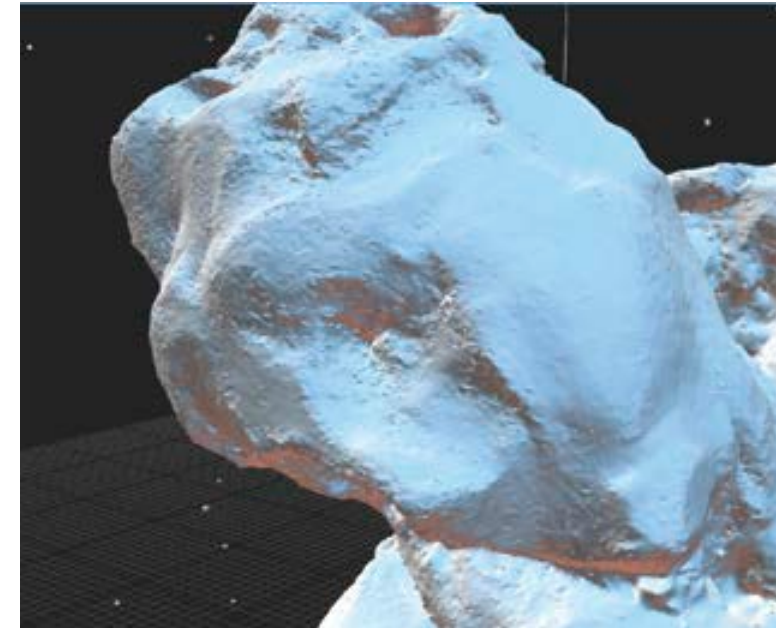
Structured Light Scanning

Structured or 'white light' scanners record 3D data, including information about surface texture. They work by analysing the way projected light behaves on the surface of an object. Structured light scanners are widely used in conservation because both their recording and processing methods are user-friendly and produce accurate results.

Factum Foundation uses, amongst others, the Breuckmann SmartScan 3D to record detailed high-resolution 3D data. The Breuckmann projects patterns of light onto an object and a camera records the deformation created as it moves across the three-dimensional surface. With a combination of digital image analysis and triangulation, the integrated scanner software uses the images taken by the camera to extract the 3D (xyz) coordinates of the object's surface. The software generates a 'point cloud' by plotting the xyz coordinates in 3D space and joins them together to output a 'geometric mesh' – a 3D model made of vertices, edges and flat planes which describes the shape and texture of an object.

Close-range photogrammetry is currently overtaking structured light scanning as the preferred technology for recording high-resolution 3D data. It is proving cheaper and faster than many commercial scanning technologies whilst producing data of similar, or even better, quality. Nevertheless, structured light scanners still have a number of advantages over photogrammetry, including reduced post-processing time and lower complexity. Structured light scanning can sometimes produce data with a better signal to noise ratio than photogrammetry and thus can be used to complement photogrammetry. It is possible to merge the two datasets in order to combine the advantages of each; for example, structured light data can be substituted into a final model in areas where complex geometries make it particularly difficult to extract good photogrammetry data.

Recording Canova's statue of a horse using a Breuckmann structured light scanner.

LiDAR

LiDAR (Light Detecting And Ranging) systems are most commonly used for surveying and long-range scanning purposes. They work by sending out a pulsed laser light and measuring the time it takes the laser to return to a sensor. They then use this measurement to calculate the distance the light has travelled as an xyz coordinate, and plot this information in 3D space. When many points have been measured the result is a point cloud which maps the object, interior or building. A scanning session using LiDAR will be composed of 360° scans taken from multiple positions. The scans are unified by placing control points – points chosen manually by a user who identifies common features in scans taken from different positions. The unified point cloud data can be turned into a 3D model or 'geometric mesh' through post-processing software that connects the data points to each other with a series of edges and planes.

LiDAR is used in cultural heritage documentation to produce metrologically accurate 3D recordings of large spaces or objects. However, the data does not provide detailed information about the texture of a surface. Instead, LiDAR is employed as a surveying technique that complements recording methods such as photogrammetry or panoramic photography. The LiDAR data acts as a digital 'canvas' onto which higher resolution 3D surface scans can be placed. When used together with panoramic photography, the 3D data from LiDAR is used to rectify the geometric distortion present in the high-resolution photographic images.

LiDAR data can be manipulated and output in a variety of ways. Factum Foundation, for example, used a FARO recording of the Tomb of Seti I to create a digital, and reduced-scale physical, walkthrough of the whole tomb.

LiDAR scan showing the fresco scheme on the vaulted roof of the lower burial chamber of the Tomb of Seti I.

Clockwise from top left:
Photographing a painting using a telephoto lens. Hundreds of photos are taken, with a significant overlap between each.

Photographing with Pantone swatches to allow accurate colour matching in post-processing.

The composite panorama, in which each section represents a single photo. The distortion in the composite image is due to the fact that the camera stays in a single position throughout shooting, with only the angle of view changing. This can be corrected later in the process.

Close-up on the composite panorama. The uneven edges of each image block represent decisions made by a digital processing expert to use parts of one photo instead of those which adjoin and overlap it; the aim is to have every part of the canvas in as high focus as possible.

Panoramic Photography

To capture accurate and high-resolution colour for a flat or gently curved surface such as a painting or a mural, Factum Foundation employs a specialist version of the technique known as panoramic photography. Many people are familiar with the basic concept from landscape photography, where overlapping photos of a view are stitched together to create sweeping panoramic pictures. Factum uses panoramic photography in such a way as to produce images of cultural heritage objects with resolutions of up to 900 dpi at 1:1 that also contain accurate colour information. This kind of image is the most useful for studying the detail of a painted surface, particularly if the colour is merged with 3D data. The data can also be printed onto different media as part of the process of creating a facsimile – if the print is directly compared to the original painting, the colour will look very similar or even identical.

Overlapping, high-resolution images of the surface of the artwork are taken from a single point using a 300mm or 600mm lens. In post-processing, the photographs are stitched together with the PTGui software to create a single large image file. PTGui is used to correct geometric distortions arising from the fact that the camera is usually positioned in front of the middle of the painting, whose corners are therefore further away from the lens than the centre. Such distortion can be corrected by carefully mapping the colour onto a scaled 3D model, recorded using another technology such as the Lucida, to create a layered archive of information.

During a recording, the photographer follows a set procedure to guarantee the accuracy of the colour data, and ensure it is 'true to life'. Flashes are used to evenly illuminate the surface of an artwork, although their configuration differs depending on the specific characteristics of the surface being photographed. It is normally recorded from 3 different positions and the results merged to remove reflections. The photographer also takes a number of photos of the artwork which incorporate an X-Rite ColorChecker Passport, which contains colour swatches with known RGB values. During post-processing, these photos are used to correct and unify the colour across the individual, overlapping photographs taken in the recording. The colour checker images are also used to correct any differences in the way the light falls across the surface.

Although digital colour management produces files that closely correspond to the original colour of a painting, Factum Foundation also implements 'physical' colour correction methods as an extra form of quality control. These usually involve matching Pantone colour swatches to different colours on the painting. Where possible, printed samples of the facsimile are compared to the original during the process of re-materialising the work. Both methods usually result in a slight adjustment of the digital file prior to a final printing.

Partially corrected panoramas for Murillo's *Miracle of the Fish and Bread*. The complete painting measures 2.36 x 5.75 m.

Photometric Stereo Recording

Since 2017, Factum Foundation has been developing a new surface scanning system to record the fine surface texture of flat or semi-flat surfaces such as paintings or murals. The objective is to produce a fast and portable system capable of recording high resolution 3D surface texture for both digital visualization and material output.

The scanning system is based on two different techniques: photometric stereo and Reflectance Transmission Imaging (RTI). Both employ computational methods to extract very detailed information about the surface of an object using 2D images taken with multiple light sources. Factum's recording system will integrate data from other 3D recording techniques such as photogrammetry.

The scanner is currently in the developmental phase and the project is being led by Jorge Cano and Enrique Esteban from the Engineering Department at Factum Foundation. Adam Weigert and Abhu Dhanda from Carleton University have been spending time at Factum on the development of the photometric stereo system.

Small Object Scanner

The Small Object Scanner is a photogrammetry rig designed to 3D scan objects that are up to 30 cm tall. The concept for the scanner evolved following Factum's work to record the many small fragments from the Tomb of Seti I (Luxor) that can be found dispersed in various museums around the world – a time-consuming and laborious process. The end result of this research and development project will be a mechanised photogrammetry rig capable of efficiently recording large numbers of small objects; only a minimal knowledge of photogrammetry will be required to operate the scanner.

The idea behind the scanner is relatively simple: an object is placed on a mechanised rotary table, and as the table rotates the object is photographed from different angles and positions with a camera that can move towards and away from it on two axes. A recording session can be programmed according to the camera lens used and the overlap required between images. The scanner completes the recording without any further input from the operator and the images are later processed using photogrammetry software to obtain a 3D model. The script used to run the scanner has been designed to work with Sony A7 cameras and three focal distances (35, 55 and 90 mm).

Preliminary tests have revealed the scanner to be more effective than manually recording a small object with photogrammetry.

The scanner is being developed by Matt Marshall, Quinner Baird and Otto Lowe at Factum Foundation.

Layered Archives (a digital passport)

Anyone with internet access can view the high-resolution data that Factum Foundation captures of paintings and other 2.5D objects via the layered archives we make available online. Our digital browsers open the door to a different way of looking at works of art – researchers and the general public alike can study a painting in minute detail outside the gallery walls.

As part of the process of producing a facsimile of a painting, colour data is mapped onto (colourless) 3D surface texture to produce a digital image that tells us something about the relationship between the two layers of information. These datasets make up what we term a layered archive – an archive of information about an object comprised of datasets that are understood in relation to each other rather than in isolation. Factum Foundation's simplest archives have three layers: colour, 3D, and 3D merged with colour. The datasets can be rematerialised through CNC-milling and 3D or elevated printing, but they also function as an end in themselves.

A layered archive can function as a 'digital passport' – an accurate and complete record of a painting's condition at the time of data capture. Paintings have complex histories which leave their mark on and below the surface: the artist may have painted over an existing image, or the painting may have undergone a particularly invasive restoration. By carefully mapping ultraviolet, X-ray or infrared data – which reveal what is hidden beneath the surface of a painting – onto surface texture and colour, it becomes possible to untangle the complex relationship between the surface and what lies beneath it.

From top to bottom: colour, 3D, and 3D merged with colour data for Powhattan's Mantle.

Printing colour

Factum's flatbed printer – built in-house – is unique in that it enables the operator to very precisely over-print the same surface. A printed image can thus be built up in layers of ink to up to 2mm, giving our system a greater tonal range than many commercially available printers.

To begin the process, an image file is split into several layers in Photoshop. The layers are created in such a way as to extract as much information as possible about the different tones that are present in the image. The first printed layer contains information about the darkest tones in the image. Each subsequent layer builds on previous layers – the darkest areas in an image are over-printed the greatest number of times to produce a large range of tones. This is particularly significant, for example, if printing an image by an artist such as Goya, for whom dark colours are of special importance.

The other benefit of being able to over-print a surface is that it becomes possible to very accurately print on relief surfaces. We refer to this as the process of 'registering' the printer to the surface being printed.

A depth map representing the 3D surface is printed onto an acetate sheet and the printer is precisely 'registered' to match this information. The acetate is then replaced by the relief surface in preparation for printing over it in colour. When producing a facsimile of a painting, the fine surface relief will already have been reproduced in gesso on canvas and the process of printing over this surface in colour using the flat-bed printer is the final step before varnishing.

Factum's printing process, perfected over years of producing exact facsimiles of paintings and other objects, also involves carrying out printing tests to verify colour accuracy before printing a final version. Although images are digitally corrected for screen viewing, when printing, physical colour matching must also take place. This is because the colour profile changes depending on the material being printed on – even the final varnish can completely alter the tonalities, and colour checks must be constantly carried out as a vital component of the printing process.

Factum's first flatbed printer was built by Dwight Perry in 2013; the printer has been updated several times since then.

3D printing

The term '3D printing' refers to a series of computer-controlled additive manufacturing techniques, all of which involve material being joined together to create a three-dimensional object. Various types of models can be 3D printed, including 3D models obtained via 3D scanning. One of the main advantages of 3D printing over CNC-milling is that it enables the rematerialisation of objects with complex geometries (in particular, undercuts), as well as very fine surface relief. Factum Foundation employs a number of 3D printing techniques as part of the process of creating of a facsimile.

We use stereolithography (commonly referred to as SLA or 'resin printing') to print complex three-dimensional objects such as the Jamnitzer ("Cellini") Bell. In SLA printing, a 3D object is built up in layers through the action of a Ultraviolet (UV) laser, which converts the liquid photopolymer in the printer vat into a solid. SLA printing, like most other 3D printing techniques, requires the use of printing supports – scaffolding structures which are printed alongside the object to prevent deformation during the process and which have to be manually removed in order to reveal the finished object.

Factum also uses Océ (a Canon Company) elevated printing to produce 3D prints of the fine surface texture of paintings and other 2.5D objects. Océ elevated printers are similar to the flat-bed printers used to print images, although in this case, layer upon layer of ink is deposited onto a surface to produce high-resolution three-dimensional surfaces.

All the 3D prints we produce undergo a process of physical mediation to recreate the material qualities of the object being copied – the 3D print of the Jamnitzer Bell, for example, was painted in a ceramic layer prior to gilding.
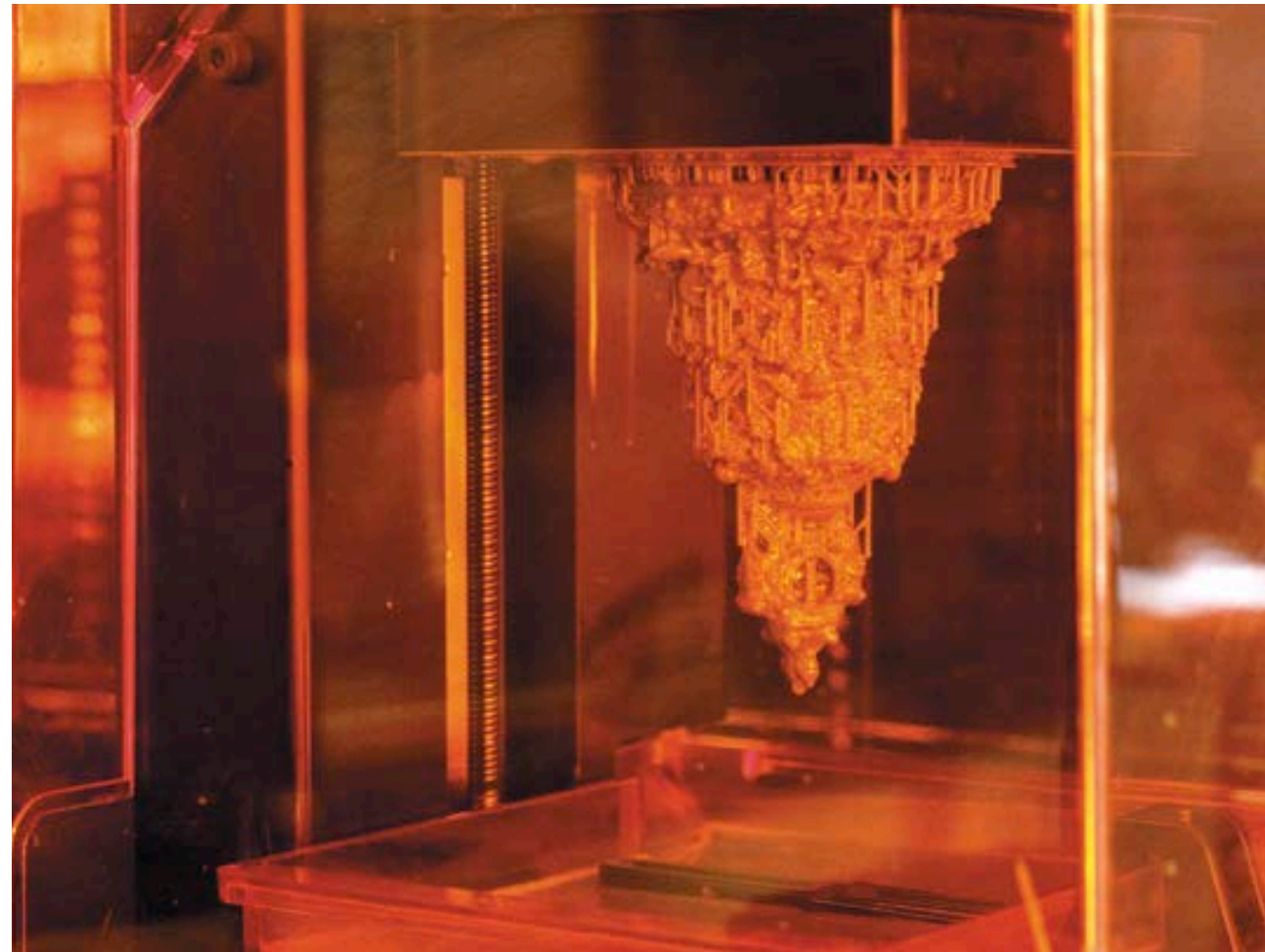
CNC-milling

Milling is the process of removing material from a workpiece using drills. Computer Numerical Controlled (CNC) milling, commonly known as 'routing', is a digitally automated form of this technology. CNC-milling, a subtractive manufacturing technique, can be used to physically output the digital 3D models produced by the 3D scanning technologies discussed in the previous section.

An advantage of CNC-milling is that it can be used to output high-relief surfaces at a large scale; where Océ elevated printing is designed for low relief surfaces such as paintings and where 3D printing is limited by the size of the printers used (which at this stage in the development of the technology are usually still relatively small), milling can be used for large and complex surfaces, for example, the cave walls at the petroglyph site of Kamukuwaká in the Xingu Indigenous Territory.

Moreover, milling can often be performed directly onto the material which will be used in the final object.

3D prints are usually only a stage in a process in which the ultimate object uses a cast rather than the print itself, but CNC-milling can be used with a wide range of materials, from the high-density polystyrene and polyurethane of Kamukuwaká to the silver of the al-Idrisi map. Some of these surfaces will subsequently need hand-finishing, but others are complete as soon as they leave the drill head.

One problem of CNC-milling is that lines created by the mechanical drill bit, essentially a physical form of 'noise', are often visible in the final object. But Factum's engineers have developed ways of reworking surfaces in obsessive detail, programming the drill head to pass and re-pass over the same area multiple times in order to reproduce the subtle contours of different surface types. No one else works for so many hours on one surface, and the detailed surfaces which emerge reveal almost no visible traces of the means of their manufacture.

Mould of the Virgen de las Nieves; making a cast of the Cimera de Jaime I using epoxy resin.

Casting and sculpting

At the core of Factum Foundation's work is the constant dialogue which we generate between the digital and "traditional" arts - although the innovations introduced by Factum's sculptors, painters, and finishers means that in their hands, these "traditional" arts are transformed and revitalised to fit contemporary methodologies and materials.

Casting is a process which is used in the making of many of our facsimiles, from the low-relief surfaces of paintings and the walls of Seti's tomb to sculptures in the round such as the Virgen de las Nieves. But while traditional plaster casts of artworks, much used in the 19th century, were taken directly from the originals - and often caused significant damage in the process - Factum's casts are taken from 3D prints of digital scans and can be made without any of our team ever touching the original object.

To make a cast, the 3D print or other surface to be reproduced is coated in liquid silicon. When this has dried, it can be pulled or cut to reveal a mould of the object. For works like the Virgen de las Nieves,

a gesso support is constructed around the silicon, allowing it to retain its shape during the following stage. Silicon's flexibility means that unlike for 19th century plaster moulds, where a single sculpture would have to be made in a large number of parts, it is not usually necessary to make moulds in more than two parts - for the Virgen, one was made for the front and one for the back.

The mould can then be used to create a cast. For the surfaces of paintings and the Seti reliefs, a layer of plaster gesso reinforced with a layer of acrylic gesso is used, while for sculptures an acrylic resin or an epoxy resin might be used. For the Cimera de Jaime I, an epoxy resin, known commercially as a wooden axon, was used owing to its unique characteristics, being incredibly suited for the painting process, carried out using traditional techniques.

Factum's artisans also employ the techniques of sculpture in order to make fine adjustments to cast objects, refining rough edges and ensuring that outlines are clear.

Opposite page: creating silicon moulds for the reliefs of the Tomb of Seti I facsimile; creating a silicon mould for the facsimile of the Virgen de las Nieves.

Painting and surface finishing

While our colour printer is able to reproduce colour to an exceptionally high degree of fidelity, it is often necessary to retouch objects, either along the joins of the printed "fibreskins" or because an object has such a complex relief that it cannot be printed out on a planar surface. In order to develop pigments and finishes which look like the original even when the base object is made of epoxy resin or acrylic gesso, Factum's painting and surfacing specialists conduct research into historic pigmentation techniques, which they then modify in relation to the new base material. For the Cimera de Jaime I, so-called 'skins' were created, which were adhered to the surface of the facimiles following careful alterations of the layers of colour to later be able to brown and abrade the surface.

Framing and gilding

The base structure of Factum Foundation's frames usually consists of a routed or 3D printed model derived from photogrammetry data. If 3D printing is used, the frame is printed in parts which are then glued together and filled with epoxy resin for stability. Factum's framing and gilding specialists have developed new techniques for finishing these surfaces, first coating them with a layer of acrylic gesso and a further layer of bole, a liquid ceramic coating, and then performing traditional water-based gilding. They have developed techniques for gilding materials as diverse as polyamide and aluminium. The 3D printed frame, usually made from polyamide or polyurethane, often requires hand-finishing before these coatings are applied. This is done using traditional tools and carving techniques, and with close reference to 1:1 photos of the original object. In the case of the frame pictured to the right, from a small Boucher painting of Madame de Pompadour, the original frame had been restored between the recording and the exhibition of the facsimile, and Factum's frame- makers had to decide how far to "restore" the facsimile frame - whether to fill in cracks and to what extent the gilding should be patinated and aged.

Working on the facsimile of the *Cimera de Jaime I.*

I. FACSIMILES

"Reproduction... is more than just a technical achievement - it is the window to lost works, to mysterious worlds of great beauty, and is a vital educational tool helping bring the stories of myriad cultures to a much wider audience."

Lucia van der Post, Spears, May/June 2018

The statue of Idrimi (c. 1600–1500 BCE) was excavated in the 1930s in what is now the Hatay region of Turkey. The inscription states that Idrimi, originally from Aleppo, travelled across the Middle East to Emar and Canaan before becoming ruler of Alalakh (in Hatay). A facsimile was made for the charity Making Light, forming part of an exhibition about migration and refugees from the conflict in Syria.

Statue of Idrimi

Location British Museum, London
Client Making Light
Date February-September 2017
Materials of original magnesite, glass
Main recording techniques white light, photogrammetry
Main output technologies Stereolithography (SLA 3D printing)
Materials of copy plaster
Funding Factum Foundation for Making Light

'Whoever changes or erases [this statue], may IM, the lord of heaven and earth, and the great gods drive out his progeny and seed from his land.' – Inscription from the statue of Idrimi

The project to create a facsimile of the statue of Idrimi is one with both technical and cultural significance: as well as marking a major breakthrough in Factum Foundation's use of a new technology, photogrammetry, it has allowed a fragile object of great historical and present significance to travel beyond its current home in the British Museum to new audiences and in new contexts.

The statue of Idrimi is over a metre tall and is made of magnesite with inlaid glass eyes. The statue itself is now too delicate to travel, but the cuneiform inscription which crosses its front tells us that in around 1500 BCE Idrimi himself journeyed all over the Middle East: from the ancient kingdom of Aleppo to Emar in what is now Iraq, then across to Canaan, probably in southern Lebanon, and finally, travelling by sea, to Alalakh in the Hatay region, modern Turkey. The inscription tells us that Idrimi then ruled Alalakh for thirty years. It ends with a curse, directed towards anyone who defaces the statue or changes its inscription. A connected text, inscribed across Idrimi's cheek, asks those who read about his achievements to bless him.

The statue was brought to the UK by the archaeologist Leonard Woolley in 1939, a year of political turmoil in the Hatay region. It is kept behind glass in the British Museum, making close examination difficult. But in a recent collaboration with the charity Making Light, Factum Foundation has created a high-quality 3D model and has rematerialised this data as a facsimile, allowing the image of Idrimi to travel once more.

Recording Idrimi at the British Museum using a white-light scanner.

45

Opposite page (clockwise from top left): recording Idrimi at the British Museum using a white-light scanner; patinating the surface of the facsimile; writings on the surface of the facsimile.

Model of Idrimi's left arm, extracted from thewhite-light scanned data.

The statue was recorded in its gallery at the British Museum, where it was removed from its case during the museum's opening hours so that the public could watch part of the process. Two different recording methods were used: a Breuckmann white light scanner, which produced an accurately scaled 3D model, and photogrammetry, which captured the fine detail and colour. In recording terms, the project marked a major breakthrough in Factum's use of technology: for the first time, it was possible to produce higher-quality surface relief data - for most of the statue at least - from photogrammetry than from the white light scanner.

To make the facsimile, the digital model was 3D printed in resin by Hobs Studio in London, and a mould taken from this print was used to cast the statue in a hard plaster. The data for the initial 3D print was taken from the photogrammetry recording, but the information for the left arm was noisy, probably as a result of photographic glare caused by the flash units. The team at Factum therefore extracted the Breuckmann data for this section in order to 3D print a new arm, which was again cast in resin and used in place of the first arm.

The surface of the cast was then worked on by artists at Factum, who applied a patina made from natural pigments and wax to mimic the complexity of the eroded magnesite. The ability to convincingly replicate the surface of a statue is one of the things that sets Factum Foundation's facsimiles apart from other high-quality 3D prints or casts; the technologies used to create these effects are often ones which involve highly traditional craft skills.

The facsimile of Idrimi was unveiled by the Archbishop of Canterbury, Justin Welby, at Lambeth Palace in London, and now forms part of a travelling exhibition, organised by Making Light, which aims to challenge negative stereotypes of present-day Syrian refugees. Making Light was set up by Jessica Pocock, the sister of the British journalist John Cantlie, who was kidnapped and killed by ISIS in 2012.

With thanks to Making Light and to the staff at the British Museum, in particular Jessica Pocock and Jamie Fraser.

Facsimile of the *Portrait of Madame de Pompadour* by François Boucher, recorded at the Alte Pinakothek in Munich.

Display panel with the different layers of data: colour from panoramic photography, 3D data from the Lucida scan and both data merged.

Boucher's paintings of Madame de Pompadour

Location Alte Pinakothek, Munich; Waddesdon Manor, Aylesbury, UK
Client Waddesdon Manor
Date 2018-present
Materials of original oil paint, canvas
Main recording techniques Lucida 3D Scanner, panoramic photography, photogrammetry
Main output technologies Océ elevated printing, gesso cast, Factum relief printer, stereolithographic printing, gilding
Materials of copy pigment, gesso vacuum-glued onto canvas, gilded wood material of frame
Funding Waddesdon Manor

An exhibition organised by Factum Foundation in collaboration with Waddesdon Manor, 'Madame Pompadour in the Frame' (May 2019-Spring 2020), is allowing audiences to appreciate a major artwork in the context of the collection to which it once belonged, and also to examine a facsimile and an original side by side.

Madame de Pompadour, the erudite and powerful mistress of Louis XV, continues to fascinate to this day. One of the most famous images of her is that painted by François Boucher, a leading figure of the French rococo style, in 1756, at the height of her influence at court. The painting is currently on display at the Alte Pinakothek in Munich, where it is on permanent loan from its owner, the HypoVereinsbank, Member of Unicredit. But in the late 19th century it was in the collection of Baron Ferdinand de Rothschild, a member of the well-known financial dynasty and a collector with a particular passion for the arts of the Ancien Regime.

In 2018, Waddesdon Manor commissioned Factum Foundation to produce a facsimile of the painting, allowing Madame de Pompadour to take her place once more within the Rothschild family's historic collections, and even within the frame which the painting once occupied, which never left England. In addition, Factum Foundation made a facsimile of a smaller oil sketch owned by a Rothschild trust, also showing Madame de Pompadour and also by Boucher; in this case the frame was recorded and rematerialised as well.

The large canvas (201 x 157cm) was scanned in the galleries of the Alte Pinakothek in Munich. The Lucida

3D Scanner was used to capture the very fine surface relief typical of Boucher's painting technique, a process that took over twenty hours and required that the scanner be built to its maximum 2m height. A second recording was made, using panoramic photography, to record the colour. After processing, the colour was mapped onto the 3D model to produce a layered archive, and the colour data was printed out several times so that the digital recording could be compared to physical colour samples taken next to the painting.

In order to make the facsimile, the surface relief of the painting was first printed in 3D using Océ elevated printing. Silicon was poured over the print to make a mould, and this was used to make a cast in acrylic-reinforced gesso, which preserves the surface relief of the original painting. The cast was vacuum-glued onto a canvas. The colour data was then printed onto the textured surface using Factum's unique flatbed printer, which enables pigment to be built up in layers in imitation of the depth of colour achieved by paint. Finally the canvas was varnished to match the finish of the original painting.

The smaller painting and its frame were recorded in Buckinghamshire, the painting using the Lucida and panoramic photography, and the frame using photogrammetry. The frame was 3D printed in parts using stereolithographic printing, strengthened with resin, and finished and gilded by hand.

The arrival of the facsimiles at Waddesdon is accompanied by an exhibition, 'Madame de Pompadour in the Frame'. Alongside the facsimiles and the original small oil sketch, cabinets of samples and offcuts explore the process of making facsimiles, inviting viewers to reflect on their uses and on the philosophical implications of a copy which is indistinguishable from its original.

Charlotte Skene Catling's exhibition design sets this conversation between objects in an atmosphere of both intimacy and grandeur: panels printed with designs by Boucher pull the viewer through successive frames into an illusionistic rococo fantasy, while an enfilade of bevelled mirrors dissolves the boundaries of the space still further, creating an infinity of reflections of original and facsimile alike. It was in the Hall of Mirrors at Versailles that Louis XV first met Jeanne-Antoinette Poisson on the night of February 23rd 1745, at a masked Yew Tree Ball. The king was disguised as a tree.

