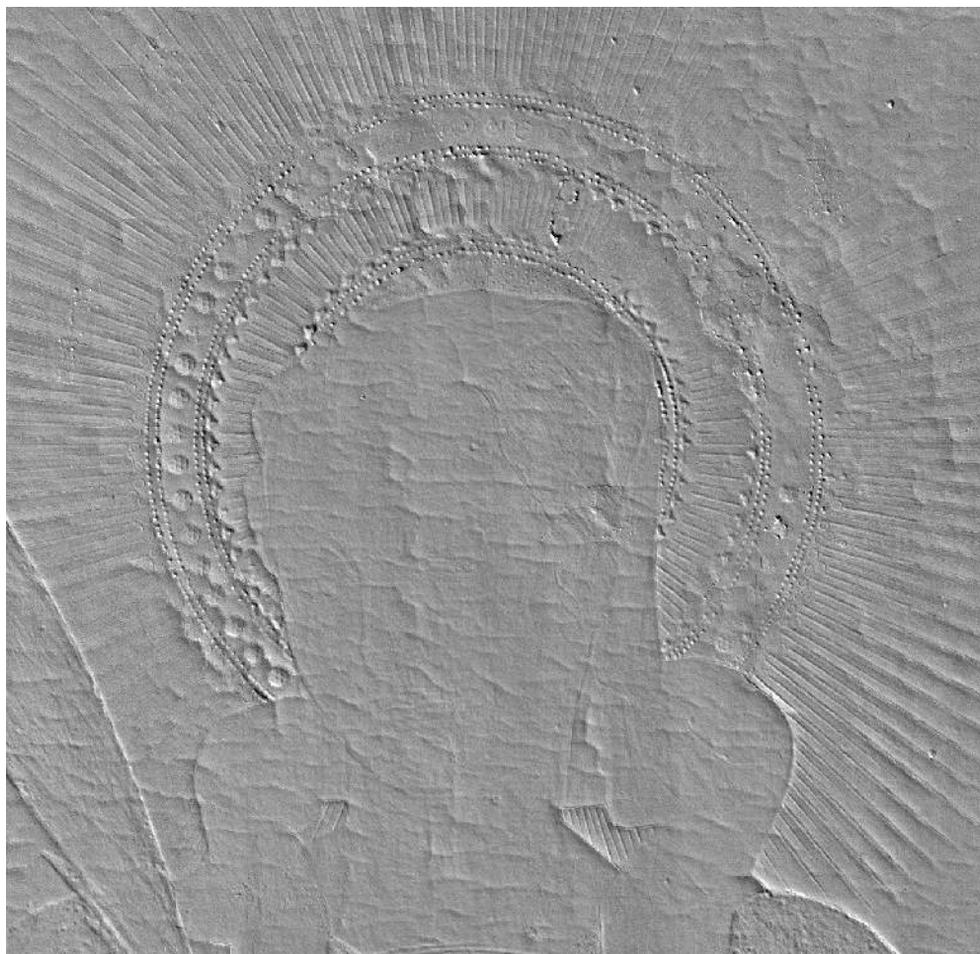


Lucida 3D Scanner

Factum Foundation



Selected projects I

Front cover render image: Francesco del Cossa,
Saint Lucy, 1472-73, oil on poplar, 79 x 56 cm,
National Gallery of Art, Washington



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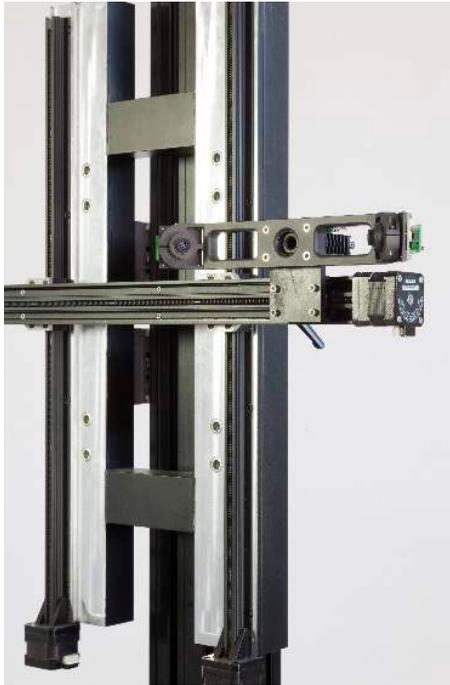


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Recording for cultural heritage preservation

Facsimile of Veronese's *Wedding at Cana*, made by Factum Arte after the original in the Louvre, and installed in San Giorgio, Venice, in 2007.



The photographers Gennady Viktorov and Shamil Gadzhidadaev from Daghestan being trained in the use of 3D recording technologies in Factum Arte, Madrid, in 2016.



The recording of fragile sites and objects for preservation is as important as the transfer of skills and technology to the local communities. Abdu El Reheem Ghaba preparing to scan.



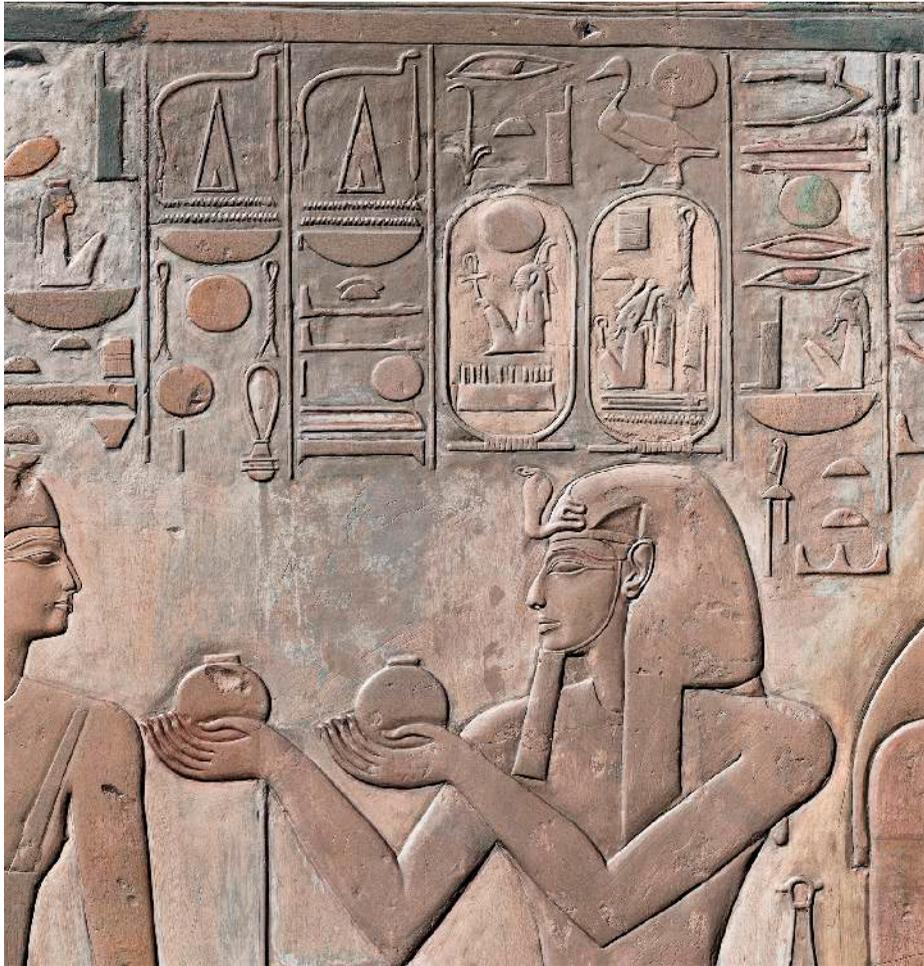
Columbia University students carrying out 3D scanning of a panel in the Island of San Giorgio, Venice.



Factum Foundation for Digital Technology in Conservation

Factum Foundation was established in 2009 as the sister organisation to Factum Arte, a multi-disciplinary workshop mediating the complex boundary between technology and contemporary art. In a world in which mass tourism, iconoclasm, or neglect, amongst other factors, pose a serious threat to works of art and culture, the Foundation was formed as a not-for-profit organisation dedicated to the digital recording and rematerialisation of cultural heritage for the purpose of conservation, study and dissemination. Through its work on endangered cultural heritage sites, in museums or cultural institutions, and its research into the newest scanning and rematerialisation technology, Factum Foundation is committed to establishing the importance of high-resolution 3D recording

with a view to preserving our shared cultural heritage for future generations. To this end, a large part of its work is dedicated to empowering local organisations and individuals with the education and technology required to actively participate in the digitisation of archaeological sites, monuments or artefacts, thereby engaging their interest and involvement in culture on a local level. In line with the Foundation's ideals, ownership and copyright of the data recorded always remain with the institution tasked with looking after the object or site on all current and future commercial applications. In return for this commercial control, the data is made freely available for academic, conservation and research applications.



Coloured 3D render of a section of the Tomb of Seti I, recorded in Luxor in 2016 with Lucida and other non-contact methodologies.

Why is 3D scanning relevant?

In recent years, high-resolution 3D recording has become part of a coherent non-contact approach to the documentation of cultural heritage and to strategies for its long-term preservation. This not only creates new opportunities for presenting culture in both virtual and physical ways, but also transfers skills and technologies to create a new economy benefitting local communities. The methodology advocated by Factum Foundation involves 3D recording both the general shape and the surface texture and colour of artefacts and sites. The processing of the data depends on its intended use, but it is essential that the recording takes place at the highest resolution. The data can be archived in various forms, although storing the raw data offers the possibility of reprocessing in the future. Different visualisation techniques now make it possible to stream this data safely so it can be accessed, studied and shared without specialist software. 3D printing and CNC milling can result in accurate re-materialisations only if the data is correctly recorded. The conservation community, restoration specialists, exhibition designers, visitor centres, academic institutions, schools, and interested parties can all benefit from this approach.

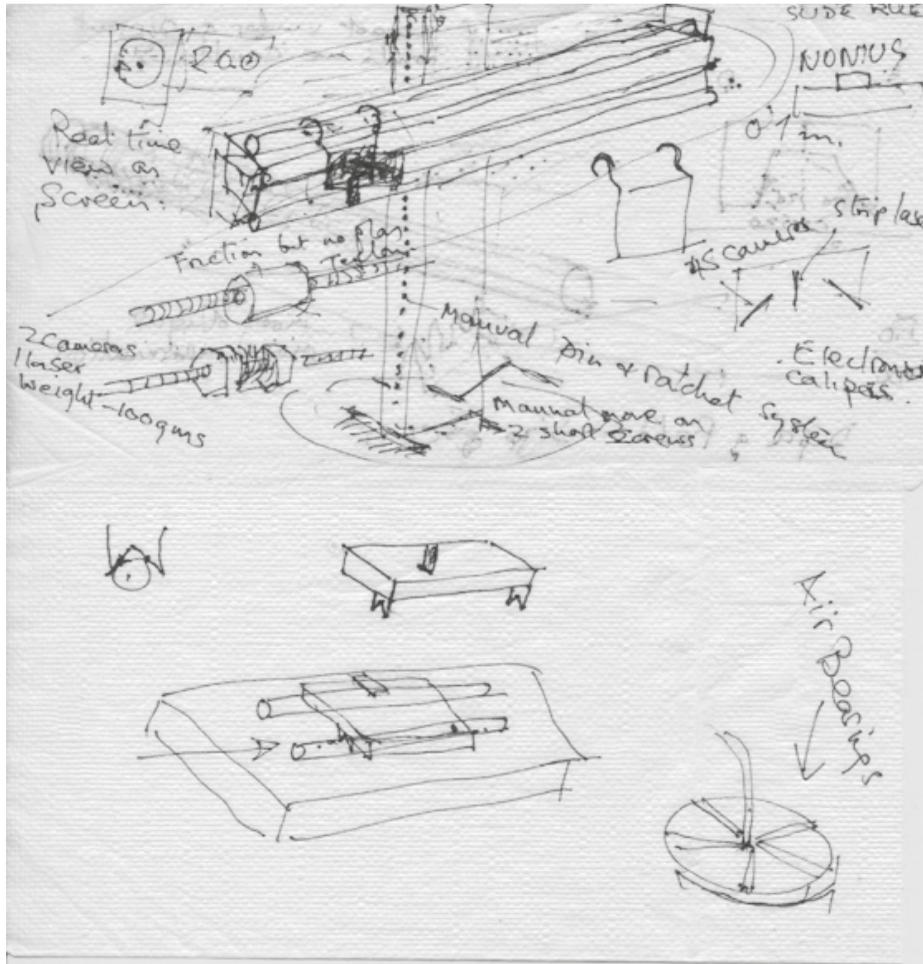
Exact facsimiles, made possible through advances in 3D recording and output technologies, are also integral to the work carried out by Factum. Nevertheless, a great deal of misunderstanding still exists about the role they can play in cultural heritage preservation. However, a realisation of the threats to cultural heritage is resulting in the re-evaluation of the significance of facsimiles. This is a multidisciplinary approach that can help visitors to exhibitions or cultural heritage sites understand the complexity involved in preservation and leading to a renegotiation of the relationship between the original and the authentic. If people become more conscious of the fact that visiting monuments such as the tombs in the Valley of the Kings, Luxor significantly contributes to their degradation, then it is likely that a new sense of public awareness will emerge. Through the careful employment of

facsimiles, we can develop a form of preservation of the original object that doesn't deny the public a close and intellectually stimulating interaction with art and culture.

Close range 3D scanning

It is important that the right type of 3D recording is undertaken for each heritage site or object and that the application is considered prior to the recording phase of a project. In general, the more complete the dataset – a complete dataset would comprise high-resolution colour, high-resolution surface texture as well as an accurate rendition of shape – the more uses it will have for academic, conservation and research purposes. Close-range 3D scanners (working distance greater than 8cm and less than 100cm) are used to record the shape and surface of objects in detail. Triangulation based 3D laser scanners use a laser light and one or two cameras to record a subject. The distance of the object to the scanner is calculated through trigonometry to create a precise map of the surface. Structured light scanners use projected patterns of light instead of a laser for triangulation – the camera(s) records these patterns and calculates the position of every point in the field of view. (See Appendix A for more information on the types of 3D scanners used by Factum Foundation). The Lucida 3D Scanner is an example of a close-range 3D laser system. Accurate close-range 3D recording will facilitate meaningful monitoring of the condition of the surface and is essential in the compilation of layered archives of different types of data. For a considerable time now, it has been common practice to carry out various types of multi-spectral photography in tandem with X-ray, Infra-red and ultraviolet recording, which reveal preliminary drawings, overpainting, infills and previous restorations. Together with a 3D recording of the surface, such multi-layered archives effectively become 'digital passports' for a work. Close-range 3D scanning is also essential for the acquisition of the high-resolution surface data required to produce a facsimile.

Lucida is a close-range 3D laser scanner custom-built by Factum Arte with financial and logistical support from Factum Foundation. Conceived and developed by artist and engineer Manuel Franquelo, this system is the result of fourteen years of investigation into the high-resolution recording of the surface of paintings and relief objects.



