RESEARCH DEPARTMENT REPORT SERIES no. 19/2007 ISSN 1749-8775

CHISWICK HOUSE, LONDON
LASER SCANNING TESTS ON A GILDED 18TH-CENTURY TABLE

METRIC SURVEY REPORT

Paul Bryan

Research and Photography by Martin Cooper and Annemarie LaPensée,
Conservation Technologies

IMAGING, GRAPHICS
AND SURVEY

ENGLISH HERITAGE

ENGLISH HERITAGE

Chiswick House
London
W4 2RP

Laser Scanning Tests on a Gilded 18th Century Table

Report by: Paul Bryan
Research by: Martin Cooper and Annemarie LaPensée, Conservation Technologies
Research date: December 2006
Photography by: Martin Cooper

NGR TQ424740
ISSN 1749-8775
Research Department Report Series 19/2007

Comments or queries regarding the content of the report should be made to the author at:
ENGLISH HERITAGE, 37 TANNER ROW, YORK, YO1 6WP
Tel: 01904 601959 Fax: 01904 601999

Applications for reproduction should be made to:
THE NATIONAL MONUMENTS RECORD
ENGLISH HERITAGE, KEMBLE DRIVE, SWINDON SN2 2GZ
Tel: 01793 414600 Fax: 01793 414606 e-mail: nmrinfo@english-heritage.org.uk

The National Monuments Record is the public archive of English Heritage
www.english-heritage.org.uk

The Research Department Report Series

The Research Department Report Series incorporates reports from all the specialist teams within the English Heritage Research Department: Archaeological Science; Archaeological Archives; Historic Interiors Research and Conservation; Archaeological Projects; Aerial Survey and Investigation; Archaeological Survey and Investigation; Architectural Investigation; Imaging, Graphics and Survey, and the Survey of London. It replaces the former Centre for Archaeology Reports Series, the Archaeological Investigation Report Series and the Architectural Investigation Report Series.

Many of these are interim reports which make available the results of specialist investigations in advance of full publication. They are not usually subject to external refereeing, and their conclusions may sometimes have to be modified in the light of information not available at the time of the investigation. Where no final project report is available, readers are advised to consult the author before citing these reports in any publication. Opinions expressed in Research Department reports are those of the author(s) and are not necessarily those of English Heritage.

CONTENTS

1. AIM

The aim of this work was to investigate the feasibility of using laser scanning to produce a three-dimensional (3D) digital record of a gilded wood table at Chiswick House. Laser scanning tests had been carried out on small areas of the same table in 1999 using an older version of the scanning system used for these tests. A second aim of this work was to compare the 'new' and 'old' datasets to see whether the change in scanning equipment used has had any effect on the quality of data collected.

2. DESCRIPTION OF TABLE

The table is one of a pair of 18th-century tables at Chiswick House designed by William Kent. The table (fig. 1) comprises detailed carvings in wood of angels and cherubs, shells, acorns and leaves and other carved features which are gilded and a marble tabletop. Scanning tests were carried out on the 'right' table (normally situated to the right of the doorway, as you look from the outer room inwards towards the domed central hall on the first floor).

The table has dimensions: 840 (height) x 1400 (width) x 680 (depth) mm.

The smallest features to be recorded were of the order of 0.5 mm.

Figure 1.
William Kent table, Chiswick House

3. SCANNING TESTS

Scanning tests were carried out using a 3D Scanners Modelmaker X laser scanning system. This system comprises a laser sensor mounted on a Faro gold arm. The arm is mounted on a heavyweight tripod that can be fixed to the floor. The sensor is guided by hand around the object being scanned, at a distance of approximately 100 mm. For these tests a 70 mm sensor was used; this provides a laser stripe of 70 mm, along which one data point is collected every 70 μm. The camera (housed within the sensor unit) captures 25 frames every second, so that the scanner records approximately 25,000 points per second. The accuracy of the scanner is ±0.1 mm approximately (this will depend on several factors including the nature of the surface being scanned and the scanner set-up).

A portable tripod was used. The tripod was not glued to the floor for fear of staining the stone tiles.

Scanning was carried out in the domed hall on the first floor of Chiswick House. Only a small amount of natural daylight entered the room through windows high up. There was no problem with overly bright ambient lighting.

For full details on the scanning process, see Appendix 1. For screenshots of the raw data collected see Appendix 2.

Confidence checks were carried out on a calibration cube of known dimensions on arrival, to check that the scanner was performing within its specification.

Scanning was carried out from two stations (see fig. 2). Access to the table was only possible until 4.30 pm. Approximately 6.5 hours scanning was carried out (1.5 hours was spent setting up and carrying out confidence checks).

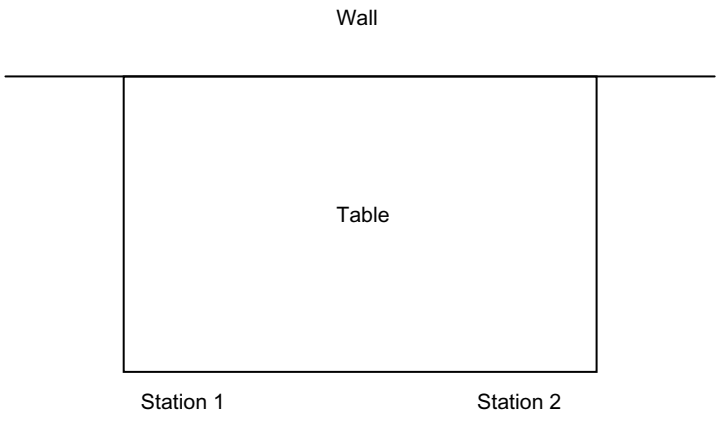


Figure 2.
Schematic plan showing position of stations relative to table.

Figure 3.
Laser scanning in progress.

Figure 4.
Detail showing sensor and laser stripe.

4. PROCESSING OF DATA

The raw scan data was processed to convert the point clouds into a single polygon mesh model using 3D Scanners Modelmaker v. 7, Innovmetrics Polyworks v. 9.1.7 and Inus Technology Rapidform 2006 software as follows (full details in Appendix 1)

(1) Raw data 2D sampled (Modelmaker) at 0.2 mm to remove excess points so that no two points are closer than 0.2 mm. This leads to a better quality mesh and reduces the file size to a manageable level.

(2) Sampled raw data imported into Polyworks and meshed. Decimated to a tolerance of 0.01 mm to reduce polygon count to manageable level. Exported in STL format.

(3) Mesh files imported into Rapidform and decimated by 50% to enable merging. All files from station 1 were meshed together. The one file from station 2 was then registered to the file resulting from station 1, using common features. A shell-shell deviation was carried out to check the accuracy of overlapping data from stations 1 and 2; a mean value of 0.24 mm was observed. The final model was decimated by 70% (i.e. number of polygons in final model = 0.7 x number in initial model) to leave 4.7 million polygons in the final model.

(4) Two small sections were cut out of the model and hole-filling carried out in Rapidform to illustrate post-processing of the mesh.

Figures 5-8 show screenshots of the final raw polygon mesh model. The screenshots show the extent of data collected after slightly less than one day's scanning (6.5 hours). Due to the position of the table (standing up against a wall), it was not possible to capture any data from the back. The table top also prevented data capture from some of the surfaces just below the top, e.g. hair on top of the angel's head (see fig. 9). Some data is missing from the leaves and acorns due to areas of 'shadow' created by the complexity of the carved surface and other parts of the table and the floor preventing access from some angles. In general, the flexibility offered by the handheld scanner proved very important for this project.