Madame de Pompadour was known for encouraging innovative techniques and technologies in her patronage of the arts, and was also an image-maker herself. In the bottom-left-hand corner of the Munich painting, the pile of discarded papers includes the just-visible copy of an etching of a putto, recognisable as one of her own. As if caught in a hall of mirrors, this is itself a copy of a copy: it reproduces a drawing by Boucher, itself a reworking of a carnelian carved by Jacques Guay. While copying is now often thought of with negative overtones, in the 18th century such highly skilled translations between different media – gem to drawing, drawing to engraving – were highly regarded. Factum Foundation's facsimile translates Madame de Pompadour's putto into yet another medium, using printed pigment on acrylic gesso rather than the etching press of the mid 18th century.

With thanks to Jacob Rothschild, Pippa Shirley, Cristina Alfonsín, and Mia Jackson at Waddesdon, and to Elisabeth Hipp and Jan Schmidt at the Alte Pinakothek.

Making the facsimile of the frame of the oil sketch of *Madame de Pompadour*.

Opposite page: Top: Entering the exhibition, on the left are the small portrait and its facsimile, ahead is the facsimile of the Munich portrait. Bottom: Detail of the oil sketch of *Madame de Pompadour*.

Twelve of the facsimile panels in a packing case, waiting to be transported to Bologna.

Exhibition of the Polittico Griffoni at Palazzo Fava

Location Basilica di San Petronio; Palazzo Fava, Bologna. Scanning took place at the National Gallery, London; Pinacoteca di Brera, Milan; Pinacoteca Vaticana, Vatican City; Collezione Vittorio Cini, Venice; Museum Boijmans Van Beuningen, Rotterdam; Pinacoteca Nazionale, Ferrara; Museo di Villa Cagnola, Gazzada; National Gallery of Art, Washington DC; Musèe du Louvre, Paris
Client Basilica of San Petronio; Palazzo Fava
Date 2012-present
Materials of original tempera, poplar panels
Main recording techniques Lucida 3D Scanner, composite photography
Main output technologies Océ elevated printing, gesso cast, Factum relief printer
Materials of copy gesso, pigment
Funding Basilica of San Petronio / Factum Foundation

Factum Foundation has worked at the Basilica di San Petronio, the main church of Bologna, since 2012, and has undertaken various projects there including the recording of the statuary on the unfinished façade. None, however, has been more logistically complex than bringing together as a facsimile the scattered panels of the altarpiece known as the Polittico Griffoni, the Griffoni polyptych.

The Polittico Griffoni was painted between 1471 and 1472 by Francesco del Cossa and Ercole de' Roberti for the Griffoni chapel in the Basilica, but it was dismembered and sold in 1725, when the chapel was re-dedicated to the Aldrovandi family. Sixteen panels survive, but they are dispersed around the world in nine different museums. The aim of Factum Foundation's project was to record and rematerialise each of these panels and to 'return' the altarpiece, through the surrogate of a facsimile, to the recently restored Chapel of St Vincent Ferrer.

Travelling to each museum over a three-year period, Factum employed the Lucida 3D Scanner to record the fine surface relief of the panels, and panoramic photography to obtain high-resolution colour. The relief data was printed using Océ elevated printing, and

St George, now in the collection of the Fondazione Giorgio Cini, Venice. Photographs and renders of the front and back.
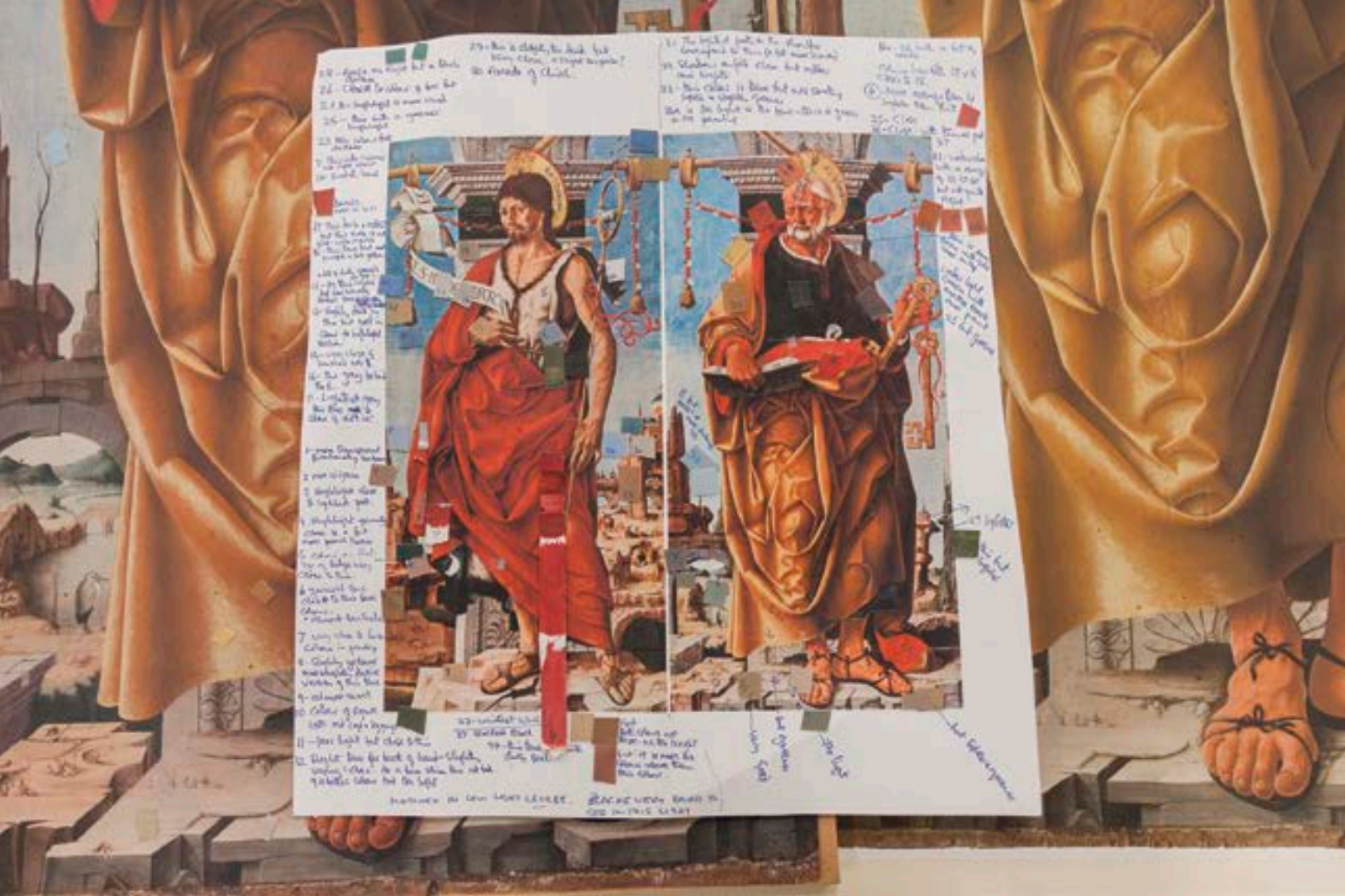
silicon moulds of these resin prints were cast in gesso. The resulting casts were printed with the colour data using Factum's relief-sensitive flatbed colour printer.

In October 2017, all sixteen of the facsimile panels were returned to San Petronio in time for the visit of Pope Francis, where they were displayed for a single day. As it is not known precisely how the original panels were arranged, as some panels are now missing, and as the frame no longer exists, the facsimile will never be able to perfectly replicate the original. Instead, it offers a new staging of the paintings, and in some ways a new artwork. But the assembly of the panels has also made it possible, for the first time in almost 300 years, for the paintings to be appreciated in the context for which they were originally painted.

From late 2019 to early 2020, the facsimile will be displayed at the Palazzo Fava in Bologna, alongside as many of the original panels as possible; it is hoped that we will be able to show all 16. The exhibition will contextualise both originals and facsimiles within larger narratives of high-resolution reproduction and display, and will demonstrate the potential of facsimiles as one possible tool in the debates surrounding cultural repatriation.

With thanks to the Basilica di San Petronio, Cavina Terra Architetti, Genus Bononiae - Musei nella Città, and Fondazione Cassa di Risparmio in Bologna.
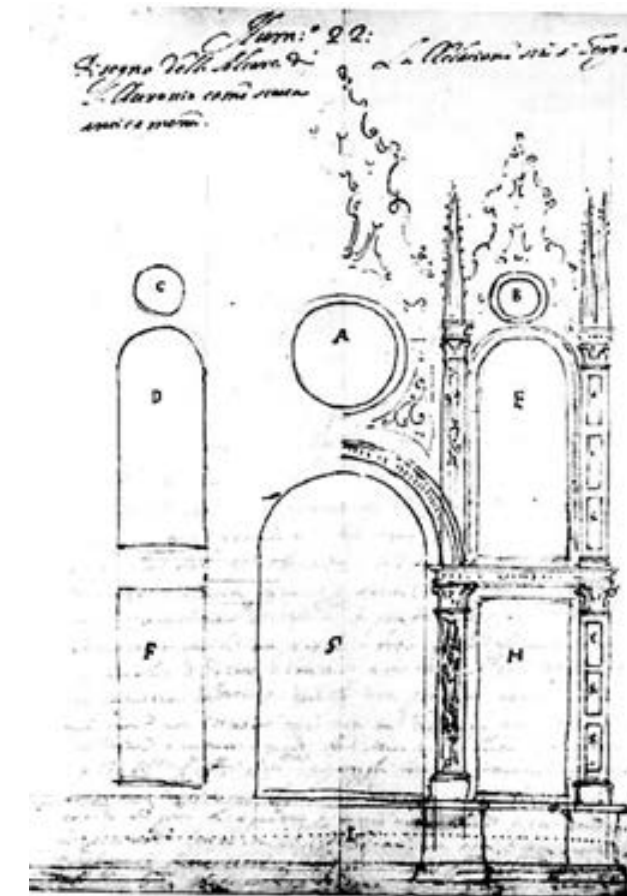
Drawing by Stephen Orlandi made in 1725, before the dismemberment of the polyptypch. Stefano Orlandi Bologna, Archivio di Stato.

Reconstructing the altarpiece in San Petronio in Bologna in October 2017.

Opposite page: colour checking for the panel showing St John and St Peter; scanning St Peter using the Lucida 3D Scanner in the Pinacoteca di Brera, Milan.

Lamassu from the palace of Ashurnasirpal II

Location British Museum
Client British Museum, London; Rijksmuseum, Amsterdam;
Spanish Ministry of Defence; Spanish Embassy to Iraq
Date 2005-present
Materials of original gypsum
Main recording techniques white-light scanning
Main output technologies CNC-milling, 3D printing
Materials of copy scagliola coated with wax
Project Funding Factum Foundation with support from the Spanish
Ministry of Defense / Rijksmuseum van Oudheden

Factum Foundation is delighted to announce that in autumn 2019, two facsimiles of lamassu from the palace of Ashurnasirpal II at Nimrud, whose originals are currently in the British Museum, were sent to the University of Mosul, as a donation from Factum Foundation, the British Museum and the Rijksmuseum Van Oudheden. The Ministry of Defence and the Spanish Embassy to Iraq have generously supported the transport of the statues to Mosul.

Factum's project to create facsimiles of the two lamassu and to send them to Mosul is one which has so far extended over 15 years. In 2004, Factum Arte used white-light scanners to record these 3.5m-high winged guardians in the British Museum, as well as several other reliefs removed by Austen Henry Layard from the throne room of Ashurnasirpal in the 1840s and 50s and now in museums across Europe and North America. Efforts were also made to record the reliefs still in situ in Nimrud, 30km to the south of modern Mosul, but due to instability in the region in the wake of the invasion of Iraq, this ultimately proved not to be possible at the time. It was also impossible, due to a lack of funding, to rematerialise the lamassu as facsimiles at that time.

In May 2014, the British Museum gave Factum Foundation permission to create facsimiles of some of the relief panels from the throne room of Ashurnasirpal II and send them to Baghdad. The originals are in Mosul marble but Factum's facsimiles are made in scaliogla to imitate the gypsum of the originals. They were sent to Bagdhad by lorry. Their whereabouts is currently unknown and they have probably been destroyed.

In 2017, permission was given to make the facsimiles of the lamassu for the exhibition 'Nineveh' at the Rijksmuseum van Oudheden in Leiden. These monumental sculptures will now be sent to Mosul, where they will be displayed not in their original location at the palace gates of ancient Nimrud, which was the site of some of Islamic State's most violent attack on antiquities, but within the grounds of Mosul University.

As with the Polittico Griffoni, these lamassu can never be equal replacements for the originals; instead, they make a contribution to the ongoing careers of these still-relevant objects, and also to specific debates taking place right now about the role of digital archaeology in the Middle East. We believe that where facsimiles are to be made of objects which come from this region, it is vital that they be accurate and that they be offered within wider contexts of discussion and the sharing of skills. As such, it is our hope that alongside the project to return the lamassu, it will be possible to work with archaeologists at Mosul University and to share with them skills such as photogrammetry which will allow them to make their own recordings of Iraqi and Mesopotamian cultural heritage. This sharing of skills with Iraqi colleagues is intended as the inaugural project of the Factum Frontline initiative, discussed in the Training section of this book.

Opposite page: the facsimile of the lamassu, different steps from the making of a silicon mould from high-density polyurethane sections to the final facsimile in scagliola.

Top: creating a silicon cast of the hind legs of one of the lamassu. Bottom: installing the facsimile in the Rijksmuseum van Oudheden, 2017.

Top: the routed high-density polyurethane models from which the final facsimiles were made . Bottom: the lamassu on display at the Rijksmuseum in Leiden.

Bakor monoliths

Since 2016, Factum Foundation has been working with the Trust for African Rock Art (TARA) and the University of Calabar (UNICAL) on a project aimed at identifying, documenting and raising awareness about the Bakor monoliths, a group of at-risk sculptures from the Cross River State region of south-eastern Nigeria, many of which have been illegally removed from the region and are now held by international collectors, dealers, and museums.

The Bakor monoliths are phallic-shaped sculptures in a wide range of sizes, carved from basalt or limestone, and with a variety of features including beards, protruding navels and other decorative features probably referring to scarification. In their original contexts the monoliths were usually arranged in a circle and at some sites they are still found in this configuration. Over time, a number of individual monoliths have been removed from unprotected locations in the forest to the central meeting places of villages. Their dating and original contexts of production and use remain the subject of speculation, particularly in the absence of extensive archaeological work. However, ritual practices associated with the ancestors that the stones represent are still current – at the annual yam festival, for example, the monoliths are re-painted along the lines of the carved relief.

311 monoliths and fragments have been identified in 29 sites, but those still in situ remain at risk. Many have been damaged by fire, casualties of the annual burning of vegetation at the end of the cycle of yam production. Others have been stolen: several were taken out of Nigeria following the Biafra conflict in the late 1970s, encouraged by the appetite of European and American museums and collectors for large sculptural artefacts. Due to the poor representation of this region in the Nigerian government, little effort has been made at the national level to encourage the development of conservation or tourism infrastructure. The government has developed protective measures at just two sites, and at one of these, the village of Emangebe, the supposedly preservative removal of tree cover has actually accelerated the degradation of the relief carving. The monoliths have recently been added to the World Monuments Fund list of endangered sites and an objective of the project is to have the Bakor monoliths for inclusion on UNESCO's list of World Heritage Sites.

The aim of the joint project is to promote the preservation and understanding of the monoliths at both a local and an international level. Despite the incorporation of the stones into local ceremony, vandalism and theft remain common, and there are few resources to promote local understanding about their value as part of the region's heritage. There has also been a lack of research into the current locations and condition of the monoliths. The last survey was made by Phillip Allison in the early 1960s, before the Biafran conflict, and many monoliths pictured in situ by Allison have now left Nigeria; several are in European and American museum collections. The aim of the current collaborative project is to trace and document

Opposite page (clockwise from top left): the chief of Neborokpa surveying a monolith; recording the top of a monolith from Ntitogo in the Metropolitan Museum; render of a monolith in the collection of Didier Claes, unidentifiable from Philip Allison's survey, though similar in style to monoliths found at a newly recorded site, Bornima; painting the monoliths for the yam festival at Alok village.

Chief and elders of Oyengi with the last remaining carved monolith in the village.

the existing monoliths, to use 3D visualisations and facsimiles to communicate their importance to a wider audience, and to encourage the introduction of appropriate preservation measures for monoliths under imminent threat of deterioration and destruction.

The project's first trip to the Bakor region in October 2016 focused on site identification, documentation (photography, photogrammetry, aerial photography), and on liaising with local communities. The project was discussed at a meeting of regional community leaders, who expressed approval and offered support. Several 3D models resulting from the photogrammetry recordings made on this trip can be seen on the Foundation's website.

Following this initial survey, Factum Foundation was able to trace several of the monoliths recorded by Allison in the Bakor region in the 60s but now no longer in situ. Photogrammetric recordings were made of a complete monolith from the site of Eting Nga, now in the Musée du Quai Branly, and of two examples from the collection of the Brussels-based dealer Didier Claes, one from Oyengi, the other of unknown provenance. Two monoliths which Allison had documented were at Galerie Pierre Dartevelle in Brussels, and the top half of one was identified in the Metropolitan Museum in New York. Factum Foundation had already used photogrammetry to record the base of this monolith at the site at Ntitogo, and after receiving permission from the Metropolitan Museum to record the section held by them was able to produce a 3D model of the two parts joined together. A scale copy of this

was subsequently 3D printed and then cast in resin.

In spring 2018, a conference on the significance and future preservation of the monoliths was organised by the Department of History and International Studies at UNICAL. Following this, the project team travelled to the Bakor region to update community leaders on the conference and the general progress of the project, and to present the scaled resin casts of the Ntitogo monolith sections, along with two other casts from Alok at Njemitop, as a gift of the Factum Foundation. It was agreed that the next stage of work in the region would focus on preserving the monolith site at Eting Nta, where there are a number of impressive monoliths in relatively good condition. The meeting concluded with the performance of a masquerade ceremony and the suggestion that a Bakor cultural week could be instituted in the near future.

In spring 2019, Factum's team returned to Cross River State to document further monoliths and to make a film about them. During this visit, several monoliths were recorded which were not present in Allison's catalogue, an important finding suggesting that further research should be undertaken in the region.

The US Ambassador's Fund for Cultural Preservation has now generously offered to fund a further trip in September 2019 and also an exhibition on the monoliths. This will promote the value of the monuments to a Nigerian audience, beginning in Lagos and ending in Calabar; it is hoped that it will also travel to one or more international museums.

Photogrammetry render of the two parts of the Ntitogo monolith, the top half of which is now in the Metropolitan Museum.

In July 2019, the Carène Foundation offered to support the renovation of the Alok Open Air Museum and the return of facsimiles of the Eting Nta and Ntitogo monoliths to the Bakor region.

STRAWBERRY HILL HOUSE
Reviving an architectural jewel

A politician, writer, collector, and the son of Britain's first Prime Minister Sir Robert Walpole, Horace Walpole (1717-1797) built his "little Gothic castle", one of the earliest and finest examples of English Gothic Revival architecture, at Strawberry Hill in Twickenham. Here he displayed his collection of artistic and historical treasures, which included more than 1200 ceramic pieces, portraits of friends and relatives, and a selection of historical curiosities. Walpole's collection was sold by one of his successors in an infamous sale in 1842 and dispersed worldwide. The house itself passed through the hands of a succession of private owners, some of whom carried out extensive alterations to the decor and the grounds, before being leased in 2007 to the Strawberry Hill Trust, which opened it to the public as a museum in 2010.

Thanks to Walpole's detailed descriptions of Strawberry Hill and its collections, the Trust has been able to undertake an extensive restoration of the house and faithfully 'recreate' many of its original features. Since 2015 Factum Foundation has worked with them to produce facsimiles of paintings and objects that once belonged to the collection and 'return' them to their original locations within the house. In addition to the artworks described here, facsimiles have been made of a painting of the Marriage of Henry VII, a double portrait by John Giles Eccardt of Walpole's parents in an elaborate frame in the style of Grinling Gibbons, and a portrait of Robert Walpole.

Making the frames for the facsimiles of George Vertue's drawings after Holbein.
Opposite page: facsimile of a portrait by Allen Ramsay of Walpole's nieces, in the Gallery at Strawberry Hill.

STRAWBERRY HILL HOUSE : The Ladies Waldegrave

Location Scottish National Gallery, Edinburgh
Partners Scottish National Gallery, Strawberry Hill Trust
Date 2018-2019
Materials of original oil on canvas
Main recording techniques Lucida 3D Scanner, photogrammetry, panoramic photography, Factum relief printer, SLA printing, gilding
Main output technologies Océ elevated printing, casting
Materials of copy ink on gesso cast of 3D print
Project Funding Strawberry Hill House / World Monument Fund

The Ladies Waldegrave (1780) by Sir Joshua Reynolds (1723-1792) depicts Horace's grandnieces, Charlotte, Elizabeth and Anna Horatia Waldegrave, as the three fates. The sisters were unmarried at the time and the painting, commissioned by Walpole for the dining room at Strawberry Hill but first shown at the Royal Academy in 1781, was intended to attract wealthy potential suitors. It left Strawberry Hill in 1842, and in 1952 entered the collection of the Scottish National Gallery in Edinburgh.

Factum Foundation recorded the painting in the galleries of the Scottish National Gallery with the canvas unframed and mounted on an easel to facilitate the work. The central section of the canvas was recorded with the Lucida 3D Scanner to obtain a high resolution model of the surface texture, and the entire surface was recorded using photogrammetry, during which process hundreds of photos were taken at a constant distance of 40cm from the painting. The use of both technologies was a strategy which combined the respective advantages of each method: close correspondence to surface texture, and speed in the capture process. The painting's frame (which is probably not the original one) was recorded using photogrammetry.

The data was used to create a layered archive/browser and a facsimile of the painting with the frame, using the methods described in the article on Boucher's portraits of Madame de Pompadour (see page 49).

With thanks to Lesley Stevenson, Senior Painting Conservator, and Aidan Weston-Lewis, Chief Curator and Head of the Print Room at the Scottish National Gallery.

Screenshot showing the photogrammetric data processing; final facsimile with frame.
Opposite page: (top) the Lucida 3D Scanner recording the canvas surface; (bottom) details of the facsimile's surface.

STRAWBERRY HILL HOUSE : The Jamnitzer ("Cellini") Bell

Location British Museum
Partners British Museum, Strawberry Hill Trust
Date 2018
Materials of original silver
Main recording techniques photogrammetry
Main output technologies SLA 3D printing, silver-plating
Materials of copy 3D print, silver
Project Funding Strawberry Hill House / Factum Foundation

The "Cellini bell" is a tiny silver bell that throngs with insects, lizards and all manner of flowers and plants cast in delicate relief. Walpole, who believed the bell to be the work of the Italian Renaissance sculptor Benvenuto Cellini, acquired it in 1772 through an exchange of rare Roman medals with the Marquis of Rockingham. It became one of the author's most beloved objects, and he kept it in a cabinet of the so-called 'Tribune' room at Strawberry Hill House, which only the most distinguished guests were allowed to enter. Like almost everything else in Walpole's extensive collections, the 'Cellini bell' was sold in 1842. It has now been firmly attributed to the German goldsmith Wenzel Jamnitzer, and is on display at the British Museum, where it forms part of the Waddesdon Bequest.

The bell's small size, shiny surfaces, and intricate relief made it an especially complex object for 3D recording at high-resolution. It was eventually recorded using photogrammetry, but the level of detail on the small bell required many more photographs, taken with higher precision, than would normally have been needed for an object of this size. Moreover, in order to get around the issue of the shiny surface, the bell needed to be photographed twice: once with normal lenses, and once with cross-polarising filters, which invert colour polarity. This allowed areas with high levels of glare under normal conditions to be viewed without glare through the filters. Two different 3D models were made from these two datasets, and then combined – a laborious task which involved comparing the tonal range of hundreds of images before setting shared control points which allowed them to be merged.

The highly detailed 3D model that resulted had to be reduced in size before being visualised and printed. The SLA 3D print in resin was then silver-plated and patinated to produce an object that may not feel as weighty as the original, but that looks incredibly convincing as one of the first objects on permanent view in the 'Tribune' room at Strawberry Hill.

Detail from the 3D model showing the intricacy of the metal surface acquired using photogrammetry.
Opposite page: the final facsimile of the Jamnitzer Bell.

STRAWBERRY HILL HOUSE : Portrait of Laura Keppel and Charlotte, Lady Huntingtower, by Allen Ramsay

Allen Ramsay's 1765 portrait of Laura Keppel and Charlotte, Lady Huntingtower, Horace Walpole's nieces, was sold along with the majority of his collections in 1842 and is now in the collections of the Museum of Fine Arts in Boston.

Factum Foundation recorded the painting using the Lucida 3D Scanner and panoramic photography, and the frame using photogrammetry. The painting was then rematerialized via a 3D print of the relief data, while the frame was routed in high-density polyurethane before being water-gilded by artesans in Factum's frame studio.

The completed facsimile now hangs in its original location at one end of the Gallery in Strawberry Hill House.

STRAWBERRY HILL HOUSE : George Vertue's copies of 33 drawings by Hans Holbein

In 1743, the renowned artist and engraver George Vertue made copies of 33 drawings by Holbein, newly discovered in a bureau in Kensington Palace and depicting members of Henry VIII's court. Purchased in 1757 by Horace Walpole, they are now at Sudeley Castle in Gloucestershire.

In 2017, Factum Foundation used the Lucida 3D Scanner and photogrammetry to record the drawings in their frames, and created a facsimile of each one. Factum's facsimiles of George Vertue's copies are now displayed in the Holbein Chamber at Strawberry Hill, a room which functions as a microcosm of different varieties of artistic and architectural replication and recreation: the ceiling, made of papier-mâché and plaster, was inspired by the now-destroyed ceiling of the Queen's dressing room at Windsor Castle, the chimneypiece was based on the Tomb of Archbishop Warham in Canterbury Cathedral, and the walls themselves have recently been re-papered using techniques based on those of the 18th century.

Opposite page: the final facsimile of the *Portrait of Laura Keppel and Charlotte, Lady Huntingtower*, being photographed in Factum's workshop.

Two paintings by Murillo

Location Instituto Andaluz de Patrimonio Histórico, Seville
Client Hermandad de la Santa Caridad
Date 2017-present
Materials of original oil on canvas
Main recording techniques Lucida 3D Scanner, composite photography, photogrammetry
Main output technologies Factum relief printer
Materials of copy pigment, canvas
Project Funding Factum Foundation / The Auckland Project

In 2017, Factum Foundation recorded two paintings by Bartolomé Esteban Murillo now in the Hermandad de la Santa Caridad in Seville: the *Miracle of the multiplication of the bread and fishes* and *Moses and the water from the rock of Horeb*. The paintings, which had been removed from their usual locations high up on the walls of the Hermandad for conservation by the Instituto Andaluz de Patrimonio Histórico (IAPH), were recorded using the Lucida 3D Scanner and composite photography. Their frames were recorded using photogrammetry. High resolution copies (though not facsimiles) have been made from the data at a 1:1 scale; these will be displayed in the Hermandad de la Santa Caridad in a setting which will allow visitors to examine these magnificent works at close range. Exact facsimiles are in production for a new visitor centre at the hospital in Seville.

With thanks to the staff at the Hermandad de la Santa Caridad and the Instituto Andaluz de Patrimonio Histórico, and to Casilda Ybarra.

Colour correction using PTGui software.
Opposite page: retouching the *Miracle of the multiplication of the bread and fishes*.

The two facsimiles of Murillo's *Miracle of the multiplication of the bread and fishes* and *Moses and the water from the rock of Horeb* in Factum's workshop.

Hereford Mappa Mundi

Location Hereford Cathedral, UK
Client Trustees of Hereford Cathedral
Date 2013-present
Materials of original pigment and gold on vellum
Main recording techniques composite photography, photogrammetry,
Lucida 3D Scanner
Main output technologies CNC-milling, pigment digital print on acrylic
medium support finished with microcrystalline wax, SLA 3D printing
Materials of copy plaster, acrylic skin, pigment inks, gold leaf
Project Funding Factum Foundation

In 2013, a team from Factum Arte used photogrammetry and the Lucida 3D Scanner to record the Hereford Mappa Mundi (c. 1300 CE), the largest medieval map in the world and one of the treasures of Hereford Cathedral. It was rematerialised in plaster, without colour and with an exaggerated surface relief, and has been on display at the cathedral since 2014, allowing blind and partially-sighted visitors to experience a highly fragile object whose original is kept behind glass. From 2016-2019, a new collaboration took place: Factum Foundation used the Lucida 3D Scanner and photogrammetry to record the wooden backboard to which the map was attached before its removal by conservators in the 1970s, and re-recorded the map's colours using composite photography. As well as resulting in a new facsimile, in colour and complete with backboard, it is hoped that the data from this project will help experts to determine the date and provenance of the map.

For the makers of the Mappa Mundi, the centre of the world was Jerusalem, and a tiny compass hole at the centre of the walled city marks the centre-point of the circular map as well. This compass hole is also visible on the wooden backboard, leading to suspicions that board and map could be coeval. Dendrochronological analysis of the board has shown that it came from oak trees felled in Hereford in 1295 CE, suggesting that the map too could have been made in Hereford rather than, as previously thought, in Lincoln. The Lucida recording of the board will allow close, non-intrusive study and could help in the resolution of this question.

The new recordings will also make the map more accessible to the public. The 2016 colour data has been corrected to fit the colourless 2013 render, and the 3D model has been digitally attached to its new digital backboard. A facsimile has now been produced using a pigment digital print on an acrylic skin support, finished with microcrystalline wax; the backboard was created using a combination of CNC-milling and Océ elevated printing.