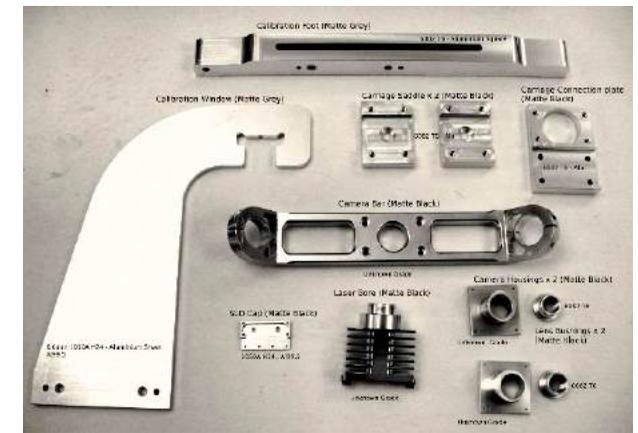
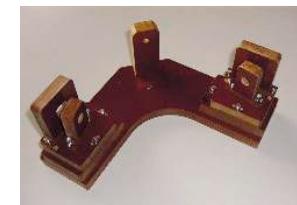
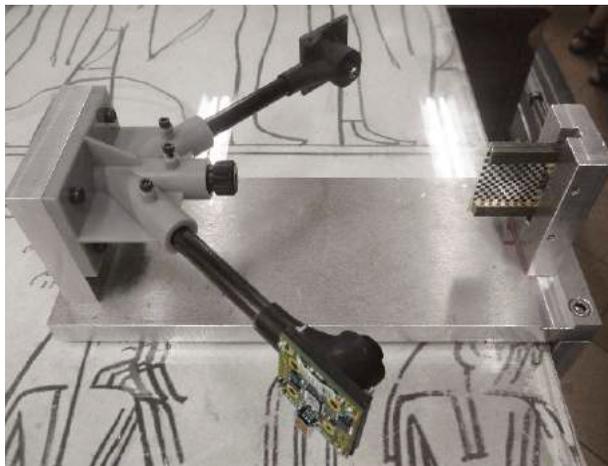
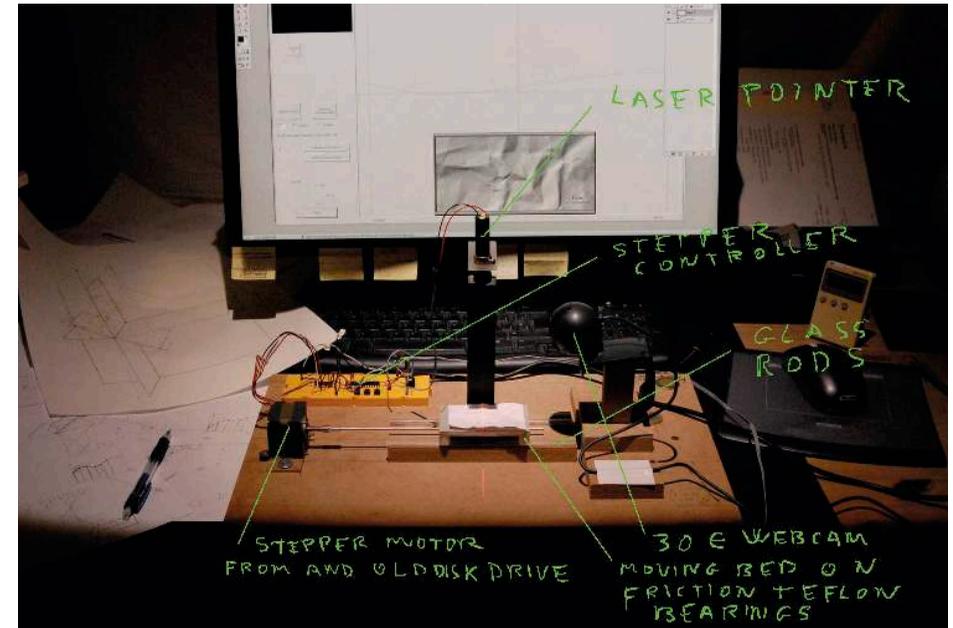
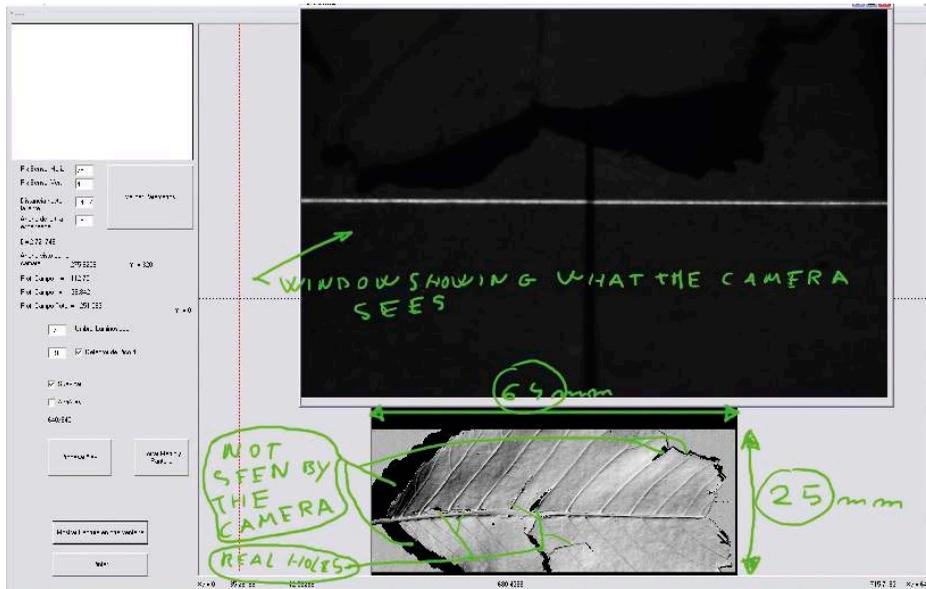
Preliminary concept sketches of the Lucida 3D Scanner on a napkin, by Manuel Franquelo and Adam Lowe.

Factum Arte and Factum Foundation have extensive experience in employing commercially available digital technology to record cultural heritage sites and objects for rematerialisation in diverse locations around the world – from the Valley of the Kings in Egypt to the Musée du Louvre in Paris.

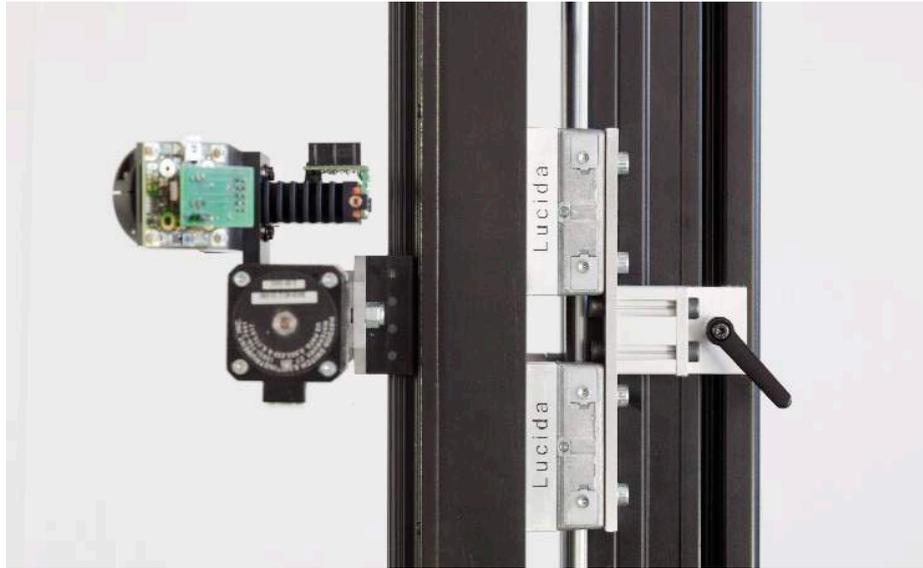
From the early 2000s, due to the complex requirements of each project, Factum has also been adapting and improving commercial close-range 3D recording systems in order to achieve higher conservation standards and better data. Factum Arte started working with 3D Scanners UK in 2000, using and adapting their Reversa scanner for work in the tomb of Seti I. The SETI Scanner, mounted onto CNC controlled X, Y, and Z axes, was the first variation. The Yabba Scanner was the second variation, a crucifix scanner specially prepared for work in the British Museum. The Reversa head mounted onto the SETI frame was used in the tomb of Tutankhamun in 2009, but by this time, the system was becoming obsolete. In order to improve control of both the hardware and

software it was decided that a new scanner would be developed in house. The idea was to create a laser scanner for conservation that would record high-resolution texture of any 2.5D surface.

The first iteration of the scanner, a two-camera laser system employing linear guides for vertical and horizontal movement in 48x48 cm 'tiles', was first used in 2011 to record the preparatory panels for The Triumph of the Eucharist by Rubens at the Prado Museum in Madrid. Between 2011 and 2013 new prototypes were created with a stable and modular frame to support the linear guides and to allow the user to scan a number of tiles in succession. Other changes were made including the introduction of z-axis movement – to/from the object – which permits re-scanning at various depths within a single tile; or the development of a simple user interface and the creation of the editing, merging and blending applications, enabling full control of the data processing. Although research into this system is ongoing, the scanner currently in use is from 2015.



Various stages in the development of the Lucida scanning head prototype from 2010 to present.



The Lucida 3D Scanner

The final version of the system consists of a two-camera, one-laser scanner with bidirectional recording. It is compact, easy to operate and has motion along x, y and z axis by means of linear guides fitted to a rigid, lightweight aluminium structure. The intensity of the laser can be increased or reduced depending on the nature of the material being recorded. The specialised software and hardware enable the recording of both dark and light colours within one object, as well as high gloss and even reflective materials like gold. The recorded data is dimensionally accurate and bears a close correspondence to the surface of the object being recorded. The graphic user interface has been developed with practicing conservators and specialists and is intuitive and easy to operate. The system can be powered by battery or mains electricity, which facilitates recording in complex locations where stable electricity supplies are not available. The batteries can be recharged with solar power.

The scanning process is controlled from a portable computer through a simple, intuitive user-interface. The depth of field is limited to 2.5 cm but a custom software application allows the user to select specific sections of the target if re-scanning is necessary. Re-scanned data can then be automatically merged with the previous scan. The z-axis (enabling movement towards/away from an object) is mechanical in order to ensure absolutely safe use and avoid any accidental damage in case of motor malfunction.

All stitching of the data is done using an innovative 'switch' between a rendered image and 3D co-ordinates: the rendered images are used to position the files as required before stitching the 3D data, an approach that means this operation can be performed by means of standard image-stitching software. All files are saved as raw black and white video data, ensuring that they can be processed at higher resolutions in the future as the technology

develops. The data from the scanner can be viewed on screen and used for virtual operations, but when required it can also be re-materialized. The quality of the data is such that, if outputted in physical form, it bears very close resemblance to the original surface.

Factum Foundation has employed the Lucida 3D Scanner in the Museo del Prado (Madrid), the National Gallery (London), the Vatican Museums, the Courtauld Institute (London), The Royal Collection (Windsor and Hampton Court) amongst a number of other public and private collections. The Lucida scanner can be installed in museums with conservation departments or in cultural heritage sites with locally trained operators. With the Lucida, the intention is to make the 3D surface recording standard practice in conservation, in such a way that it will transform the way we monitor and protect our cultural heritage. These recordings enable institutions to obtain a permanent record of surface of paintings and low relief carvings at a specific moment in time, but will also make it possible to accurately monitor the condition of works sent out on loan, in anticipation of any intervention or restoration and establish a protocol for measuring change and ultimately to make exact replicas – conservation facsimiles that are becoming accepted as an important part of sustainable cultural tourism.

Free software upgrades will be provided by the Foundation, which will also offer training courses to ensure a complete transfer of skills and technology. The eventual aim is to make the hardware and software for the scanner open source and freely available such that digital recording can be carried out where it is most essential. All data collated using the Lucida scanner will remain the property of the custodian/owner of the work of art who will own all rights related to the data and any revenues that the data might generate from current and future applications.

Recording dark and glossy surfaces

The standard board is a textured and coloured plaster panel (26 x 52 cm) fabricated by Factum Arte to test the performance of different 3D scanning systems. The panel is composed by a combination of various areas with different surface finishing that usually present problems for most commercial scanners.

Firstly, the panel is divided in three sections, each of them with a specific texture and background colour:

- A. Low-relief, white matt
- B. Cracked surface, white matt
- C. Colored surface

Secondly, a few circles were added with different combinations of tone and glossiness:

- 1. Shine on white
- 2. Grey 70% matt
- 3. Grey 90% matt
- 4. Black matt
- 5. Glossy on colour
- 6. Glossy on black

This last combination (Glossy on black) is usually the type of finishing that generates bigger problems for conventional 3D scanners. The tests carried out with the Lucida scanner resulted in a uniform recording of the panel's surface, regardless its colour, glossiness or finishing. Lucida has also obtained high quality data from gilded surfaces and metal.



Above: colour image of the standard board photographed with raking light to highlight its relief.
Below: 3D rendered data generated with Lucida.



Rubens

The Triumph of the Eucharist over Idolatry

The first prototype of the Lucida was used in the Museo del Prado in Madrid to digitise the surface of a painting that was about to undergo a major restoration. This panel (65 x 91 cm) is one of a series painted by Rubens as preparatory sketches for the tapestry cycle *The Triumph of the Eucharist*. Lucida was used to record the relief of the front of the panel at a resolution of 100 microns. The colour was recorded with a Clauss panoramic photography system.

The 3D information that was obtained is now of great value as the shape, size and texture of the painting changed significantly during the restoration process. It is unusual that size changes dramatically but in this case a previous addition of several centimetres on each side of the painting was removed. The restoration was intended to stabilize the paint and wooden panel before it was exhibited in front of the tapestry that was based on the design. The recording was done in conjunction with the curatorial and conservation teams at the Museo del Prado. The data will now become an important part of the history of the painting and was supplied to the museum both as a digital archive and as a physically routed plaster panel. In line with Factum Foundation's commitment to conservation the copyright on this data and on all future applications of the data belongs to the owner of the artwork.

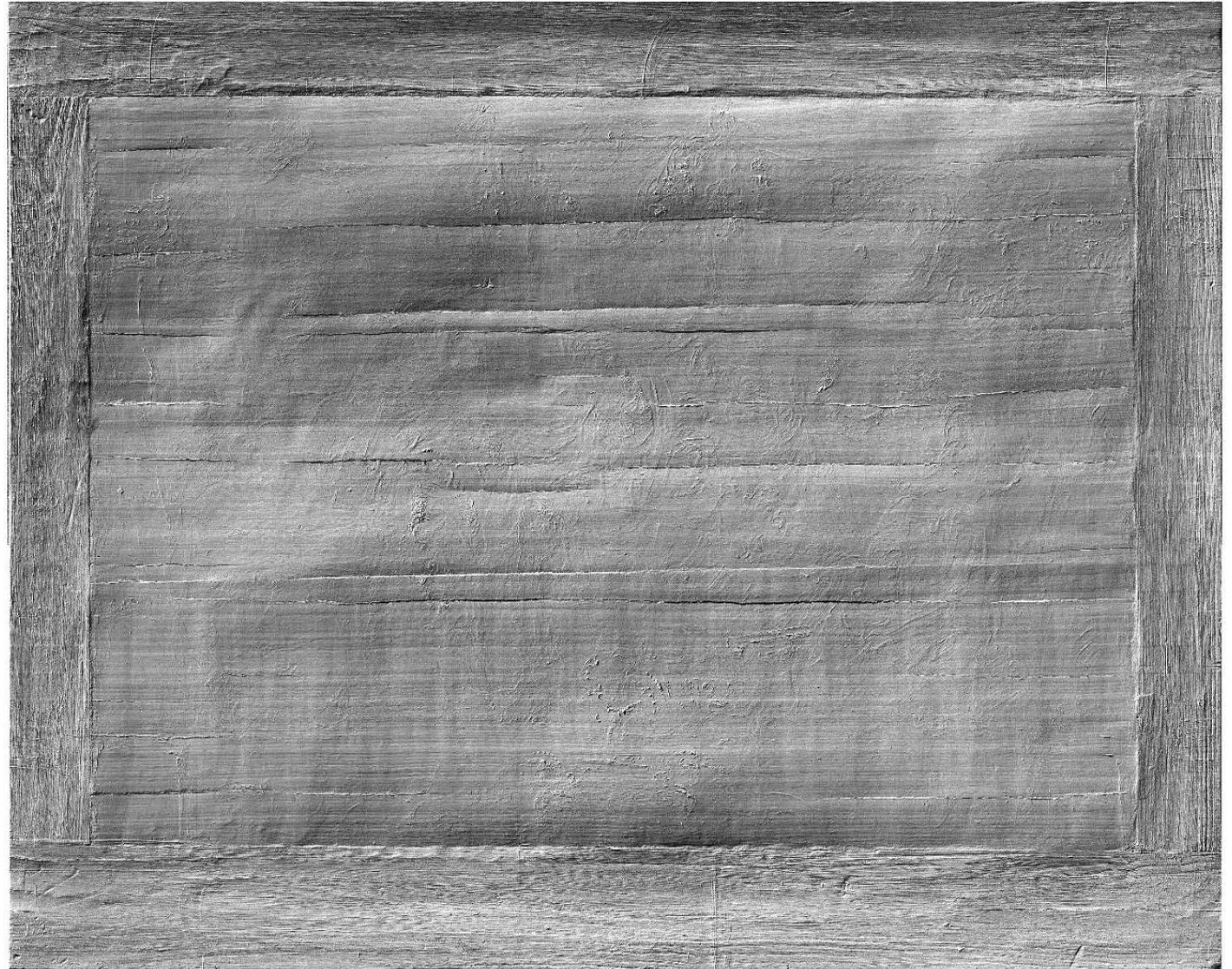
How do you 3D scan a black glossy surface? How do you scan a black glossy surface that is next to a white glossy surface, or a tooled gold surface? Paintings have specific qualities that require focused solutions... Lucida is the 3D scanner specifically created for recording the surface of paintings and low-relief objects.



Rubens, *The Triumph of the Eucharist over Idolatry*, c. 1625, 65 x 91 cm, Museo del Prado, Madrid.