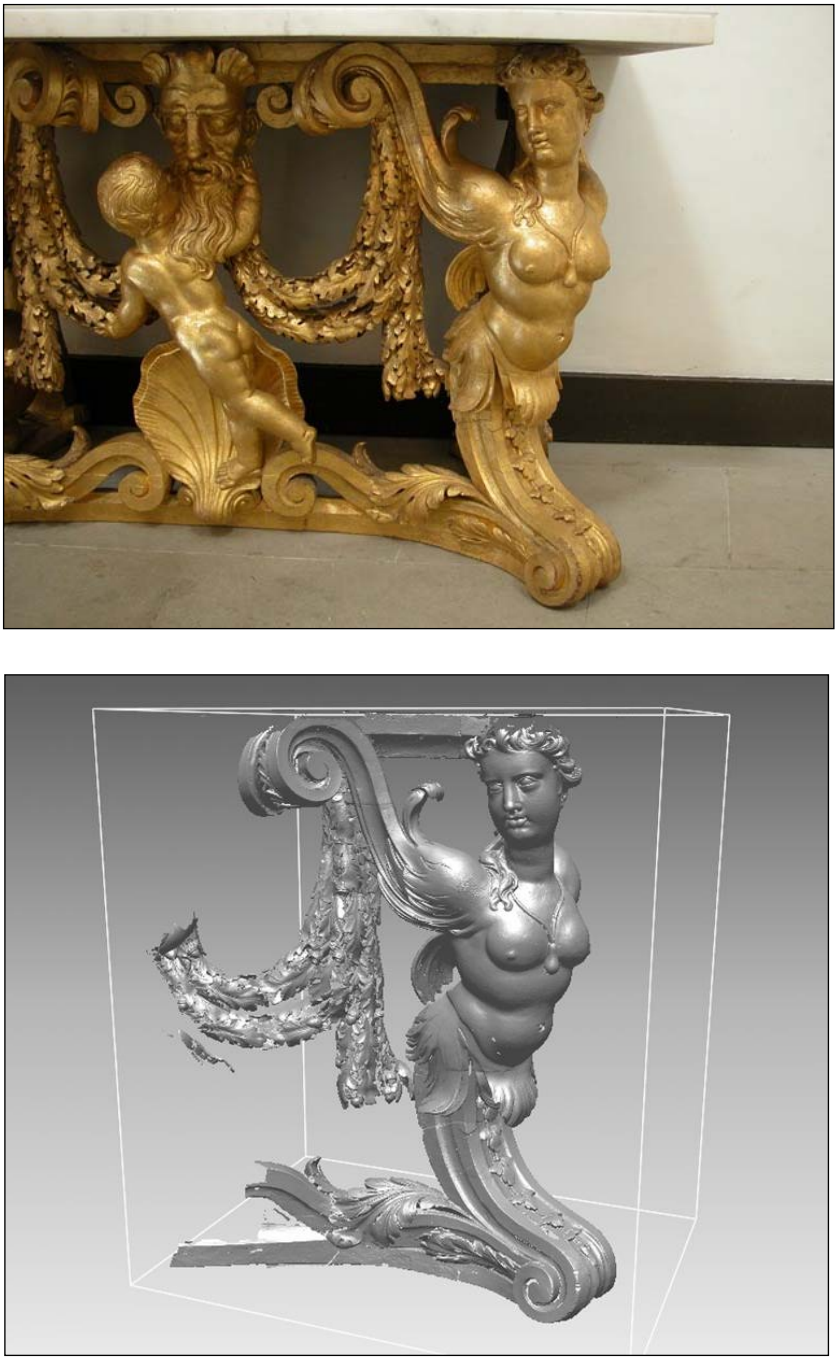


Figure 5.
Screenshot showing raw mesh from scan data (upper image), viewed from left side.
Photograph of same section of table shown for comparison (lower).

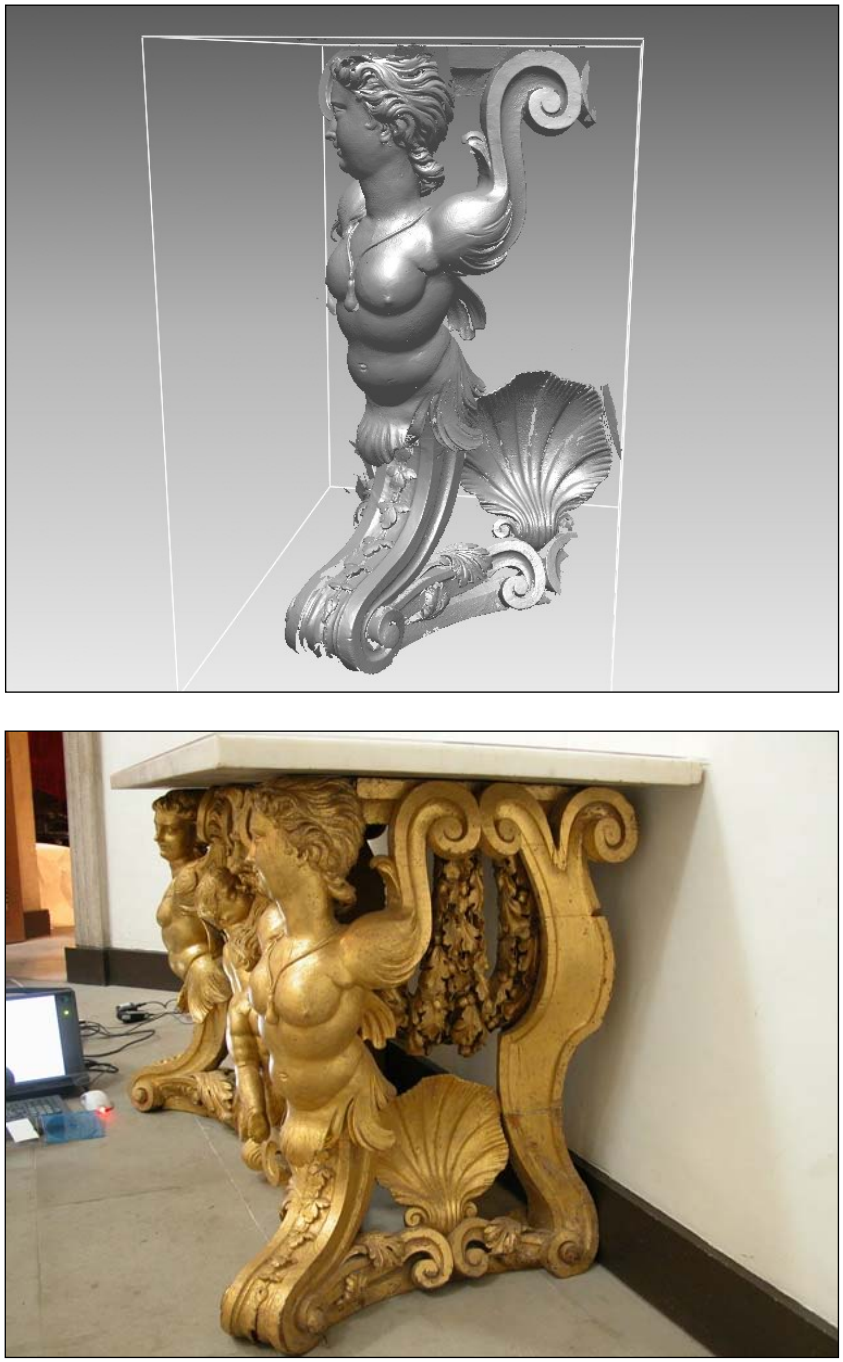


Figure 6.
Raw mesh (upper image) from scan data, viewed from right side.
Photograph of same section of table shown for comparison (lower image).