In addition, Hereford Cathedral have used Factum Foundation's 2013 data to create an interactive website where visitors can explore the surface of the map, searching for exotic animals and for the strange peoples, like the dog-headed Cynocephali, once thought to inhabit the margins of the known world. The website also uses the colourless 3D render to allow visitors to explore the various factors influencing the relief of the map's surface, from distortions in the vellum to the ways in which ink and gesso are used to build up surface relief. It is a combination of micro and macro mapping which gives a new materiality to the surface of the world at the dawn of the 14th century: a time when the North Pole sat on the left hand side of the map, Noah's Ark still stood beached on Ararat, and the encircling ocean was pockmarked by what was probably an insect bite to the calf whose skin the whole thing was painted onto.

This project would not have been possible without the help of Peter Barber, Christopher Clarkson, and Rosemary Firman.

Clockwise from top left: facsimile of the mappa mundi; facsimile of the backboard; attaching a coloured skin to the plaster relief.
Opposite page: attaching a coloured skin to the plaster relief.

Goya's painting of María Luisa on Horseback

Location Museo Nacional del Prado, Spain
Date 2018-present
Materials of original oil paint on canvas
Main recording techniques Lucida 3D Scanner, panoramic photography
Main output technologies Océ elevated printing, gesso cast, Factum relief printer
Materials of copy pigment, gesso vacuum-glued onto canvas
Project Funding Julian Schnabel

Factum Arte's 2018 recording of Goya's *María Luisa on Horseback* is an exemplary case of a fruitful collaboration between a public institution, the Museo Nacional del Prado, and a private donor, the artist Julian Schnabel. It is a collaboration which will facilitate access to one of the museum's masterpieces for experts, artists and the general public, producing a record of the painting for current and future generations. It also sits in a long tradition of museums as places which encourage the making of copies and the diffusion of their images beyond their own walls.

The vast painting (338 x 282 cm) was recorded in the Prado, with the Lucida 3D Scanner used to gather relief data and panoramic photography to document the colour. A particular challenge of this project was the vibration of the canvas, a phenomenon caused by the museum's air conditioning. Tiny movements of the painting were picked up by the scanner, creating noisy data which required post-processing to eliminate small vertical vibration lines. In processing the data from

recordings, there is always a choice to be made between noise and information: where noise is eliminated, useful information will also be lost. For María Luisa on Horseback, the choices to be made in this regard were particularly critical.

The painting was recorded prior to undergoing restoration, and the data from Factum's recordings, which will belong to the Prado, will allow current and future conservators to look back at this particular stage in the object's career. In recognition of a donation towards the cost of the restoration, the Prado has also given Julian Schnabel permission to have a single facsimile made of the work for his own use; this has been produced in Factum's Madrid workshop.

Thanks to Manuela Mena, Enrique Quintana, José de la Fuente, Cristina Alovisetti and Carmen Huerta from the Museo del Prado.

Opposite page: colour recording of the painting at the Prado.

Salviati's ceiling in the Palazzo Grimani

Location Musée Jacquemart-André, Paris; Palazzo Grimani, Venice
Client Palazzo Grimani, Venice
Date 2018-19
Materials of original oil on canvas
Main recording techniques photogrammetry, panoramic photography
Main output technologies Factum flatbed printer on gesso
Materials of copy pigment on gesso, varnish
Project Funding Venetian Heritage with support from Factum Foundation

Parmigianino's Self-portrait in a Convex Mirror

Location Kunsthistorisches Museum Wien (KHM)
Client Museum Moderner Kunst Stiftung Ludwig Wien (MUMOK)
Date 2018-19
Materials of original oil on poplar wood
Main recording techniques Lucida 3D Scanner, panoramic photography
Main output technologies Océ elevated printing, Factum relief printer, 3D printing
Materials of copy Océ 3D print, pigment, elastic skin, polyurethane
Project Funding MUMOK

A sixteenth-century painted ceiling has been returned to the Palazzo Grimani in Venice in the form of a facsimile. The ceiling, which shows the dispute between Minerva and Neptune over the city of Athens, was commissioned for the Vestibolo della Tribuna in the Palazzo Grimani and was painted by Giuseppe Porta, also known as Giuseppe Salviati. In the late nineteenth-century it was sold, and some years later entered the collection which was to form the basis of the Musée Jacquemart-André in Paris.

Factum Foundation recorded both the ceiling itself and the oval space which it once occupied. As the painting is fixed to a ceiling in the Musée Jacquemart-André and could not be recorded using the Lucida 3D Scanner, Factum Foundation used panoramic photography and photogrammetry to scan the work. The original oval ceiling in the Palazzo Grimani was also recorded, this time using a FARO scanner, to ensure that the eventual facsimile would fit into a space whose contours have changed over the course of a century.

The return of the ceiling to the Palazzo Grimani is designed to coincide with the return of many of the Palazzo's original statues, which will be loaned for two years while repairs are performed to roof of their current location, the Biblioteca Marciana.

Parmigianino's *Self-portrait in a Convex Mirror* (1524), painted when he was barely twenty-one, plays cleverly with a convex mirror's ability to offer a distorted representation of the person who looks into it. It is a painting which seeks to offer a "true", undistorted representation of the distorting image: the wooden board on which the work was painted is convex, just like the mirror it pretends to be – leaving the viewer unsure of their own position when they see the young artist looking out at them from a distorted room. It is a painting which provides important context for understanding Parmigianino's later works in the Mannerist style, where bodies are often shown with unnatural proportions and distorted symmetry.

Factum Foundation was asked to create a facsimile of Self-portrait for the exhibition 'Vertigo. Op Art and a History of Deception 1520–1970.' The exhibition, which will run at MUMOK from May to October 2019, will explore the Op-Art movement of the 1960s and its roots in other historical artistic movements which have contemplated the nature of perception and illusion.

The 3D data for the facsimile was recorded with the Lucida and colour was captured using panoramic photography following the methods described in the article on Boucher's portraits of Madame de Pompadour. Parmigianino's elaborate illusion, however, complicated the rematerialisation – it is impossible to print colour directly onto a convex surface. Instead, Factum's print studio worked with a flexible adhesive 'skin' that was moulded onto a 3D print made by Océ so that it took on the subtle surface texture of the 3D printed board. The colour was printed onto the textured skin, which was then attached to the convex board and varnished.

With thanks to Dr. Karoline Schweizer at KHM and Markus Wörgötter, Eva Badura-Trisk and Daniela Hahn at Mumok.

Bronze cast of the front legs of Canova's horse, recorded in high-resolution at the Museo Civico di Bassano del Grappa.

II. DIGITAL RESTORATIONS

"Indeed, the healing of historical wounds has become an essential aspect of Factum Arte's endeavours, as, fittingly for a postquantum era, it enables iconic objects to exist in two places simultaneously."

Emma Crichton-Miller, Country Life Magazine, Summer 2019

The facsimile lampshade.

Lampshade from the Museo Sorolla

Location Museo Sorolla, Madrid
Client Museo Sorolla
Date 2016
Materials of original silk
Main recording techniques panoramic photography
Main output technologies printing on fabric
Materials of copy polyester cotton mix fabric, inkjet print
Project Funding Museo Sorolla

The conserved silk surround from the original lampshade.

Traditional conservation and restoration involve the use of paint, varnish, plaster, and a whole range of other materials to keep objects in a stable condition, or to "return" them to what is thought to be an earlier, even original, condition. Digital conservation offers a different approach. Rather than involving interventions to the object itself, it works by making a digital model of an object and then manipulating the data to "restore" the model. Different alternatives for restoration can be explored without any possibility of harm to the original object; these alternatives can either be kept as digital files, rematerialised as facsimiles, or used by traditional conservators as aids for conducting physical restoration. The projects described in this section use digital restoration for several different ends, from the reconstruction of damaged originals to the provision of models for artists and practitioners working today.

An early 20th century silk lampshade at the Museo Sorolla, Madrid, is one of very few decorative objects that belonged to the house when the Spanish painter Joaquín Sorolla was in residence. It is of significant value to the museum, adding character and atmosphere to the rooms. However, the silk taffeta material of the shade, with its delicate hand-painted flower and bird motifs in vibrant blue, has suffered damage as a result of exposure to the elements. Following a recent assessment, it was decided that it would be impossible to restore the physical object with a view to re-exhibition. Instead, Factum Arte's textile specialist performed preventative conservation on the lampshade itself, and Factum recorded and digitally restored the fabric, producing a facsimile to take the place of the original within the museum.

First of all, the lampshade was comprehensively photographed to record its conservation state prior to intervention. The silk and trimmings were then gently cleaned of surface dust using a micro-vacuum technique. The material was carefully removed from the metallic frame and old restorations were detached. The piece was placed onto a flat, rigid support, allowing it to be stored in a less exposed setting than the public space of the museum.

Once laid out flat, the fabric was photographed using panoramic photography. The resulting image file was digitally restored: for the many areas where the decorative floral and bird motifs had been lost, the pattern was reconstructed by importing imagery from elsewhere on the repetitive design. The digital nature of this operation allowed integrity to be restored to the piece without the need to alter the original object.

The structure and appearance of textiles is determined by the type of fibre and weave, as well as the final finish, all of which must be taken into account when choosing the material for a facsimile. In this case, the facsimile called for a very flat fabric with a soft gloss to resemble the distressed satin-finish of the original silk. A polyester cotton mix was selected, in which the cotton tempers the shine of the polyester filaments.

The textile was primed for printing with Factum's unique flatbed printer, which allows flat-plane printing with Inkjet pigmented Epson Ultrachrome inks on all types of ground. We then performed a series of tests which ultimately allowed the high-resolution data to be printed onto the fabric - an innovative procedure which had never been carried out before by Factum.

The final step in the process was remounting the facsimile fabric onto the original lampstand. The completed piece – lampshade and earthenware vase stand – is now on display in the Museo Sorolla.

With thanks to the director of the Museo Sorolla, Consuelo Luca de Tena.

Assembling 3D printing fragments to reconstruct a physical maquette of Canova's horse as part of a digital restoration initiative.

Works by Antonio Canova at Bassano del Grappa

Location Bassano del Grappa, Italy
Client Museo Civico di Bassano del Grappa
Date 2017-present
Materials of original terracotta (*Three Graces* maquette); plaster (equestrian statue; Venere Italica; three busts); paper (albums and sketchbooks)
Main recording techniques photogrammetry; white-light scanning (*Three Graces* maquette, equestrian statue, Venere Italica, three busts); photography (albums and sketchbooks)
Materials of copy epoxy resin (*Three Graces* maquette); bronze (equestrian statue); paper treated with gesso, pigment (albums and sketchbooks)
Project Funding Museo Civico di Bassano del Grappa / Factum Foundation

Factum Foundation is currently partnering with the Museo Civico di Bassano del Grappa to digitise and create facsimiles of its collection of works by Antonio Canova, perhaps the most famous artist of the Neoclassical movement of the 18th and early 19th centuries. While a part of the project is focused on recording and creating facsimiles of drawings and albums, and on creating digital models of sculptures in the museum's collections, the centrepiece of the collaboration involves the digital restoration and rematerialisation of what was once a 3-metre high equestrian statue, now in fragments in the museum's collections.

DIGITISATION AND FACSIMILES OF ALBUMS AND SKETCHBOOKS

The Museo Civico possesses significant holdings of Canova's drawings, preparatory models, and paintings, donated after the artist's death by his half-brother, Giambattista Sartori Canova. However, as many of these are fragile works on paper, they can be consulted only within the museum's library and under supervision. Chiara Casarin, the director of the museum, has therefore initiated a project to digitise the entire corpus, with a view to making these precious drawings more widely available to scholars and to the general public.

One of the digitised sketchbooks.

Creating a silicon mould from the 3D print of the *Three Graces*.

The plaster horse in its original context in the Museo Civico di Bassano del Grappa, prior to being broken up.

Around 1890 drawings in ten albums and eight notebooks were photographed over the course of one week, using lighting conditions carefully calibrated to capture the colour and texture of the original documents. Two students from IUAV university in Venice, who had previously catalogued the museum's Canova collection, worked with the Factum Foundation photographer.

The albums will be presented online in a digital viewer, and two have been rematerialised as facsimiles in editions of six copies each. For the facsimile albums, the images were printed onto a modern paper stock which closely resembled the texture of the original paper, and the paper was coated with gesso to give it sufficient weight and to allow finer printing results. The Museo Civico will be able to sell copies of the albums to other institutions, thereby providing revenue for its own projects and simultaneously enabling these works to reach a wider audience.

DIGITISATION AND FACSIMILE OF 'THREE GRACES' MAQUETTE

Towards the end of his career and at the height of his fame, Canova created two large-scale marble sculptural groups of the *Three Graces*, reinterpretations of a well-known group from classical antiquity. The Museo Civico di Bassano del Grappa owns a small terracotta maquette of the Graces made in 1813, a preparatory model which experiments with a very different relationship between the three bodies to that shown in the final versions. Factum Foundation recorded the maquette using photogrammetry, and used the resulting data to create a 3D print. A silicon mould was made from this print and used to produce a cast in plaster which was coloured to resemble the original.

DIGITISATION AND FACSIMILE OF AN EQUESTRIAN STATUE

Following the success of the maquette recording, Factum Foundation embarked on a much more ambitious project: to create a digital model of the horse from a 3-metre equestrian statue of Ferdinand I of the Two Sicilies, the plaster prototype for which was made
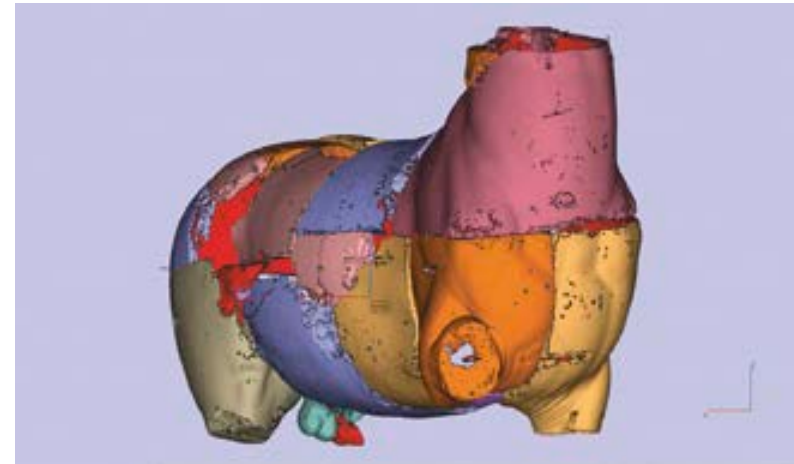
Clockwise from top left: positioning the tail for photogrammetry scanning; recording the head with white-light scanning; casting process of the model of the horse; fitting together the scanned parts using ZBrush software.

The plaster fragments of the original statue.

by Canova shortly before his death and finished - with many alterations - by his pupil Antonio Calì in 1827. Until 1969, the plaster sculpture was a focal point of the museum's collections, but it was subsequently broken up to allow for the construction of a new lecture hall, with the parts stored in a local palazzo.

Most sections of the statue were scanned using a Breuckmann white light scanner, while others were recorded using photogrammetry. The entire scanning project took two weeks.

Back in Madrid, the processed data was used to reconstruct the horse from the various fragments. To get an idea of how the pieces fit together, scaled versions were 3D printed and assembled manually. Once it was known how the pieces fitted together, the parts were reassembled digitally to create a 3D model, allowing the horse to be visualised in its entirety for the first time in over half a century.

While the fragmentary statue in the Museo Civico is made of plaster, this was only a preparatory stage for a bronze statue. Factum Foundation has used the digitally restored data to cast a scaled bronze model of the horse, at a 1:10 scale, which preserves the cracks of the re-assembled fragments, and intends to rematerialise the statue as a full-size statue in bronze.

Given that the bronze finally made by Calì differs from Canova's plaster sculpture in many details, this could in some senses be regarded as a more authentic version of the final sculpture intended by Canova.

VENERE ITALICA AND THREE BUSTS

Factum Foundation has also recorded four plaster sculptures by Canova from the museum's holdings – three busts and one life-size sculpture of Venere Italica, a version of the ancient Greek Aphrodite of Knidos. The digital files will preserve a record of the fragile plaster sculptures in their current state, allowing the museum to keep track of the deterioration of the originals and to conduct non-intrusive examinations of them. The intention is to record the remaining plaster sculptures in the museum's collections in the near future.

With thanks to Paola Perozzo and Edoardo Zanollo from IUAV, and to Chiara Casarin, Marco De Paoli and Giorgio Detogni from the Museo Civico di Bassano del Grappa.

The digitally reconstructed horse rematerialised as a bronze statuette.

The sepulchre of Cardinal Tavera, with the face modelled from the cardinal's death mask (see following page).

Sepulchre of Cardinal Tavera

Location Hospital de Tavera, Toledo
Partners Fundación Casa Ducal de Medinaceli
Date 2018-present
Materials of original Carrara marble
Main recording techniques photogrammetry, LiDAR, white light scanner
Project Funding The Auckland Project

The sepulchre of Cardinal Tavera, the focal monument of the church of the Hospital de Tavera in Toledo, was commissioned while Tavera was still alive from the famous sculptor Alonso Berruguete. Written into the contract was the express requirement that the tomb should be "equal" to a previous commission of Berruguete's, the sarcophagus of Cardinal Cisneros, and when representatives were sent to compare the two they agreed that the stipulation had been "met and even surpassed" by the sculptor. The ornate sarcophagus, finished shortly before Berruguete's death in 1561, was his final commission; it is now regarded as one of the finest works of Spanish Renaissance sculpture. However, it was damaged by nationalist troops during the Civil War, and some of the personified Virtues who surround the figure of the Cardinal are now missing limbs and other body parts.

In 2018, Factum Foundation was commissioned by the Fundación Casa Ducal de Medinaceli to record the sarcophagus and the church in which it is located. The church itself was recorded using LiDAR, while the sarcophagus was recorded using LiDAR, white light scanning and photogrammetry. Marble is an especially complex material for photogrammetric recording, because the processing software cannot detect common points between very similar images of a white, nearly featureless surface, and is thus unable to create the pairings of images which it uses to generate 3D data. However, photogrammetry produces some of the most detailed 3D recordings currently possible. For this project, therefore, the method was complemented with white light scanning and LiDAR to create an accurate, scaled, but also highly detailed model of the sepulchre. LiDAR was used to situate the sarcophagus in relation to the larger model of the church, and where the reflective surface of the marble made the photogrammetry data too noisy, the white light scan was used to supplement the model.

In addition to producing a digital 3D model of the sarcophagus, Factum Foundation plans to create a second 3D model based on scans of casts of the original taken before it was damaged. The resulting 3D data will be layered over the 3D data of the sepulchre, after which the missing sections will be digitally 'isolated' to fill in missing areas. This digital merging of the current and former state of the object will provide the Fundación Casa Ducal de Medinaceli with a range of possibilities with regard to its future preservation and restoration: they will be able to leave the original as it is while retaining a restored digital model; they will be able to use the casts to recreate, via 3D printing, the missing parts of the original; or they will be able to rematerialise the restored data to rematerialise a new, restored facsimile of the entire sarcophagus.

With thanks to Juan Manuel Albendea Sols, Antonio Fernández López, and Javier Barbasán.

93

Death mask of Cardinal Tavera; render of a damaged Virtue; a render of the sarcophagus derived from photogrammetry data.

Opposite page: photographing the sepulchre; photogrammetry model showing the positions from which the sepulchre was photographed; LiDAR scan locating the sepulchre within the larger church building.

Carvings on the cave prior to the act of vandalism.

The vandalised carvings.

Reconstructing the damaged carvings.

The sacred cave of Kamukuwaká

Location Xingu, Mato Grosso, Brazil
Partner Wauja people
Date September 2018-present
Materials of original engraved rock
Main recording techniques LiDAR, photogrammetry
Main output technologies CNC-milling, 3D printing, hand-finishing
Materials of copy cast fibreglass panels
Project Funding Factum Foundation with support from People's Palace Projects

The project to record the sacred cave of Kamukuwaká began as an effort to document a fragile piece of cultural heritage, but due to an act of vandalism which took place shortly before recording was about to begin, it has transformed into a project of digital restoration, and also of the tentative re-creation of what is now a tragically damaged original.

Within a region whose material culture is largely defined by impermanent objects, the sacred cave of Kamukuwaká provides a vital physical record of ancient Xingu cosmogonic and ethno-historic cartography. It is the legendary site at which the mythical hero-ancestor Kamukuwaká and his people sought refuge, and is still associated with the origin of the ear piercing initiation ritual of young Xingu leaders. Its engravings are a central reference point for the Xingu traditional graphic repertoire, and are widely reproduced in ritual body paintings, traditional pottery, and basketry. Although the cave is held sacred by all the peoples of Xingu, it is particularly associated with the Wauja and is situated on their land.

In September 2018, a Factum Foundation team arrived to record the cave only to find that its petroglyphs had been systematically vandalised at some point since the last known visit in January. The exact identity of the perpetrator is unknown, but destruction should probably be seen in the context of ongoing tensions between indigenous and farming communities in the state of Mato Grosso. Deforestation at the headwaters upstream had already resulted in increased sedimentation and rising water levels, aggravating the erosion to which the rock art panels in the cave are directly exposed. This act of vandalism, however, marked a new escalation of the conflict, and is certainly in large part a consequence of the exclusion of the cave, a vital site of indigenous, national, and world heritage, from the demarcated territory of Xingu.

Despite the irreparable damage, Factum Foundation, together with the Wauja people, decided to continue with the recording. Laser-scanning and photogrammetry were used to document the cave in its damaged condition, and on return to Madrid the data was processed to create a 3D model.

It was subsequently decided to use this data, along with earlier photographic documentation of the petroglyphs in their undamaged state, to perform digital restoration on the cave. The scanned data was cross-referenced with photographs to reconstruct a proposed 3D model, and photographs of this initial restoration were printed out in Brazil so that the Wauja community could make additions and corrections on acetate. These corrections were then scanned and returned to Factum for assimilation into the model.

The digitally-restored cave has now been rematerialised as a facsimile at 1:1 scale (9x5x4m), and will be exhibited in Madrid before being flown to Brazil and given to the Wauja people. This is a project which opens up a host of issues and possibilities focused around the emerging field of digital restoration, but Factum Foundation also hopes that the display of the cave will help in gathering support for the Wauja in their efforts to safeguard Kamukuwaká, an endeavour which would involve reclaiming the cave and its surroundings as indigenous lands and reinstating a village nearby. With the unprecedented political threat to the Amazon rainforest posed by the current Brazilian government, the restoration of the cave of Kamukuwaká will serve as a platform for the voice of its indigenous communities.
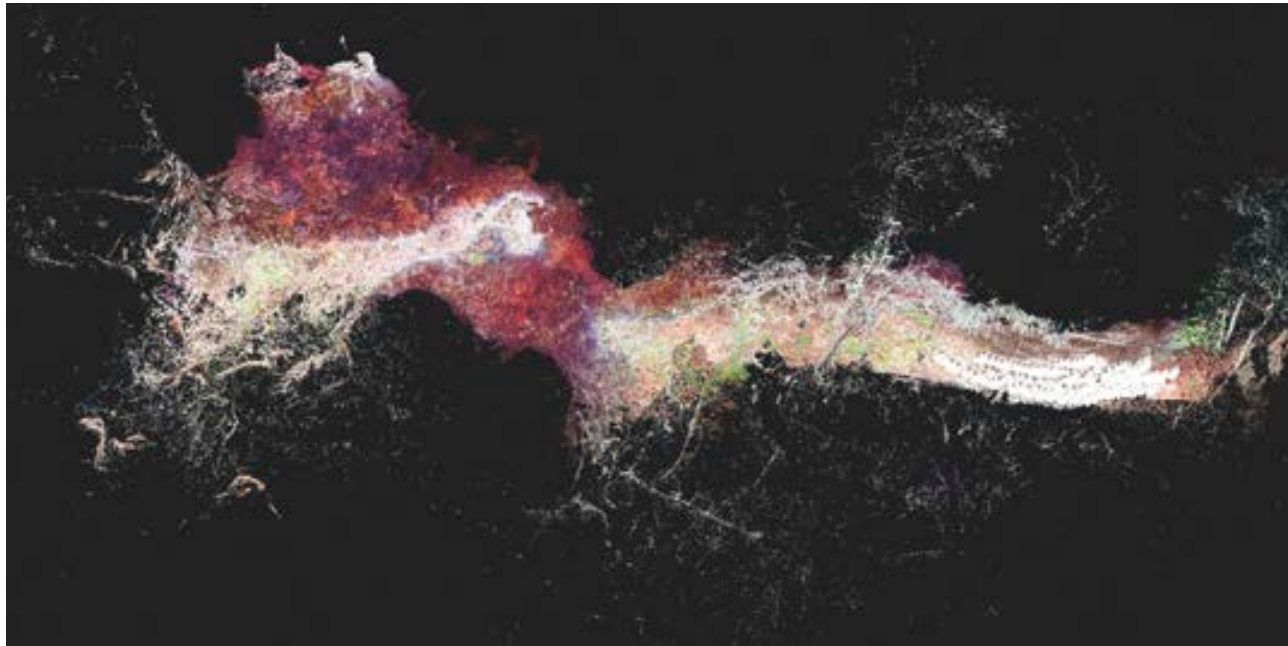
With thanks to the Wauja people, the villages of Piyulewene, Piyulaga, and Ulupuwene, the team of pro-bono consultants for the Wauja Indigenous Associations under the coordination of Mafalda Ramos with Gabriele Viega Garcia, the Tulukai Indigenous Association, FUNAI (the National Indian Foundation (Brazil)), Kumaré Txicão, Patricia Rodrigues, Awapataku Waurá, Pere Waurá, Tukupé Waurá, Akari Wauja, Akaim Waurá, Pirata Wauja.

The digitally restored images sent to the Wauja community as A3 renders; using maginc markers and acetate sheets to clarify the meaning of the inscriptions.

Opposite page, clockwise from top: LiDAR recording of the vandalised cave; a combined LiDAR and photogrammetry model of the cave and immediate surrounding area; members of the Wauja community teaching their children about the cave; reconstructing the damaged carvings on acetate.

Working on the physical recreation of the Sacred Cave of Kamukuwaká.

Al-Qatt wall paintings

Location Asir, Kingdom of Saudi Arabia
Client Community Jameel/Art Jameel
Date May 2017
Materials of original paint on plaster
Main recording techniques composite photography, photogrammetry
Project Funding Community Jameel/Art Jameel

As part of an ongoing partnership with Art Jameel, Factum Foundation has recorded key examples of a deteriorating group of wall-paintings in southern Saudi Arabia, and is working to publish them in a form which allows them to serve as a tool and reference point for current and future practitioners of this artform.

In the villages of the Asir region, the vibrant tradition of Al-Qatt wall painting is the preserve primarily of women. Practiced in a similar style for at least a hundred years, the paintings reference the woven textiles which would adorn a house or a tent, and some are even shown drooping in the middle in imitation of hanging cloth. They constitute a unique repository of cultural memory, and practitioners such as Sharifa Bint Ahmed, who worked in the village of

Rijal Alma from the 1950s to the 1980s, are well-respected to this day. Rijal Alma was once a stopping point on the Hajj route from Yemen to Mecca, and contains over 60 tower-houses built of stone, clay, and wood, financed by the taxes it levied on travellers. It has been on UNESCO's tentative World Heritage List since 2015, and the Al-Qatt paintings were recognised by UNESCO as part of the Intangible Cultural Heritage of Humanity in 2017.

However, as a living tradition, Al-Qatt painting is also a changing one: when older paintings deteriorate, they will often be repainted – an alternative method of ensuring visual and cultural continuity to Western conservation and restoration practices, which seek to impede or reverse the decay of the original. Many
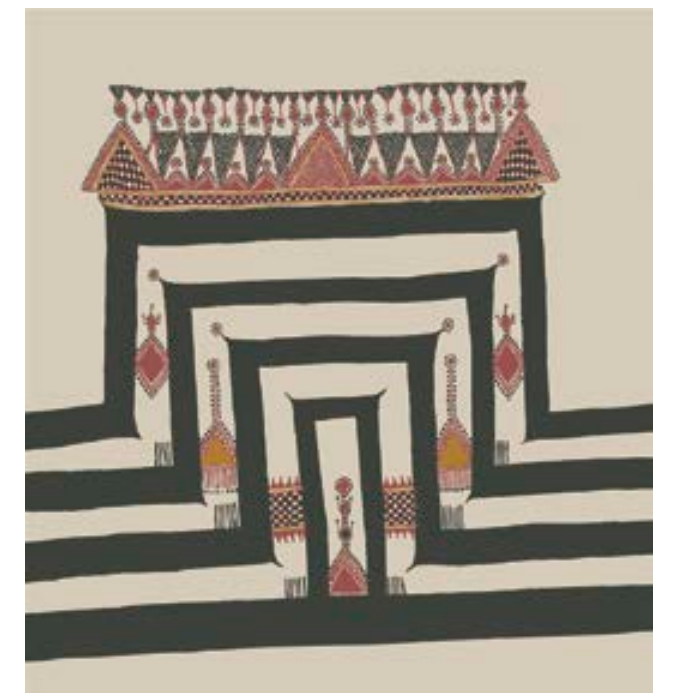
Before and after digital restoration.
Opposite page: details of the damaged surface of the wall paintings.

of the mid-20th century paintings documented by French photographer Thierry Mauger in a series of publications of the 1990s and 2000s no longer exist. And while a strong sense of stylistic continuity with these earlier works remains, there are also inevitable changes. One clear example of this is found in pigment choices and availability: where earlier styles were characterized by a narrow range of earth pigments (black, grey, burnt siena) which were probably bound with milk, the dominant colour palette is now much brighter, with green, blue, yellow and orange the most popular colours.

In May 2017, at the invitation of Community Jameel, a team from Factum Foundation travelled to Asir to document the wall-paintings of four villages: Rijal Alma, Al-Makhad, Zebnah and Al-Sudah. The team was graciously shown around by Ali Mughawi, and accompanied by Saudi artist Ahmed Mater. During the visit, composite photography was used to record wall paintings in five houses, and photogrammetry was used for the panel of a relief-carved wooden door. The records are of a sufficient quality to allow reproduction at a 1:1 scale.