Rubens

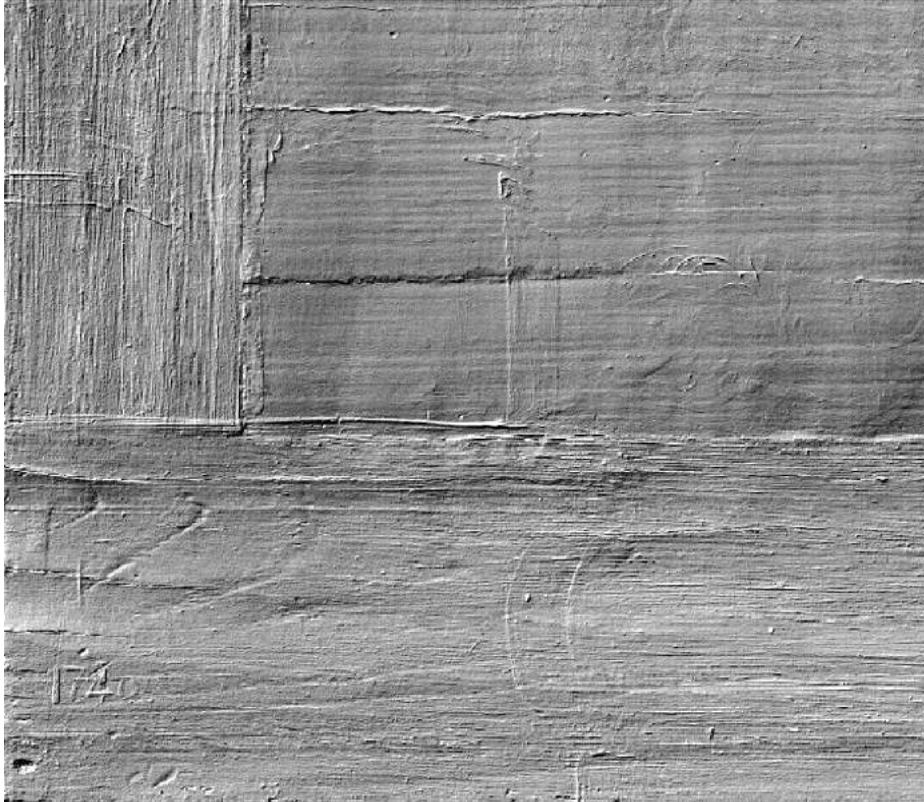
For 3D recording technology to be meaningful for cultural applications it is essential that the correspondence between the surface and the recording of that surface is as close as possible. Lucida has overcome the problem of contrast and reflection through innovative algorithms designed to reduce noise without altering the characteristics of the texture.



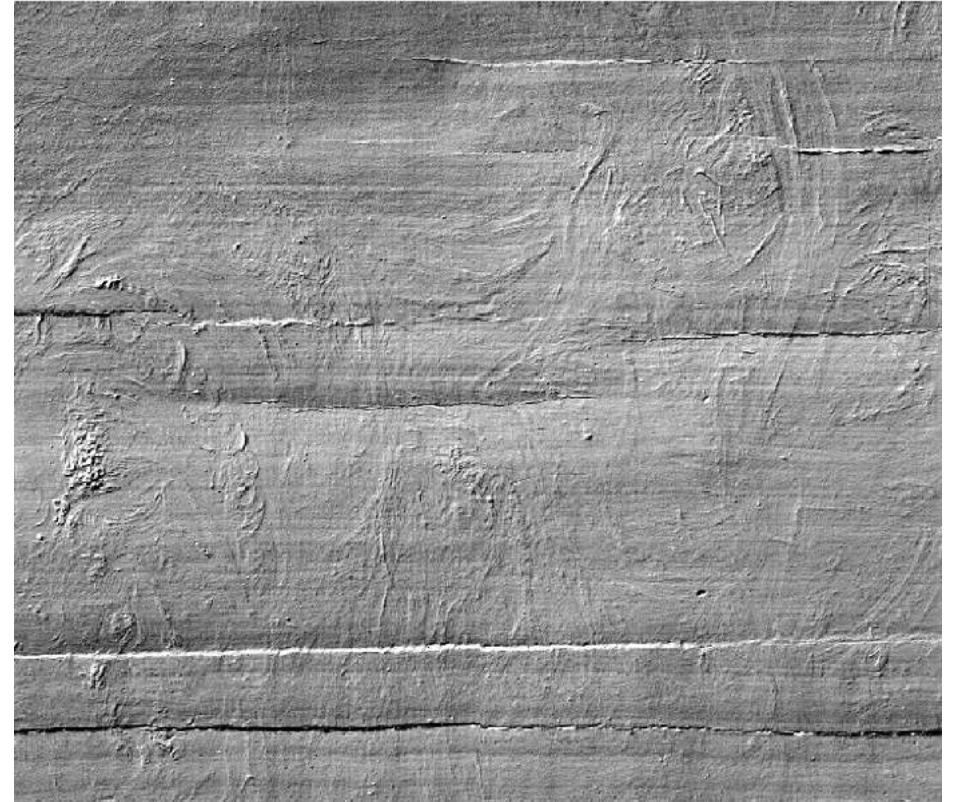
The Triumph of the Eucharist over Idolatry, 3D render.

Rubens

Instead of processing the captured data as it is being recorded, Lucida stores the data as raw tonal video. It will be possible to re-process this 'condensed' data in the future at a higher-resolution and with improved software. This is a unique feature that reflects a deep understanding of the needs of the art conservation community.



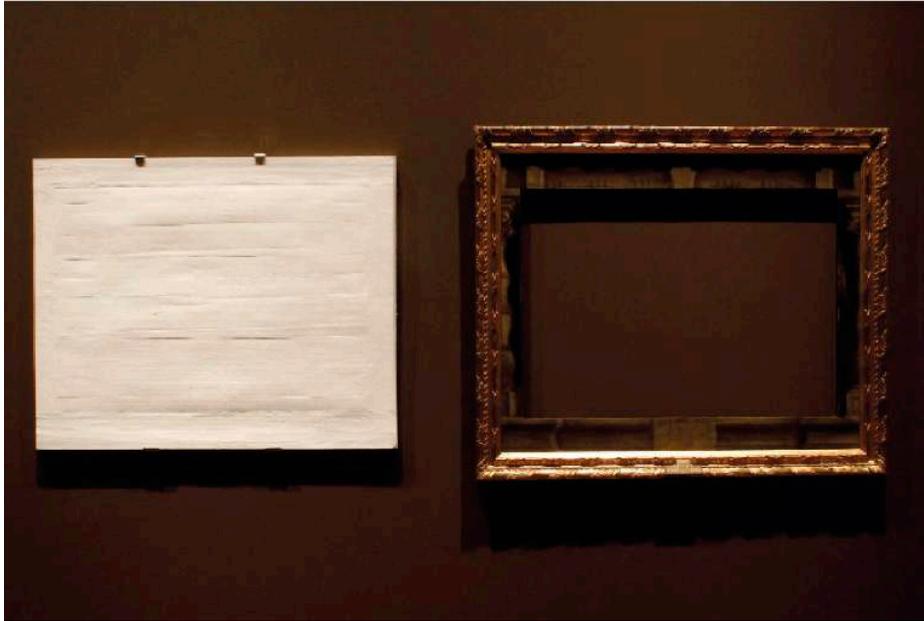
The Triumph of the Eucharist over Idolatry, 3D render, detail of the panel's perimeter.



The Triumph of the Eucharist over Idolatry, 3D render, detail of the cracks and paintbrush relief.

Rubens

The 3D information of this painting obtained by Lucida is the only accurate record that exists of the shape and texture of the board before its latest restoration, after which the size and curve of the material have changed significantly. This is why it is essential to record the surface of paintings before and after every restoration process.



The relief data of the painting recorded with Lucida was CNC routed in high resolution, and then reproduced in plaster.



The plaster cast reproduction was included in the exhibition *Rubens: the Triumph of Eucharist* in the Museo del Prado (Madrid) in 2014.

Mappa Mundi



Hereford Mappa Mundi

In early 2013 a team from Factum Arte made a high resolution recording at the request of Hereford Cathedral and the Trustees of the Mappa Mundi. The glass cover is only removed once every two years for inspection. The team used the Lucida 3D scanner mounted onto a custom designed structure to provide absolute safety to the map and a firm platform for the highly accurate no-contact surface scanning process. Each frame was post-processed to create the high resolution three-dimensional record. The three dimensional "map" of the surface of the Mappa Mundi will provide visitors to Hereford Cathedral, including the blind and partially sighted, have the opportunity to explore and experience the map as never before. In addition, a new website that features an interactive exploration area for the Mappa Mundi has just been launched, providing access to the Folio Society digitally enhanced version of the Map and the Factum Arte three-dimensional surface scan. By studying the 3D recording in conjunction with

other methods of forensic study, new discoveries have been made about the map including compass points at the centre of Jerusalem and in the centre of the Labyrinth of Crete. Further research is being carried out on the data, and may suggest that the map was made in Hereford rather than in Lincoln. Thanks to the physical reproduction of the high-resolution 3D data, visitors to Hereford Cathedral, including the blind and partially sighted, have the opportunity to explore and experience the map as never before. In addition, a new website that features an interactive exploration area for the Mappa Mundi has just been launched, providing access to the Folio Society digitally enhanced version of the Map and the Factum Arte three-dimensional surface scan.

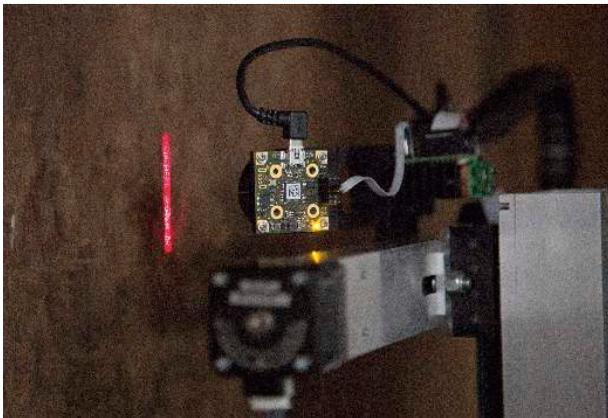
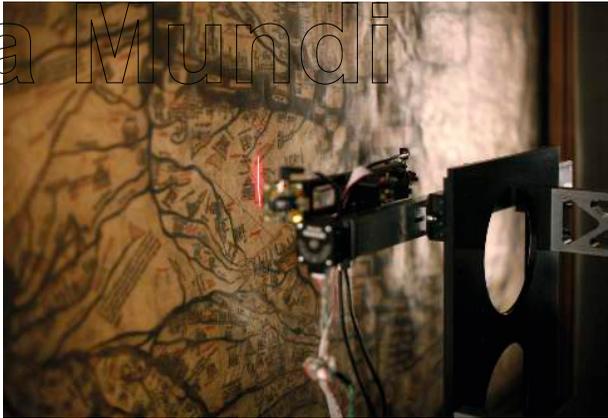
Lucida 3D scanner recording the Mappa Mundi.

High resolution digital documentation of our shared cultural heritage is an essential part of its conservation. Along with the duty of preserving and disseminating the artworks, we also have the responsibility of digitising, in the most faithful way, their physical characteristics for future generations. Lucida has been designed to help make this possible.



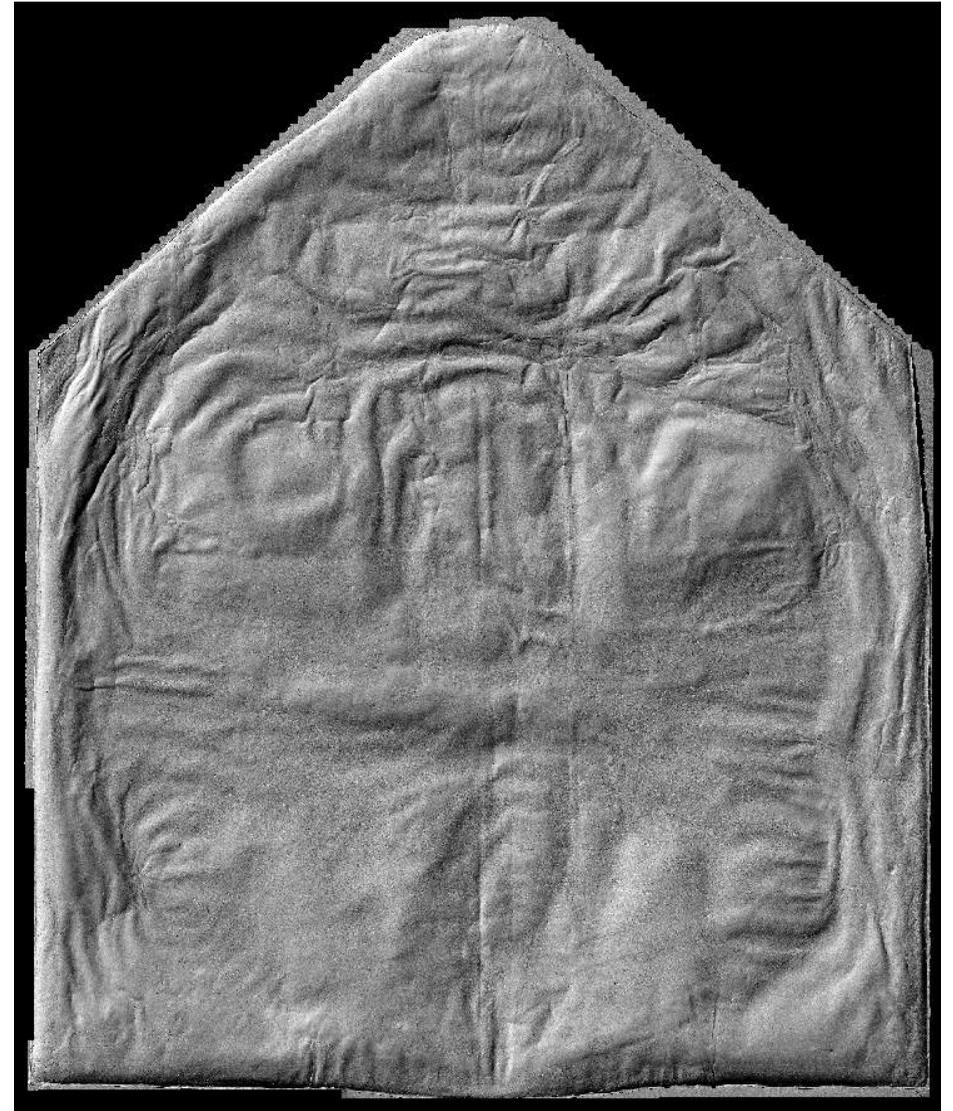
The Hereford Mappa Mundi, c. 1300, 159 x 134 cm, is one of the world's unique medieval treasures.

Mappa Mundi

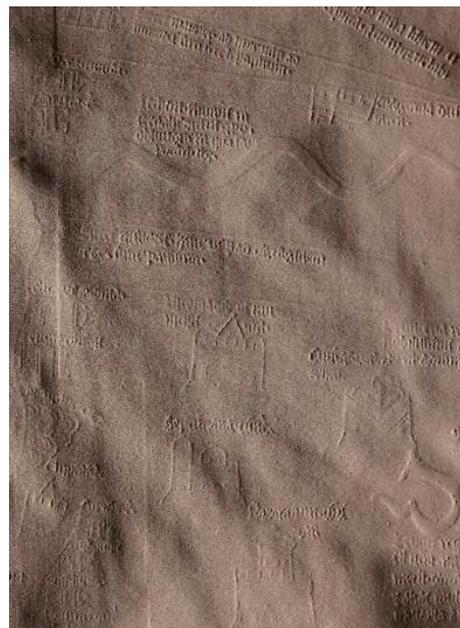


The Mappa Mundi was recorded in 2013 at the Hereford Cathedral. The backboard was then scanned in 2016 with the aim of establishing a comparison between both sets of 3D data.

Lucida is not just concerned with shape, but with both shape and relief, and the complexity of the surface texture. This intimate understanding of surface is leading to new insights about how an artwork has changed, how it has been looked after, how it has been valued and what has been done to it...



3D render of the Hereford Mappa Mundi's surface data.



Mappa Mundi

The goal is the acquisition of a reliable, high-resolution and dimensionally accurate map of the texture that can be studied on screen or re-materialized in the physical domain. If data can be re-materialized with the exact characteristics of the original it is clear evidence of the quality of the data.



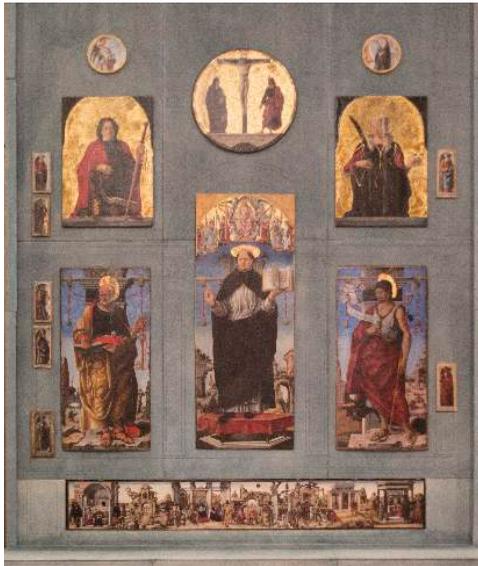
Installation of the Mappa Mundi's reproduction in the Hereford Cathedral.