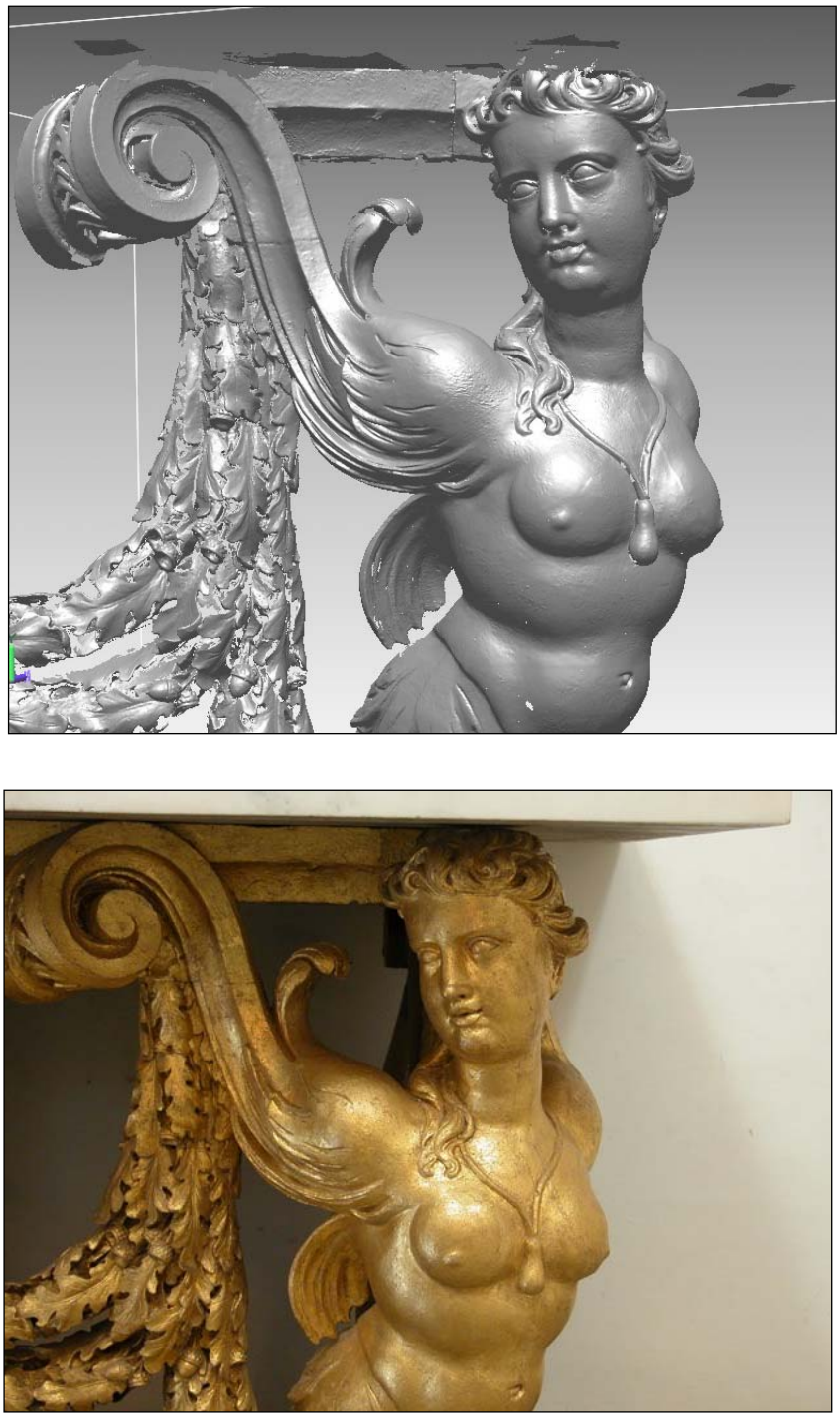


Figure 7.
Detail of upper section of raw mesh (upper image) with photograph of same section (lower image)

Figure 8:
Detail of lower section of raw mesh (upper image) with photograph of same section (lower image)

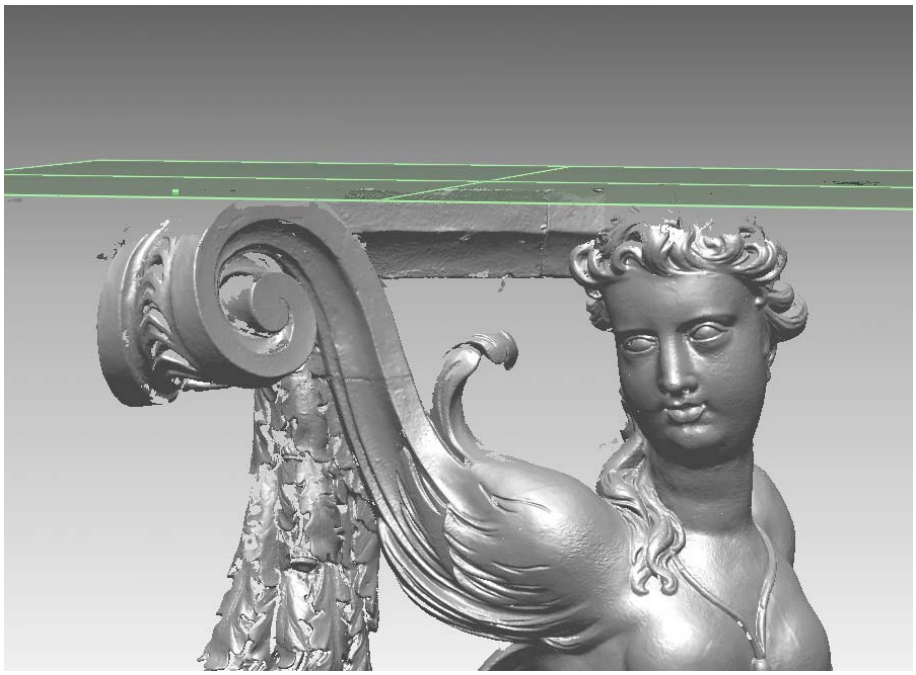


Figure 9.
Screenshot of raw mesh showing relative position of table top.

4.1 Hole Filling and Cleaning of Mesh

Two small sections were cut from the complete polygon mesh model and post-processing of the mesh carried out in Rapidform 2006. Post-processing work would normally be carried out if a 'watertight' mesh is required, e.g. for visualisation or replication. The highly reflective and shiny nature of the gilded surface meant that the 'raw' mesh contained some irregularities, e.g. crossing faces, spikes etc. Generally these features are easily discernible from actual features on the object's surface. Where there is uncertainty, comparison with photographic evidence is made before a decision is undertaken as to what to do. Figure 10 shows two 'spikes' in the mesh, before and after removal. In this case, the spikes are approximately 0.2 mm in height. The polygons of which the spikes were composed were highlighted and deleted; the resulting holes were then filled (using curvature-based filling).