One major aim of the project is to create a record of a specific moment in an ever-changing historic process. Al-Qatt painting has been categorised by UNESCO as an intangible heritage of the Asir region, but it also has an inescapably tangible, material aspect, and Factum's recordings provide a way of documenting

and (at least digitally) preserving older works without impeding the renewal and transformation of these walls by contemporary practitioners. In some cases, Factum's data already constitutes the most detailed record of wall paintings whose originals no longer exist: two of the buildings where wall paintings were recorded were on the point of collapse at the time of recording, and a further building was about to be demolished.

A second, equally important, purpose is to provide a resource for practitioners or artists working today and in the future. Together with Art Jameel, Factum Foundation is publishing a pattern book which can be used by students working in the tradition of Al-Qatt painting. The book will show images of the original paintings alongside graphic reconstructions of the designs (not digital restorations in the strict sense, although some of the tools of digital restoration were used in this process). A test has also been done in the printing of these designs onto silk, raising the possibility of the transfer of this traditional art-form into new media. It is hoped that projects such as this will contribute to a wider revitalisation of interest in the traditional crafts of the Asir region.

Recording the frescoes at the Ferapontov Monastery.

III. RECORDINGS FOR CONSERVATION, STUDY AND DISSEMINATION

"Factum preserves evidence, neither reconstructing nor reformulating narratives."

Katrina Kufer, Harpers Bazaar Arabia, Autumn 2018

Malevich's *Black Square* paintings

Location Tretyakov Gallery, Moscow
Client Tretyakov Gallery
Date March 2018
Materials of original oil on linen
Main recording techniques Lucida, panoramic photography
Project Funding Tretyakov Gallery / Factum Foundation

'A painted surface is a real, living form.' – Kazimir Malevich,
*'From Cubism and Futurism to Suprematism', 1915*

Kazimir Malevich's *Black Square*, 1915 is the most iconic painting of the Russian avant-garde, and one of the most comprehensively analysed artworks in the world. However, questions surrounding its conception and biography still remain: while Malevich claimed that it was painted in 1913 (a critical year in the development of an international abstract style) and that it was the first work of Suprematism, analysis of the canvas has indicated a 1915 date and X-rays have shown that two earlier, brightly coloured compositions, Suprematist at least in the eyes of modern art historians, existed on the canvas before the black square was painted on top of it.

In March 2018, a team from Factum Foundation travelled to the Tretyakov Gallery in Moscow to record the two versions of the painting housed there: *Black Square*, 1915 and *Black Square*, 1929. Panoramic photography was used to record the colour of the two paintings, and the Lucida 3D Scanner was used to capture the delicate craquelure on the surface of *Black Square*, 1915, as well as the relatively featureless surface of the 1929 version. The resulting high resolution data has been used to produce a layered archive which can be viewed through a computer browser. Recent infrared and X-ray images of the paintings provided by the Tretyakov Gallery have been 'mapped' onto the 3D data, and users can now view two types of data simultaneously – for example, Factum's data showing the bright colours visible through the cracks on *Black Square*, 1915 can be seen alongside the X-ray image showing the works underneath.

It is hoped that Factum Foundation's data visualisations, which will allow new comparisons between surface and sub-surface and the study of detail invisible to the naked eye, will shed light on some of the more obscure issues surrounding *Black Square*, 1915. In addition, they offer the Tretyakov an accurate record of the current state of conservation of the painting a century on from its creation, enabling conservators and restorers to monitor change on the fragile surface through time.

With thanks to Yulian Khalturin and his colleagues at the The State Tretyakov Gallery.
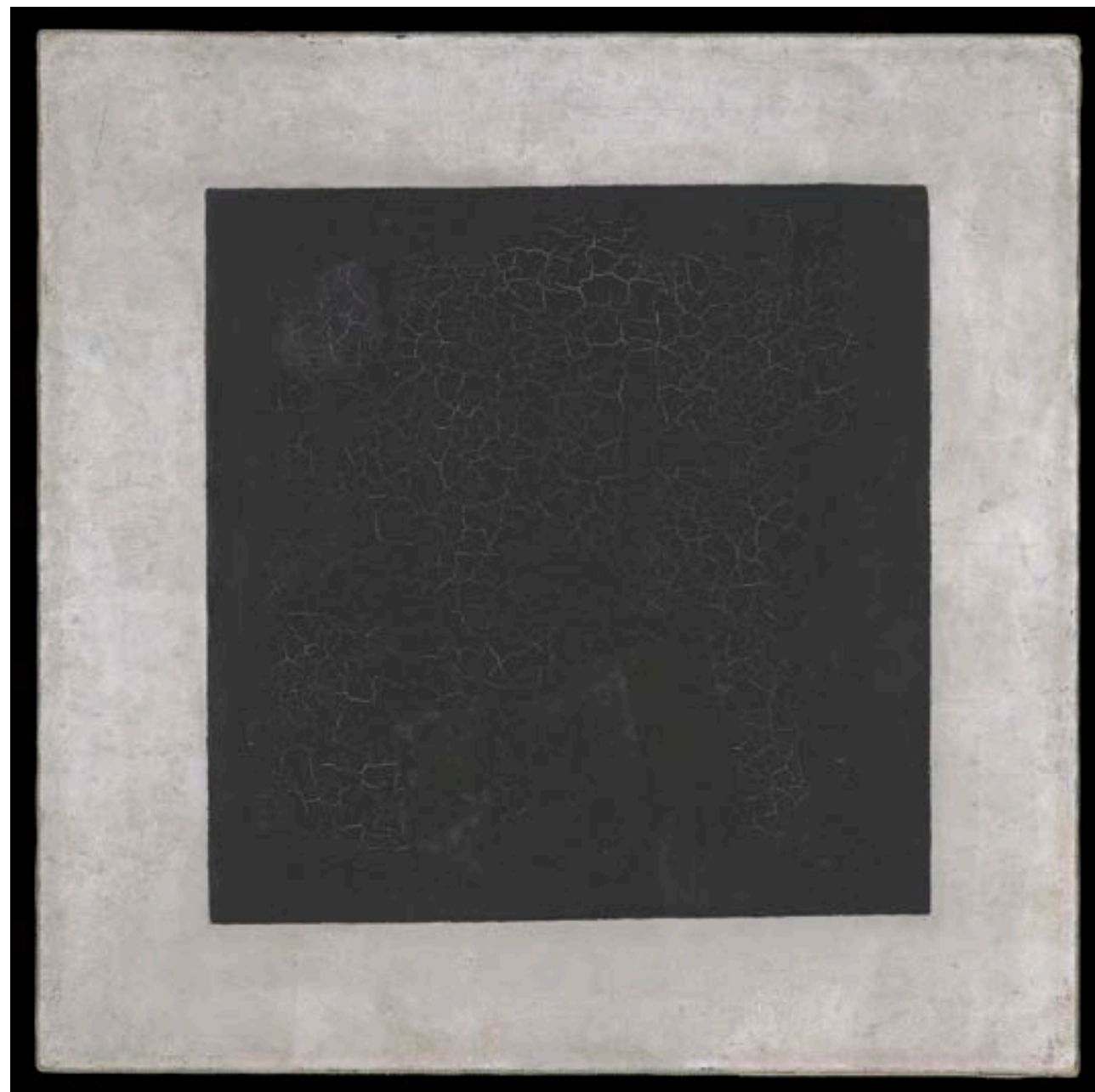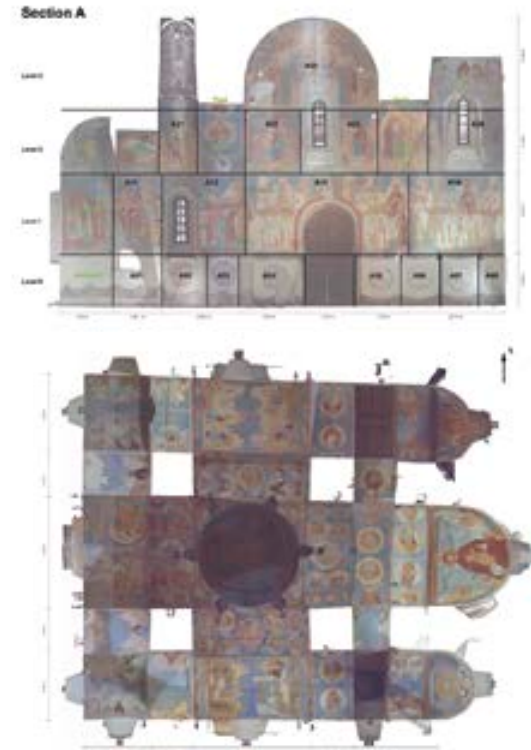

Colour data of *Black Square*, 1915 © Tretyakov Gallery.

Opposite page: setting up the Lucida 3D Scanner for 3D recording of the *Black Square*, 1915 © Tretyakov Gallery.

Dionisy's frescoes at the Ferapontov Monastery

Location Vologda Oblast, Russia
Client Peri Foundation
Date 2017-2018
Materials of original fresco
Main recording techniques panoramic photography, LiDAR, photogrammetry
Project Funding Peri Foundation

Clockwise from top: recording the cathedral using LiDAR; plans extracted from LiDAR data showing sections for panoramic photography recording; LiDAR model showing the internal fresco scheme.

The fifteenth century monastery complex at Ferapontov is a UNESCO world heritage site in a remote area of the Vologda Oblast, Russia. Within the complex, the Cathedral of the Nativity of the Virgin (1492) stands out for its elegant architecture, but it is best known for the frescoes which cover its interior, identified by an inscription as the work of the great 15th-16th century icon painter Dionisy and his sons. It is one of very few sites where frescoes from this period in Russian art have survived in a near-complete state, and the discovery of the identifying inscription in the early 20th century allowed the monastery to become a state museum under the Soviet Union, ensuring its ongoing conservation.

Since the mid-20th century a dedicated group of conservators have worked tirelessly to preserve the frescoes. The isolation of Ferapontov means that tourists visit in relatively small numbers, and even prevents many scholars interested in Russian art and history from visiting this unique site. But immense care is still taken to prevent damage by visitors: the interior of the church is kept under a strict climatic, dust-free regime, and guided tours last on average only fifteen minutes. Although the frescos are in a good state of conservation, it remains necessary to closely monitor their condition.

The recording project by Factum Foundation and the Peri Foundation marked the first time that the entire area covered by Dionisy's frescoes in the Nativity cathedral (over 300 square metres) had been digitally photographed at high resolution. The aim of the project focussed on capturing accurate colour data, but in order to plan this recording it was necessary first to produce a three-dimensional model of the complex interior of the cathedral – a compact space with high vaulted ceilings and a central cupola. This task was carried out on an initial visit in 2016 using a FARO scanner; in areas where the FARO data was noisy, photogrammetry was later used to refine the 3D model.

During a second, two-month trip in spring/summer 2017, the Factum Foundation team recorded the frescoes using panoramic photography. The team worked from 5pm to 1am in order to avoid the museum's opening hours, photographing the frescoes from elevated platforms which they positioned and built up to the correct height before work each evening and dismantled at the end of the night. In order to photograph the cupola the platform was built to a height of 11m and photographers spent more than three hours at a time gently swaying under the figure of the Christ Pantocrator. By the end of the recording, more than 50,000 images had been taken of the frescoes.

Accompanying the Factum team were two Dagestani photographers who had trained at Factum the previous year, as well as two trainee photographers from nearby Vologda, who were able to learn at first-hand the techniques and methodology of a major recording project.

The photos were processed by our colleagues in Russia, and the data will be able to be used in different contexts, including for conservation purposes, study, or to produce digital walkthroughs of the magnificent space.

With thanks to our colleagues at the Peri Foundation, and to Elena Nikolaevna and everyone else who works at the Ferapontov Monastery Museum.

Scanning Veronese at the Homo Faber exhibition

Location 'Homo Faber: Crafting a more Human Future', Fondazione Giorgio Cini, San Giorgio Maggiore, Venice
Client Gallerie dell'Accademia, Venice
Date September 2018 - November 2018
Materials of original oil on canvas
Main recording techniques Lucida 3D Scanner
Project Funding ARCHiVe

Filling all 43,000 feet of the Fondazione Cini on the island of San Giorgio Maggiore in Venice, the exhibition 'Homo Faber: crafting a more human future' showcased the work of expert artisans of all crafts and artistic industries, from the most traditional to those in the vanguard of technological innovation. As part of the category 'Restoring Art's Masters', Factum Foundation collaborated with the Milanese art restoration company Open Care to demonstrate the possibilities of the skilled recording of paintings: the Lucida 3D Scanner and panoramic photography were used to record a diptych on loan from the Gallerie dell'Accademia: the *Prophet Isaiah* and the *Prophet Ezekiel* by the great Venetian artist Paolo Veronese.

The collaboration with Open Care set in relief the potential of Factum's recordings: over the course of the project, the diptych was recorded twice, once before and once after restoration by Open Care. The first

recording took place during the exhibition, allowing visitors to watch the Lucida in action. The high-resolution viewers from the two recordings, which have been supplied to the Gallerie dell'Accademia, can now be used to compare the pre- and post-restoration paintings, offering a detailed record of the changes and inevitable subjective decisions which form part of any restoration process.

The project was the first to be carried out by Factum Foundation through the new ARCHiVe centre, also housed in the Fondazione Cini, which is discussed later in this volume.

With thanks to our colleagues at the Gallerie dell'Accademia and at Open Care - Servizi per l'Arte.

Powhatan's Mantle

Location Ashmolean Museum, Oxford
Client Trustees of the Ashmolean Museum
Date 2017
Materials of original leather, shell, sinew
Main recording techniques photogrammetry
Output high-resolution multi-layered viewer
Project Funding Factum Foundation

The front of the mantle.

Composed of four white-tailed deer hides sewn together with sinew and decorated in elaborate shell beadwork, "Powhatan's Mantle" is an extraordinary survival from the early period of European colonisation of the Americas, and one of the most significant items held by the Ashmolean Museum. Probably a wall-hanging rather than a mantle, it was acquired by John Tradescant the younger, whose collections went on to form the core of the Ashmolean, from the Powhatan chief Wahunsenacawh; the means of acquisition are not known. Wahunsenacawh was the leader of a major military coalition against the English at the beginning of the 17th century, and is also remembered today as the father of Pocahontas.

Factum Foundation used photogrammetry to record the densely decorated surface of the mantle on both

sides, and has produced a detailed model of the front side which can be viewed on the Foundation's website. The publication of this multi-layered archive will allow conservators and scholars to inspect the mantle without removing the delicate original from its case, museum visitors to examine in microscopic detail an object which they would otherwise only be able to see behind glass, and those on both sides of the Atlantic who are unable to travel to Oxford greatly improved access to this important historical artefact.

With thanks to André Jáuregui and Halley Ramos, and to our colleagues at the Ashmolean Museum.

Detail of the colour layer and of the 3D surface.

Digitisation of Islamic manuscripts in Dagestan

Location Makhachkala, Republic of Dagestan, Russia
Client Peri Foundation; IHAE
Date 2016-present
Materials of original manuscripts (paper, vellum)
Main recording techniques photography with custom-made manuscript scanners
Project Funding Peri Foundation / Factum Foundation

The Portable Manuscript Scanner and the Static Manuscript Scanner.

The Institute of History, Archaeology and Ethnography (IHAE) in Makhachkala (Republic of Dagestan, Russia) holds a world-class archive of more than 3000 Islamic manuscripts dating from the 11th to the 20th centuries, alongside an extensive collection of letters and early Arabic printed books. Private collections in Dagestan are thought to represent an even greater and almost entirely unstudied resource of over 25,000 manuscripts. The wealth of these collections attests to the importance of scholarship and the Islamic written tradition in the northern Caucasus from the Middle Ages onwards. The region's significance, however, has not been reflected in Western scholarship in large part due to the difficulty associated with accessing the relevant materials.

As part of a wider preservation effort that also involves the conservation of manuscripts in their archive, the IHAE is digitising its own collections and, looking forwards, is planning to record and make available for study as many privately-owned manuscripts as possible. As of January 2019, operators at the IHAE had digitised well over one third of the archive.

Since 2016, Factum Foundation has provided hardware, software and technical support to the IHAE's digitisation laboratory, which has recorded over one thousand manuscripts to date. This has included the provision of two custom-made photographic manuscript scanner prototypes and accompanying software, together with remote technical supervision and advice for the scanner operators and staff at the IHAE.

STATIC MANUSCRIPT SCANNER

The operator brings the methacrylate plates of this V-shaped scanner into contact with the book, gently flattening the pages without risking the integrity of the paper or applying pressure to the binding. The Canon 5DSR cameras are activated through the custom-made

ManuCapture software and the images - with resolutions up to 800 dpi - are automatically downloaded onto the computer. The operator lifts the plate to turn the page and continue the recording. Unlike many commercial manuscript scanners, Factum's uses relatively inexpensive photographic equipment to produce very high quality images which allow a good appreciation of the physical materiality of these books as well allowing their texts to be read.

PORTABLE MANUSCRIPT SCANNER

The portable manuscript scanner is lightweight, easy to assemble and fast. It uses two Canon 7Ds and flash-lighting to produce images at 300 dpi, and of repeatable quality, in any environment. It combines standard photographic hardware with custom made pieces, all of which are easy to replace or remake, so that components can be quickly and cheaply replaced without the need for specialist assistance. The scanner will be transported into the mountain villages of Dagestan to record manuscripts in private collections.

Recording Kuikuro heritage

Location Xingu, Mato Grosso, Brazil
Partner People's Palace Projects, AIKAX (Associação Indígena Kuikuro do Alto Xingu)
Date 2017-present
Main recording techniques LiDAR, photogrammetry, drone
Project Funding Factum Foundation / People's Palace Projects

In May 2017, Factum Foundation was invited by People's Palace Projects to participate in their collaboration with the indigenous filmmaker Takuma Kuikuro, in the village of Ipatse in the Xingu region of Mato Grosso, Brazil. Unlike the majority of Factum Foundation's projects, where a specific subject or set of subjects for digital recording is identified in advance, the project in Xingu was intended to emerge from a collaboration in which Takuma and the community would direct the areas of focus following a demonstration of the technologies available. This was intended to contribute to their own extensive efforts to document and communicate Kuikuro culture, evident in films such as Takuma's 2012 *As Hiper Mulheres*, *'The Hyperwomen'*.

In preparation for the project, Factum Foundation assembled a number of different recording technologies aimed at capturing three-dimensional information at different scales: from photogrammetry for the high-resolution capturing of surfaces to LiDAR laser-scanning for mapping natural or human environments. In addition to this, a number of sound recording methods were assembled: from ambisonic microphones that capture 360-degree sound environments to hydrophonic microphones that capture sound underwater.

Following the team's arrival in Ipatse and an initial dialogue with Takuma and other senior members of the community, it was established that since the entire village was about to begin the process of moving to an adjacent site, the most valuable use of Factum Foundation's expertise and time would be to document the current state of the present village using LiDAR technology. It is a traditional Kuikuro practice to move the site of the village every 30-40 years, with families transferring gradually from one to the other. However, multiple lightning strikes on one of the ocas (the name for the distinctive thatched vernacular buildings inhabited by the Kuikuro) had led to the acceleration of this process.

To achieve a complete recording of Ipatse, Factum Foundation's team first carried out a drone survey of the village and the immediate surrounding environment. The resulting 1.25 gigapixel image enabled the planning of the necessary number of stations for the FARO scanner, which would be used to carry out more detailed recordings. The team also created a low-resolution photogrammetric model of the whole village, using images gathered from the drone, to show community members the kind of eventual results that were to be expected from LiDAR. 92 Faro scanning stations were subsequently plotted around the village, including 10 stations within one of the ocas.

Following the LiDAR mapping of the village, the Foundation's team ran an introductory photogrammetry workshop for Takuma and other members of the community. The subject chosen for this demonstration was a pair of masks normally used in the Kuarup (the Xingu funerary ritual), where they are adorned with grasses and paints. The Foundation's team also recorded a pair of termite hills and generated a low-resolution model of one of the nearby lakes to indicate the potential application of the technology in a natural environment. It is hoped that in the future that Takuma and other interested persons will be able to gather images to be processed by the Foundation in Madrid, thereby continuing the collaborative relationship.

With thanks to Takuma Kuikuro and the village of Ipatse, to our colleagues at People's Palace Projects, and to Jerry Brotton and Mark Rickards.

Clockwise from top: drone photo of Ipatse; image showing the locations from which drone images were taken; LiDAR model of the village; map showing locations of LiDAR scanning stations.

1 ... 2 ... 3

4 ... 5 ... 6

7 ... 8 ... 9

10 ... 11 ... 12
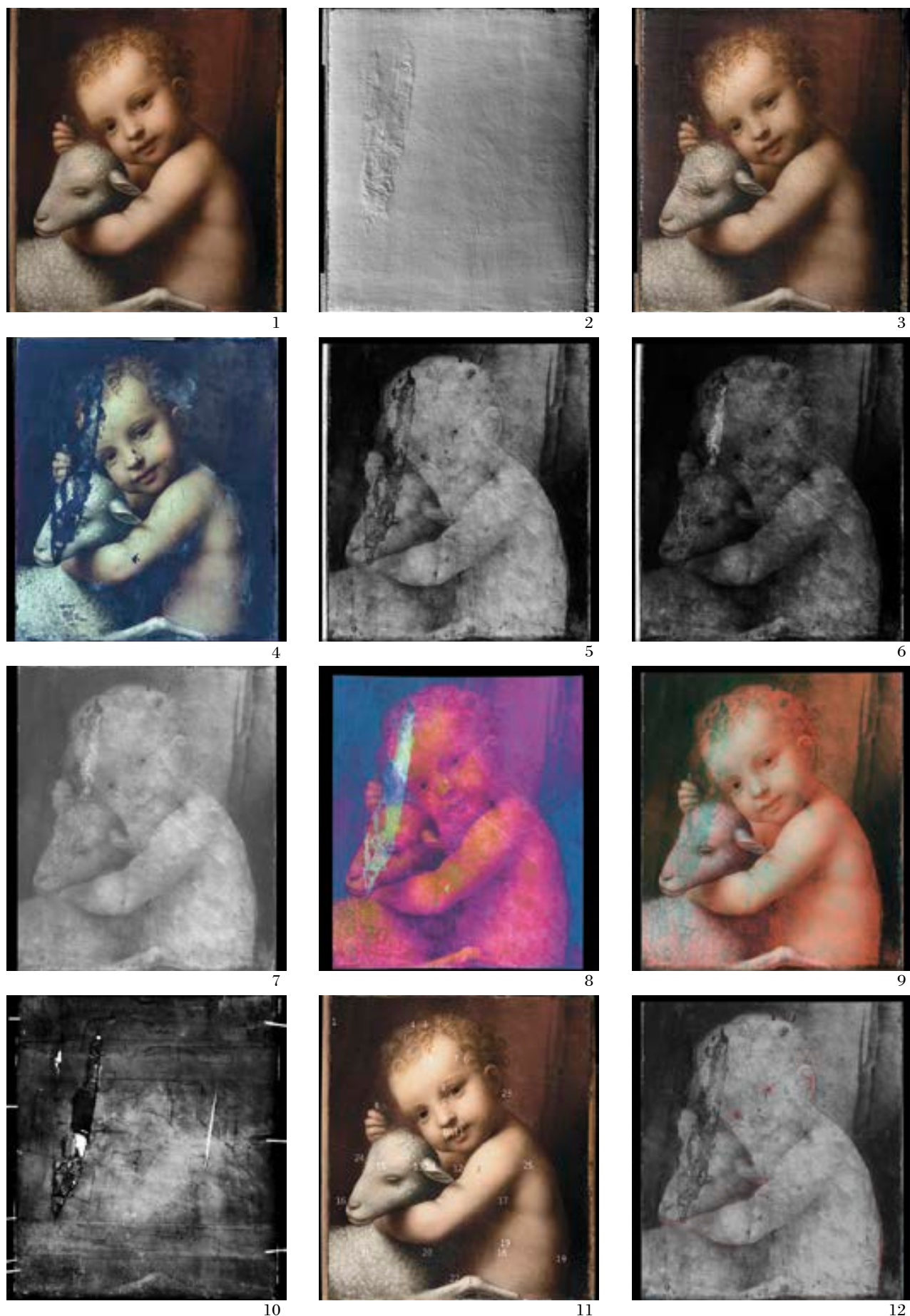
Five paintings by Bernardino Luini

Location Pinacoteca Ambrosiana, Milan
Date January 2017 - November 2017
Materials of original oil on panel (*Holy Family*), tempera and oil on panel (*Baby Jesus with Lamb*), albumen on paper (*Tobias and the Angel*), tempera and oil on panel (*Nursing Virgin and Child*), oil on canvas (*Noli me Tangere*)
Main recording techniques Lucida 3D Scanner, panoramic photography
Project Funding Pinacoteca Ambrosiana; Fondazione Cariplo; Fondazione Gianmaria Buccellati; Alvise di Canossa; Swiss Lab for Culture Projects

As part of an international research initiative into the work of Bernardino Luini (c.1480-1532), a painter of the circle of Leonardo, Factum Foundation has recorded five pictures in the Pinacoteca Ambrosiana in Milan: *Holy Family, Baby Jesus with Lamb, Tobias and the Angel, Nursing Virgin and Child, and Noli me Tangere*. This is a project which sets new standards for the digitisation of cultural heritage, offering experts and art-lovers an unprecedented variety of approaches to these pictures: alongside the Lucida and panoramic photography data for the paintings, Factum's multi-layer browsers integrate X-ray, infrared 1705 nm, and infrared 1230 nm data provided by other institutions (Politecnico di Milano, Università degli Studi di Milano-Bicocca, Università degli Studi di Bergamo, and Consiglio Nazionale delle Ricerche (Istituto di Fotonica e Nanotecnologie, Istituto Nazionale di Ottica)). Looking forward, the Pinacoteca Ambrosiana intends to extend this project by recording more major works by Luini from international collections.

Opposite page: 1. full colour (Cristana Achille and Francesco Fassi; Politecnico di Milano); 2. 3D data from Lucida 3D Scanner (Guendalina Damone and Carlos Bayod; Factum Foundation); 3. Colour and 3D scan data combined; 4. UV (Gianluca Valentini; Politecnico di Milano); 5. IR 1705 nm (Accesso Molab, CNR-INO, Anna Galli; CNR-IFN) (Letizia Bonizzoni; Università degli Studi di Milano); 6. IR 1230 nm (Accesso Molab, CNR-INO, Anna Galli; CNR-IFN) (Letizia Bonizzoni; Università degli Studi di Milano); 7. IR 900-1700 nm (Gianluca Poldi; Università degli Studi di Bergamo); 8. PCA (Accesso Molab, Anna Galli e Michele Caccia; CNR-IFN); 9. FC (Accesso Molab, CNR-INO, Anna Galli; CNR-IFN) (Letizia Bonizzoni; Università degli Studi di Milano); 10. RX (Marco Gargano; Università degli Studi di Milano); 11. Punti Misura XRF + FORS (BIANCHI) + RAMAN (ROSSI) Letizia Bonizzoni (Università degli Studi di Milano) (Daniela Comelli; Politecnico di Milano) (Anna Galli; CNR-IFN) (Marco Gargano; Università degli Studi di Milano) (Austin Nevin; CNR-IFN) (Gianluca Poldi; Università degli Studi di Bergamo); 12. Underdrawing (Valeria Villa).

Possible fossilised dinosaur footprint in Balochistan

Location Zhob, Balochistan, Pakistan
Client Sadiq Malkani, Nicholas Allen
Date 2017-2018
Materials of original sandstone
Main recording techniques photogrammetry (ground-based and aerial)
Project Funding Pakistan Museum of Natural History / Factum Foundation

In December 2017, Factum Foundation co-led a trip to Balochistan province in the Islamic Republic of Pakistan, with the intention of recording a 70-million-year-old sandstone slab thought to contain the markings of a fossilised dinosaur footprint.

During the Mesozoic era Balochistan contained fertile plains which were home to dinosaurs, and earlier excavations, as well oil and gas prospecting campaigns, have revealed numerous fossils. Little excavation has been carried out in recent years, however: due to its border with Afghanistan and the ongoing insurgency against Islamabad, Balochistan is generally considered off-limits to the outside world.

In 2012, unusual markings were revealed on a sandstone slab during blasting work for the construction of a highway. Sadiq Malkani, a former regional director of the Geological Survey Pakistan and an amateur palaeontologist credited with unearthing Pakistan's first verified dinosaur remains in 2000, believes that the markings are dinosaur footprints and include evidence of 'gliding marks', meaning that the creature slipped.

In collaboration with Iconem (France), the Pakistan Museum of Natural History, Palaeostreet Studio (Poland), and Dust and Scratches Films (UK), Factum Foundation recorded the surface of the slab using a mixture of ground-based and aerial photogrammetry. Due to the danger of improvised explosive devices appearing at the site overnight, recording was limited to one day; despite this constraint, over 11,000 photos were taken of the rock surface.

The identification of the markings remains uncertain, with several experts suggesting that they were caused by a bubble from gas deposits rather than belonging to a dinosaur. Whatever the eventual outcome, however, Factum's data will allow experts with no possibility of visiting the site to examine the evidence, opening up debate to a much wider audience than would otherwise have been the case.

With thanks to Sadiq Malkani, ICONEM for their help with the aerial photogrammetry, Luke Tchalenko from Dust and Scratches, Paleostreet Studio, Nick Allen, and the Pakistan Museum of Natural History.
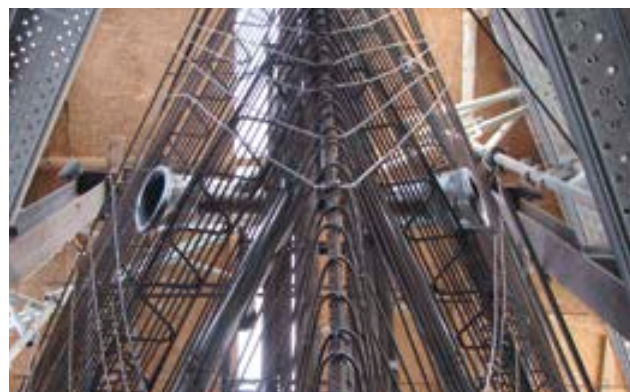
Heraclitus research vessel, Institute of Ecotechnics

Location Roses, Spain
Client Institute of Ecotechnics
Date 2014-2020
Materials of original concrete, iron
Main recording techniques LiDAR
Project Funding Factum Foundation for Ecotechnics

Launched by the Institute of Ecotechnics in 1975, the Heraclitus has sailed 270,000 nautical miles across six oceans. The ship is the lynchpin of a long-running project to better understand the oceans and the people who inhabit their shores and surface, and functions both as a base for scientific research and as a travelling platform for artistic projects.