The plaster cast reproduction of the surface turned the Mappa Mundi into a tactile object: the mapping of a map.

Previous pages: Top left: detail of the 3D render generated by Lucida; Top right: CNC routing the surface in high resolution; Bottom left: details of the routed texture in resin; Bottom right: plaster cast of the surface.

Polittico Griffoni



Polittico Griffoni. Digital technology applied to the re-unification of a scattered altarpiece
The restoration of the chapel of Saint Vincent in the Basilica di San Petronio (Bologna) has provided scholars with a chance to re-consider an altarpiece originally painted for the chapel: the Polittico Griffoni – one of the most important masterpieces of the Renaissance, painted between 1471 and 1472 by Francesco del Cossa and Ercole de'Roberti. The work was commissioned by the original patrons of the chapel, the Griffoni family, but was removed, dismembered and sold when the chapel came to the Aldrovandi family in 1725. The sixteen surviving panels are in nine museums in different parts of the world.

Over the past three years the surface of the panels of the Polittico Griffoni have been recorded in three dimensions, with Lucida. In addition to the 3D scanning the paintings were also photographically recorded at high resolution. For the high-resolution colour recording Factum Arte uses a planar system to record the small panels and a panoramic photographic system record the larger panels. Large numbers of photographs are taken and stitched together using PTGui software. Recent developments in both hardware and software are opening up new possibilities for macro photographic recording that allow the paintings to be studied with forensic accuracy. The resulting archives are evidence that the application of technology can ensure that cultural artifacts can be documented, studied and transmitted in a faithful way.

Above: Facsimile of the Polittico Griffoni altarpiece mounted on a provisional display in the Basilica of San Petronio, Bologna.



Polittico Griffoni



Comparison between 3D render and colour, detail of a gilded area with pouncing marks around the angels' heads.

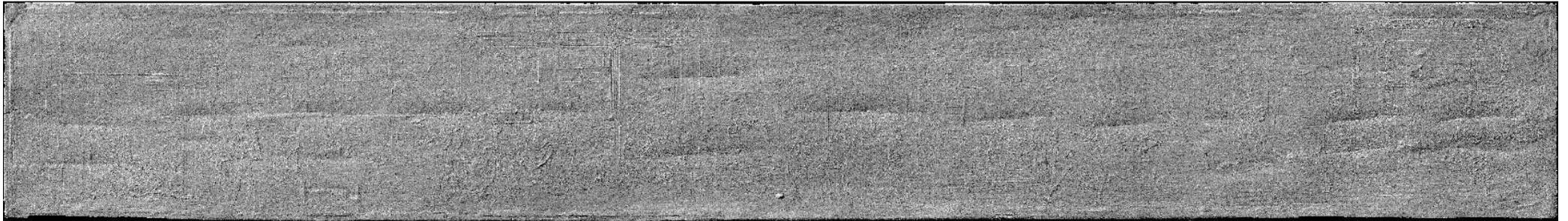


Next page: 3D render generated by Lucida.

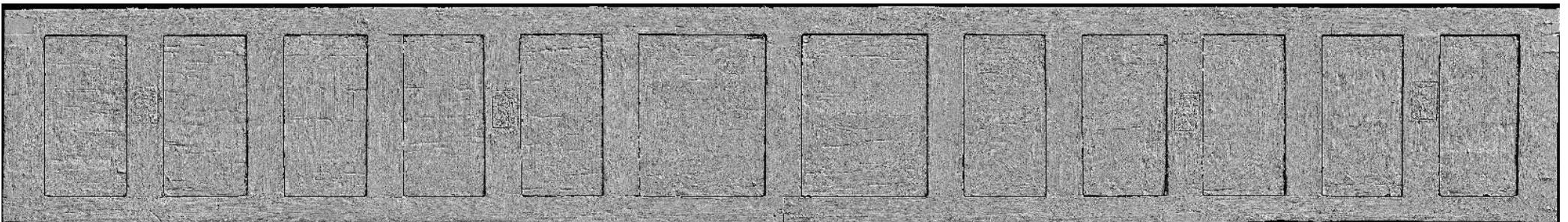
Polittico Griffoni



Ercole de'Roberti, *Stories of Saint Vincent Ferrer*, c. 1473.

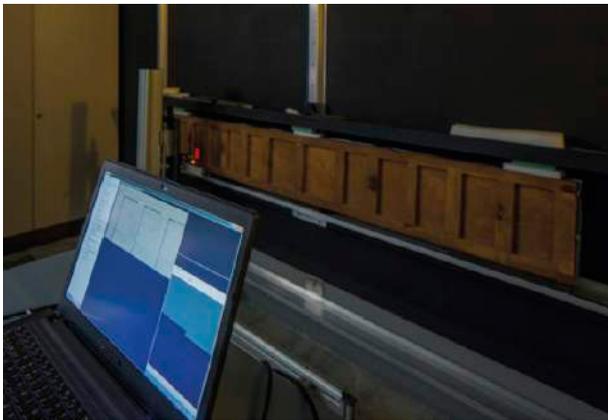
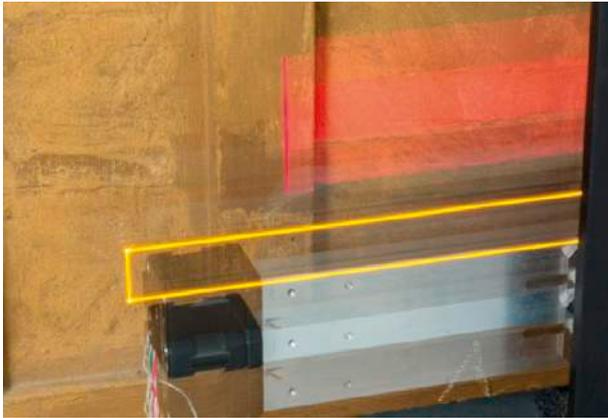


3D render of the panel generated by Lucida.

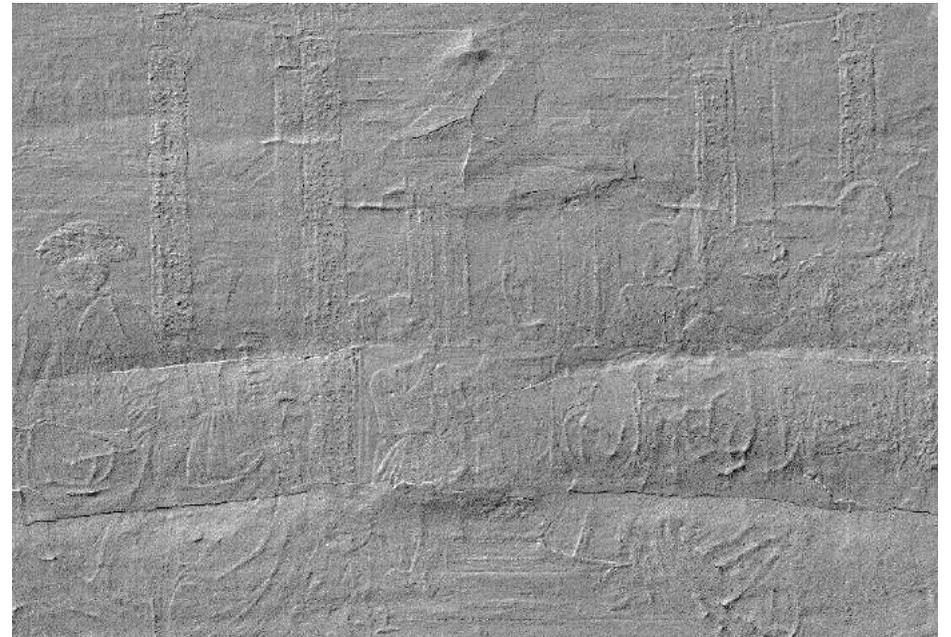


3D render of the panel's back. The modulation corresponds to the pattern of horizontal cracks visible in the front side.

Polittico Griffoni



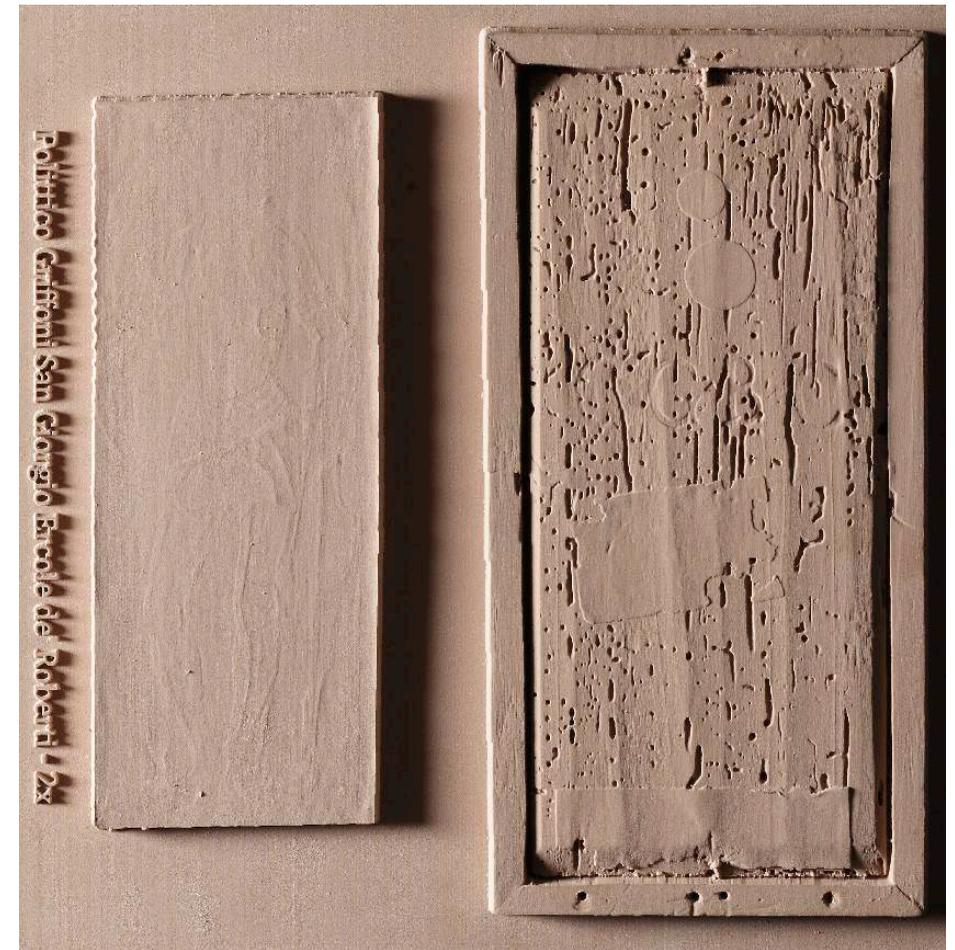
The front and back of the *predella* were recorded in the Pinacoteca Vaticana in October 2013.



Comparison between 3D and colour, detail of the cracks visible in the 3D render of the panel.

Polittico Griffoni

The 16 panels that once formed the Polittico Griffoni were removed from their original location in the Basilica of San Petronio in Bologna and are now scattered in different museums around the world. A physical reconstruction has been made and symbolically 'returned' to the chapel.



3D data of the *Saint George's* panel CNC routed into high density resin board, front and back.

Previous page: Top: Ercole de'Roberti, *Saint George*, c. 1472, 26.3 x 9.3 cm, Fondazione Giorgio Cini, Venice, front and back; Bottom: 3D renders generated by Lucida, front and back.

Polittico Griffoni



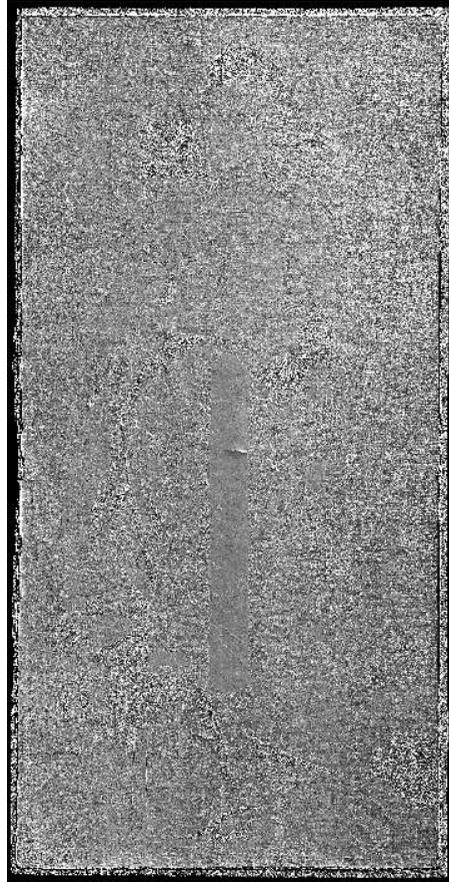
Top: Ercole de'Roberti, *Saint Petronius*, c. 1472, 26.3 x 9.3 cm, Pinacoteca Nazionale, Ferrara, colour and 3D render.
Bottom: Lucida scanning *Saint Anthony the Abbot* at the Museum Boijmans van Beuningen, Rotterdam.



Top: 3D data of Francesco del Cossa, *Annunciation Angel*, c. 1472, diam. 25 cm, routed into gesso coated material.
Bottom: Lucida scanning *Annunciation Angel* and *Annunciation Virgin* at the Museo di Villa Cagnola, Gazzada, Italy.

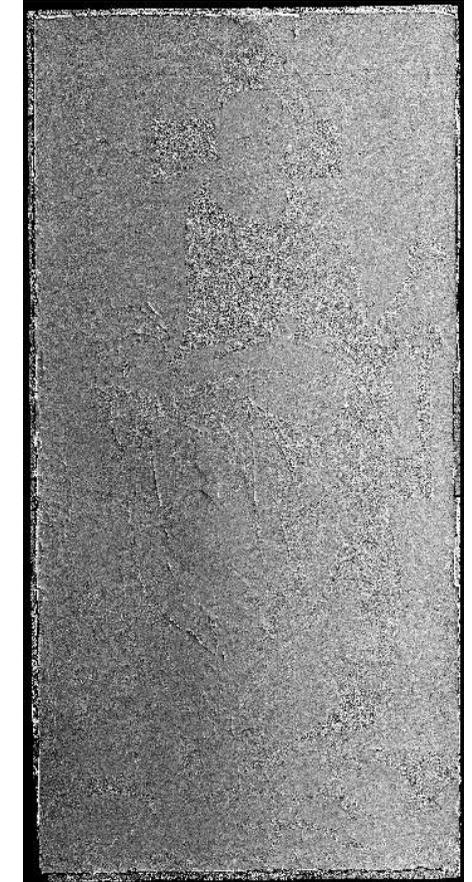
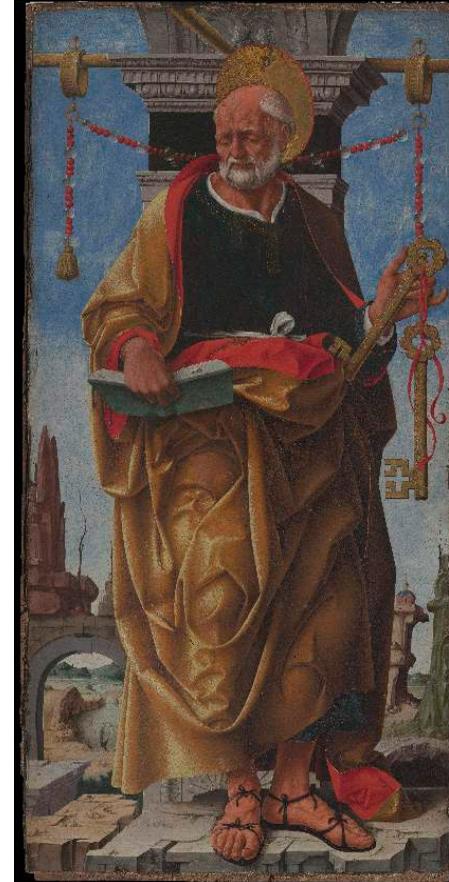
Polittico Griffoni

The panels in Brera are undergoing restoration to consolidate the paint surface and address the curved nature of the poplar. After the restoration process, the panels will be recorded again, to monitor the changes and establish a comparison that will be of great value for historians, researchers and conservators in the future.



Francesco del Cossa, *Saint John the Baptist*, c. 1472, 112 x 55 cm, Pinacoteca di Brera, Milan.

3D render generated by Lucida.