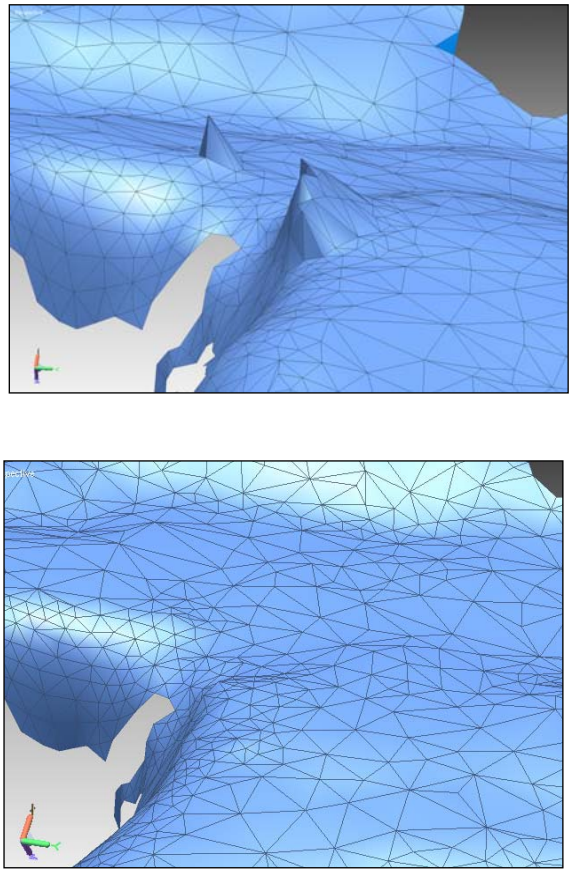


Figure 10.
Spike irregularity in raw mesh (upper image).
After post-processing (lower image).

Curvature-based hole filling was carried out on holes where there was sufficient data in the surrounding part of the mesh to produce a surface that blended well (see fig. 11). Initially the edge of the hole was 'tidied up' by either removing or adding single polygons to produce a smooth edge. 'Bridges' were then inserted to divide the hole into smaller sections that could then be filled separately.

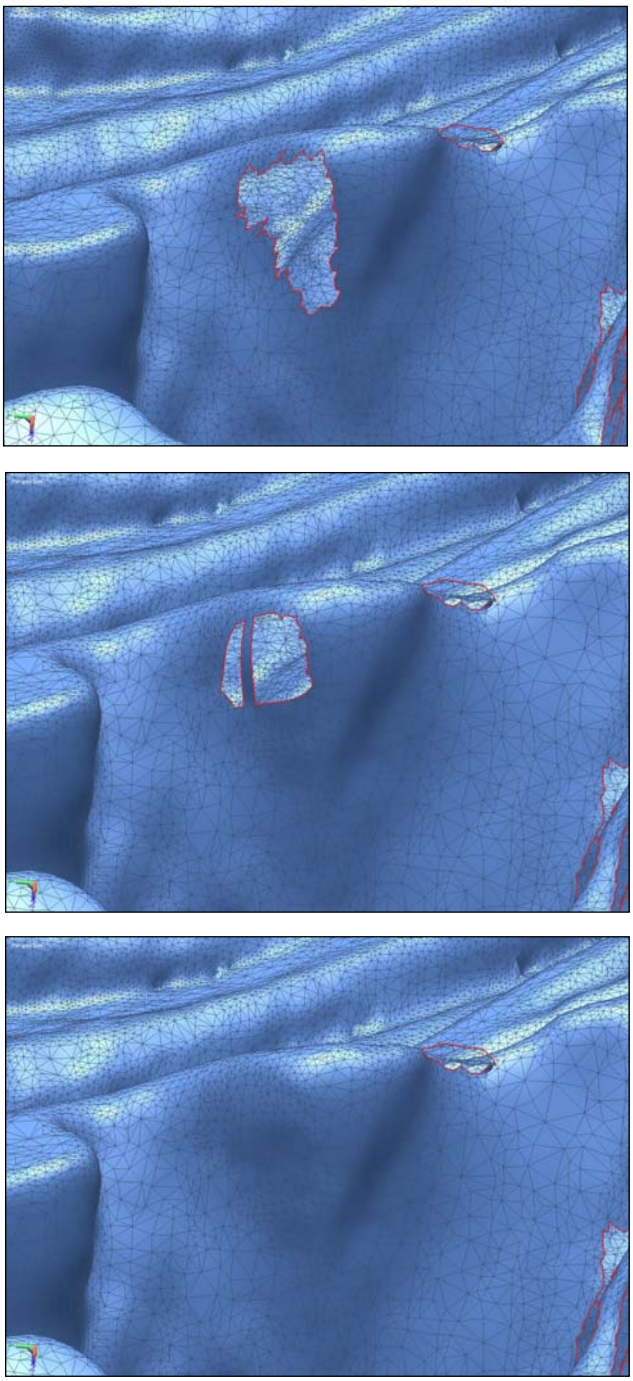


Figure 11.
Hole filling. Upper image: before;
Middle image: during; Lower image: after.

4.1.1 Section of One Angel

Figure 12 shows a section of one angel before and after post-processing. The work undertaken took 8.75 hours. This is longer than would normally be spent on an object of this size and is due mainly to the highly reflective nature of the surface causing irregularities in the mesh and the position of the figure relative to the table top and other protruding features of the table. Given sufficient time, almost all of the remaining holes could be filled using Polyworks. Movement of the table away from the wall would be required if sufficient data from the back of the angel was to be captured.

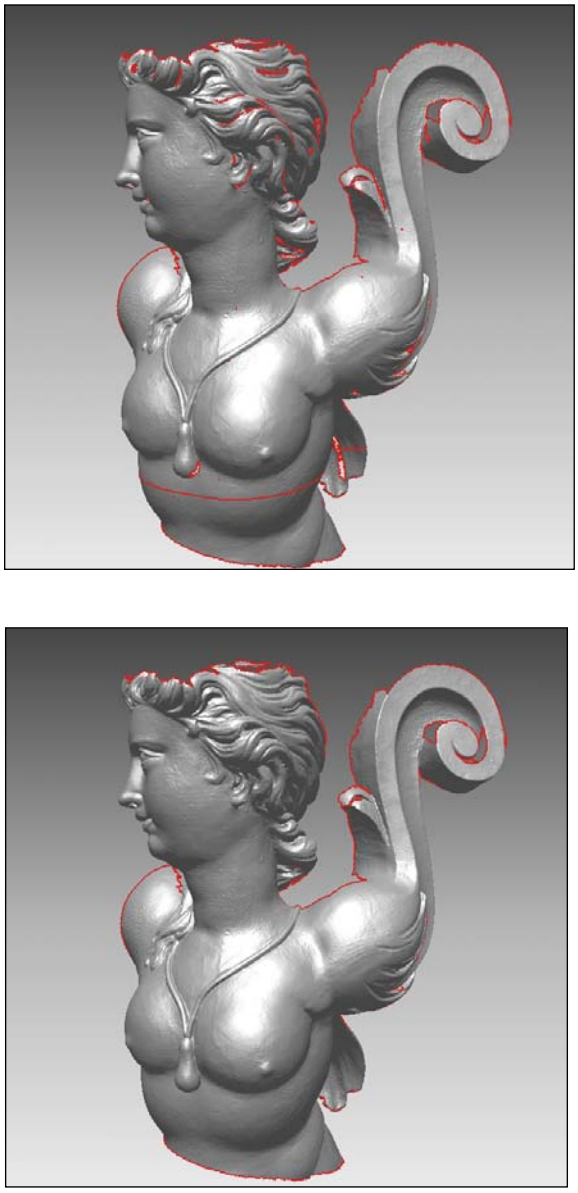


Figure 12.
Section of one angel before (upper image) and after (lower image) post-processing (8.75 hours).