Following damage to its hull in 2012, the Heraclitus was put into drydock in Roses, Spain, so that it could be reconstructed and updated before setting sail once more. The boat is built on the model of a Chinese junk, allowing stability in bad weather, and has a ferro-cement hull, a method of boat-building common in the 60s and 70s. The labour-intensive nature of ferro-cement construction makes it undesirable for much modern boat-building, but for the Institute of Ecotechnics, which has a large volunteer workforce, it remains the most viable option even today due to its strength, the possibility of conducting emergency repairs quickly and the cheapness of the base materials.

In 2012 Factum Arte, working in collaboration with Scan Lab Projects, used a LiDAR scanner to create a 3D visualisation of the vessel. In 2018 a team from the Factum Foundation returned to Roses, this time to record the iron frame, now stripped of its original cement. Both recordings have been used by the IE to assist in the reconstruction process.

When the restoration is complete the plan is that the Heraclitus will set sail on a five year Ethnosphere Expedition to West Africa, South America and the Caribbean, documenting coastal cultures and sea-peoples whose traditions and existence are at risk from climate change and from political and economic pressures.

With thanks to our colleagues at the Institute for Ecotechnics, the October Gallery, and Scan Lab Projects.

Opposite page, clockwise from top: placing spherical recognition targets for LiDAR scanning; LiDAR scan of the vessel; examining the Heraclitus prior to the reconstruction of the hull; the iron frame, stripped of its cement.

The Heraclitus on the water.
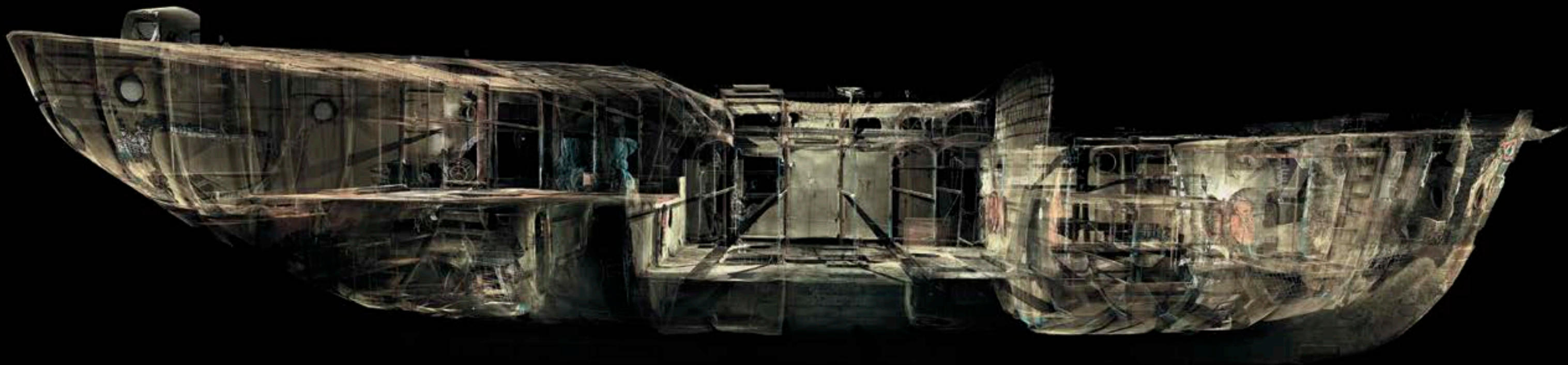
Colour tests for the recreation
of *Lo Spasimo di Sicilia*.

IV. RE-CREATIONS

"Wounded artifacts may sometimes need heroic surgery, but they always need nursing, forms of artful care that sustain objects' lives and maintain their vivacity. This is why the Factum Foundation needs every support in its plans to encourage state of the art digital curatorship, and to use this curatorship to help transform the arts of the cultural state."

Simon Schaffer, Professor of History and the Philosophy of Science,
University of Cambridge, BBC documentary, 2013

Top: Detail of the Bodleian copy of the *Entertainment for those wanting to discover the world*.
Bottom: Composite image of the pages laid out as a whole map.

Al-Idrisi's world map from the Book of Roger

Location Bodleian Library, Oxford
Client Trustees of Bodleian Library
Date 2017 – present
Materials of original pigment and gold on vellum
Main recording techniques composite photography
Main output technologies CNC engraving
Materials of copy silver
Project Funding Factum Foundation with the Bodleian Library

The map of the world made by the 12th century Islamic cartographer al-Idrisi for Roger II of Sicily (completed AH 548/1153 CE) was a masterpiece of mapping which remained the most technically sophisticated world-map for three centuries after its production. Drawing on several centuries of Islami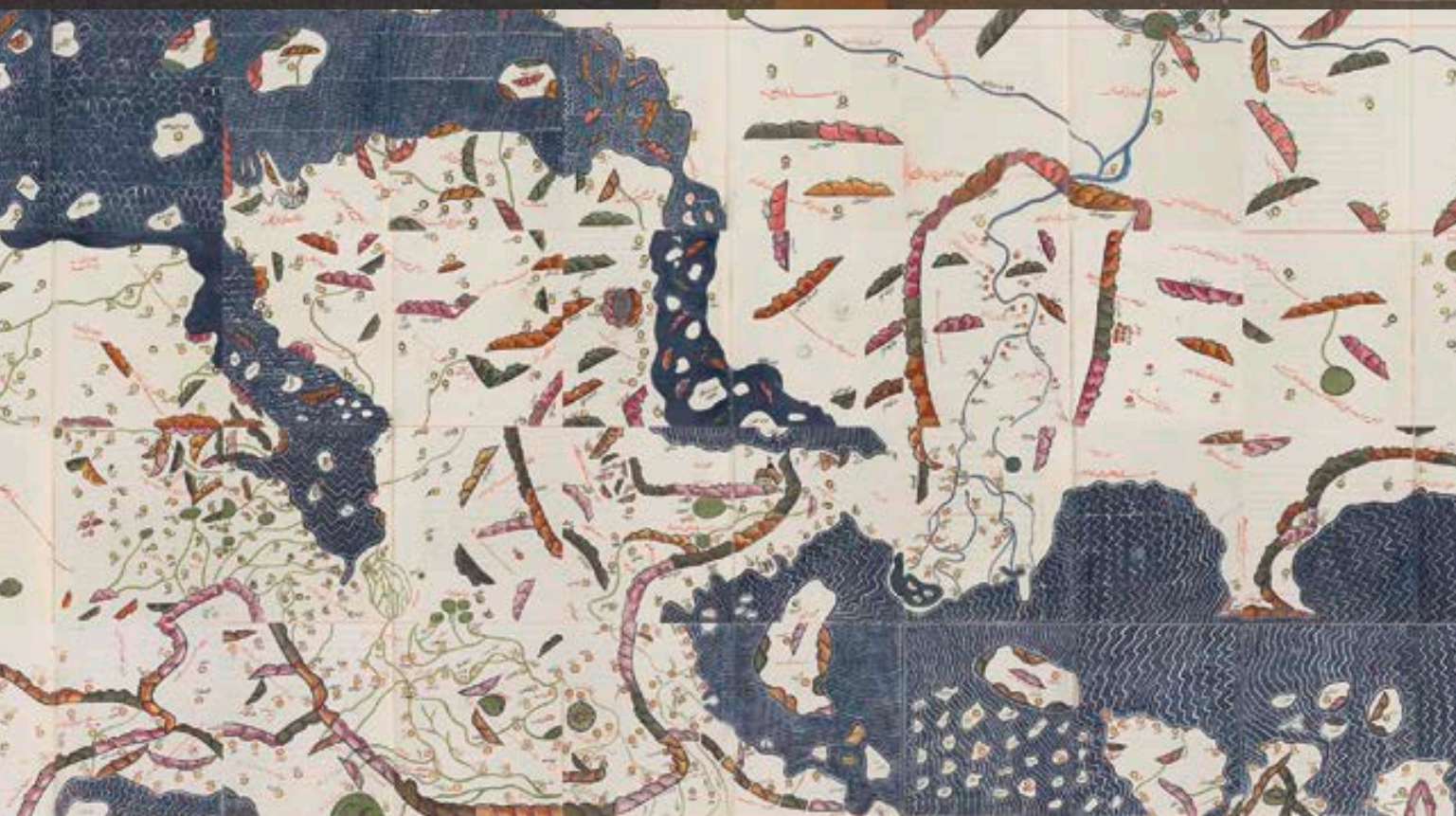c cartographic research, al-Idrisi produced both a book of 70 maps covering the surface of the known world, and a single, round map engraved onto a silver disk and set into a wooden table, with Mecca at its centre.

The silver disk is now lost, and the *Entertainment for those wanting to discover the world (Nuzhat al-mushtāq fi'khtirāq al-āfāq)*, survives only through later copies. But in a groundbreaking project, Factum Foundation has undertaken to re-create al-Idrisi's fabled map. Neither facsimile nor copy, this re-creation, which has a diameter of 2 metres, nonetheless combines painstaking historical research with advanced digital techniques and the highest levels of craftsmanship, paying tribute to the lost original and offering yet another layer to add to the complexity of its transmission.

In order to re-create the map, the Foundation began by using high-resolution photography to digitise the pages of the *Entertainment*, working from one of the best preserved copies, now in the Bodleian Library in Oxford. In post-processing, the 70 regional maps were edited into a single, composite world-map, and discrepancies on the borders between one map and the next were corrected. The resulting rectangular image was then distorted into a circle, a process which required each one of the Arabic toponyms to be extracted and then re-inserted to prevent deformation. Both rectangular and circular composite maps can be viewed in detail on the Foundation's website.

Where al-Idrisi's map would have been engraved by hand, Factum Foundation's re-creation uses CNC-milling machines to engrave the contours of cities and coastlines onto the silver surface. Far from representing a de-skilling of the engraving process, Factum Foundation's use of these machines pushes them to limits usually thought impossible: where CNC routing is often regarded as an imprecise method of rematerialising data due to the 'noise' left by the head of the drill, Factum is able to create remarkable precise reproductions by reworking the same surface multiple times in finer and finer detail, in materials ranging from wood to resin to alabaster.

Engraving the map in silver required that the composite circular map be converted into a vectorised image - a line drawing readable by a CNC-milling machine. The map was then engraved in eight separate parts, each one 500x1000mm and requiring 48 hours of milling time. The CNC machine used a spring-loaded tool which is able to cut without rotating, and which applies a similar pressure to the 0.3mm-thick plate to that made during the hand-engraving process. The engraved plates were then cut by a silversmith and fitted to a hard backboard ready for insertion into a wooden table frame.

Factum's intention is to make 3 copies of the map that will be sold to fund the production of a copy for the Bodleian and one for the city of Palermo. The recreation of the map was exhibited at the Bodleian Library in the exhibition *Talking Maps* that opened on 5th July 2019.

This re-creation is neither a facsimile nor a copy. It combines historical research with advanced digital techniques and the highest levels of craftsmanship, paying tribute to the lost original and offering yet another layer to add to the complexity of its transmission.

With thanks to Richard Ovenden and everyone else at the Bodleian Library, and to Jerry Brotton.

129
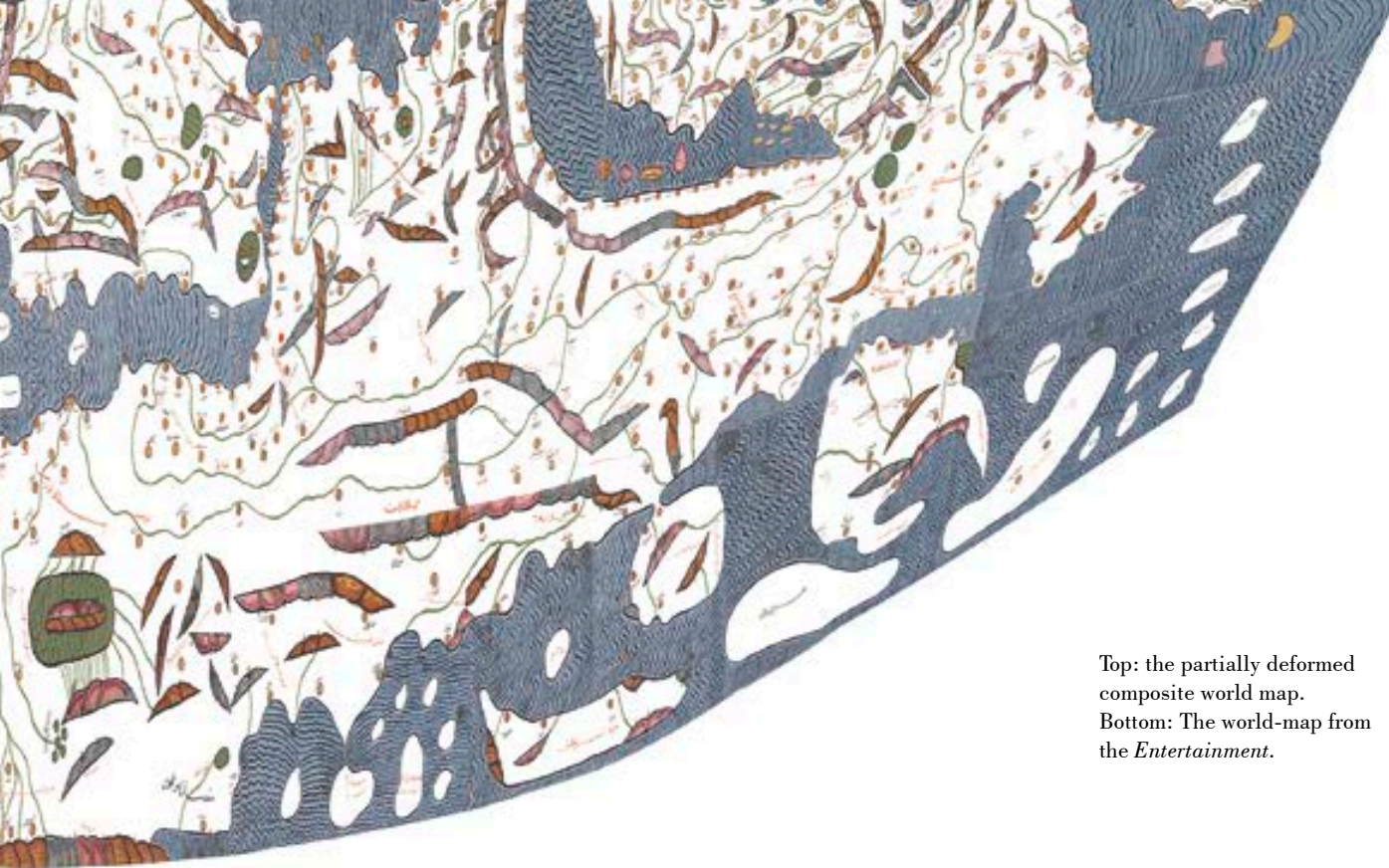
Top: the partially deformed
composite world map.
Bottom: The world-map from
the *Entertainment*.
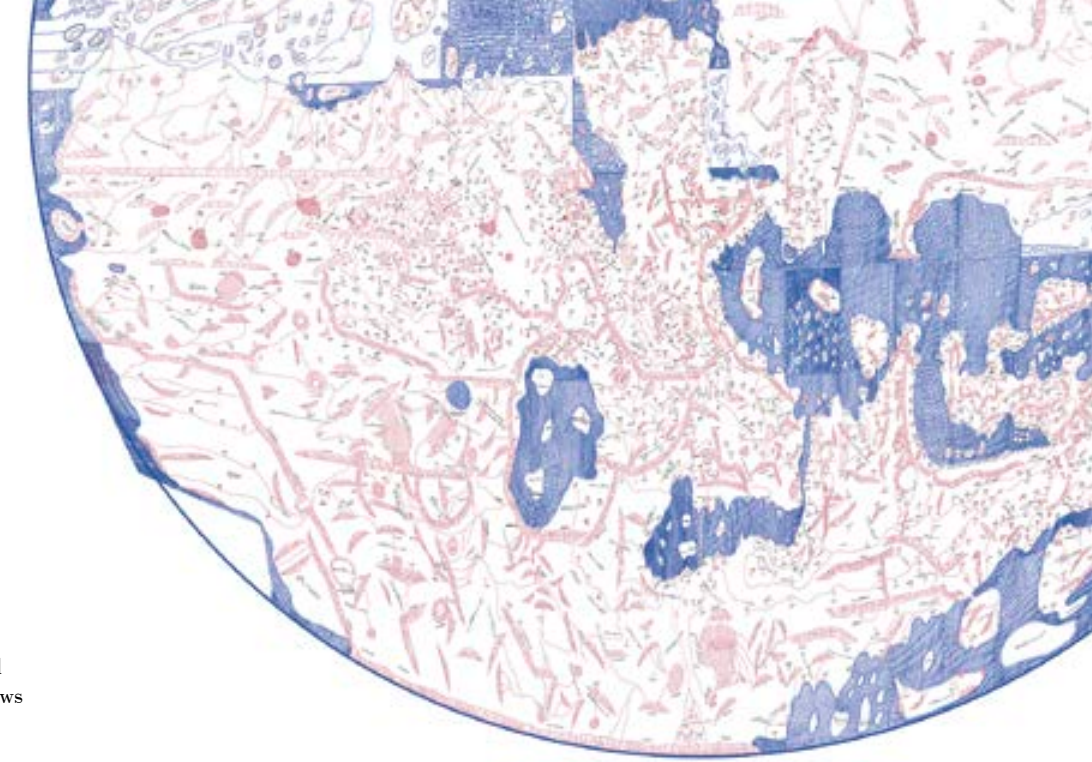
Top: the world map in vectorised
form, one of the steps which allows
it to be reproduced using CNC-
milling. Bottom: test in copper.
Engraving in silver.

Raphael's 'Lo Spasimo di Sicilia'

Location Museo del Prado, Madrid; Santa Maria dello Spasimo, Palermo
Client Peter Glidewell
Date 2018-present
Materials of original oil paint removed from wooden panel and remounted on canvas
Main recording techniques panoramic photography
Main output technologies CNC-milling, hand sanding, flatbed printing
Materials of copy medium density polyurethane fixed to Alucore board, pigment
Project Funding Factum Foundation with support from Peter Glidewell

Factum Foundation's version of Raphael's painting *Christ Falls on the Route to Calvary* (1515-16), more often known as 'Lo Spasimo di Sicilia', is not a facsimile in the usual sense, but rather a re-creation of the artwork which reinterprets it in the light of an earlier stage in the object's trajectory.

The original artwork, which was painted onto a wooden board, was made for the Sicilian monastery of Santa Maria dello Spasimo in Palermo. Legend has it that it was shipwrecked on the boat to Sicily in 1520 – an event which has since been regarded as proof of its miraculous powers. It was bought from the monastery by Philip IV of Spain in 1561, but in 1813, during the Peninsular War between France and Spain, it was removed to Paris, where, in line with one of the most popular conservation practices of the period, the oil paint was removed from the board and fixed to canvas. In 1819, when France was forced to repatriate many artworks looted during the Napoleonic Wars, the painting returned to the Spanish royal collections, which in that year were opened to the public for the first time as the Museo del Prado.

Factum Foundation's experimental project re-materialises the painting as a work on rigid boards, a suggested 're-creation' which seeks to recover the original surface character of the artwork. Subjective decisions were made throughout this process, which is reflective of Factum's understanding of originality as a dynamic trajectory, in which a digitally mediated version can add value to, and enhance our understanding of, the "original" artwork in its current state.

The first stage in the process was to record the painting in the Museo del Prado using high-resolution panoramic photography, resulting in an image file with a resolution of 350 ppi at 1:1 scale. Both digital and physical techniques were employed to ensure an accurate recording of the colour of the work.

Subsequent stages involved a greater degree of choice. Throughout the re-creation, decision making was based on conversations with the Prado's conservators and on a detailed understanding of the production and behaviour of oil-painted wooden panels from the period. Examination of contemporary paintings led to the realisation that the original panel would probably have been concave in shape, while an infrared spectrograph image provided by the Prado showed a series of three roughly parallel lines crossing the painting from top to bottom, indicating that the panel was formed of four sections with varying widths. Based on the available information, the panel was digitally modelled in 3D and then materialised with CNC-milling in medium density polyurethane, which was fixed to an Alucore board for stability. The surface was hand-sanded and finished to simulate the undulations and natural movements of the wooden surface. Factum's custom-made relief-sensitive printer was used to rematerialise the painting's colour, and a coat of varnish was applied.

Now complete, the painting is ready to begin the voyage back to Santa Maria dello Spasimo, where it will be displayed in its original frame. It is hoped that this time no miracles will be necessary along the way.

With thanks to Peter Glidewell, Bernardo Tortorici di Raffadali (Presidente Amici dei Musei Siciliani), Miguel Zugaza, and Enrique Quintana, José de la Fuente and Cristina Alovisetti (Museo del Prado).
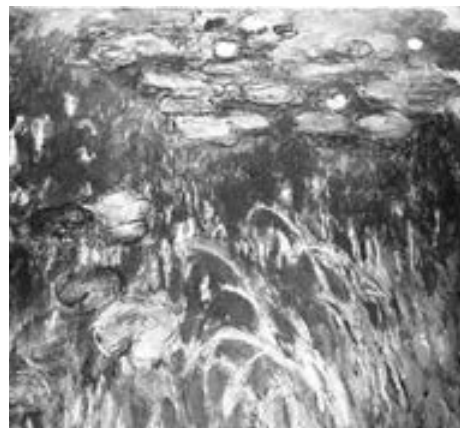
Clockwise from top: printing the artwork; the damaged original, which is held together in many places with protective gauze; the museum's only photo of the painting from before the fire; varnishing the finished work.

Lost Paintings: Monet's *Water Lilies*

Location Museum of Modern Art, New York
Client Sky Arts
Date 2017
Materials of original oil on canvas
Main recording techniques photogrammetry, Lucida 3D Scanner
Main output technologies Océ elevated printing, gesso cast, Factum relief printer
Materials of copy gesso, pigment
Project Funding Sky Arts

For the Sky TV series *The Mystery of the Lost Paintings*, Factum Arte recreated seven paintings which have been lost over the course of the 20th century, many during WWII. Remaining photographs, often in black-and-white only, and scans of similar paintings by the same artists, allowed digital and traditional artists at Factum to imaginatively reconstruct works such as Gustav Klimt's *Medicine* panel from the Great Hall of the Universität Wien, destroyed by retreating Nazi troops in 1945, or Vermeer's *Concert*, stolen in 1990 in Boston.

An eighth "lost" painting, Monet's *Water Lilies* (1916), was not in fact lost but instead badly burned in a 1958 fire in the Museum of Modern Art (MoMA) in New York. Only one conservation image of the painting exists from before the fire – but as it is in black and white it gives a very limited idea of a painting in which colour played a vital role. In a project which sits on the borderline between creative re-imagining and digital restoration, Factum Foundation recreated a version of this painting, reconstructing the appearance of the original as accurately as modern technology can allow.

The burnt canvas was first recorded using photogrammetry, and sections of it were captured using the Lucida 3D Scanner to corroborate the quality of the photogrammetry data. This data was rematerialised via Océ elevated printing as a plaster cast, and experts in Factum's sculpture department worked to level and integrate areas where the fire had caused the paint to bubble and distort, or where consolidation tape made it impossible to see the surface clearly.

The powerful flashes used to light the painting during the recording revealed far more usable data than initially expected: they showed remnants of colour hidden within the charred surface. Based on this information, it was decided to restore the painting digitally in Photoshop, cloning colour from areas where it was visible to those where the paint was burnt.

Reconstructing patched or severely damaged areas was more complex; here the existing black and white image was used as a guide when recreating shapes and brush strokes. The colours remaining on the canvas were checked against those of other paintings by Monet from the same period; while the turquoise and green shades remained unchanged, the blues had lost their original tones in the fire and needed to be corrected in order to recreate the appearance of the original. The modified colour data was printed onto the prepared gesso surface using Factum's relief-sensitive flatbed printer, and finished with rabbit glue varnish.

This project explores the limits of recovery possible for damaged objects, and raises questions about what we value in an artwork: whether it is more important to be able to see the painting as it originally looked, or whether it is more important to possess the original object, however damaged and distorted. It also raises the question of the recording of cultural heritage using the latest digital technologies: MoMA's decision not to record this painting using colour photography, even though that technology was available in the 1950s, means that it is much harder to reconstruct the appearance of the original. This is an issue which is still live today, and which is set into stark relief every time a fire or other natural or manmade disaster destroys badly documented sites, objects, or institutions.

With thanks to Jim Coddington, Lynda Zycherman, and Ellen Davis from MoMA, and to Hannelore Roemich, Shan Kuang, and Amelia Catalano from NYU.

John Baptist Jackson woodblocks

Location Palazzo Sturm, Bassano del Grappa
Client Palazzo Sturm, Bassano del Grappa
Date July 2018-present
Materials of original wood
Main recording techniques Lucida 3D Scanner
Main output technologies CNC router
Materials of copy resin
Project Funding Factum Foundation

In addition to recording and making facsimiles of finished works of art, Factum Foundation is interested in historical methods of art fabrication and technologies of image transmission – and in the possibility of recovering these methods for use today. It is in this context that the Foundation has made facsimiles of 24 woodblocks made by the 18th century artist John Baptist Jackson, and has used these woodblocks to make new versions of seven of Jackson's prints.

Jackson was one of the most innovative printmakers of the 18th century, creating embossed prints using a rolling press of his own construction, and developing new oil-based inks for use in polychromatic prints. Among other experiments, he revived Renaissance techniques of carving multiple woodblocks for a single print, printing in a separate colour with each one to give depth to the reproduced images. The 24 woodblocks recorded by Factum Foundation are now in the Remondini Collection, a major collection devoted to prints and printmaking at the Palazzo Sturm in Bassano del Grappa. They were used in the production of Jackson's book *Titiani Vecelii, Pauli Galiarii, Jacobi Robusti et Jacobi de Ponte opera selectiora*, considered a monument of 18th century printing, which reproduced seventeen of the greatest Venetian paintings by Titian, Tintoretto, Veronese, Leandro da Ponte Bassano, Jacopo Bassano, and Francesco da Ponte Bassano. Several blocks were used for each print, and the 24 preserved blocks would have been used to print seven images in total.

After scanning the woodblocks with the Lucida 3D Scanner, Factum Foundation rematerialised them as facsimiles, using a CNC-milling machine to rout blocks of wood into the shapes of the originals. Factum's expert printmakers then used these blocks to print facsimile versions of Jackson's original prints. Factum Foundation also used high-resolution photography to record the museum's entire corpus of drawings and chiaroscuro woodcuts by Jackson. Among these is the woodcut print of Veronese's *Wedding at Cana*, which was also one of the first paintings rematerialised by Factum in 2007.

With thanks to Luigi Gollin from Palazzo Sturm and Roberto Dalle Nogare from the Museo Civico di Bassano del Grappa.

The finished facsimile prints. Opposite page: (top row) routing the woodblocks using a CNC-milling machine; routing in fine detail; (second row) inking a block; printing; (bottom) the four separate inked blocks used for a single print.

Soane's Ark: Building with Symbols

Location Foyle Space, Sir John Soane's Museum, London
Partner Sir John Soane's Museum; United Grand Lodge of England; Houghtons of York
Date 11th October 2017 - 21st January 2018
Materials of original mahogany
Main output wooden facsimile, exhibition
Materials of copy mahogany
Project Funding United Grand Lodge of England / Factum Foundation

To coincide with the tercentenary of the establishment of freemasonry in London in 1717, Factum Foundation organised an exhibition in Sir John Soane's Museum exploring the celebrated English architect's relationship with the masonic order. The exhibition was curated by Ferdinand Saumarez Smith. Its centrepiece was a reconstruction of a piece of ritual furniture which Soane designed for the freemasons in 1813, but which was destroyed by fire in 1883: the Ark of the Masonic Covenant. The Ark was an ornamental cabinet intended to hold the document that concluded the union of the 'Ancient' and 'Modern' Grand Lodges, two rival organisations of freemasonry that had emerged in the course of the 18th century. In its translation of a historical design into a three-dimensional object, the exhibition may be seen as a sequel to Factum Foundation's 2014 exhibition at Sir John Soane's Museum, 'Diverse Maniere: Piranesi, Fantasy and Excess', which likewise translated a number of Giovanni Battista Piranesi's furniture designs into three-dimensional objects through rapid prototyping techniques and traditional craft skills. Factum Foundation used the extant documentation of the original Ark to reconstruct its form, which was then produced by master carvers and joiners at Houghtons of York.

With thanks to our colleagues at the Soane Museum, the United Grand Lodge of England, and Houghton's of York.

V. TRANSFORMATIONS

"Factum Arte presents museum visitors with an opportunity to understand the poetic powers that museum authorities use when they display historical accounts through their curatorial decisions, while also inviting visitors to think about the epistemological obstacles that artisans must overcome (such as museology's policing of fact and fiction) when they set out to reproduce a historical object."

Bryan Markovitz,
Verum Factum Arte: Scanning Seti and the Afterlife of a Pharaonic Tomb, 2020

Tolkien's Map of Middle-earth

Client Bodleian Library
Date 2017-2018
Main output technologies routing on methacrylate resin
Project Funding Bodleian Library / Factum Foundation

In late 2017, Factum Arte was commissioned by the Bodleian Library in Oxford to create a relief map of J.R.R. Tolkien's Middle-earth for an exhibition on the esteemed writer's drawings. The exhibition, 'Tolkien: Maker of Middle-earth' was on show in the Weston Library in Oxford from June to October 2018.