Francesco del Cossa, *Saint Peter*, c. 1472, 112 x 55 cm, Pinacoteca di Brera, Milan.

3D render of *Saint Peter* obtained by Lucida.

Bellini

Lucida is now being used at the National Gallery's Scientific Department to record the surface of a work by Bellini as part of its conservation. By scanning the front and back of the painting before, during and after the restoration process, it is possible to keep accurate records of its treatment for current and future applications.



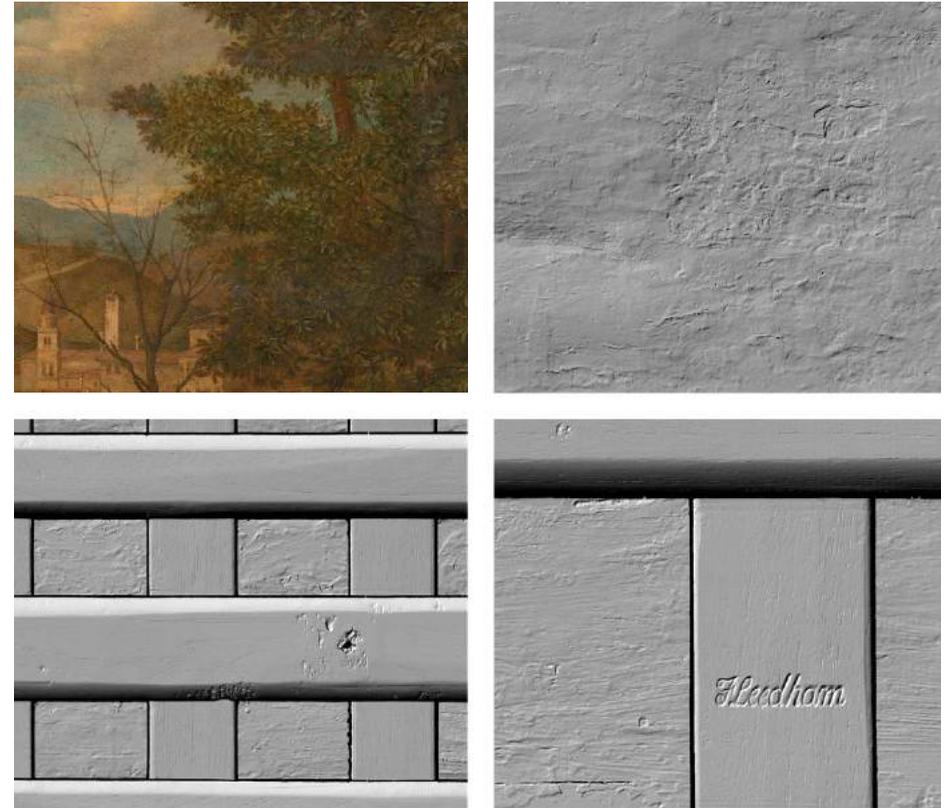
The Assassination of Saint Peter Martyr, 3D render generated by Lucida.

The Assassination of Saint Peter Martyr

Following the successful recording of Francesco del Cossa's *Saint Vincent Ferrer* in 2013, the Lucida 3D scanner was taken back once more into the National Gallery of London to take part in another major research and conservation project. *The Assassination of Saint Peter Martyr* (c.1507) by Giovanni Bellini, is the first work to be 3D scanned in high resolution before, during and after a complex restoration process. The first session, consisting of a 3D recording of the front and back of the panel before restoration, was carried out in late September 2014.

The Factum Foundation and The National Gallery are pioneering the way towards a more comprehensive approach to painting conservation, in which a 3D recording of the state of an artwork is an essential part of the process. The data recorded with the Lucida 3D scanner of this important painting remains the property of the Gallery. It will be useful not only for the researchers and conservators working with this painting, but will also serve as a record for the general public and future generations.

Lucida can be especially useful to monitor the changes in the material support of a painting produced by the consolidation treatment of the board. The capacity to capture not only the general shape of the board but also the texture, makes it the ideal tool to understand the small changes on the relief that are part of every restoration process.



Top: comparison between colour and 3D data, detail.
Bottom: 3D render of the back, details.

Kirchner

Scanning test, The Courtauld Institute of Art

A series of tests involving the 3D scanning of paintings are being carried out at The Courtauld Institute of Art in London, in order to evaluate the potential of the Lucida scanner in monitoring the condition of works of art. This research project, conducted in collaboration with Dr. Christina Young, involves the 3D scanning of five paintings as examples of different techniques and supports. The first painting, a work by German expressionist painter E. L. Kirchner (72 x 92.3 cm, thick oil paint on paper) was recorded in July 2014 in order to understand its texture as well as the overall deformation of the support.

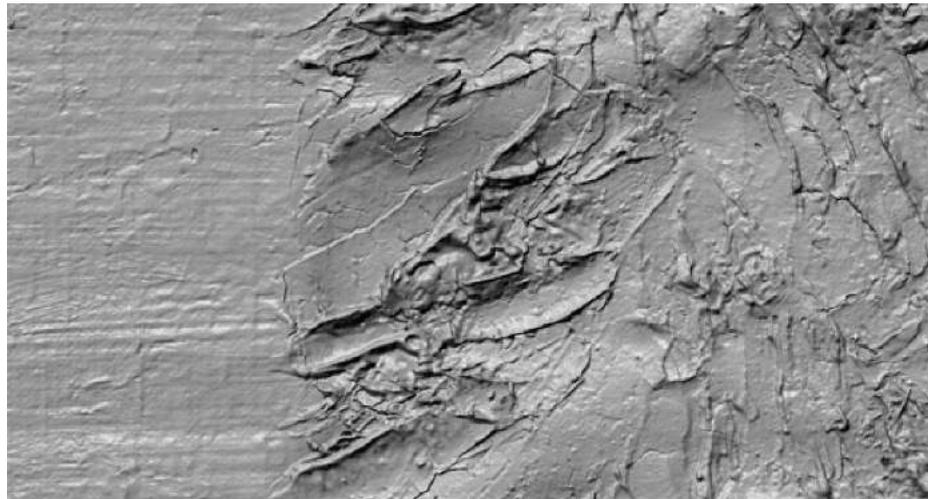
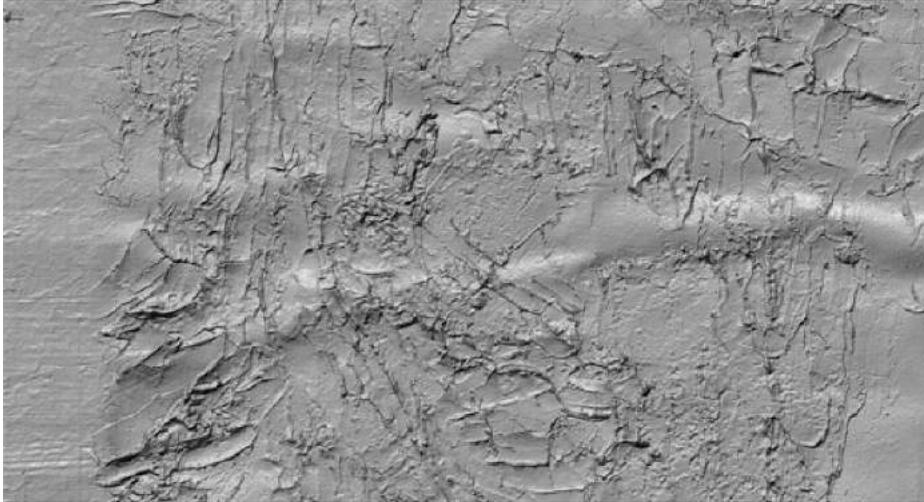
One of the most interesting tests within this research project will be the systematic high resolution recording of the surface of a large poplar panel under varying degrees of relative humidity. The 3D data obtained with Lucida will enable researchers to measure and monitor the deformation of the support to an accuracy of 100 microns.



E. L. Kirchner, 72 x 92.3 cm, 3D render by Lucida.

Kirchner

Lucida allows the 3D data to be viewed as a rendered image so that it can be compared with other layers of 2D information. This permits the user to process the data with image processing software rather than specialized 3D software, which tends to be expensive and requires regular updates. The data can also be exported to different 3D formats such as STL or OBJ.



E. L. Kirchner, render of the 3D data in STL format, details.

E. L. Kirchner, render of the 3D data in STL format, details.

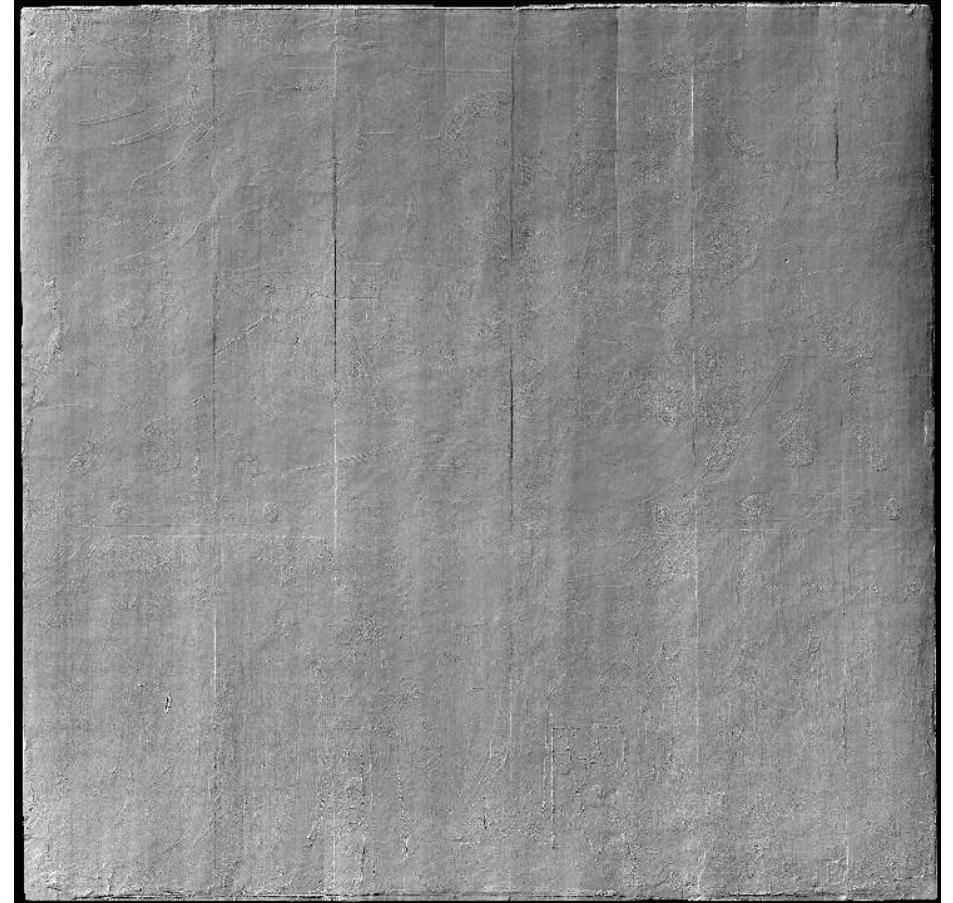
Royal Collection

Strawberry Hill House



The Family of Henry VIII with Saint George and the Dragon is a work of the Flemish School, of the 16th century which is part of the Royal Collection Trust.

A facsimile is an exact replica of a work of art done with the goal of helping the preservation of the original or adding value to it in some way. For the facsimile of a painting (on canvas, board, etc.) to be meaningful the relation between colour and relief should be as complex and rich as in the original.



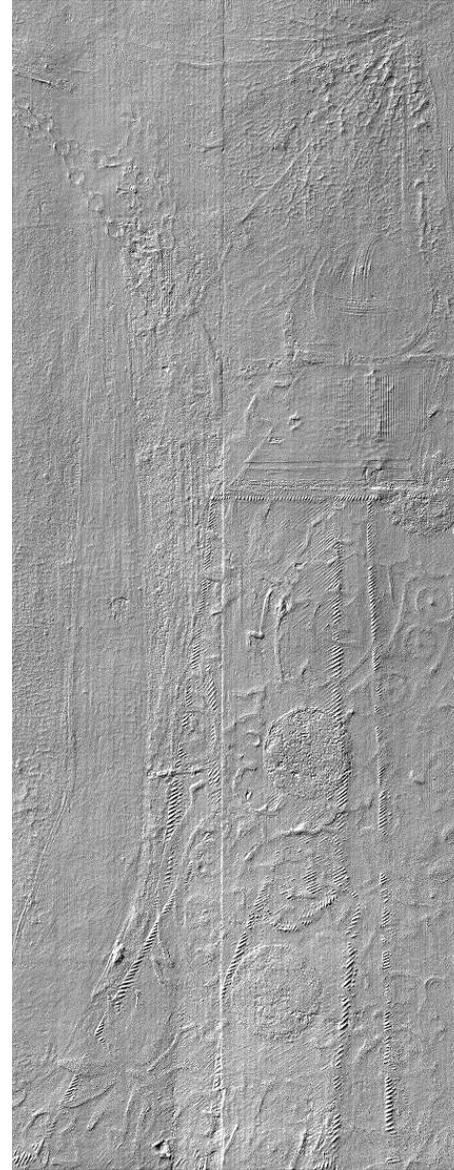
The painting was recorded at Hampton Court Palace in order to make a facsimile for Strawberry Hill House.

Next pages: Comparison between the colour data obtained with panoramic photography and the relief data obtained with the Lucida 3D scanner, two details.

Royal Collection

Strawberry Hill House

This painting originally adorned the staircase of Strawberry Hill House before becoming part of the Royal Collection. Factum Arte produced an exact facsimile of the work which has been returned to its original location in 2015. Relief data obtained with the Lucida 3D scanner has been combined with colour photography to create the facsimile.



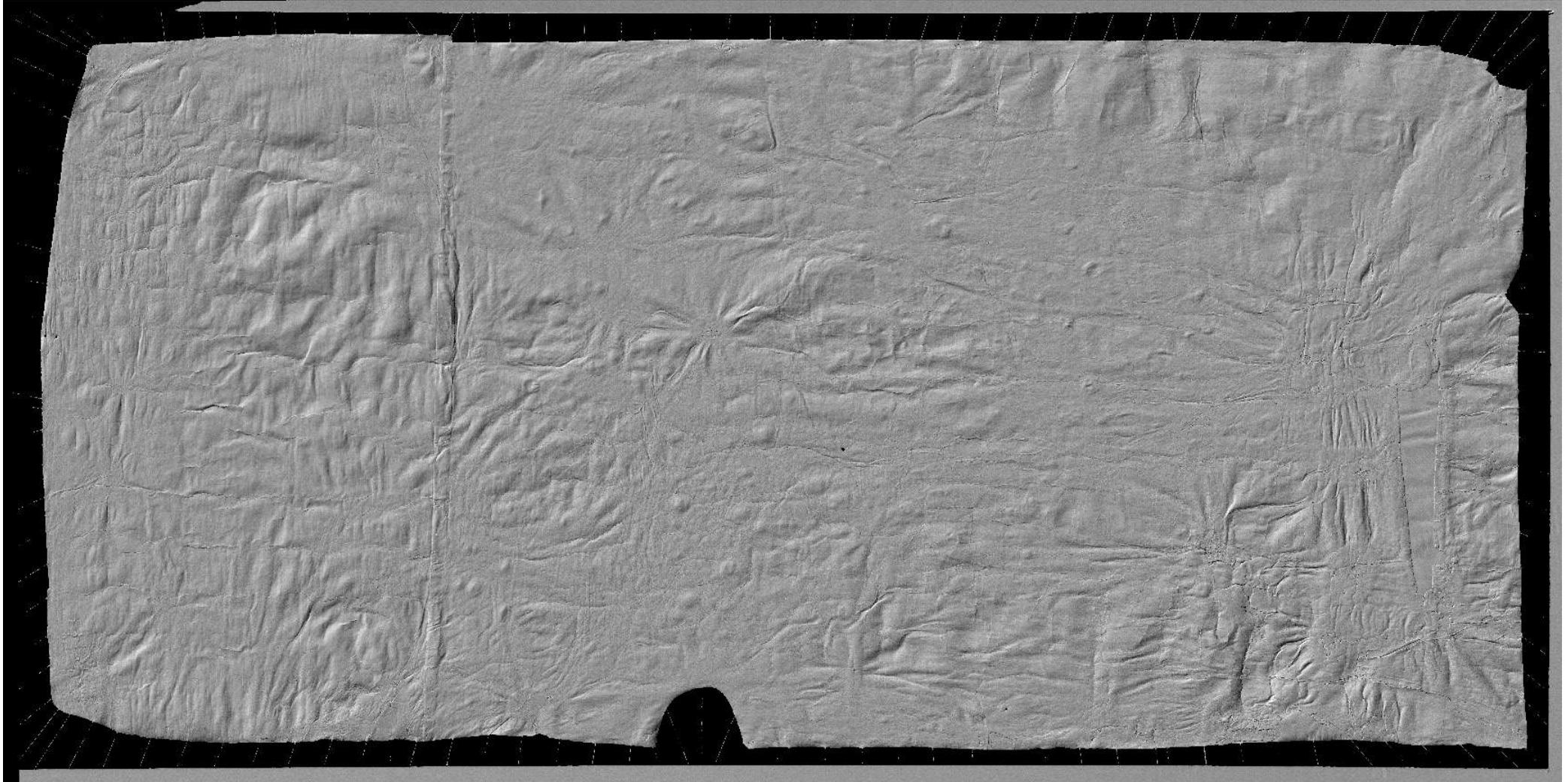
Gough Map

The Gough Map, kept at the Bodleian Library in Oxford, is internationally renowned as one of the earliest maps to show the British Isles in a geographically recognizable form. Nevertheless, questions remain over how the map was made, its provenance and exact age... The surface of the map has been 3D scanned for the first time in order to help unveil some of these questions.