4.1.2 Section of Leaves and Acorns

A section of the leaves and acorns was also post-processed in the same way as the angel (see 4.1.1). Figures 13 and 14 show the extent of work completed in 4.75 hours. This part of the surface contained many more holes due to the complex nature of the carving.

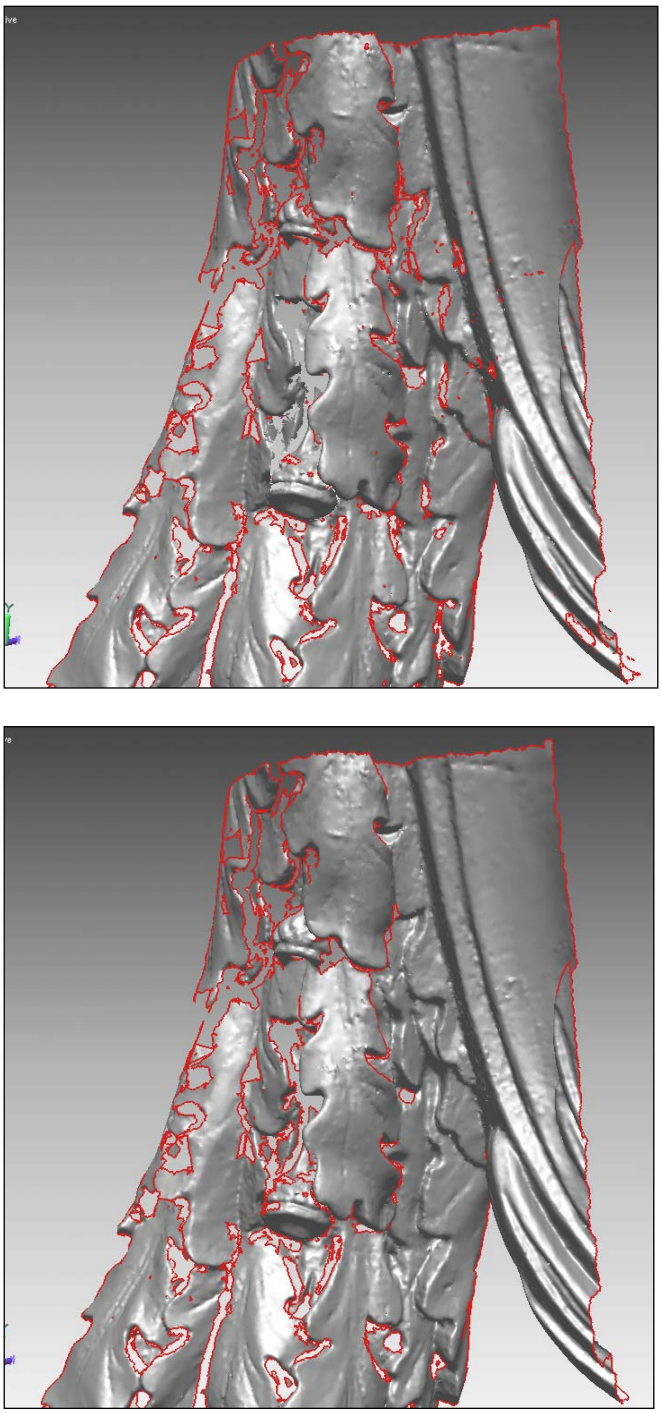


Figure 13.
Section of leaves and acorns before (upper image) and after (lower image) post-processing (4.75 hours).

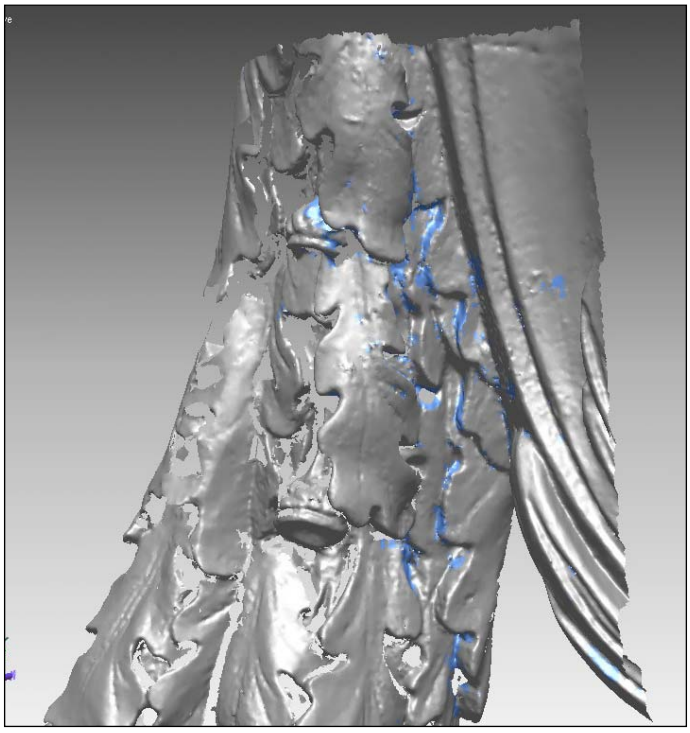


Figure 14.
Detail of carving showing areas of post-processing (highlighted in blue)

Figure 15.
Laser scanning with the old 3D Scanners Modelmaker H system, used for the Chiswick tables test in 1999.

5. COMPARISON BETWEEN 1999 AND 2006 SCANNING TESTS

A section of the angel's head has been compared with the same area scanned as part of an earlier test carried out in 1999 using a Modelmaker H laser scanning system (see figs. 16, 17). The Modelmaker H system (see fig. 15) was two generations before the Modelmaker X. It worked by the same principle, i.e. by triangulation, but captured data more slowly (approximately 7,000 points per second). The articulated arm had less reach, was less flexible and the sensor head significantly larger and harder to manipulate. The point accuracy of the data collected by the H was similar to that of the X. The original scan data captured in 1999 has also been meshed using Polyworks v. 9.1.7 (fig. 16, right). The same parameters were used as for the new data. No post-processing was carried out on the models meshed in Polyworks. Unfortunately, it is not known whether any work was carried out on the original mesh.