The brief was broad and the team had wide scope for creativity. What Factum produced was a physical relief map, made from translucent metacrylate resin, featuring a front and back projection that was mapped to the relief.

The back projection came from an 85" flat-screen TV and the front projection came from a ceiling mounted projector. The projection displayed the geography, topography, and the journeys of the protagonists of the Lord of the Rings trilogy.

The map was set into a solid black plinth and bordered by aluminium panels inscribed, in the original Black Speech and Elven Tengwar characters, with the iconic poem from the side of the titular Ring: 'One ring to rule them all; One ring to find them; One ring to bring them all; And in the darkness bind them.'

With thanks to Madeline Slaven and Catherine McIlwaine at the Bodleian Library.

The finished map on show in Oxford.

The Blind Photographer

Client Redstone Press
Date 2016
Main output technologies 3D printing, woodburytype printing, digital printing
Project Funding Galerie Huit / Factum Foundation

In 2016, Factum Arte worked with Redstone Press to create ten prints for the exhibition 'The Blind Photographer' at the Galerie Huit in Arles. The prints are based on images from Redstone's book of the same name, and each is based on a photograph taken by a blind or partially sighted photographer, which is reinterpreted as a tactile image-object. The ten prints use different processes and materials, and range from 3D prints to Woodburytypes, a 19th century print-making process revived by Constanza Dessain at Factum over the last few years. Displayed alongside the original photographs, the prints made it possible for blind and partially-sighted visitors to the exhibition both to gain a sense of the photographs and to experience something different altogether. One of the prints is now in the Photographer's Gallery in London.

VI. THE THEBAN NECROPOLIS PRESERVATION INITIATIVE:

THE FIRST TEN YEARS

Detail of the inside of the sarcophagus of Seti I (3D render).

"The gift of the facsimile is a metaphor for the relationship between Europe and Egypt - the skills and technology that have been developed in Europe to create the facsimile are going to be transferred to Egypt where the local workers will be trained and those very skills and technology will become Egyptian."

Baroness Ashton, EU High Representative, on the occasion of giving the facsimile of the Tomb of Tutankhamun to Egypt; Cairo - November 14th 2012

10 YEARS OF FACTUM FOUNDATION IN LUXOR

Top: Reliefs for the facsimile of Seti's tomb.
Bottom: The Theban Necropolis Preservation Initiative team recording with two Lucida 3D Scanners in 2019.

2019 marks the 10-year anniversary of the Theban Necropolis Preservation Initiative (TNPI), a collaboration between Factum Foundation and the University of Basel under the aegis of the Egyptian Ministry of Antiquities. Over the past decade, the TNPI has worked to record and rematerialise major monuments in the Valley of the Kings and to develop sustainable ways of conserving Egyptian cultural heritage using non-contact digital technology. As of early 2019, Egyptian staff are in charge of all operations on the ground and external involvement is focussed on capacity development, training, support and technology transfer.

The TNPI and Factum Foundation were formed to record the Tomb of Tutankhamun in 2009, following work by Factum Arte in the Tomb of Seti I in 2001 and a project in 2002 to build a replica of the Tomb of Thutmosis III. The recording of Tutankhamun's tomb was carried out with the University of Basel as academic partner and in collaboration with Erik Hornung and Theodor Abt from the Society of Friends of the Royal Tombs in Egypt.

In 2012, a physical facsimile of the burial chamber of Tutankhamun was given to the people of Egypt by the EU High Representative Baroness Ashton. It was presented to the Prime Minister of Egypt at a special event at the Conrad Hotel in Cairo, organised by the European Union.

In 2014 the facsimile was installed in an underground building designed by the Tarek Waly Center for Architecture & Heritage next to Carter's House at the entrance to the Valley of the Kings. The project was funded by Factum Foundation. Tutankhamun's burial chamber and the associated exhibition have been open to the public since 2014, allowing many tourists to see both the original tomb and its facsimile and understand the problems of preserving sites that were never meant to be visited.

In 2016, the complete recording of the Tomb of Seti I began and the first local Egyptian operators were trained. In parallel with this, painted wall fragments and other objects which had been removed from the tomb were recorded at museums and in private collections across Europe and the US.

In October 2017 the exhibition 'Scanning Seti: The Regeneration of a Pharaonic Tomb' opened at the Antikenmuseum in Basel, marking the bicentenary of the discovery of the tomb and demonstrating the potential of high-resolution recording to transform our understanding of historic sites.

Also in 2017, the restoration of Hassan Fathy's Stoppelaëre House, a building of great architectural significance at the entrance to the Valley of the Kings, was completed. This restoration was carried out by Tarek Waly Center and funded by Factum Foundation in exchange for free use for 10 years; the house now functions as the base for the TNPI and a new 3D Scanning, Archiving and Training Centre.

In 2018, Factum Foundation began equipping the new Centre in Stoppelaëre House with state-of-the-art scanning, data processing and archiving equipment. This work is ongoing and the server to store the data will be installed in October 2019.

In February 2019, the TNPI team moved into Stoppelaëre House and recording work restarted in the Sarcophagus Room within the Tomb of Seti I. A training program has begun at the Centre which by 2022 will see ten Egyptian students complete training in a range of recording technologies.

The TNPI's work will continue until the high-resolution recording of the Tomb of Seti has been completed. The 3D Scanning, Archiving and Training Centre will also offer services to the Ministry of Antiquities and other foreign Missions working in the area. This will provide a sustainable work flow and economic security for the locals who are trained in the documentation of cultural heritage. As the project develops, the digital data generated will be stored locally, owned by the Ministry of Antiquities and made accessible globally.

The following articles describe in more detail some of the major projects carried out by the TNPI over the last three years. Further information can be found on the Foundation's website, where books, articles, videos and virtual tours expand on the discussions in this section.

Restoration of Hassan Fathy's Stoppelaëre House

In order to house the TNPI's new 3D Scanning, Archiving, and Training Centre, Hassan Fathy's Stoppelaëre House, a significant work of 20th century architecture (completed 1951) positioned at the entrance to the Valley of the Kings, was restored by Factum Foundation and the Tarek Waly Centre. In exchange for this work, the TNPI has been granted the use of the building for 10 years.

As the house had been abandoned for some time, major structural interventions were necessary to ensure the building's future stability. Underground concrete reinforcements around the perimeter of the house were completed, and the roof and walls underwent major restoration. The focus throughout was on preserving the detail and the overall character of Fathy's original building while ensuring that it was fit for its new role as a digital conservation training centre: although new electrical wiring, plumbing and air-conditioning, as well as German dust-proof windows, were installed to fit the house for its new function, the restorations were performed using locally-made mud-brick and the doors and lattice work were all remade by local carpenters.

The restored building was opened on Friday, February 2017, with the opening ceremony attended by the Egyptian Minister for Antiquities, Khaled El Enany, the Director General of UNESCO, Irina Bokova, and the Swiss Ambassador Markus Leitner.

Details of the restored Stoppelaëre House and the TNPI team beginning training with the Lucida 3D Scanner.

3D Scanning, Training, and Archiving Centre in Stoppelaëre House

Following its restoration, Stoppelaëre House has become the base for the Theban Necropolis Preservation Initiative (TNPI), an initiative to train a local, Egyptian team in the skills necessary for digital preservation, such as high-resolution scanning, composite photography, data processing and archiving. The training program has emerged from a partnership between Factum Foundation and the University of Basel, working under the supervision of the Egyptian Ministry of Antiquities, and the centre as well as the training program are run by Aliaa Ismail. The first two operators have now completed their training, and in February began to assist Aliaa Ismail in the 3D scanning of works at the Tomb of Seti. Between 2019 and 2021, ten students in total, selected from 26 applicants nominated by the Ministry of Antiquities, will be trained in the skills necessary to record objects and buildings within the Valley of the Kings. Although Factum specialists are available to offer back-up support where necessary, the project is now fully run and operated by Egyptian digital conservators and students, and a foundational assumption of the Centre and of the TNPI more broadly is that the development of local skills and the local economy are vital for the recording and preservation of cultural heritage.
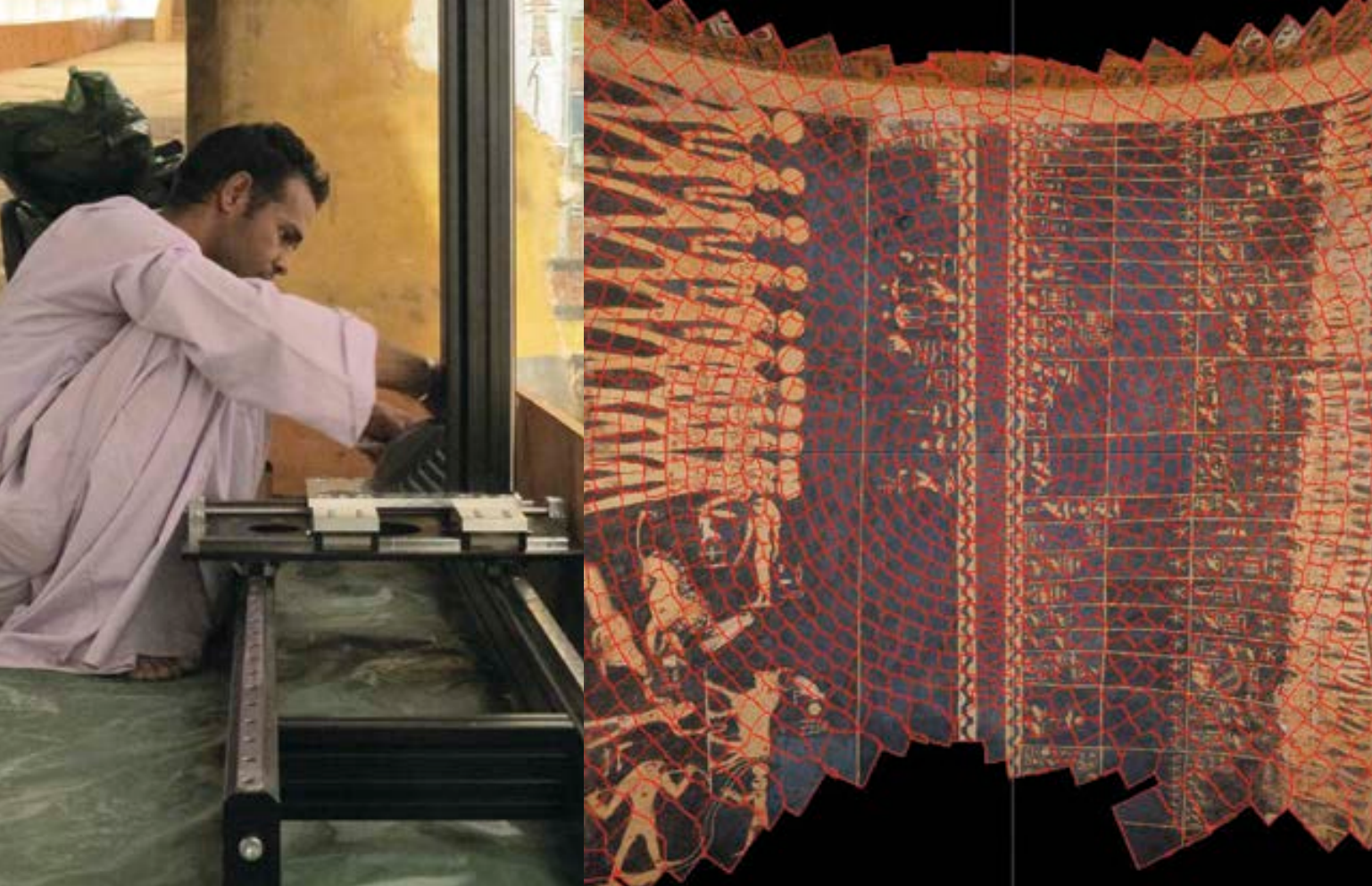
Left: setting up the Lucida 3D Scanner inside Seti I's tomb. Right: processing the panoramic photography data to map the colour of the sarcophagus hall ceiling.

Scanning Seti's tomb

Location The Tomb of Seti I, the Valley of the Kings, West Bank, Luxor
Partner Egyptian Ministry of Antiquities, University of Basel and the Friends of the Royal Tombs of Egypt
Date 2016
Materials of original painted stucco on limestone
Main output Océ elevated printing, CNC routing, colour printing
Materials of copy polyurethane resin, layered UV-curable ink, pigments
Project Funding Factum Foundation

The scanning of the Tomb of Seti is one of the most complex projects ever carried out by Factum Foundation, encompassing not only the tomb as it stands today, but also the thousands of fragments excavated from it, some of which are no longer in the Valley of the Kings or even in Egypt.

In 2016, a complete survey of the tomb was carried out with a medium/long-range scanning system from over 70 different scan positions, significantly improving on the previous recordings of the Theban Mapping Project. Throughout 2016, two or three Lucida 3D Scanners could be found working in the tomb at any one time, resulting in complete close-range recordings of the Hall of Beauties and Pillared Hall J. FARO scanners, photogrammetry and panoramic photography were used to record areas whose contours made it impossible to scan them using the Lucida.

This data allowed the making of a digital model and a small-scale physical model of the whole tomb (shown in the exhibition Scanning Seti), as well as a full-size facsimile of the Hall of Beauties, one of the most famous chambers from the tomb, and Pillared Hall J.

Scanning fragments from the Tomb of Seti I

Location Valley of the Kings; Paris; Florence; Boston; Berlin; London
Partner Egyptian Ministry of Antiquities; Universität Basel; Musée du Louvre; Galerie Eberwein; Museo Archeologico di Firenze; Museum of Fine Arts Boston; Ägyptisches Museum Berlin; British Museum
Date 2017-2018
Materials of original painted stucco
Materials of copy Océ digital print, SLA 3D printing resin
Main recording techniques Lucida Laser Scanner, photogrammetry
Main output technologies Océ elevated printing, SLA 3D printing
Project Funding Factum Foundation / University of Basel

The main current aim of the TNPI is to scan all known fragments from the Tomb of Seti. Recent excavations (1998-2005) in the nearby Tomb of Ramesses X brought to light around 8,000 decorated fragments from the Tomb of Seti I, while further large fragments unearthed in earlier excavations were found inside Seti's tomb itself. In addition to recording all of these fragments, the TNPI is assisting with the computer visualisations that will help the team from Basel to study them and to piece together larger sections.

In 2016-17, Factum Foundation scanned all of the fragments known to have been removed from the tomb and sold outside Egypt by Belzoni – which are now located in museums and a private collection in Boston, Paris, Berlin, Florence and London. The assembly of these fragments within a single archive will allow Egyptologists working on the tomb to make connections between its different parts more easily than ever before. Factum Foundation is also seeking to record any known existing squeezes (an invasive 19th century conservation technique) – examples of which are thought to exist at the MFA in Boston and at the British Museum. These squeezes contain vital evidence about the surface of the tomb and also help us to understand damage to the reliefs caused since their excavation in 1819.

In addition to allowing Egyptologists to better reconstruct the original state of the tomb, the juxtaposition enabled by the digital recording of fragments allows those interested in the history of restoration to make detailed comparisons between the modes of conservation and restoration practiced in different museological traditions. Two panels from the same column of the tomb, for example, one in the Musée du Louvre and one in the Museo Archeologico di Firenze, now very different in appearance, offer a stark reminder of the choices and changes made by restorers – arguably telling us more about the aesthetics of the 19th century than about those of the 19th dynasty.

Top: finishing the facsimile. Bottom: recording in Sir John Soane's Museum.

The facsimile of Seti's sarcophagus

Location Sir John Soane's Museum
Partner Sir John Soane's Museum
Date 2016
Materials of original alabaster
Main recording techniques photogrammetry
Main output CNC-milling, Océ elevated printing
Materials of copy resin, high-density polyurethane
Project Funding Factum Foundation

The facsimile of Seti's sarcophagus, materialised in summer 2017 from recordings made in 2016, was another extremely challenging project. It's completion resulted in significant innovations to previously existing printing technology.

After its discovery by Belzoni in the tomb in the Valley of the Kings in 1817, Seti's sarcophagus was brought to London. When the British Museum declined to buy it the sarcophagus was sold to John Soane, and it subsequently formed the centrepiece of the collection at his house on Lincoln's Inn Fields. In 1825, Soane held three parties for his society friends during which the semi-translucent, carved alabaster sarcophagus was illuminated by the light of candles placed inside it, and the Soane museum still organises monthly candlelit tours today, creating a resonant – although certainly not an Egyptian – set of viewing conditions for the tomb of the 13th century BCE pharaoh.

200 years after its discovery by Belzoni, Factum used photogrammetry to create a detailed digital model of the sarcophagus for the Soane Museum. The reflective surface of the alabaster complicated the recording process, and it took five days in all to record the sarcophagus. The resulting RealityCapture model, made up of 2.7 billion polygons, was displayed as part of an exhibition at the museum.

Factum Foundation has also created a facsimile of the sarcophagus. CNC routing was used to carve a full-size model of the sarcophagus box in high-density polyurethane, and a 'skin' was printed using Océ's elevated printing method, which was able to reproduce the 3D data from the surface of the sarcophagus with perfectly registered colour. The maximum thickness of Océ's prints is usually 5mm, but a combined effort on the part of Océ and Factum engineers over the course of this project enabled the printing of sheets with a thickness of up to 1.5cm. The 'skin' was printed in multiple different sections, which were integrated onto the surface of the polyurethane by skilled restorers using acrylic putty, acrylic paint and watercolour. The surface was finished with natural waxes in order to imitate the varied gloss of the original alabaster.

The facsimile was unveiled at the exhibition "Scanning Seti: The Regeneration of a Pharaonic Tomb", and has since been exhibited as part of the exhibition "Images of Egypt" at the Museum of Cultural History in Oslo.

Left: digital 3D model of the sarcophagus produced using photogrammetry. Right: the goddess Nut from the inside of the sarcophagus, picked out in the blue paint whose traces were found on the original.

Reconstruction of the 'Hall of Beauties' as it appeared to its first excavator Belzoni.

Visualising the damage caused by the taking of plaster 'squeezes' in the 19ᵗʰ century.

Exhibition "Scanning Seti: The Regeneration of a Pharaonic Tomb"

The exhibition "Scanning Seti: The Regeneration of a Pharaonic Tomb" took place at the Antikenmuseum Basel from October 2017 to May 2018; it was a collaboration between Factum Foundation, the Antikenmuseum, and the University of Basel, with design by Skene Catling de la Peña. As well as showcasing the recording work done by Factum Foundation in the Tomb of Seti, the exhibition proposed a new way of exhibiting the past, challenging the authenticity of the historic objects displayed in modern museums, and even the authenticity of a visit to Seti's tomb as it now stands.

The final room of the exhibition contained Factum Foundation's facsimile of the Hall of Beauties as it is today. But before they reached this "real" copy of the tomb, the visitor was asked to go through a whole process of re-discovery, framing their encounter with the plaster gods on the walls through the processes of desecration and display by which this tomb has come down to us. One room, lit with battery-operated candles, allowed visitors to see the Hall of Beauties in the state in which it was discovered by Belzoni, reconstructed on the basis of watercolours made by Belzoni and his colleague Alessandro Ricci. Another room staged a visceral encounter with the damage caused by plaster squeezes, a favoured 19ᵗʰ century recording method, and used projection mapping to show the loss of colour from the famous relief of the heavenly cow, which was once painted in a lustrous yellow ochre. Hacked-out fragments were set into the context of their original reliefs, and in one case a series of facsimiles were brought together to recreate a relief which since its destruction and dispersal by 19ᵗʰ century excavators has existed only as mutilated fragments.

For the first time since its removal by Belzoni it was possible to see the sarcophagus of Seti alongside painted reliefs from the tomb itself – all facsimiles, but allowing a contextualised viewing impossible in the sarcophagus' current location in Sir John Soane's Museum in London, where it is inevitably subordinated to the compelling master-narrative of Soane as collector and creator.

While the exhibition was not able to replicate every aspect of a visit to the Valley of the Kings, in some senses at least it offered viewers an even richer and more multilayered understanding of Seti's tomb than would be available to them in Luxor – and without any of the damage inevitably caused to the original tomb by tourism. The Tomb of Seti may have been built to last for eternity, but it was not built to be visited.
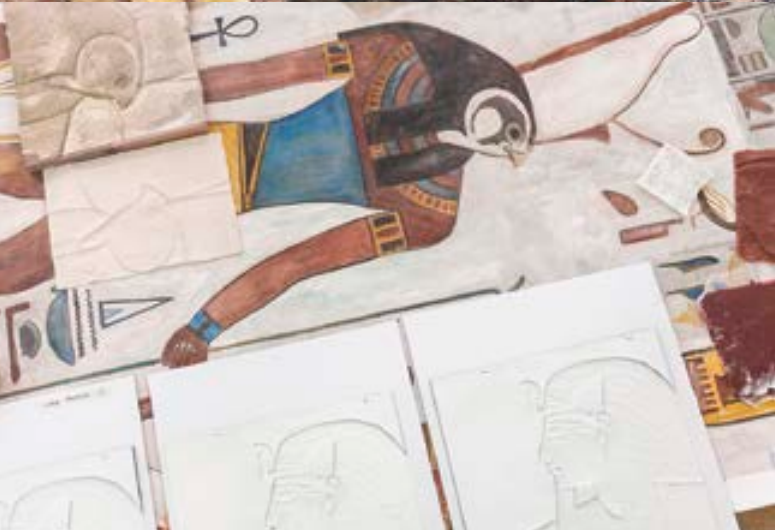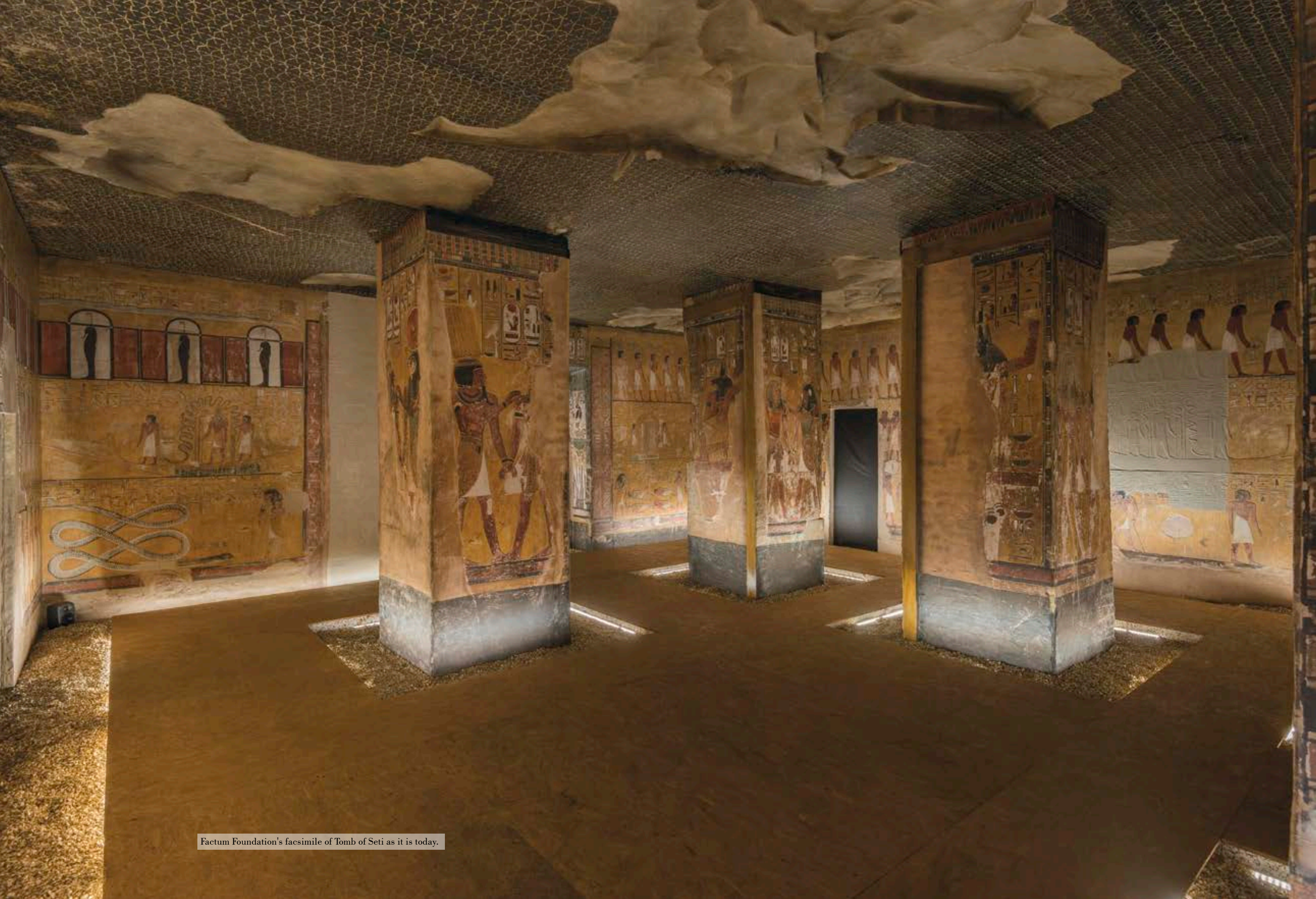
Factum Foundation's facsimile of Tomb of Seti as it is today.

Facsimile of a funerary garden from the Twelfth Dynasty

Location Dra Abu el-Naga, Luxor
Partner Spanish National Research Council (CSIC)
Date 2018-2019
Main recording techniques LiDAR
Materials of original mudbrick
Main output CNC-milling
Materials of copy fibreglass & resin
Project Funding CSIC / Factum Foundation

Two other recent projects, carried out by Factum Foundation rather than the TNPI, have also concerned material from the Valley of the Kings: an early Twelfth Dynasty funerary garden and the Debod Stele.

The funerary garden recently excavated at Dra Abu el-Naga in Luxor is only the second Egyptian funerary garden ever to be excavated, and the first to have received proper archaeological documentation. Found in 2017 by a team led by the Spanish National Research Council at the entrance to a rock-cut tomb, this grid of 30 by 30 cm mud-brick squares is in a remarkable state of preservation, complete with 4000-year-old traces of pollen and seeds from lettuces, shrubs, and trees. But as a structure made up of mud-brick the garden is extremely fragile, and the act of excavating it already will already have resulted in irreparable changes to its constitution and stability. In order to keep it from further erosion, the decision was made to re-cover the original garden with a protective structure and to create a model of it to display in the same spot, so that visitors to the tomb can see what the garden looks like without the garden itself undergoing further deterioration.

The garden was scanned using LiDAR equipment in a collaboration with Leica Geosystems. The data was rematerialised in high-density polyurethane using a 3-axis CNC-milling machine working at a resolution of 200 microns. The polyurethane base was covered in 4 layers of fibreglass and in the resin *Acrylic One*, which was mixed with sand in order to provide maximum resistance to the elements. The details of the walls, the soil within each square, and a remaining tree-stump (still in place as a result of the remarkable preservation conditions in the Valley of the Kings) were then sculpted in resin coloured with natural pigments. Six different colour mixtures which had been matched with soil samples taken from the original garden were incorporated into the model, allowing it to emulate the coarse, crumbling appearance of the original. This model is a copy and not a facsimile; its dimensions are not identical to those of the original, although the two bear a close resemblance to one another.

Following its installation, the model will offer visitors the chance to see the garden as it looked in 2017. In this sense it is an artefact of contemporary archaeological interpretations and decisions as much as it is of a Twelfth Dynasty garden; particularly with a context made up largely of soil, the decision of where to stop removing earth and start recording is always a subjective one. A recording of the sort made by Factum Foundation could never hope to reproduce the living garden itself, though perhaps a different sort of "copy" would seek to replant the original plants in a rebuilt structure made of mudbrick. The model is designed to last for at least 10 years.

The facsimile funerary garden installed on top of the original.

Debod Stele

Location Dra Abu el-Naga, Luxor; Templo de Debod, Madrid
Partner Spanish National Research Council
Date 2018
Materials of original mudbrick
Main output model of stele
Materials of copy low-density resin
Project Funding CSIC / Factum Foundation

In 2018, the archaeological mission led by the Spanish National Research Council (CSIC) at Dra Abu el-Naga, Luxor, provided Factum Foundation with a LiDAR recording of a stele from the entrance to Djehuty's tomb. Using this data, Factum Foundation created a copy of the stele for exhibition in an Egyptian writing workshop organised in the Templo de Debod in Madrid, routing the model in low-density resin which was retouched and patinated to resemble the original. As LiDAR scanning is a recording method which cannot capture the details of surface relief, however, the carvings and writing on the stele had to be traced again, meaning that Factum's copy cannot be described as a true facsimile.

Working on the routed resin surface.

TRAINING

"The V&A's founding director, Henry Cole, showed great foresight with his 1867 Convention calling for the 'mutual exchange of copies'. Plaster casts, electrotypes and photographs were shared acreoss European collections for widespread educational benefit."

Dr.Tristram Hunt, Director of the Victoria and Albert Museum

TRAINING

Factum Foundation takes an open, non-proprietary approach to skills and technologies, aiming to teach the expert recording of cultural heritage objects and sites as widely as possible. We focus particularly on transferring skills and technologies to communities outside European and North American institutions and traditions of cultural heritage, developing and sustaining long-term, mutually informative relationships and ultimately aiming to make our partners self-sufficient in their use of recording technologies. The section on Egypt elsewhere in this book describes one such successful collaboration, while articles in this section document a collaboration with the Peri Foundation in Dagestan and an ongoing collaboration with Art Jameel in the Kingdom of Saudi Arabia.

We also seek to integrate digital restoration into mainstream academic and professional conservation practice in Europe and America. A major training initiative of the last three years has been the course taught by Factum Foundation experts as part of the Historic Preservation masters degree at Columbia University. The incorporation of such a course into a formal graduate curriculum means that those training for careers in historic preservation will now be able to incorporate digital recording and restoration into their practice and into their sense of the field of historic preservation as a whole.