The Gough Map of Great Britain, original 56 x 115 cm, Bodleian Library, Oxford, combination of 3D render and colour of the front.

Gough Map



The Gough Map of Great Britain, 3D render of the front by Lucida.

Gough Map

Gough Map of Great Britain

The Gough Map dates to the mid-fourteenth century and is regarded as the earliest route map of the British Isles. Factum Arte is currently involved in a new initiative together with the Bodleian Library in Oxford and Queen Mary University to scan this fascinating object. Its exact dating, authorship and function are unknown and with the data resulting from the scanning process, researchers are hoping to shed light on these and many other aspects of its creation. Factum Arte is committed to demonstrating the importance of digital technology in the analysis and documentation of our cultural heritage. Non-contact, high-resolution 3D scanning will provide valuable data of the subtle relief of the map, which can then be combined with other layers of information such as colour in order to monitor its condition and understand its biography.

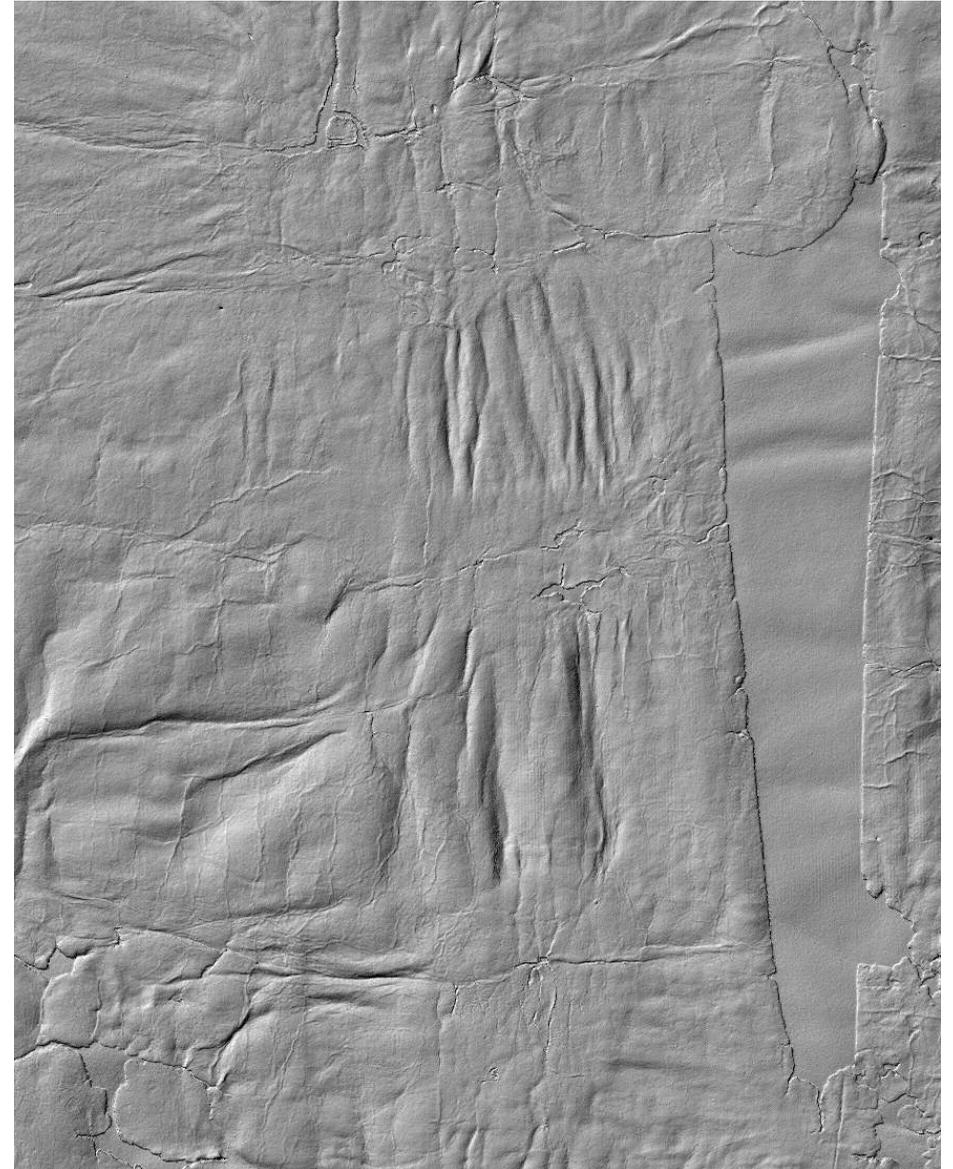
Selden Map of China

The Factum Foundation is also examining the Selden Map of China (p. 56-57), another of the Bodleian's most important and most enigmatic maps. Only recently rediscovered, it dates to the early seventeenth century and is anonymous. It is believed to have been made by a Chinese mapmaker as it shows Southeast Asia and its maritime sea routes. Factum Arte and the Factum Foundation, working with the Bodleian's Map and Conservation departments as well as a number of other companies, hopes that it may unearth the secrets of two of the history of cartography's most prized maps.

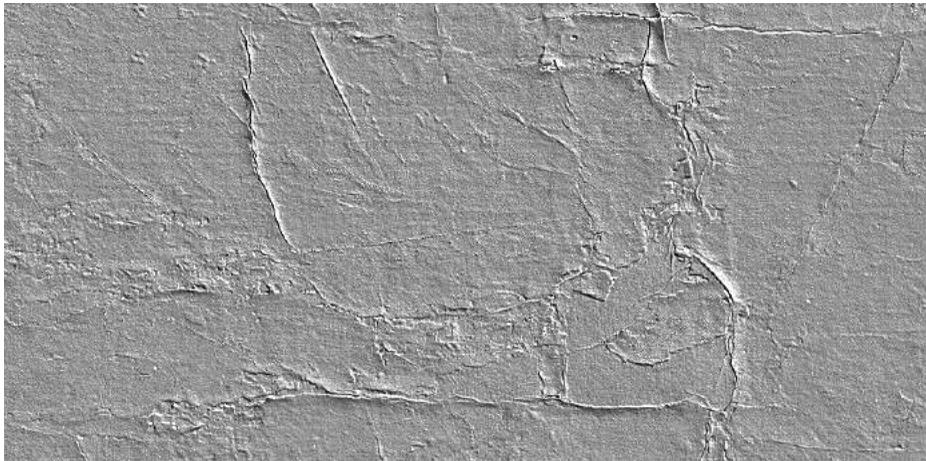
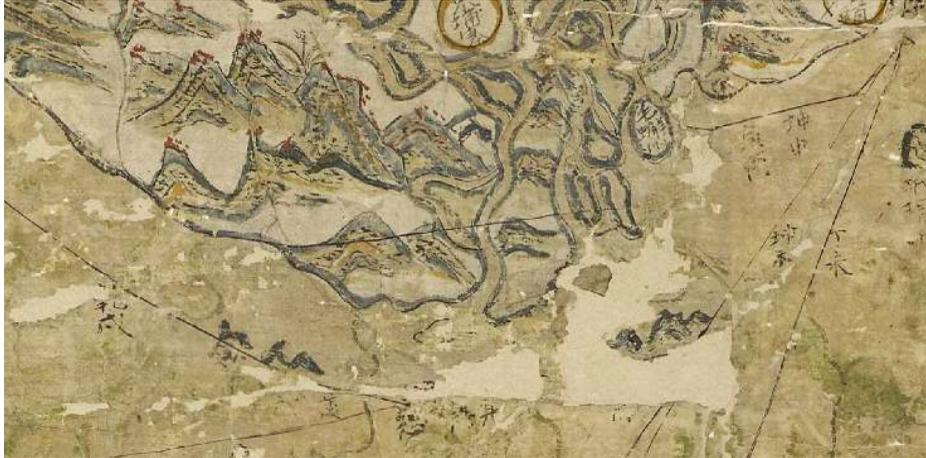
Detail of the surface of the Gough Map, recorded with Lucida 3D scanner in January 2015 after restoration.

“(...) I’m finally getting around to adding my own marks to yours - to identify both the pinholes and the other features that have left a 3D trace. (...) From all this you can see that your scan has done pretty well - showing a few things we couldn’t see before and supporting a few of our assumptions.”

Damien Bove, visual artist and researcher.



Selden Map



Comparison between colour and 3D data, detail.

Next page: the Selden Map of China, recorded with the Lucida 3D scanner in January 2015 after restoration.

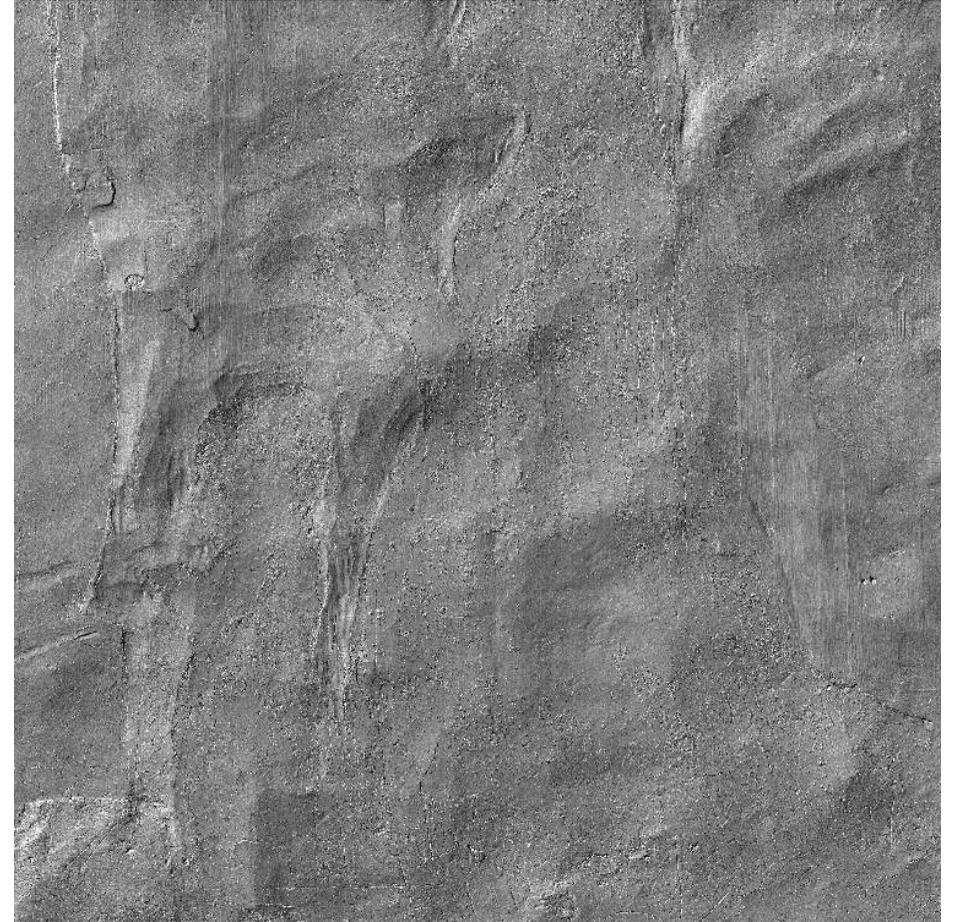


Crocifissione



Dontato Montorfano, *Crocifissione*, 1495, Santa Maria delle Grazie, Milan, combination of 3D render and colour data, section of about 1 sqm, detail of Leonardo's addition to Montorfano's fresco.

A section of 1 sqm of Montorfano's *Crocifissione* was recorded as a demonstration of the possibilities of the Lucida 3D Scanner. The high resolution 3D data that was obtained, in combination with the colour data captured with photography, have made possible the creation of a multilayer archive to inspect and understand the complex relation between colour and relief.



Crocifissione, 3D render generated by Lucida, section of 1 sqm.

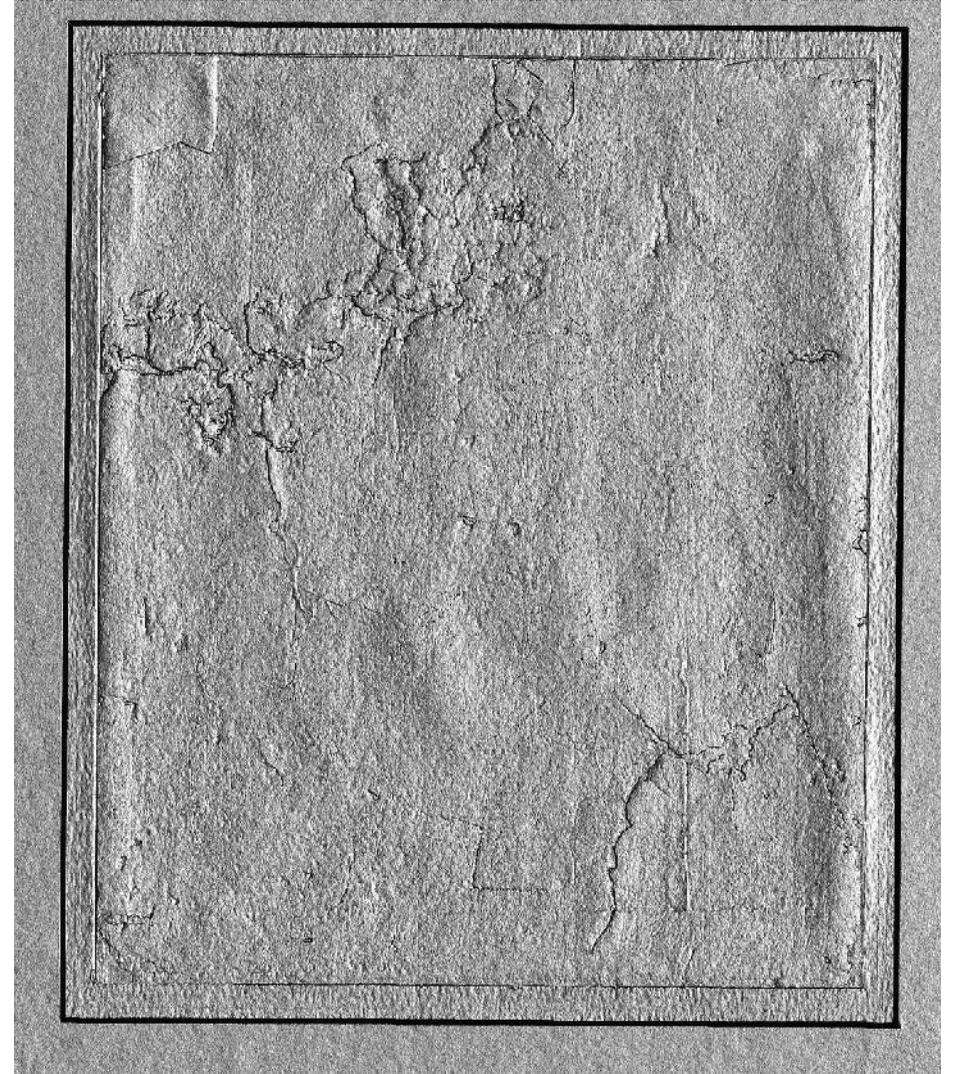
Raphael

Raphael drawings, Ashmolean Museum

A series of eight original drawings by Raphael, including *The Holy family with Lamb*, 27.5 x 22.7 cm (pictured on the right) were recorded with the Lucida 3D scanner in 2015 at the Ashmolean Museum, University of Oxford. For the first time, high resolution texture data has been obtained from a very flat surface, so it is possible to see very clearly the pouncing along the drawing lines and other marks in the relief. Different rendering modes have been used to highlight the subtle pouncing marks that are present in the drawing, following the contour lines of the main figures. The conservators in the Ashmolean Museum can check, correct and add more marks and layers of information to these data, especially in combination with other data such as colour, etc. using Factum Foundation's online multilayer browser. This is an ongoing research project that will involve the addition of new layers of information of these drawings, in order to increase the knowledge and disseminate the significance of such important works of art.