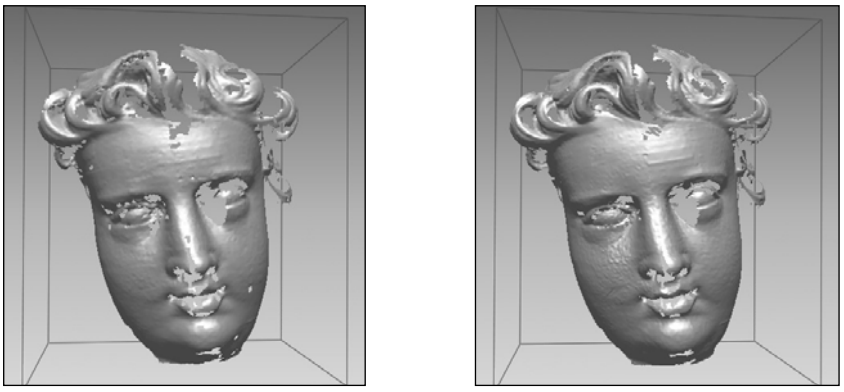


Figure 16.
Polygon meshes created from original scan data (1999). Left: data meshed in 1999; right: data meshed in 2006 using Polyworks software.

Figure 17.
Polygon mesh created from 'new' scan data (2006).

Meshing the original data in Polyworks has produced a slightly sharper model. The new scan has captured much more of the surface than the original scan. This may be partly due to the increased data capture rate, but may also be due to improvements in the design of the sensor. The X system provides much more control over the incident laser power and this may account for some of the differences; during scanning it was necessary to vary the laser power to optimise data collection as different parts of the surface responded in different ways. The X system is certainly more flexible and this will account for some of the extra data gathered.

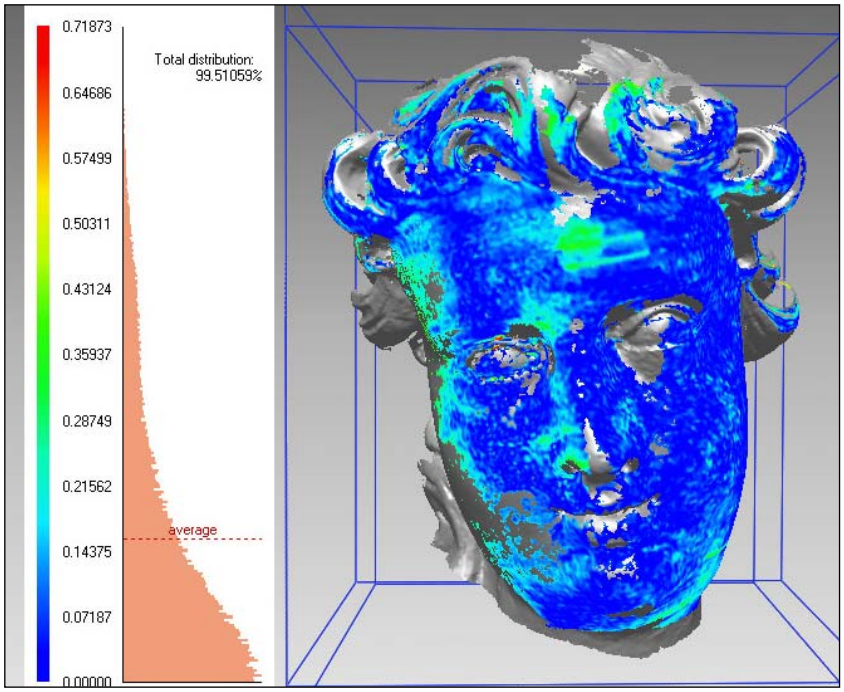


Figure 18.
Shell-shell deviation between the original data (meshed in Polyworks) and the new polygon mesh, showing how well the two models match.

Figure 18 shows a direct comparison between the models created from the original and new scan data (both meshed in Polyworks). Most of the surface matches to within 0.1 mm. Some parts differ by up to approximately 0.4 mm, which is slightly larger than would be expected if both scanners were working within specification. This may be due to a number of reasons:

(1) The surface of the object has changed slightly in the seven years since the initial scanning test was performed.

(2) Movement of the tripod during scanning (the scanner was not fixed to the floor this time and we do not know about 1999).

(3) Scanning a shiny gilded surface is more problematic than many other surfaces and it is possible that the scanner does not perform to its specification in this instance (specifications are normally quoted for 'ideal' conditions, as opposed to 'real life' conditions).

Figures 19-22 show a similar comparison for a section of leaves and acorns.

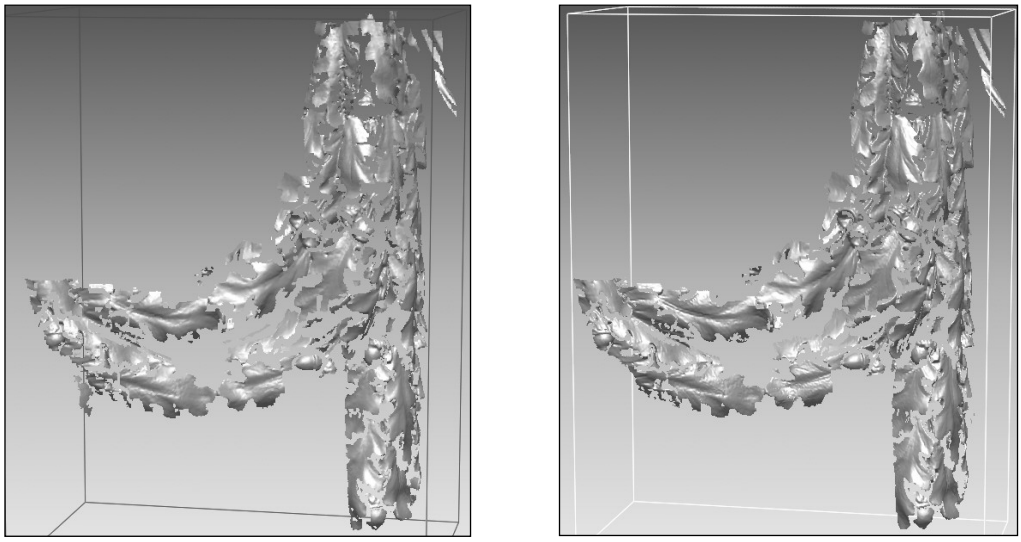


Figure 19.
Polygon meshes created from original scan data (1999).
Left: data meshed in 1999; right: data meshed in 2006 using Polyworks software.

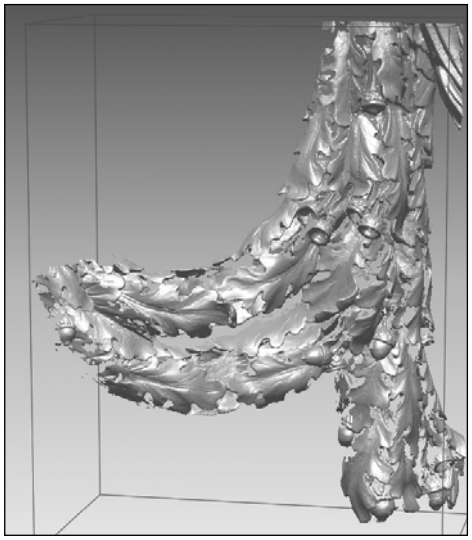


Figure 20.
Polygon mesh created from 'new' scan data (2006).