A third strand of training is described below in the article on the Factum-Frontline initiative. In contrast to the formal academic structure provided by GSAPP at Columbia or the varying contexts of local partnerships, Factum-Frontline takes advantage of existing structures in international media reporting, offering training to journalists who already possess the correct equipment and are present in places where threatened cultural heritage is located, and encouraging them to use skills such as photogrammetry to supplement more traditional modes of documentation and reportage. It is a collaboration which illustrates well Factum's willingness to explore unconventional avenues and to fit into existing networks in an effort to ensure that the world's cultural heritage can be recorded as widely and as responsibly as possible.

Al-Balad Jeddah

Location Jeddah, Kingdom of Saudi Arabia
Date 2017
Client Art Jameel
Main recording techniques photogrammetry and LiDAR
Project Funding Art Jameel

Factum Foundation's first project in the Arabian peninsula took place in March 2017. The trip was a pilot project with Art Jameel, an organisation based in Jeddah and Dubai which promotes a broad range of arts and educational initiatives across the Middle East and North Africa. The project was to record parts of Al-Balad, the old town of Jeddah, and to provide a short introductory training in photogrammetry to the students of the Jameel House of Traditional Arts. The aim of the course was to illustrate the ease with which technical know-how of photogrammetry can be passed to local people.

Using a LiDAR scanner and photogrammetry the team recorded the façades and gypsum relief carvings of eight buildings. Many of the buildings in the old town are an extremely bad state of conservation, and there are frequent collapses, meaning that the data captured constitutes a valuable record of this fast-changing urban environment.

The team also conducted a three day training course for the students at Art Jameel's school, the Jameel House of Traditional Arts. Twelve students from the school, all women, were taught the basics of photogrammetry capture and were able to put their newfound skills to the test recording doorways around the old town.

AlUla

Location AlUla, Kingdom of Saudi Arabia
Client Royal Commission of AlUla and Art Jameel
Date 2018
Main recording techniques photogrammetry
Project Funding Lord Rothschild

Following the success of the project in Al-Balad, Factum Foundation partnered again with Art Jameel to conduct a training course in the town of AlUla in the north of Saudi Arabia. Under the stewardship of the Royal Commission of AlUla, a member of the Factum Foundation 3D recording team was sent to AlUla to teach 16 local residents of both genders how to record cultural heritage using photogrammetry.

Once again, the aim was to illustrate the efficacy of teaching photogrammetry to local people, who are better placed than outsiders to record at risk cultural heritage. This is especially important as the Royal Commission is currently exploring ways of opening the region to tourism in a sustainable manner.

Following a two-day introductory classroom lesson, the team were taken into the field to record at three different sites. The first site is closed to visitors and consists of a valley filled with epigraphy from the pre-Islamic Lihyanite civilisation. The second site is covered in petroglyphs depicting oxen, camels and ostriches; it had only recently been surveyed by archaeologists. The final site was well known to locals and still easily accessible; it was a canyon containing epigraphy which stretched from the Lihyanite period to the modern era and featured inscriptions in Aramaic and very early Arabic.

Over 4TB of high resolution recording of the inscriptions and rock faces were returned to Madrid for processing.

Factum Foundation aims to return to AlUla in 2019 to continue the training and to set up a training and recording centre, empowering local people to record and protect their own cultural heritage.

Training in Russia

Location Madrid, Kala-Koreysh and Vologda
Client Peri Foundation
Date 2015-2017
Main recording techniques photogrammetry, Lucida 3D Scanner, panoramic photography
Project Funding Peri Foundation

In 2015, Factum Foundation worked with the Peri Foundation to run a training initiative with two photographers from Dagestan, Gennady Viktorov and Shamil Gadzhidadaev. The training began with a month of hands-on digitisation activities in Madrid, which was followed by a recording trip to Kala-Koreysh in Dagestan. Together with a team from Factum, Viktorov and Gadzhidadaev used photogrammetry to 3D record the tombstones at the Mosque of Kala-Koreysh and were later involved in processing the results. This was followed in 2017 with the project at the Ferapontov Monastery, where they took a leading role in the digitisation. They were also instrumental in teaching two photographers from Vologda the recording tools and methods mastered at Kala-Koreysh.

The initiative has demonstrated the effectiveness of dynamic, on-the-ground training for cultural heritage digitisation, as well as the importance of involving local individuals in conservation schemes. The transfer of new skills and technologies means that the preservation of cultural heritage can continue even after a particular project has ended.

Both Viktorov and Gadzhidadaev have since gone on to use the skills learned at Factum in their own projects. From taking on aerial photogrammetry with drones, to obtaining a government grant to digitise paintings at an important museum in Makhachkala, Dagestan, they have made the technologies their own.

With thanks to our colleagues at the Peri Foundation, the Ethnographic Complex Dag-Aul and Mrs Zumrud Suleymanova.

The team from Factum Foundation were joined by two Dagestani photographers, winners of the competition 'Cultural Heritage 2.0'.

Opposite page (clockwise from top): the recording of the entire hilltop was completed in just over two weeks; 3D model of one of the tombstones; photogrammetric 3D drone-recording.

Advanced Preservation Technology Studio at GSAPP, Columbia

Location GSAPP, Columbia University, New York
Client GSAPP, Columbia University
Date 2016-present
Main recording techniques Lucida 3D scanning, photogrammetry, panoramic photography, LiDAR 3D scanning
Project Funding Columbia University

The Advanced Preservation Technology Studio at the Graduate School of Architecture, Planning, and Preservation (GSAPP) at Columbia University is a course which has been taught by Adam Lowe and Carlos Bayod for the last three years, with additional teaching support by Factum Foundation experts including Gabriel Scarpa, Anna Paola Ferrara, Irene Gaumé, Otto Lowe and Pedro Miró. It allows students on the Historic Preservation masters program at GSAPP to explore advanced applications of technology for digital preservation.

The Studio teaches several of the main technologies used by Factum Foundation, moving from recording (Lucida 3D scanning, close-range photogrammetry, composite photography or LiDAR 3D scanning) through processing (tonal imaging as relief information, photogrammetric processing, digital restoration) to physical output (CNC-milling, elevated printing). Training in the use of these methods is integrated into a practical course which requires students to design their own digital preservation projects, working both in teams and individually, and is focused on a specific historic site or sites each year. The artworks and buildings chosen are ones in which a study of surfaces can play a real role in understanding the objects and helping with their preservation, and projects involve a 'learning by doing' approach in which the students have access to Factum Foundation's expertise and equipment and participate in fieldwork – giving them the opportunity to make a real contribution to the field. The course encourages students to consider the use of digital technology within wider cultural, political and aesthetic contexts, and to integrate it into their understanding of historic preservation more broadly.

In 2016, the major recording project focused on the fragmented wall paintings of the hermitage church of San Baudelio in Soria in northeast Spain. The frescoes of this 11th century Mozarabic building were partially removed using the damaging strappato technique in 1922, and sections were sold to museums in Europe and the United States, including The Met Cloisters in New York. During the course, students conducted recordings both in the Cloisters and at the church itself, and worked on digitally restoring and reintegrating the dispersed fragments.

In 2017, recordings were conducted at sites in Venice including the Fondazione Giorgio Cini, where students documented several works from the collection, and the Basilica di San Marco, where their recordings of the famous trophy wall contributed to a larger research project into the basilica's marble cladding.

In 2018, the course focussed on the Casa de Pilatos in Seville, a unique palace largely built in the 16th century which combines Renaissance, Mudéjar, and Baroque styles and which houses a major sculpture collection. The project was carried out in collaboration with Fundación Casa Ducal de Medinaceli. Students used the Lucida 3D Scanner, close-range photogrammetry, composite colour photography and LiDAR 3D scanning to record the elaborately decorated walls of the palace, many of which are covered in 16th century ceramic tiles. They proposed digital restorations to damaged areas of the walls, and processed data in preparation for the rematerialisation of parts of the decoration using CNC-milling and Océ's Elevated Printing technology. The results of this work were exhibited at GSAPP at the end of the semester.

Factum Foundation has installed a Lucida 3D Scanner in GSAPP's Preservation Technology Lab to be used during the Studio and for any other initiatives of GSAPP. We have also been active in facilitating different fieldwork experiences for alumni of these courses, allowing the students to put in practice what they have learned as part of ongoing projects at institutions like The Metropolitan Museum or New York University (NYU).

Summer traineeships have also taken place in Factum Foundation's workshops in Madrid. In 2017, GSAPP students Halley Ramos and Andre Jauregui spent several weeks working on in different projects involving digital recording and data processing, among other things participating in the scanning of Powhatan's Mantle in Oxford. After graduation, Halley and Andre founded their own office dedicated to digital preservation, where they have focused much of their energy on developing an Augmented Reality application for the hermitage of San Baudelio.

The curriculum of the Advanced Preservation Technology Studio rests on the belief that digitisation should form an essential part of every conservation process. High-resolution surface data, used in combination with other relevant diagnostic techniques, can offer present and upcoming generations of preservation specialists unprecedented perspectives on the objects they seek to preserve, and it is vital that these important new voices are added to the discussion around the future development and use of digital technologies for the preservation of cultural heritage.

Left to right: damaged tiles in the Casa de Pilatos; a Factum Foundation instructor teaching students how to use photogrammetry software; practising photogrammetry; exhibiting the end results at GSAPP.
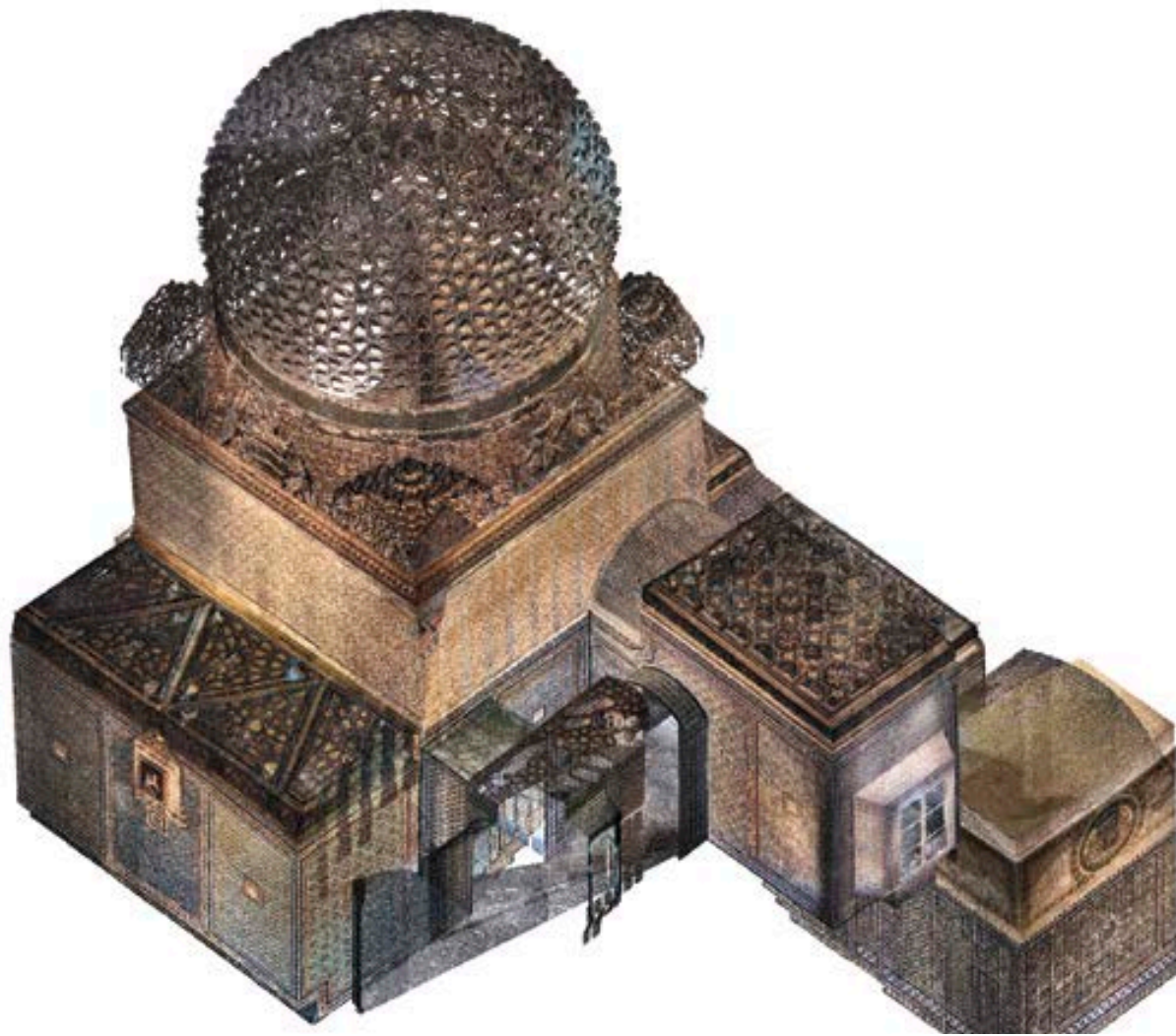
Point cloud of Casa de Pilatos,
Seville recorded using a
LiDAR laser scanner (top
left); elevation of the courtyard
(bottom left) and visualisations
of the staircase (right).

Factum Frontline

In collaboration with the Frontline Club in London, Factum Foundation has started developing an ambitious project to expand the international community's capacity to record at-risk cultural heritage, exploiting an existing niche to encourage the increased use of photogrammetry as a method of documenting sites and objects in hard-to-reach locations.

One of the main obstacles in training people to record using photogrammetry is the lack of access to good equipment for the trainee to use after training. Photographic equipment capable of recording to the required resolution is still beyond the capacity of many people to acquire, even if it is less expensive than the 3D systems available in today's market. The Factum-Frontline collaboration is based on the idea that photo-journalists already have access to good equipment and, through their work, are often in places of conflict with at-risk heritage sites. These journalists therefore already have the access, equipment and photographic know-how to easily learn and carry out photogrammetric recording.

The Frontline Club in London, founded by Vaughan Smith, promotes and supports freelance journalists, with a particular focus on conflict zones. As part of the collaboration, the Club would put forward journalists to be trained by the Foundation in recording cultural heritage. Factum Foundation, in addition to training in photogrammetry, will provide ongoing technical and other support. Once on the ground, the trained journalists will also be able to train local people in the use of photogrammetry, empowering local communities to safeguard their cultural heritage and expanding the global capacity for 3D recording.

Training for Art UK

Factum Foundation is collaborating with Art UK in their endeavour to catalogue the UK's national sculpture collection. Although the cataloguing is primarily focused on the photographic documentation of approximately 170,000 works, Factum Foundation's involvement will see this expanded to include specific 3D documentation projects as well. Towards this end, in November 2018 three photographers from Art UK visited Madrid to receive five days of instruction in photogrammetry. During this time the trainees were instructed in how to record and process 3D data. The next stage of the project will be to conduct a joint recording project in which a team from Factum Foundation will work with trainees to record sculptures in the UK.

EXHIBITIONS

"The exhibition Mindful Hands that opened last night at the Cini Foundation sets a new high standard for exhibitions on medieval miniatures… The design by the architect (Studio Michele de Lucchi) of the display is breathtaking, the miniatures themselves spectacular (some of the best in the world) and in great condition and beautifully lit to be appreciated. This collection is one of the largest and most important worldwide and it has never been exhibited or fully catalogued and only a tiny part ever studied. There is a video by Adam Lowe of Factum Arte that is a work of genius (on making medieval manuscripts), also breathtaking. It is, quite literally, the very best show of its kind I have ever seen, and I've seen them all for the last nearly 50 years."

Sandra Hindman, Professor Emeritus of Art History, Northwestern University, after the opening of the exhibition 'Mindful Hands. Masterpieces of Illumination', 2016

EXHIBITIONS

Facsimiles, like original objects, gain meaning from the contexts in which they are exhibited and experienced. Factum Foundation's facsimiles and recreations allow curators to broach new frontiers in terms of what and how it is possible to exhibit, while the exhibitions which we organise ourselves call into question traditional distinctions between authenticity and originality. We ask audiences to think about the trains of transmission which lie between the present context of viewing and the multiple "original" contexts of the objects in front of them, and to question the curatorial strategies which claim to offer direct, unmediated access to something "real" and "true". This approach is explored at most length in the exhibition 'Scanning Seti', described in the section on Luxor above and also by the artist and academic Bryan Markovitz in the article which follows this section, but it is also exemplified in the many other exhibits and exhibitions described here.

Factum's facsimiles allow immovable objects to travel to new audiences. The spectacular tombstones of Kala-Koreysh, whose originals are firmly embedded

"Madame de Pompadour in the Frame", organised by Factum Foundation and designed by Skene Catling de la Peña.

Top: 'Words of Stones' at the Victoria and Albert Museum. Bottom: Facsimiles of paintings from Horace Walpole's collection at Strawberry Hill House.

in the mountainsides of remote Dagestan, have now been seen for the first time by audiences in Saint Petersburg and London in the exhibition "Words of Stones" (State Hermitage Museum 2017; Victoria and Albert Museum 2017-18).

Our facsimiles also allow dispersed collections to be reassembled. Many of the artworks from the now-dissolved collections of Horace Walpole have been returned as facsimiles to Strawberry Hill House in Twickenham, London, where they are being used to reconstruct one of the foundational contexts of the 18th and 19th century English Gothic style. The 2019 exhibition organised by Factum at Waddesdon Manor, meanwhile, allows a major portrait of Madame de Pompadour to return to a former context.

Top: installing the facsimile of the *Polittico Griffoni* in Bologna, 2017. Bottom: meeting with the clan chiefs to present the results of the Bakor Monoliths recording project; 3D model of the Eting Nta monolith.

Clockwise from top: the Canova's plaster horse prior to being broken up and detail from the cast bronze statuette; facsimile of the Offiziolo di Carlo VIII; exhibition view of 'Mindful Hands' at the Fondazione Giorgio Cini.

Factum's facsimiles also allow fragmented objects to be exhibited as a single whole, even when their fragments are on different continents. The altarpiece known as the Polittico Griffoni will form the subject of an exhibition, organised by Factum Foundation and Genus Bononiae at Palazzo Fava, Bologna, in 2020. It is hoped that all of the original panels will be assembled for this exhibition, allowing both comparison between originals and facsimiles, and the opportunity to see the facsimile panels arranged in relation to one another in an approximation – although not a precise recreation – of the original arrangement of the altarpiece. As the process of breaking up the altarpiece for sale led to the loss of information about the polyptych, we will now never know the exact order of panels or the exact appearance of the frame, meaning that the new Polittico Griffoni will inevitably herald a new stage in the life of this object even as it seeks to return it to a previous stage.

Another example of a fragmented object reassembled is the Bakor monolith whose bottom half is is Ntitogo in the Cross River region of Nigeria, and whose top half is in the Metropolitan Museum in New York. If Factum Foundation is able to raise the funds to create a facsimile of this monolith and of others removed from the country illegally during the turbulence of the Biafran conflict, we hope to curate a travelling exhibition of facsimiles. This will allow inhabitants of the region to gain new knowledge of these missing objects which form such an important part of their cultural heritage, and will raise awareness of the circumstances of their removal.

Our re-creations allow the exhibition of objects whose originals were never finished, such as Canova's Horse at the Museo Civico di Bassano del Grappa, a project which involves both the digital restoration of the original plaster statue, dismantled in the 1950s to allow for the construction of a lecture theatre, and its casting as a full-size statue in bronze, the medium in which it would almost certainly have been materialised had it not been for Canova's death. The museum will now be able to show both Canova's plaster statue in its current, fragmentary state, and a bronze statue of the horse which arguably resembles far more closely the final work intended by Canova.

Facsimiles and re-creations also allow exhibition audiences to touch objects, and to experience them in new ways. At 'The Blind Photographer' our re-creations made it possible for blind and partially-sighted viewers to gain an (enhanced and transformed) understanding of what is usually a visual medium, while the exhibition 'Mindful Hands: Masterpieces of Illumination', held at the Fondazione Giorgio Cini (September 2016-January 2017), allowed visitors to leaf through a facsimile of a miniature Book of Hours, the *Offiziolo di Carlo VIII* – an experience usually only permitted under tightly controlled circumstances to conservators and scholars. Another new experience which Factum Foundation's craft made possible at 'Mindful Hands' was that of viewing the miniature blown up to an almost human scale: ten images from the *Martirologio di Battuti Neri di Ferrara* were expanded to allow an immersive encounter which in increasing the size of the miniature images effectively miniaturised the viewer, allowing them almost to walk into the world of 15th century illumination.

Exhibition views of "The Veronica Scanner: Live 3D Portraiture" at the Royal Academy of Arts.

In the exhibitions which we organise ourselves, we incorporate state-of-the-art technology and processes, and sometimes turn vistors themselves into artworks. The exhibition "The Veronica Scanner: Live 3D Portraiture", shown at the Royal Academy of Arts in London (September 2016) and at Waddesdon Manor (October 2016), centred on the Veronica Scanner, which was used to scan the heads of exhibition visitors.

Each visitor was subsequently given a digital file which they could view online or print out in 3D. The exhibition also showed a range of different methods of rematerializing 3D scan data, both by exhibiting the outcomes of these methods and by demonstrating them on-site. During the 2019 Pompadour exhibition at Waddesdon members of the Factum team will demonstrate the use of the Lucida 3D Scanner.

Factum Foundation's work has also been shown by the Victoria and Albert Museum, and is represented by two exhibits in the museum's permanent display. In 2016 we collaborated with the V&A on the exhibition "A World of Fragile Parts", shown at the Venice Biennale of that year. The exhibition explored the threats facing the preservation of global heritage sites and discussed how the production of copies can aid in the conservation of cultural sites and artefacts. Among the exhibits provided by Factum were three versions of Antonio Canova's sculpture of Paolina Borghese, scanned by Factum Arte in 2013 and rematerialised at a reduced scale in glass, red wax, and resin.

The three Paolinas are now on permanent display in the central gallery of the V&A's Cast Courts. A tombstone from Kala-Koreysh, the result of Factum Foundation's first major experiment with photogrammetry, is shown further down the gallery as part of a display on contemporary modes of copy-making. The decision to place Factum's productions alongside the great masterpieces of 19th century plaster casting is both a humbling juxtaposition and an exciting one: on the one hand, copies such as Domenico Brucciani's cast of the Puerta de la Gloria remain unequalled in their sheer size and scope, but on the other, modern techniques are non-intrusive (the process of making moulds for casts like that of the Puerta de la Gloria often removed much of the colour paint from the original) and enable the replication of objects at new scales and in new materials in ways which would have been unthinkable to the artisans of the 19th century.

Before their purchase by the V&A, the three Canova versions had also been shown as part of Factum Arte's stand at the 2018 Masterpiece art fair. For this exhibition, the Canova versions were shown alongside artworks from artists such as Marina Abramović, Paula Crown, Shezad Dawood, Boris Savelev, Hrair Sarkissian, Grayson Perry, El Anatsui, Mat Chivers, Ahmed Mater, Joana Hadjithomas & Khalil Joriege, Rachid Koraïchi and Bernd Nicolaisen.
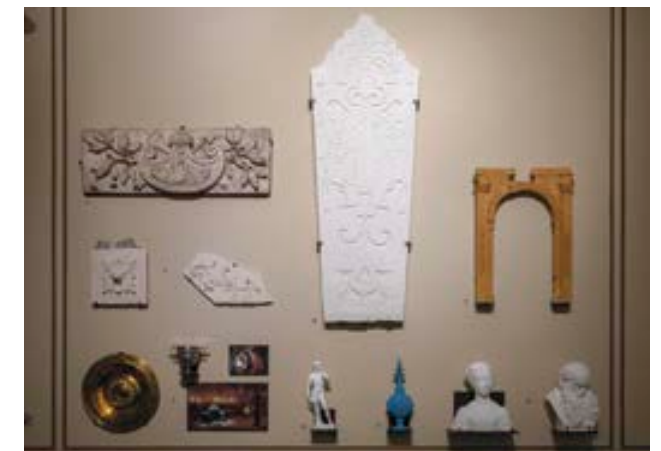
Clockwise from top: the three recreations of Canova's *Paolina Borghese* in the Cast Court at the V&A; exhibition view of Factum Arte's stand at Masterpiece Art Fair 2018; the recreated tombstone from Kala-Koreysh installed at the V&A; the three recreations of *Paolina Borghese* at the Venice Biennale.

3D model of an 18th century bell owned by Mercedes Morenés, recorded near Salamanca, Spain.

SPECIAL PROJECTS

"The Model that has been launched at ARCHiVe (The Analysis and Recording of Cultural Heritage in Venice) by Fondazione Giorgio Cini in collaboration with Factum Foundation and EPFL brings together philology, recording and the analysis of data. This mix of knowledge and technology is urgently required."

The Honorable Gianluca Vacca, Undersecretary, Ministry of cultural heritage and activities

ReACH initiative: towards a new convention on digital reproductions

Location Paris, Washington D.C., Abu Dhabi, Beijing and London.
Date 2017-2018
Project Funding Victoria & Albert Museum / Peri Foundation

In 1867, Henry Cole, the first director of the South Kensington Museum, later the Victoria and Albert Museum (V&A), initiated a *Convention for Promoting Universally Reproductions of Works of Art for the Benefit of Museums of all Countries*. The convention encouraged the exchange of artistic reproductions – primarily casts, electrotypes, and photographs – between the main powers in Europe, and was signed by 11 heads of state. The Cast Courts at the V&A are one of the major outcomes of the convention and the network of international cooperation which resulted from it.

150 years on, the initiative for the Reproduction of Art and Cultural Heritage, ReACH, seeks to update Cole's document for a global context and a new age of digital reproduction. First suggested by Factum Foundation, spearheaded by the V&A, and generously supported by the Peri Charitable Foundation, the initiative involved a series of five roundtable discussions which took place in Paris, Washington D.C., Abu Dhabi, Beijing and London over the course of 2017, and resulted in an updated convention. Factum Foundation formed a part of the core research team, which included representatives from the Musée du Louvre, the Warburg Institute, the Pergamonmuseum, the State Hermitage Museum, and the Yale Institute for the Preservation of Cultural Heritage. Over the course of the year, representatives from the Foundation offered expert advice on many of the key issues, both technological and cultural.

Alongside these discussions, Factum Foundation provided works for one exhibition focusing on copy culture, 'A World of Fragile Parts', organised by the V&A in collaboration with the Biennale di Venezia, and co-organised another, 'Words of Stone', together with the Peri Charitable Foundation. 'Words of Stone', which focused on Factum's facsimiles of tombstones from Kala-Koreysh in Dagestan and which was shown at the V&A and at the State Hermitage Museum in St Petersburg, was the first exhibition at the Hermitage Museum to comprise only facsimile objects.

ReACH resulted in the signing of a declaration at the V&A on 8th December. The new Declaration has been signed by 20 major museums and foundations invested in the use of digital technology to preserve, protect and distribute our shared cultural heritage. Along with an updated version of the convention, ReACH produced a publication, *Copy Culture: Sharing in the Age of Digital Reproduction*, which compiles examples of the best practices selected from the roundtable discussions as a roadmap for museums working with reproductions. *Copy Culture* can be downloaded for free from the V&A's website.

The articles of the ReACH convention are as follows:

REPRODUCTION

Article 1 Stewards of Works are encouraged, for the benefit of the public of today and future generations, to take advantage of technological advances to create Records of Works entrusted to their care, for purposes of documenting and preserving all Works but in particular Endangered Works.

Article 2 Those involved in the process of documenting and producing digital Records are encouraged to work to then - current accepted standards that will support academic study and monitoring the condition of the original object.

Article 3 The process of documenting and producing Records should be non-invasive for the Works involved. The preservation of the Work itself remains of paramount importance. Digital Records are a tool that can support preservation but are not a substitute for preservation.

Article 4 The process used to produce Records as well as the intended purpose for each specific Record should be documented to enable better usage and interpretation of such Records today and for future generations.

Article 5 Before making and sharing Records, the historic context of and possible cultural and national sensitivities about the Works should be considered, as well as applicable legal and ethical constraints, and the rights of donors and third parties. Transparency and participation by communities or cultural groups with ties to the Works should be encouraged.

STORAGE

Article 6 Digital Records should be contemporaneously archived and maintained by the Steward of the Work. The Works should be recorded in a manner that renders them likely to be retrievable and reproducible even if technology changes. Enabling the data migration on a continuous basis is of paramount importance.

Article 7 The Steward of the Work should own or, at a minimum, retain unrestricted and perpetual rights to use, reproduce and share the Records, unless applicable law or a contractual agreement requires otherwise.

Article 8 Digital Records should be linked to metadata that enriches the digital asset for research, education and preservation.

Article 9 Digital and Physical Records should be marked or otherwise identified as copies using methods that are sustainable and, to the extent feasible, do not rely on technologies that may become obsolete. Those involved in the process of making these Records are encouraged to develop an international system to identify copies.

SHARING

Article 10 Stewards of Works are encouraged to make Records freely available to the public for personal use and enjoyment and for non-commercial research, educational, scientific and scholarly uses.

Article 11 Stewards of Works and other parties involved in the process of documenting and producing Records are encouraged to share those Records of Works as widely as possible, but in particular to reach new audiences, especially people with special needs. This includes, where possible, proactively addressing issues of equal access to digital technology on a global scale.

Article 12 Stewards of Works and other parties involved in the process of documenting and producing Records of Works are encouraged to use established and standardized licensing schemes and symbols that convey to the public the manner in which the Records of Works may be shared and reused, including open access content.

Article 13 When Records are shared and disseminated, Stewards of Works involved should provide attribution to the original author of the Works and, where practicable, provide credit to those involved in the process of documenting and producing Records of Works.

COLLABORATIONS

Article 14 Stewards of Works with resources, skills and access to digital technology are encouraged, as much as they possibly can, to provide support for and training to develop the skills needed to document and produce high-quality Records to other cultural institutions in the world who lack such means.

Article 15 Stewards and other parties engaged in making Records should share digital technology, where feasible, and collaborate on strategies to make it more affordable.

Article 16 Stewards of Works and other parties engaged in making Records are encouraged to work collaboratively to develop compatible systems to enable the exchange of recorded data and metadata on a global scale. A set of specific technological standards and practical guidelines will be produced by a ReACH technical committee. These standards and guidelines will be revised as technology evolves.