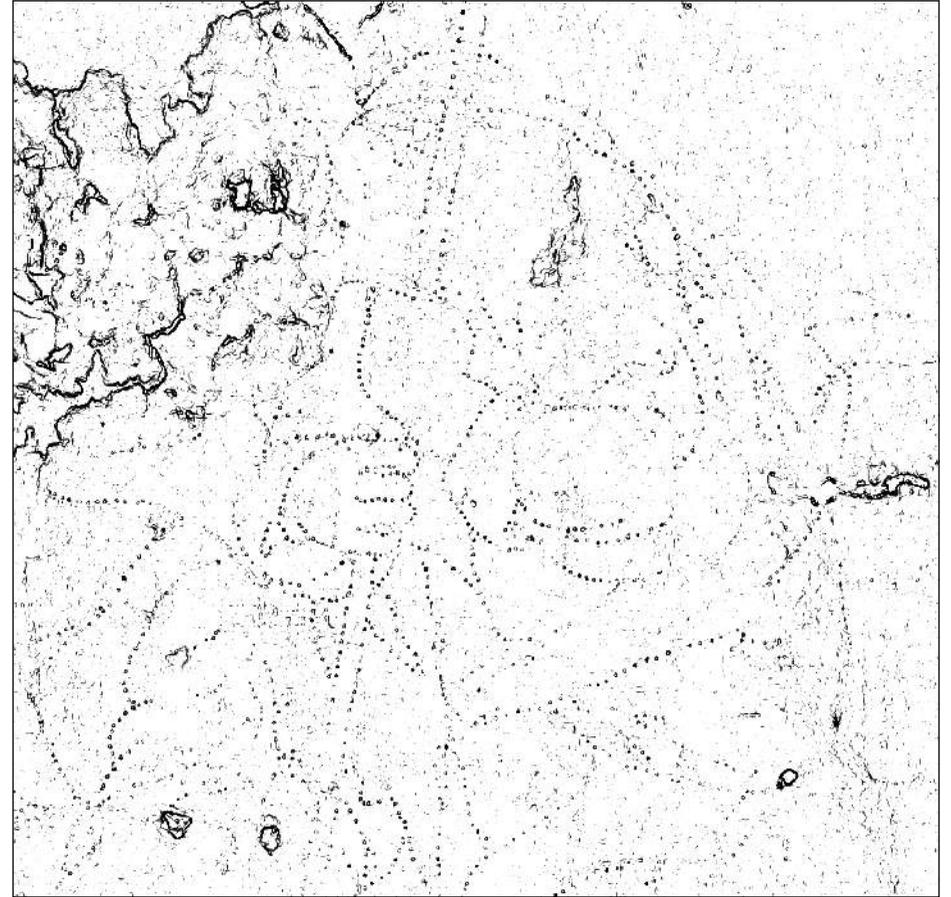
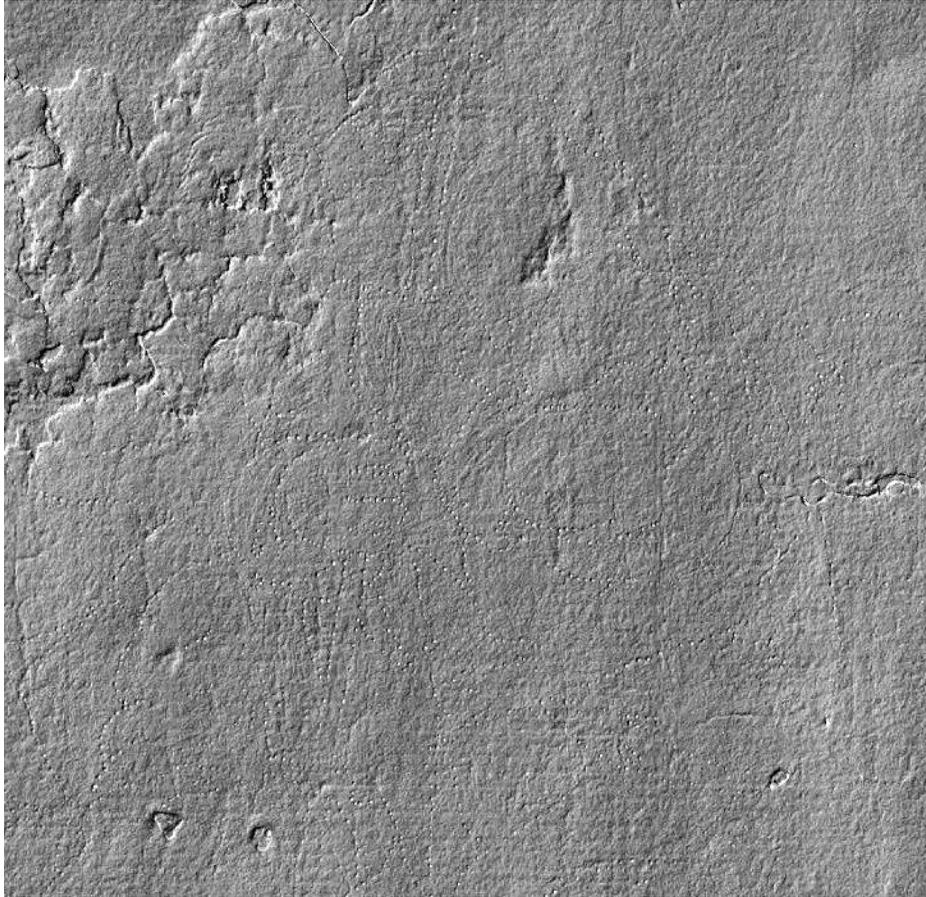


Raphael, *The Holy family with Lamb*, C16th, 27.5 x 22.7 cm, Ashmolean Museum, University of Oxford.



3D data of Raphael's *The Holy Family with Lamb*, obtained with Lucida. The 'Specular Enhancement Render' mode has been used in this image to increase the subtle relief of the drawing.

Raphael



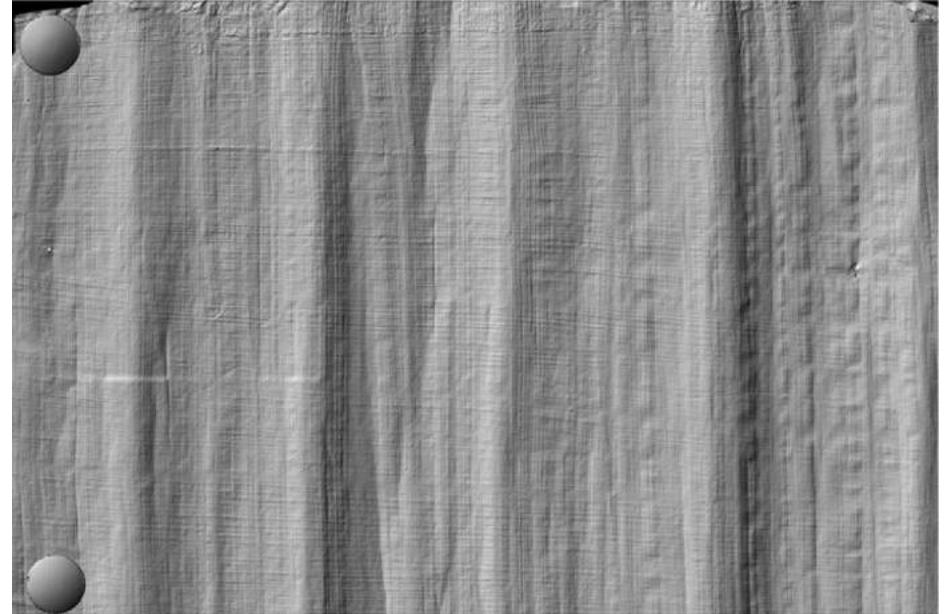
Previous page and above: 3D data of Raphael's *The Holy Family with Lamb*, obtained with Lucida. The pouncing marks that follow the contour lines of the drawing can be highlighted using different rendering modes.

British Library

Lucida 3D scanner at the British Library

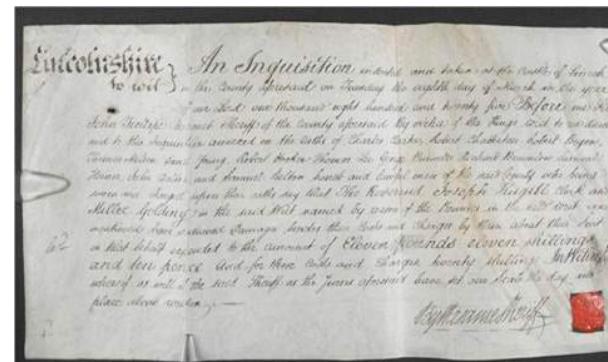
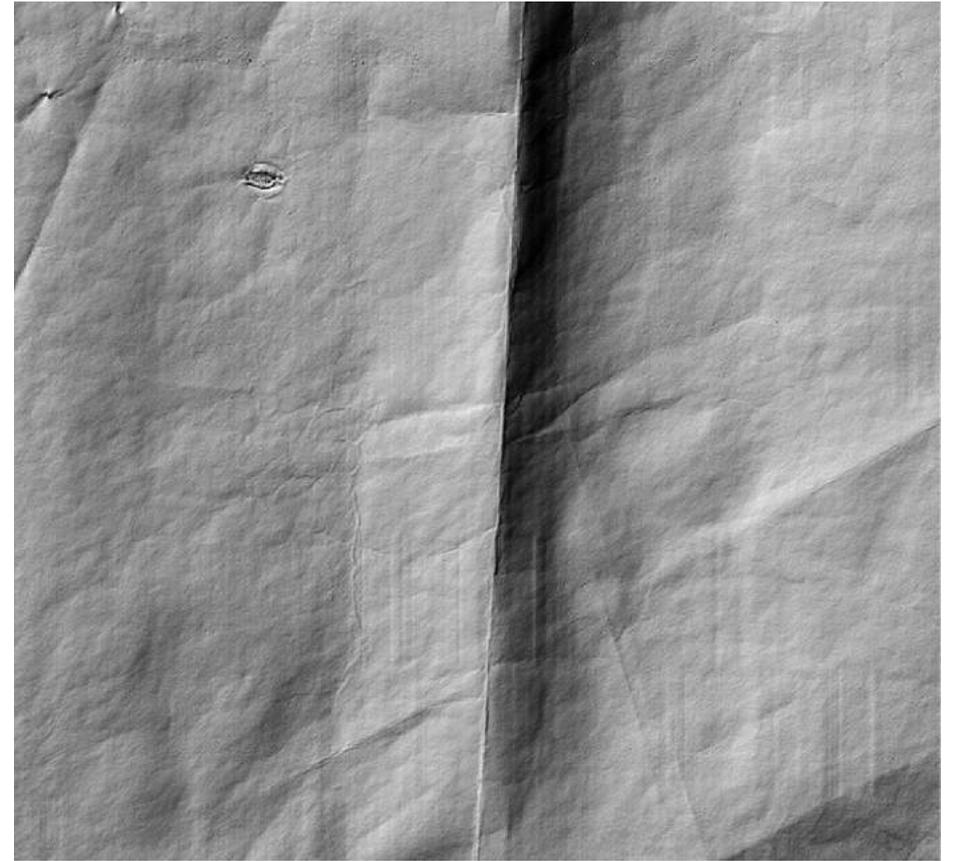
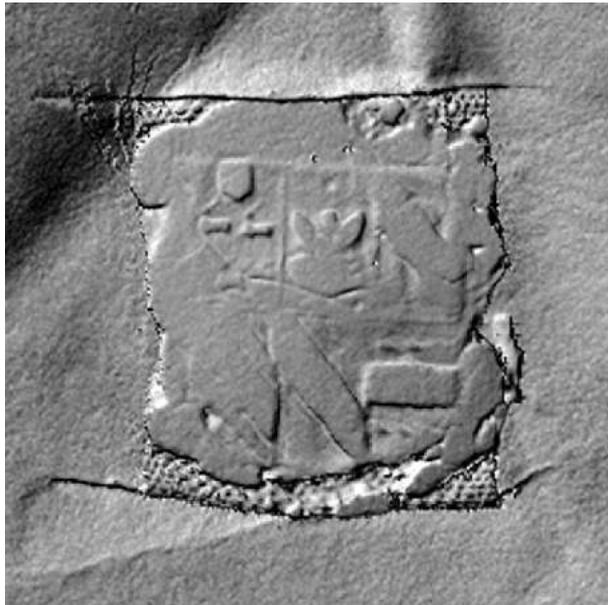
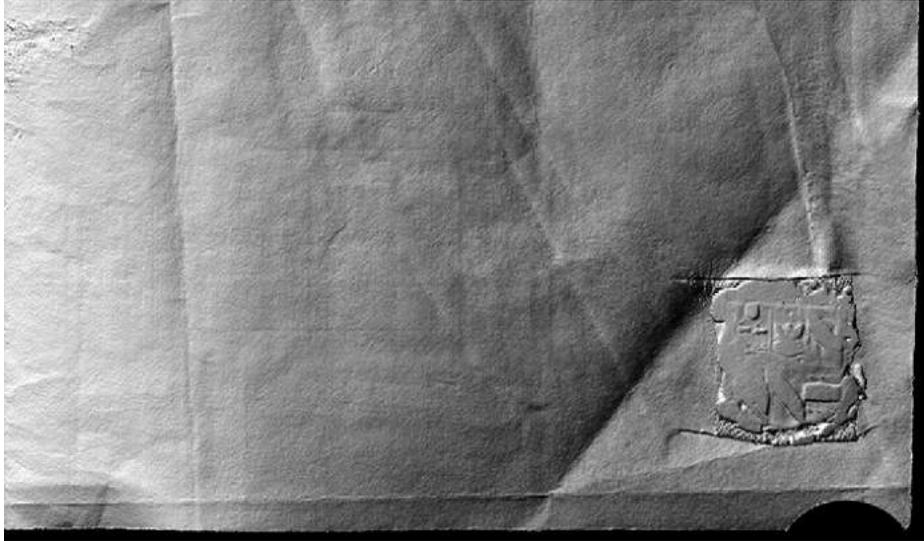
In June 2015, Imaging Services hosted a demonstration of the Lucida 3D scanner in order to assess it as a tool for deployment at the British Library. Various training samples were provided to be scanned for the demonstration. From the group on loan, 7 items were chosen to demonstrate the variety in the British Library's collections. Since the items needed to be mounted vertically for scanning, this limited the choice to primarily single folios. The items scanned were the following:

- Item 1: a modern piece of papyrus
- Item 2: a parchment document with a wax seal
- Item 3: a piece of hand laid paper with a watermark
- Item 4: a document with conservation repairs
- Item 5: a black fimo seal
- Item 6: a metal seal
- Item 7: a large parchment document



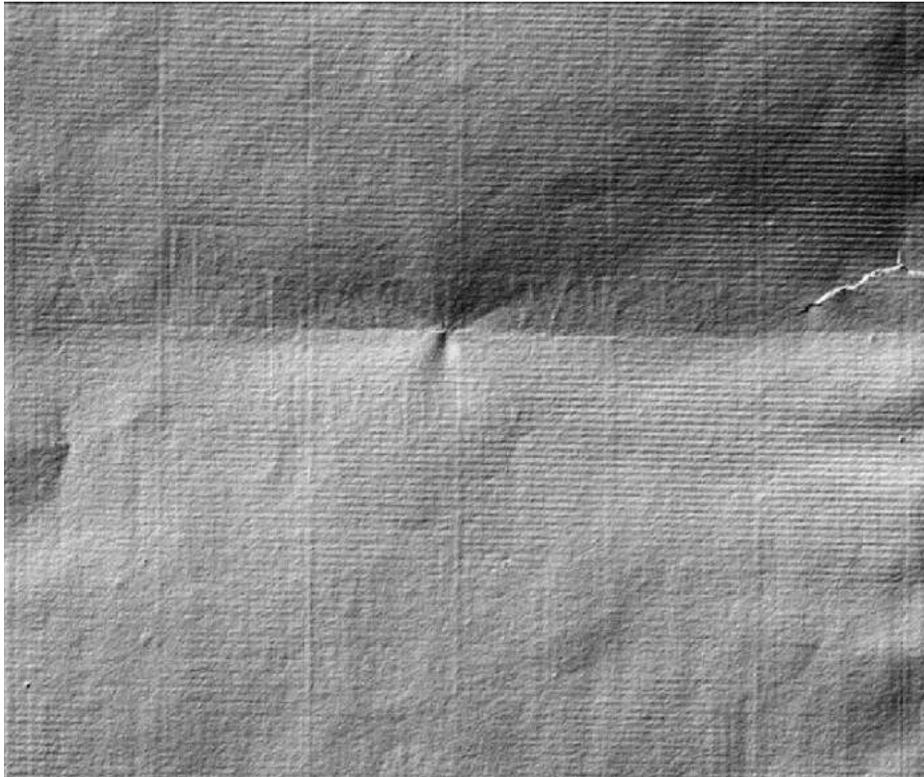
Item 1: a modern piece of papyrus.
Top: 3D render, detail; Bottom: reference photo.