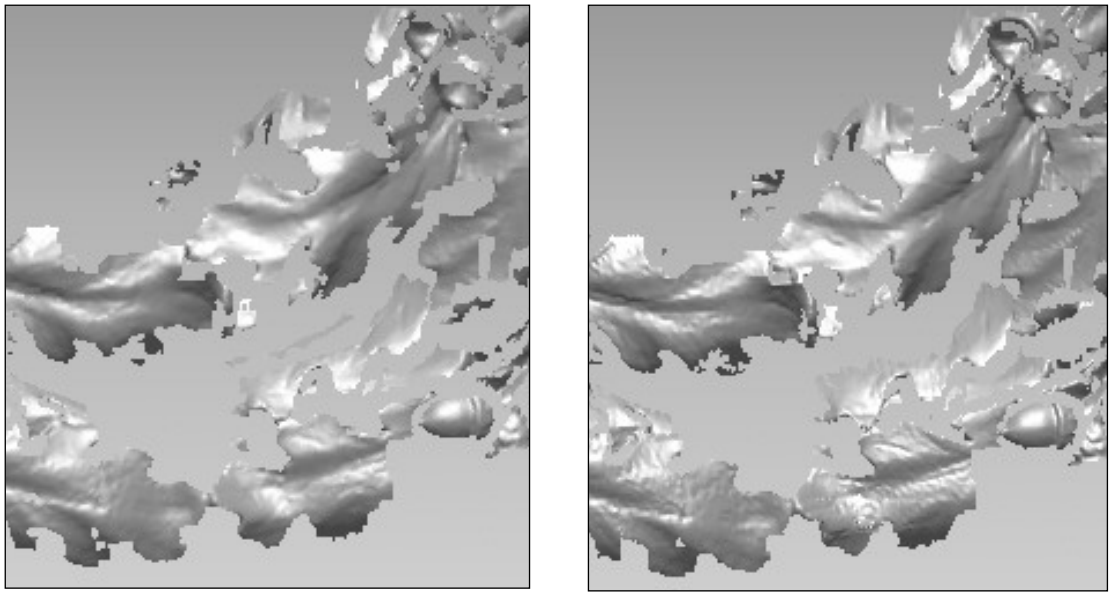


Figure 21.
Detail of polygon meshes created from original scan data (1999). Left: data meshed in 1999; right: data meshed in 2006 using Polyworks software.

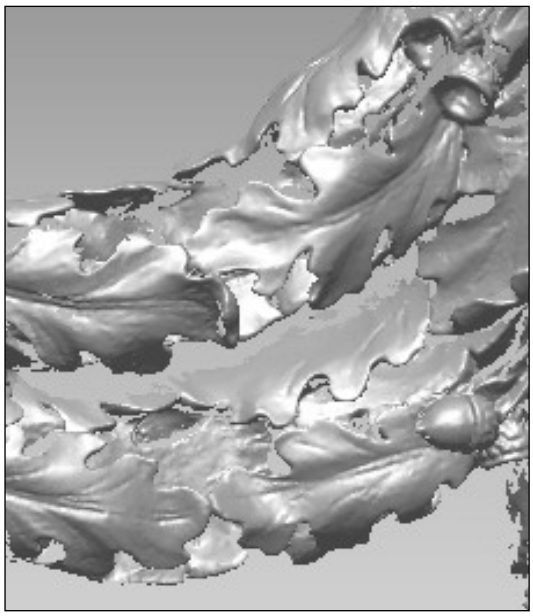


Figure 22.
Detail of polygon mesh created from 'new' scan data (2006).

Once more, the use of Polyworks appears to have produced a slightly sharper mesh. The final model (fig. 22) contains much more of the surface than that derived from the original data and appears to be of better quality (compare details on acorns and leaves).

6. SUMMARY

Laser scanning tests have been successfully carried out on an 18th-century gilded wood table at Chiswick House. Significantly more data was collected than during the initial tests in 1999. The data also appears to be of better quality. More data would be captured if the table top could be removed and the table moved away from the wall to provide access to the back of the carvings. Slightly less than one full working day was spent on site. Approximately 5 days would be required to scan the whole of one table to the level of detail presented here. Regarding post-processing work, the most appropriate level of hole-filling would be determined by the reasons for laser scanning: documentation may require little, if any, whereas replication of parts of the table would require thorough hole filling. To do this well would require a significant amount of time, especially for detailed areas such as the acorns and leaves.

7. APPENDICES

7.1 Metadata

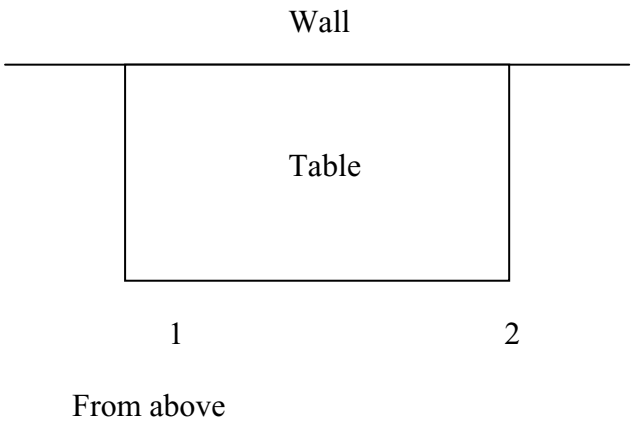
Conservation Technologies 3D Scanning Record Sheet: Modelmaker X

Job	
Job title:	Chiswick Table
Client:	English Heritage
Reason for scanning:	To look into feasibility of scanning gilded surfaces. To compare with results of earlier scanning undertaken with MMH. To evaluate time required to carry out complete scan of tables.
Deliverables:	Raw data (ASCII and SAB2) Polygon mesh in OBJ format (STL if required) Decimated and hole-filled mesh if required. Photographs of table and scanning process. Report detailing work, including: comparison of meshed model with that obtained previously (i.e. MMX with MMH); comparison of MMH data processed with PW9.1.7 and original software. Metadata Case study for Heritage3D website.

Object	
Brief description:	Pair of gilded wood 18th-century tables, William Kent, marble tops (not scanned). Carved figures, leaves, acorns etc. on 3 sides. Scanning carried out on 'right' table.
Approximate size (mm) H x W x D:	840 x 1400 x 680 (each table)
Nature of surface:	Gilded. Shiny.
Level of detail: (size of smallest feature to be recorded)	0.5 – 1.0 mm

Environment	
Location of scanning: (inside/outside, public access, tent etc.)	In domed hall of Chiswick House (1st floor). Against wall, on 'heritage' stone floor. Unable to scan from behind. 'Left' table (not scanned) in room with large windows – daylight might be a problem here (possibly need to cover windows)
Lighting (natural, fluorescent etc.):	Mainly artificial lighting from modern bulbs in chandelier in centre of room. Small amount of daylight from doorways and high level windows.