Article 17 In light of the major infrastructure requirements to ensure long-term preservation and migration of digital Records, public- private partnerships should be encouraged as well as collaborations between countries.

DEFINITIONS

A. ReACH stands for Reproduction of Art and Cultural Heritage.

B. "Work" means a work of art or other cultural item. The term Work is intended to be broadly construed and includes, but is not limited to, works of art in all media and eras, e.g., paintings, works on paper, sculptures, murals, antiquities, monuments, architecture and architectural elements, and archaeological sites.

C. "Endangered Work" means Work threatened by environmental hazards, conflicts, terrorism, mass tourism and other natural and human-made disasters.

D. "Steward" means any governmental or private entity that owns or possesses Works held for the benefit of the public. The term Steward is intended to be broadly construed and includes, but is not limited to, museums, sites, monuments, libraries, repositories, archives, places of worship, whether governmental, sovereign, or private.

E. "Record" means a digital recording or reproduction of a Work and the data generated in the process of faithfully capturing images and data of the Work so as to create a high quality digital or physical reproduction of the Work.

F. "High quality" means a level of quality sufficient to constitute a representation of a Work as faithful as possible.

Clockwise from top: aerial view of ARCHiVe's headquarters on the island of San Giorgio Maggiore; EPFL's study on machine learning; the Replica 360 Recto / Verso Scanner installed at the Fondazione Giorgio Cini; an ARCHiVe trainee using the Photographic Manuscript Scanner.

ARCHiVe:
the centre for Analysis and Recording of Cultural Heritage in Venice

ARCHiVe, the centre for Analysis and Recording of Cultural Heritage in Venice, is a new initiative and centre dedicated to innovation in the recording, archiving, interpretation and transmission of the world's cultural heritage. It will develop both hardware and software to further these ends, and will establish training programs to teach others how to record and how to conduct training in turn.

Launched in October 2018, it is a collaboration between Factum Foundation, Fondazione Giorgio Cini, and the Digital Humanities Laboratory of the École Polytechnique Fédérale de Lausanne (DHLAB-EPFL). It is primarily funded and supported by The Helen Hamlyn Trust.

All of these partners share the belief that digital conservation is leading to a deeper understanding of works of art and cultural heritage. In addition, we believe that the research and development which is conducted within the field of digital conservation should remain independent of major corporate interests. As such, the scholarship and data which result from ARCHiVe will be accessible to anyone who wishes to use them, and the tools developed will be made available for institutions involved in the study, protection and conservation of cultural heritage.

ARCHiVe's main areas of focus will be:

· The promotion of the **high-resolution 3D and colour recording** of artefacts and sites in order to facilitate their preservation, study and dissemination. This will involve research into emergent recording technologies as well as the application of existing ones.
· The **development and application of Intelligent Computer-Vision Software**, which provides ways of organising and understanding artefacts and sites after they have been recorded.
· The investigation of **long-term storage solutions for digital archives**. We will work to find the best systems for migrating data, storing it in multiple locations, and accessing and using it without expensive proprietary software. We will also focus on the storage of digital data in physical form capable of withstanding extended periods of time without electricity.

· **Transferring skills and technologies** through specialised training programmes. This ensures local guardianship of the recording process and has the potential to generate income at a local level for those with recording skills.

A major challenge faced by ARCHiVe is that of efficiency. If data is to be made widely available and is to be stored indefinitely, we must focus not only on increasing the speed of data capture and improving the quality of the resultant data but also on simplifying file formats. Similarly, if technologies are to be widely used, they must be inexpensive and reparable even in relatively remote locations.

Each of the collaborating institutions contributes to ARCHiVe's vision in a different way. Factum Foundation brings experience in the training and transfer of digital technologies as well as in the development of data capturing systems. EPFL's Digital Humanities Lab is able to analyse and extract meaning from the data collected, using the intelligent computer vision software which it has developed itself. The Fondazione Cini, a leading centre of academic research complete with extraordinary archives and collections, offers an incredible infrastructure, including a 1000m2 headquarters, with workshop and educational space, on the Venetian island of San Giorgio Maggiore.

ARCHiVe is an audacious venture, but in the absence of major shared intergovernmental initiatives working in a systematic way to turn digital technologies to cultural ends, it is also a vitally necessary one. In order for it to succeed, however, it will be vital for others to follow the Helen Hamlyn Trust in providing the enlightened support which allows recording technologies to be developed and disseminated, and the resulting data to be processed, archived, and used. The rewards will be a shared program drawing together digital pioneers from across the world, which will offer global resonance and access to highly localised cultural heritage, while at the same time leaving agency in the hands of local actors, and contributing to local economies and skill-sets.

Clockwise from top: internal courtyard of the Bell Foundry in snow (photograph by Derek Kendall); Nigel Taylor working at the Whitechapel Bell Foundry before closed in 2017; huge crowds turn out for the arrival of 'Big Ben' cast at the Whitechapel Bell Foundry (London Illustrated News, 16th October, 1858); bell cast in 2002 to commemorate the 9/11 attacks in NY (photograph by Kieran Doherty/Reuters).

Campaign to save the Whitechapel Bell Foundry

The Whitechapel Bell Foundry (WBF), established in London during the reign of Elizabeth I, was Britain's oldest manufacturing company, a working community and a repository of invaluable craft skills in a country which has long been a centre of bell-ringing and bell-making. Its Grade 2* listed buildings on Whitechapel Road in the Borough of Tower Hamlets are a cultural heritage site of worldwide importance where famous bells such as Big Ben and the Liberty Bell were cast. However, despite its unique significance, campaigns in the national press and widespread, emotional public outcry, the WBF was sold to developers and closed in 2017.

The site was acquired by Raycliff Whitechapel LLP, who have submitted a planning application that seeks to secure Change of Use in order to develop the site as a 100-bed luxury hotel, private members club, restaurant, café and shop. The plans contain reference to a 'viable and sustainable working bell foundry' – but this is a deceptive description that essentially reduces the founding activity to nothing more than window dressing and entertainment.

Factum Foundation and the United Kingdom Historic Buildings Preservation Trust (UKHBPT) have made a very different proposal that envisions an economically viable, and environmentally and socially sustainable, working foundry operating from the site of the WBF.

THE RESURRECTION OF THE WHITECHAPEL BELL FOUNDRY

The proposal by Factum Foundation and UKHBPT will bring the traditional craft of bell founding into the 21st century.

The ground floor of the site will remain a working foundry dedicated to large-scale casting activities. In order to thrive as a forward-looking enterprise, the WBF will update its bell casting techniques by integrating the latest technology in 3D recording and output methods, acoustic recording and multispectral photography. The upper floors will house studios for these new production and design methods, as well as hosting a digital archive for campanology. Factum-UKHBT offer a unique opportunity to introduce innovation and education at a world class level in Tower Hamlets. The public will be able to visit areas of the Foundry and take part in educational activities. Most importantly, the Foundry will offer apprenticeships in bell casting for the 21st century, teaching both traditional crafts and new technologies such as 3D printing and CNC-milling to a new generation.

The proposal, prepared by experts in the fields of cultural heritage preservation, architecture, engineering and modern founding, has galvanised the support of the cultural heritage community in the UK and the local community, who have come out strongly in favour of keeping a working foundry in the old industrial heart of London.

Visit Factum Foundation's website to download the full proposal.

Casting bells at Whitechapel in 1997 with the traditional loam and greensand method.

Publications

2002
Recording Seti I, Project Report 2002, Factum Arte.

2003
Recording The Dama de Elche, Project Report 2003, Factum Arte.

2004
La tumba de Tutmosis III: las horas oscuras del sol (exhibition catalogue), designed by Factum Arte, published by Fundación Santander Central Hispano.

2005
I_mmortal Pharaoh: The Tomb of Thutmose III_ (exhibition catalogue), designed and published by Factum Arte.

2006
In Pharaos Grab, die verborgenen Stunden der Sonne (exhibition catalogue), designed by Factum Arte, published by the Antikenmuseum Basel.

Lowe, Adam, _The dark hours of the sun_, Factum Arte.

2007
Lowe, Adam. 'Moulding wet materials into replicas of themselves,' in _Genesis: life at the end of the information age_, Centraal Museum Utrecht.

2011
Latour, Bruno and Adam Lowe. 'The migration of the aura, or how to explore the original through its facsimiles,' in Thomas Bartscherer and Roderick Coover, _Switching codes: thinking through digital technology in the humanities and the arts_, Chicago: University of Chicago Press.

2012
Facsimile of the Burial Chamber of Tutankhamun, Project Report 2012, Factum Foundation.

Lowe, Adam. 'An atemporal approach to Piranesi and his designs,' in Michele De Lucchi, Adam Lowe, and Giuseppe Pavanello (eds), _The arts of Piranesi: architect, etcher, antiquarian, vedutista, designer_.

2013
Factum Foundation for Digital Technology in Preservation, Annual report 2013, Factum Foundation.

2014
Lowe, Adam. 'The complex relationship between image and skin,' in Thordis Arrhenius, Mari Lending, Wallis Miller, Jérémie Michael McGowan (eds), _Place and Displacement_, Lars Müller Publishers. 213-230.

Golia, Maria. 'The science of preserving Egypt's cultural heritage,' on the website of the Middle East Institute, www.mei.edu, June 23, 2014.

Diverse Maniere:Piranesi, Fantasy and Excess (exhibition catalogue), Factum Foundation.

2015
Lowe, Adam. 'Focusing on form - the future of photography,' Factum Foundation website.

Lowe, Adam. 'Can 3D recording help preserve threatened sites in Syria and Iraq?' in _Apollo Magazine_, September 11, 2015.

2016
Factum Foundation for Digital Technology in Preservation 2016, Factum Foundation.

Lowe, Adam. 'Tomb Recording: Epigraphy, Photography, Digital Imaging, and 3D Surveys,' in _The Oxford Handbook of the Valley of the Kings_. Oxford University Press.

Lowe, Adam. 'Copying the sarcophagus,' in The John Soane Museum Magazine, Spring 2016.

2017
Lowe, Adam. 'Digital restoration in a time of tourism, iconoclasm, and anti-aging,' in _In Harm's Way, Aspects of cultural heritage protection_, British Council.

The rematerialisation of Idrimi, Factum Foundation.

Soane's Ark: Building with Symbols (exhibition catalogue), Factum Foundation.

Two Hundred Years in the Life of the Tomb of Seti I, Factum Foundation.

Lowe, Adam. _Scanning Seti I: The regeneration of a Pharaonic tomb. 200 years in the life of a tomb. Digital recording in an age of mass tourism and anti-aging_, Factum Foundation.

Lowe, Adam, and Jerry Brotton. 'Re-visioning the World: Mapping the Lithosphere,' in Simon Schaffer, John Tresch, and Pasquale Gagliardi (eds), _Aesthetics of Universal Knowledge_, Palgrave Macmillan.

Lowe, Adam. 'Computer-assisted restoration' (encylopaedia entry) in _The Encyclopaedia of Archaeological Sciences_, John Wiley and Sons.

The map of souls and circles of hell depicted in the frescoes recorded at the Ferapontov Monastery (Vologda Oblast, Russia), showing the colour data.

Partners and collaborating institutions

FACTUM FOUNDATION AND FACTUM ARTE HAVE ONGOING PARTNERSHIPS WITH THE FOLLOWING INSTITUTIONS:

Art Jameel, Jeddah
Book Works, London
Capturing Reality, Bratislava
École Polytechnique Fédérale de Lausanne
Océ, Venlo

Open Care, Milan
PIQL, Oslo
Royal Commission of AlUla, Riyadh
Reality Capture, Bratislava
Think to Thing, Toronto

PROVIDERS:

Dust and Scratches, London
Esfinge, Madrid
Fademesa, Madrid
Flanders Tapestries, Wielsbeke

Materialise, Leuven
Skene Catling de la Peña, London
Structure Workshop, London

WE HAVE COLLABORATED AND CONTINUE TO COLLABORATE WITH MANY GLOBAL INSTITUTIONS, ON BOTH ONE-OFF PROJECTS AND ON A REGULAR BASIS:

Austria
Kunsthistorisches Museum, mumok - Museum moderner Kunst Stiftung Ludwig Wien.

Belgium
Koninklijk Museum voor Schone Kunsten Antwerpen (KSMKA), La Monnaie de Munt (Bozar).

Brazil
Associaçao Indígena Kuikuro Alto Xingu, People's Palace Projects, Spectaculu.

Canada
Antimodular Research Inc., Canada Digitization, Carleton University (Ottawa).

Chad
Ministry of Culture, Ministry of Tourism.

Denmark
Aarhus School of Architecture, SMK - National Gallery of Denmark.

Egypt
Ministry of Antiquities, Tarek Waly Centre, TedX Cairo

France
Bibliotheque National de Bordeaux, ICONEM, Musée

Cluny, Musée du Louvre, Musée Jacquemart-André, Musée Quai Branly.

Germany
Alte Pinakothek Munich.

Netherlands
Mauritshuis, Rijksmuseum Twenthe, Rijksmuseum van Oudheden (Leiden).

Iraq
Iraqi Embassy in Spain, University of Mosul.

Italy
ABI - Associazione Banche Italiane, Autogrill, BALLANDI Multimedia, Basilica di San Petronio (Bologna), Berengo Studio (Venice), Biblioteca Nazionale Marciana (Venice), Biennale di Venezia, Cavina Terra Architetti, Comune di Caravaggio, Convento di Santa Maria delle Grazie e Cenacolo Vinciano, Diocesi di Bologna, Fondazione Giorgio Cini, Fondazione Musei Civici di Venezia, Galleria Continua (San Gimignano), Galleria Nazionale d'Arte Antica di Palazzo Barberini, Galleria Borghese, Genus Bononiae, ISIA Urbino, IULM Università, Michele de Lucchi, Musei Vaticani, Museo Archeologico Nazionale (Florence), Museo Civico Archeologico (Bologna), Musei Civici di Bassano del Grappa, Oratorio di San

Lorenzo (Palermo), Ordine dei Cavalieri di Malta (Venice), Palazzo Grimani (Venice), Pinacoteca Ambrosiana, Pinacoteca di Brera, Pinacoteca Nazionale (Ferrara), San Luigi dei Francesi (Rome), Sky Arte, Università IUAV di Venezia, Villa Cagnola (Gazzada).

Japan
Tokyo University of the Arts.

Kingdom of Saudi Arabia
MISK Foundation, Royal Commission of Al-Ula, Art Jameel.

Lebanon
Association pour la protection des sites et anciennes demeures au Liban (APSAD), Arab Image Foundation, Ministry of Culture.

Nigeria
University of Calabar, Kenyan Trust for African Rock (TARA).

Norway
Norsk Folkemuseum.

Pakistan
Museum of Natural History Islamabad.

Russia
Archaeology and Ethnography of the Dagestan Scientific Center of the Russian Academy of Sciences (IHAE DSC RAS), Peri Foundation, Kala-Koreysh, Institute of History, Monastery of Ferapontov, Museum Sanctuary and Ethnographic Complex Dag-Aul Museum, Tretyakov Gallery.

Spain
Ayuntamiento de Barrado, Banco Santander, Biblioteca Nacional, Museo Arqueológico Nacional, Cabildo de Gran Canaria, Calcografía Nacional, Casa de Pilatos, Catedral de Mejorada del Campo, Comunidad Valenciana, Consejo Superior de Investigaciones Científicas (and CSIC: Proyecto Djehuty), Fundación Amigos Museo del Prado, Fundación Casa Ducal de Medinaceli, Generalitat Valenciana, Hermita de San Baudelio de Berlanga, Hospital de Tavera (Toledo), Instituto Andaluz de Patrimonio Histórico, La Casa Árabe, Ministerio de Asuntos Exteriores, Ministerio de Cultura y Deporte de España, Ministerio de Defensa de España, Museo Bilbao Bellas Artes, Museo Cerralbo,

Museo de Colecciones Reales, Museo Nacional Centro de Arte Reina Sofía, Museo Nacional del Prado, Museo Sorolla, Museo Tiflológico de la ONCE, Palacio del Capricho, Real Academia de Bellas Artes de San Fernando, Real Academia de la Historia, Real Armería - Patrimonio Nacional, Real Fábrica de Tapices, Real Santuario Insular de Nuestra Señora de las Nieves, Spanish Embassy in Iraq, TEDx Madrid.

Switzerland
Antikenmuseum Basel, ARCH – The Alliance to Restore Cultural Heritage in Jerusalem, Art Basel, Carène Foundation, ETH Zurich: Department of Architecture, Universitat Basel, Wilde Gallery.

US
Adam Williams Fine Art, Columbia University, Gannon University, Morgan Library, National Gallery of Art in Washington, University of California (Berkeley).

UAE
Department of Culture and Tourism Abu Dhabi, Louvre Abu Dhabi, The Museum of Al Ain.

UK
Art UK, Ashmolean Museum, Bodleian Library, British Library, British Museum, Bronze Oak Tree Project, Burgess Studio, C. Hoare & Co., Cambridge University, Connaught Hotel, Courtauld Institute of Art, Dovecot Studio, English Heritage, Griffith Institute, Helen Hamlyn Trust, Historic Scotland, Lisson Gallery, Littoral Arts Trust, Made by Many, Mappa Mundi Trust - Hereford, Masterpiece London Art Fair, National Galleries of Scotland, National Gallery (London), National Trust, October Gallery, Pangolin Foundry, Paragon Contemporary Editions, Photo London, Re-Form Heritage, Royal Academy of Arts, Royal Collection Trust, Rupert Wace Ancient Art, Sir John Soane's Museum, Stonewall Equality, Strawberry Hill House, The Frontline Club, The Rothschild Foundation, The Auckland Project, Tolkien Society, United Kingdom Historic Building Preservation Trust, V&A Museum, Victoria Miró, Waddesdon Manor, Warburg Institute, Whipple Museum of the History of Science.

Glossary

2.5 dimensional Refers to objects that are essentially flat, but have a surface relief. For example, a painting is not a 3D object in the traditional sense as it can only be viewed from one plane. However, it is a surface which contains textural information, leaving it somewhere in between 2D and 3D.

3D mesh/model A 3D mesh is a geometrical/topographical description of an object in which the surface and shape of the object is reconstructed as millions of sets of x,y,z coordinates. Every point is connected by lines with the three nearest points, creating a mesh of triangles/polygons. The more triangles there are the more detail you can see and the higher quality the model.

additive manufacturing Manufacturing methods which form objects by building them up in successive layers, such as 3D printing. Contrast with subtractive manufacturing.

aura A quasi-religious term used by Walter Benjamin in his 1936 essay 'The work of art in the age of mechanical reproduction', describing the immaterial impact of an original work of art on a viewer. Aura encompasses the preconceived expectations embedded in the gravitas of culture gratification, including the idea that understanding the work of art is always beyond the complete grasp of the viewer. For some scholars, "aura" has provided the justification for valuing originals over facsimiles no matter what the context.

authenticity/originality Much of Factum Foundation's work rests on the idea that originality and authenticity are not the same thing. Where the 'original' object is the object in the state and location in which it exists in the present day, an authentic (re)presentation of that object might mean the reconstruction of the state or location that it was one hundred or one thousand years ago, and/or the experience of viewing the object at that time. There can be many different authentic experiences for a single object, and while it may never be possible to achieve perfect "authenticity", Factum Foundation believes that sometimes a digitally and physically manipulated version of an object, or a facsimile placed in the original location, can be more authentic, at least in some ways, than the original.

CNC-milling Computer Numerically Controlled milling. A subtractive manufacturing process in which a computer controlled drill is used to remove material from a block placed underneath it.

composite photography Any photographic process in which multiple images of an object are taken and then either manually or digitally merged with each other to create a composite digital representation of that object.

data capture Data Capture is a general term used to refer to the process of recording digital information. Examples of data capture methods used at Factum Foundation are photogrammetry, composite photography, and white light scanning.

depth map A depth map is an image file that contains and visualises the spatial information of an object. It uses tone to simulate depth, allowing the representation on a flat screen of a 2.5D object. Depth maps provide a useful way of compressing the information from large 3D files into a useable format without sacrificing information. They are especially useful when rematerialising paintings or other 2.5D surfaces.

digital connoisseurs Refers to a viewing audience with the digital skills and sensitivity to assess the quality of high-resolution data and to make inferences about its origins and context of production; comparable to the discernment of connoisseurs of traditional art forms such as painting or sculpture.

digital conservation An emerging area of research and practice in which digital technologies are used to preserve and conserve cultural heritage. Some examples of digital conservation practiced by Factum Foundation are in the creation of precise records of objects at a particular state in time (perhaps before and after traditional conservation/restoration) and in the use of digital modelling to suggest possible restorations of a damaged or fragmentary object.

digital mediation As material objects are transformed into diverse forms of digital information, attention is focused in the many decisions that are involved in the mediation from material to digital and back. Mediation is essential at every stage; in the recording, processing, manipulation, online display and diverse forms of output. Every transformation is the result of human ingenuity, electricity, computational power, software development, material sciences and manual skill.

elevated printing A type of additive printing that allows the creation of full colour textured prints. It works similarly to inkjet flatbed printing, although in this case, layer upon layer of UV-cured ink is deposited onto a surface to produce high-resolution three-dimensional surfaces. The thickness of each layer varies between 2 and $4\mu m$. This technology was developed by Océ - A Canon Company.

facsimile An exact copy. In Factum Foundation's definition, a facsimile refers to a copy which to the naked human eye is visually indistinguishable from its referent, even though the materials can be different. Can also be used by Factum Foundation as a definition for a facsimile that visually deviates from the original object in some way (ex. in size, support...). The terms replica, reproduction and exact copy can also be used.

geometry as used in this book, this refers to the representation of an object using purely geometric forms - such as the triangulated models of photogrammetry, where every contour of a surface is shown using triangles.

GIS A Geographic Information System is a system often used for mapping purposes. In Factum, GIS software is used for the manipulation of depth maps, in order to prepare them for routing or printing.

high-resolution data Factum Foundation's definition of high-resolution data is data which can be rematerialised to a degree of accuracy at which the naked eye cannot tell original from facsimile. In practice, this involves obtaining an accuracy of 1 measured point per $100\mu m$. High resolution is a term used by many institutions and organisations, but a set standard is still lacking; Factum Foundation's definition is more stringent than most. While lower resolution models are appropriate for web-based viewing, they yield poor results - or are unusable - when rematerialisation is attempted.

input/output, data inputting/outputting devices Data input refers to the capturing of data for the purposes of digital mediation and to the devices used to capture this data, such as photogrammetry or the Lucida 3D Scanner. Data output refers to the methods used to rematerialise this data, once mediated, in the physical world, such as CNC-milling or 3D printing.

layered archive/layered browser A digital archive/browser which stores the data from multiple different recordings of the same object (e.g. Lucida scans + panoramic photography for a painting) and allows them to be viewed alongside or layered over one another. Optimised rendering of the image means that the file sizes do not have to be downsized to suit web based viewing, and the files can be viewed at their full resolution.

LiDAR scanning Light Detecting And Ranging systems are most commonly used for surveying and long range scanning purposes, but cannot be used to record detailed surface relief. The system sends out a pulsed laser light towards the target object and measures the time it takes the laser to return. It calculates the distance the light has travelled, and plots that point in a digital 3D space. LiDAR provides absolute measurements which can be merged with other datasets, making it an excellent complementary tool to other systems used by Factum.

Lucida 3D Scanner A system developed at Factum for the recording of low relief surfaces, such as paintings. A laser beam is projected onto the surface, and two cameras set at 45° from either side of the laser record the deformation of the beam as it moves across the surface. The data is then rendered in real-time as a depth map.

multispectral photography/imaging The process of recording an object by gathering information from across the electromagnetic spectrum. This allows the viewer to see the image in ways not visible to the human eye, such as infrared or ultraviolet. Widely used by conservators.

noise/noisy 'Digital noise' is essentially an unwanted signal or false information present in data, a by-product of the electricity that powers the imaging sensor. Any imaging tool will contain some element of noise in its output, and the more sensitive the sensor, the more noise will be generated. Noise will also be generated when there is too much or too little information, such as where an image contains highlights or shadows.

non-intrusive/non-contact approach An approach to objects in which neither Factum Foundation digital artisans nor the machines they use ever come into physical contact with the objects being recorded.

object career/object trajectory Refers to the idea that objects are dynamic and change over time. Just as a 4-year-old child both is and is not the same as their 80-year-old self, a fresco first painted 3000, or even 30, years ago both is and is not the same fresco that we see today.

original The original object, which in almost all instances in which it is referred to here is the subject of digital recording techniques which aim to create mediated versions of it (whether digital models or physical facsimiles).

panoramic photography A form of composite photography used by Factum Foundation to accurately record colour. It involves merging multiple photos taken from a single point to create a single image.

photogrammetry A method of extracting three dimensional information from photographs. It involves taking a series of images of an object with large areas of overlap between them, and using software to recognise shared points in the images, extracting them as x,y,z coordinates. These are then mapped into a virtual 3D space to create a 3D model of the object.

photometric stereo recording A recording technique that uses 2D images taken under several different lighting angles to extract very detailed information about the surface of a 2D object.

point cloud A cluster of measured points extracted from the captured data. Each point is encoded with an x,y,z coordinate as well as colour information.

re-creation A transformed version of an existing object, perhaps using the lacunose available data to imaginatively reconstruct the past state of an object which is lost or damaged, or enhancing existing datasets to create entirely new objects which illuminate the original in new ways. A recreation is not the same as a facsimile.

rematerialisation The process of converting the recorded, digitally processed data from an object into a physical model or facsimile via processes such as casting, 3D printing, colour printing, and traditional finishing techniques.

render a digital representation of an object's topography derived from recorded data.

RTI Reflectance Transformation Imaging is a method of recording the shape and colour of a surface. This is a system that is mainly used for screen based imaging, although it can be rematerialised if need be. It involves capturing images of an object from a stationary camera position and changing the known light source in each photograph. The lighting is then synthesised to generate a depth map of the surface, and allowing the viewer to interact with the image by changing the light source.

structured light scanning /"white light" scanning A method of recording the geometry of an object. The scanner is composed of a camera and a projector. A known pattern of light is projected onto the object and the camera measures deformations in the pattern to map the geometry of the object.

subtractive (additive) manufacturing Manufacturing methods which form objects by removing material from a larger piece of material - as with CNC-milling. Contrast with additive manufacturing.

topography the study and description of the shape and features of land surfaces, and by extension of surfaces more generally. In this book it refers to the surface contours of the objects under discussion.

x-, y-, z-axis Coordinates on a three dimensional matrix. X and Y represent width and height, as on a two dimensional graph. The Z coordinate represents depth.

Upcoming projects

Ongoing and upcoming projects include

Recording
· The Raphael Cartoons at the Victoria and Albert Museum
· Michelangelo's Epifania at the British Museum
· John Eskenazi's collection of Bengali ceramics
· Statues from the Biblioteca Nazionale Marciana during their temporary relocation to Palazzo Grimani
· All the Goya paintings from Palacio del Capricho
· Fra Angelico's *Annunciation* at the Museo del Prado for an upcoming exhibition displaying the 3D data
· 'The Circle' Stradivarius in collaboration with Julia Sarano and Robert Brewer Young as a pilot project to create an archive for restoration and conservation of string instruments
· The Illés Relief at the Tower of David Museum in Jerusalem
· The Tomb of Raphael in the Pantheon for the upcoming celebrations surrounding the 500th anniversary of the artist's death in 2020
· Birdman Cult artifacts on Easter Island

Collaborations with
· Fundación Casa Ducal de Medinaceli
· Instituto Andaluz del Patrimonio Histórico and Jonathan Ruffer to record more works from the Spanish Golden Age. Facsimiles of many of these will be placed in a new Spanish Gallery at Auckland Castle
· Océ and the Mauritshuis to record and rematerialise Rembrandt's Portrait of an Elderly Man as part of the celebrations marking the 350th anniversary of Rembrandt's death
· Open Care and Euromobiliary Advisor SIM to host the first edition of the Bando Lucida

Research and developments on
· The completion of the Sacred Cave of Kamakuwaka, its complete digital restoration and its return to the Upper Xingu. An event in Madrid is also planned.
· Online and offline applications for the data the Foundation is recording
· Secure archiving
· New recording systems: Photometric Stereo Scanner and RTI (Reflectance Transformation Imaging) with Carleton University, Canada

Upcoming exhibitions (provisionary titles)
· "La riscoperta di un capolavoro" at Palazzo Fava, Bologna, in collaboration with Genus Bononiae
· "The Bakor Monoliths" at the British Museum, which is also planned to be permanently installed in Nigeria afterwards.

In order to work in fast and effective ways that result in the transfer of skills to local operators, creating local economies focused on preservation, the Factum Foundation needs financial and political support. We have grown rapidly since 2009, generating the funding for each project in different ways. We are now in a world in which the boundries that separate Art, Science and Technology are dissolving and preservation, access and sustainability are the main issues.

The value of a work of art lies in the fact that it can change your point of view. Everyone can contribute and make a difference. A revolution is taking place both online and offline as new technologies merge with traditional skills. You can be part of it.

How to contribute to the Foundation

The Factum Foundation works worldwide to ensure that future generations will inherit the past in a condition where it can be studied in depth and emotionally engaged with.

Many projects have been completed over the past three years. Some are described and illustrated on these pages, others are shown on the Factum Foundation and Factum Arte websites. Some are fully funded while others are in need of philanthropic support. If you are interested in donating or sponsoring a specific project please get in touch. Your contribution will help us continue our work in re-evaluation and preservation on a global scale.

You can donate via Paypal or by wire transfer.
Please email us at info@factumfoundation.org
or call +34 915 50 09 78.

The American Friends of Factum Foundation (AFFF), is a 501(c)(3) private foundation, founded to allow residents of the United States to make a donation.

AMERICAN FRIENDS OF FACTUM FOUNDATION INC
150 East 69TH Street, Suite 19L
New York, N.Y. 10021

Nonmonetary Support N.E.C.*
| EIN: 47-5486901 | Gt Barrington MA

Marble panel from the San Marco Cathedral in Venice.