British Library

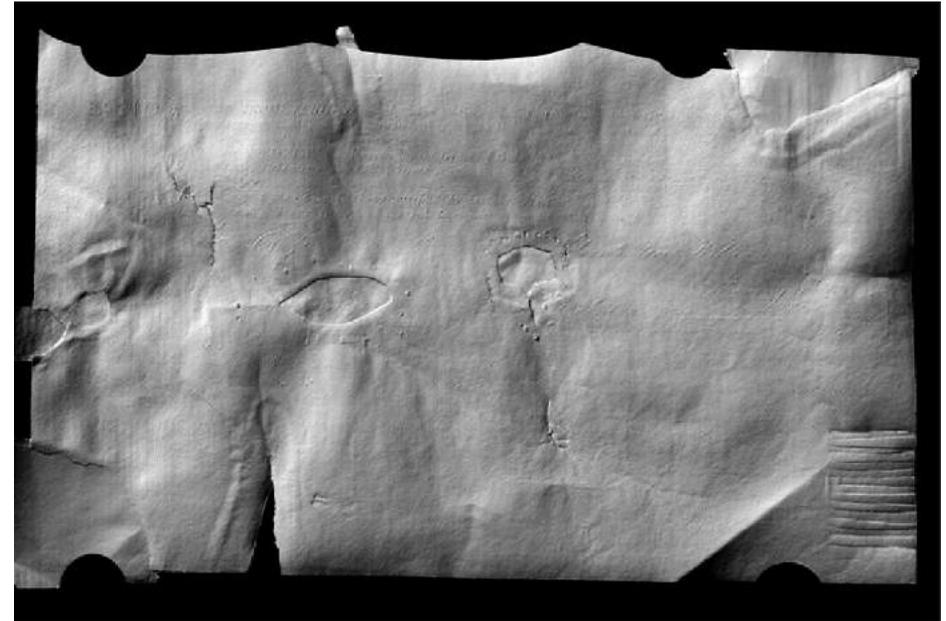


Item 2: a parchment document with a wax seal.
Top: detail of the 3D render obtained by Lucida.
Bottom: reference photo.
Previous page: 3D render, details of the wax seal.

British Library



Item 3: a piece of hand laid paper with a watermark, detail.



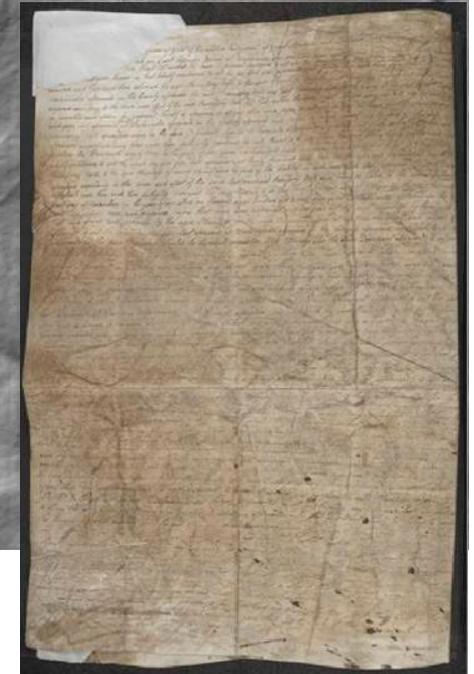
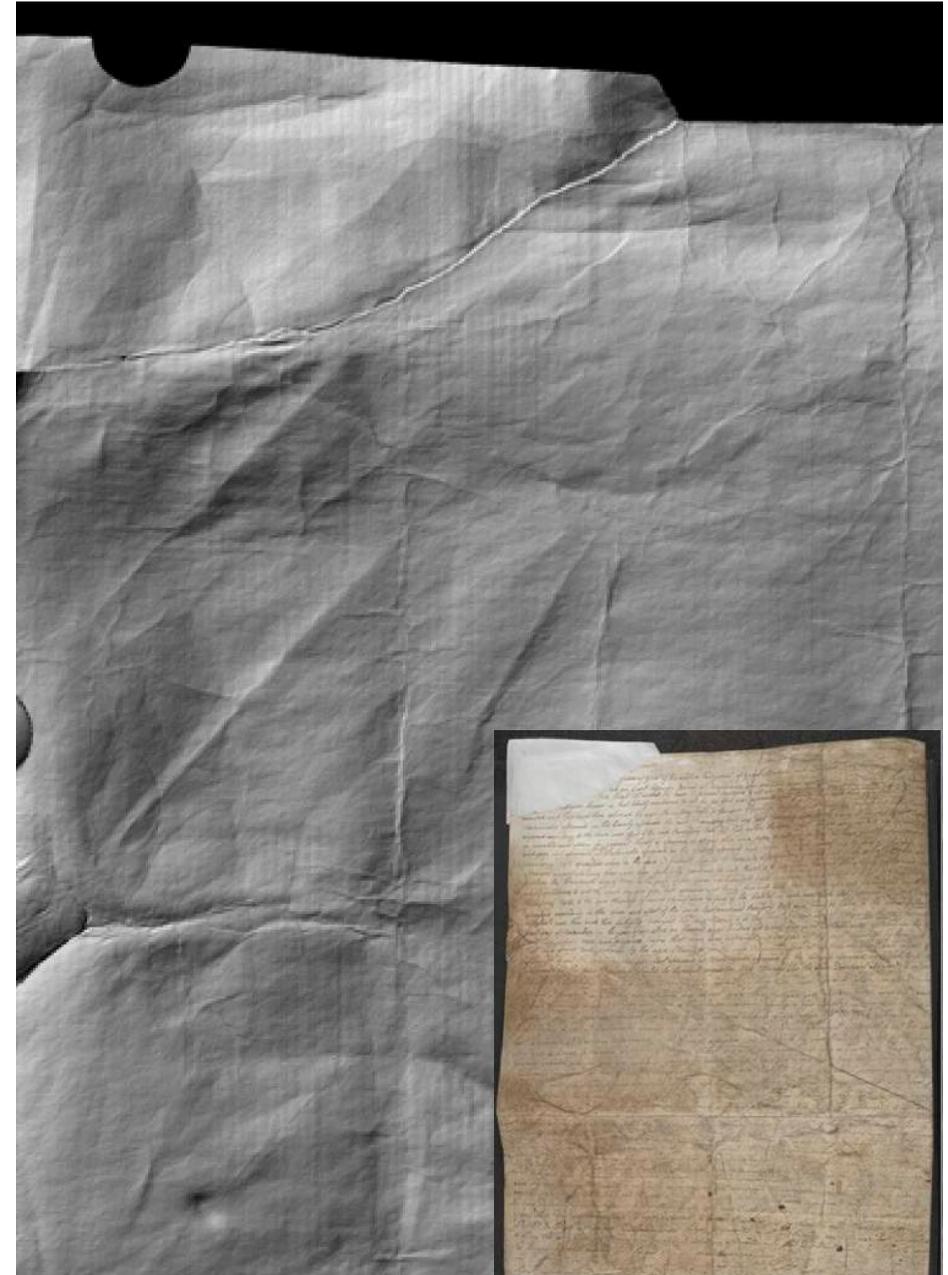
Next page: Item 4: a document with conservation repairs; Top: render of the 3D data generated by Lucida; Middle: detail of the conservation repairs; Bottom: reference photo.

British Library



Item 5: a black fimo seal.
Top: render of the 3D data; Bottom: reference photo.

Item 6: a metal seal.
Top: reference photo; Bottom: render of the 3D data.



Item 7: a large parchment document.
Top: detail of the 3D render generated by Lucida;
Bottom: reference photo.

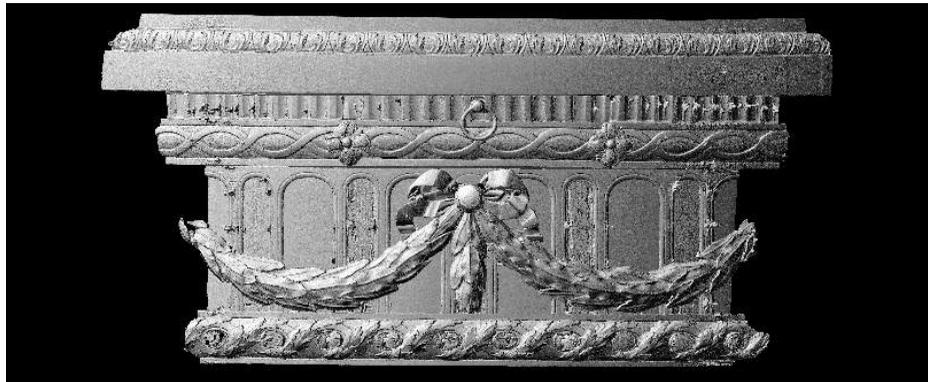
Teschen Table

The Teschen Table at the Musée du Louvre

In July 2015, a team from Factum Arte recorded the Table of Teschen (pictured right) at the Musée du Louvre, in order to make an exact copy that will be shown in the Chateau de Breteuil – where the table has been kept since it was given to the family in 1768.

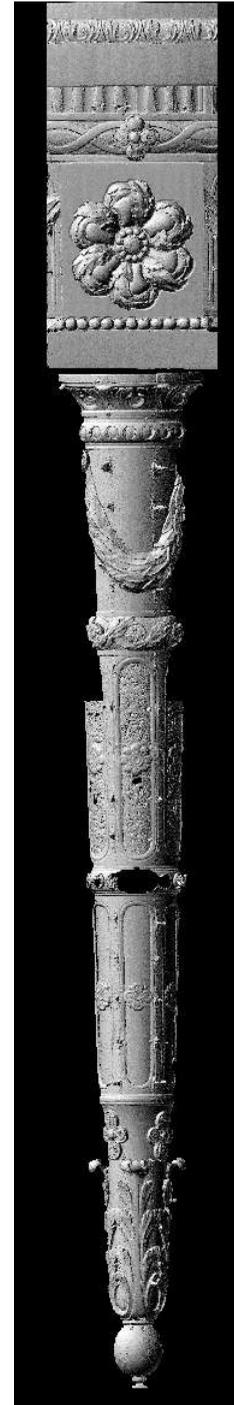
The scanning of the table was carried out using various 3D and colour recording systems. Lucida was used to digitise some of the main decorative motifs across the table's body, as well as one full leg. The recorded data will then be combined with the general 3D model of the object generated with a structured light scanner. Whereas scanning translucent materials such as crystal or some of the stones is an almost impossible task for most 3D scanners including Lucida, this project has demonstrated the ability of the Lucida 3D scanner to record data from gilded surfaces, with the highest quality and resemblance to the real texture of the object.

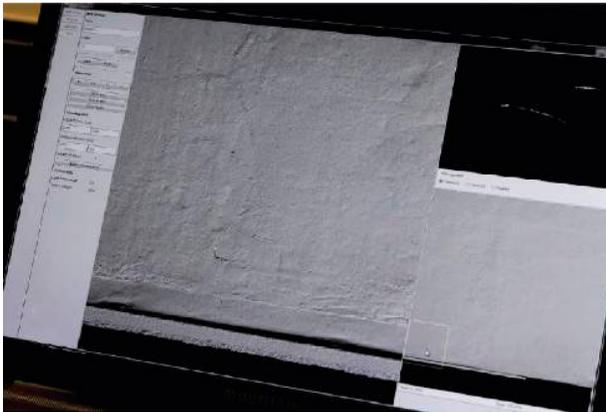
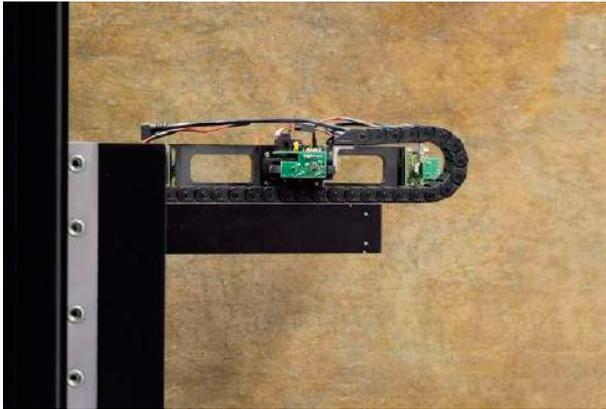
In order to record a curved surface that exceeds Lucida's depth of field of 25 mm, various successive scans can be made at different distances, which were then merged in the processing phase to complete the model.



Render of the 3D data of the table's side.

Next page: Left: 3D data of a full leg obtained with Lucida; Right: various close-up photos of the table top.





Technical specifications

Laser diode

Manufacturer and model: Laser Components ADL-65075TA2

Type: Auto Power Controlled Laser Diode. Stable light power output, compact size, high brightness laser light source.

Wavelength: 650 nm

Power: 4 mW

Cameras

Manufacturer and model: IDS Imaging Development Systems UI-1221LE-M-GL

Type of cameras: Black & White

Sensor: CMOS Mono by Aptina Imaging

Lens: Sunex DSL-300 EFL=17.1 f/4.2

Data transmission speed: max 25 Mbytes/s per camera

Interface: USB 2.0

Resolution: 752 x 480 pixels

Microcontroller

Chip: 8-bit Atmel AVR Atmega 328

Clock speed: 16MHz

Operating Voltage: 5V

Linear motion

Manufacturer and model: Haydon Kerk RGS06

Motorized hybrid linear rails & actuators

Scanning features

Depth of field: 25 mm

Maximum scanning depth using Z axis: 500 mm

Distance to the target: 65-90 mm

Maximum scanning area (m2): Only limited by storage capacity and structural frame

Scanning speed (m2/h): ca. 0.25

Data features

File formats: 3D point cloud (RIS), 3D depthmap (TIFF), 2D render (TIFF), raw video (AVI)

Point resolution: 10,000 points per cm2

Megabytes per m2: RIS (420 MB), 3D depthmap

32bit-TIFF (420 MB), 2D render 8bit-TIFF (88 MB), AVI (272 GB)

Software features

OS requirements: Windows XP 32 bits

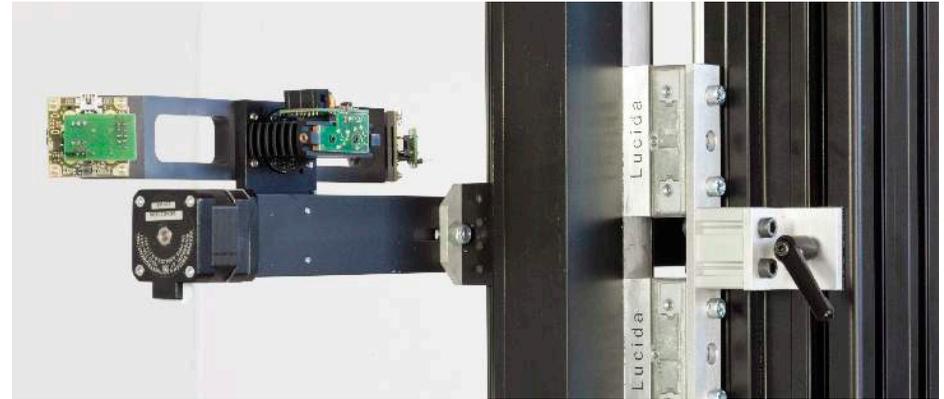
Computer requirements: 3 USB 2.0 ports

Mechanical features

Frame Manufacturer and model: Standard structural frame by Bosch-Rexroth.

Weight of the whole system: 53 Kg (with 1 m mast and 1.45 m horizontal rail)

Materials: Mostly black painted or anodized aluminum



Credits

Manuel Franquelo: concept and design of electronics, mechanics, optics, and software. Lucida 3D scanner has been fabricated and tested in Factum Arte by Carlos Bayod, Dwight Perry, Jorge Cano, Nicolás Díez, Manuel Franquelo Jr, Guendalina Damone, Enrique Esteban, Marta Herranz and Aliaa Ismail under the supervision of Manuel Franquelo.

Resources

Lucida user's manuals can be downloaded from Factum Arte's website:

Assembly Instructions

factum-arte.com/lib/kcfinder/upload/files/Lucida/manuals/2015_Lucida_A5_Assembly_Final.pdf

<https://vimeo.com/8261186> (password: factum53)

Operator's manual

factum-arte.com/lib/kcfinder/upload/files/Lucida/manuals/2015_Lucida_A5_Operator_Final.pdf

Processing applications

factum-arte.com/lib/kcfinder/upload/files/Lucida/manuals/2017_Lucida_A5_processing_Final.pdf

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