Scanning Process	
Carried out by:	MC/AL
Date:	13-14 Dec 2006
Time taken:	6 hrs scanning + 1.5 hrs set-up
Scanner:	3D Scanners MMX
Sensor:	MM70
Tripod:	Portable, not glued to floor (worried about marking floor)
Power source:	Mains 13A
Calibration (arm):	Carried out at LT, NCC
Confidence check (arm) RMS:	N/A
Calibration (sensor) RMS values: Filename:	Carried out at LT, NCC

Confidence check (sensor, <50 μm) (1) Cross RMS: (2) Repeat RMS: (3) Parallel planes RMS: (4) Repeat RMS:	 0.0242, 0.0464 dev=-0.054 0.0219, 0.0336 NSP=0.022, SP=0.025, dev=-0.054 0.0283, 0.0203 All within spec.
Scanning set-up: (tripod, floor, object arrangement etc.)	Tripod not glued to floor. Arm at lowest height possible
Scanning distance (mm):	100mm approx.
Scanning parameters Laser power: Ambient threshold: Field of view: Area 2D sampling:	 0.8 (also used 0.4 (very bright gilding) and 2.0 (dull) 96 Normal None applied during scanning
Number of stations:	2  From above
Filenames:	Chiswick_2, _3b, _4, _5, _6, _headrescan.sab2 (station 1) Chiswick_7.sab2 (station 2)
Files checked on-site (meshed, registered etc.):	Test mesh created and checked.
Photos: (camera, WB etc.)	Photos of table taken, camera white-balanced, tripod used throughout. Camera used: Nikon coolpix5700.

Post-processing	
Carried out by:	MC (Chiswick_2) AL (Chiswick _3b, _4, _7, _headrescanned)
Time taken:	Chiswick_2: 7 hrs in PW9.1.7 to produce mesh Chiswick_3b: 4 hrs in PW9.1.7 to produce mesh Chiswick_4: 4 hrs in PW9.1.7 to produce mesh Chiswick_7: 6.5 hours in PW9.1.7 to produce mesh Chiswick_headrescanned: 0.5 hrs in PW9.1.7 to mesh
Software used (meshing):	2d sampled in MM (0.2 mm); Polyworks v9.1.7
Meshing (Modelmaker v7.0, 3D Scanners UK) Area (2D) sampling:	 0.2 mm
Meshing with Polyworks V 9.1.7 (Innovmetric Inc.) Area (2D) sampled (MM): IM align: IM Merge Max. distance: Sampling step: St. dev.: Red. Tolerance: Smoothing radius: Smoothing Tolerance:	Chiswick_2 U = 0.2mm, v =0.2mm Auto-organise: step 0.2, MEL 1.0 Comparison: Max distance 0.9 Parameters: 0.9/0.45/0.2/0.1/0/05 Comparison: max. 0.25 (small areas), 0.02-0.15 (most) Overlap red: (visualisation max 12 min 1) 2 1.0mm 0.2mm 0.026 0.0052 0.6mm 0.078

Meshing with Polyworks V 9.1.7 (Innovmetric Inc.) Area (2D) sampled (MM): IM align: IM Merge Max. distance: Sampling step: St. dev.: Red. Tolerance: Smoothing radius: Smoothing Tolerance:	Chiswick_3b, _4, _7 and _headrescanned U = 0.2mm, v =0.2mm Auto-organise: Sampling step = 0.2mm, max. edge length = 1.0 mm, max. angle = 75º Comparison: Max distance 2 Parameters: 5, 4, 3, 2, 1, 0.75, 0.5, 0.25, 0.1, 0.05, Comparison: max. 0.2 (small areas), 0.02-0.15 (most) Overlap red: (from visualisation max 12 min 1) MD = 0.25mm 1.0mm 0.2mm 0.026 0.01 (decimation tolerance) 0.6mm 0.078
Software used for post-processing:	Polyworks V 9.1.7 (Innovmetric) and Rapidform2006 (InusTechnologies Inc.)
Data “cleaning”:	Topological abnormalities were removed in PW9.1.7 on completion of merging. This is the repairing or removal of abnormal faces, such as crossing faces. N.B. Topological anomalies were not removed in Chiswick_2 – the data set was cleaned on being imported into RF2006. The completed model was checked for non-manifold, crossing, and abnormal faces.
Hole filling (automatic):	Each raw mesh had all holes with edges less than 50 automatically filled in PW9.1.7. This does not include holes with edge lengths of less than 50 where a data abnormality remains despite data “cleaning”. Once the model had been merged together and decimated all holes with edges less than 50 were automatically filled in RF2006. This is to fill small holes that have occurred in the data set during the data deletion and merging processes.
Deletion of bad data:	Data obtained by scanning the floor or walls was deleted.

Merging:	
Merging (Station1):	The data from station 1 (i.e. Chiswick_2, _3b, and _4) was merged together without any fine registration in RF2006.
Shell-shell deviation:	A shell-shell deviation check had given an average reading of 0. Although this is impossible in reality it means that there was no meaningful deviation found in the data that could be improved upon by fine registration. Prior to merging, one data set in areas of overlapping data was removed manually.
Merging (Station2):	The data from station 2 (Chiswick_7) was registered to the data from station 1 in RF2006. Initial registration used 7 common points, assigned by the operator. Fine registration was undertaken, and the data was merged after manual removal of one data set in overlapping areas.
Shell-shell deviation:	Average 0.24 mm.
Merging (Headrescanned):	Headrescanned was fine registered to the merged data from 2, 3b, 4,and 7. The data was merged after manual removal of one data set in overlapping areas.
Shell-shell deviation:	Average 0.07 mm. The worst reading was 0.6 mm.
Hole filling (manual):	See also “processing procedure if different from above” section.
Location of hole filling documentation (screenshots of large holes etc):	See “smoothing” and “processing procedure if different from above” sections.
Smoothing:	Some smoothing was applied during the merging process in PW9.1.7. A smoothing radius of 0.6mm was used with a tolerance of 0.0078. These were the settings recommended by the software. No general smoothing was applied to the data set at anytime during merging and decimation. See also “processing procedure if different from above” section.

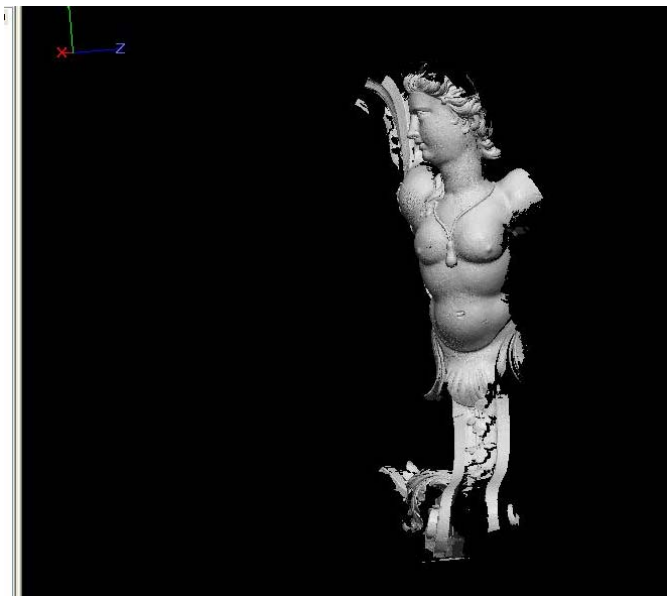
Decimation:	Chiswick_2 – a reduction tolerance of 0.0052 was included in the merging process. The raw meshed file comprised 6.9 million polygons. The data set was decimated once by 50% in RF2006 prior to removal of overlapping data and merging with other data sets. Chiswick_3b – a reduction tolerance of 0.01 was included in the merging process. The raw meshed file comprised 4.4 million polygons. The data set was decimated once by 50% in RF2006 prior to removal of overlapping data and merging with other data sets. Chiswick_4 – a reduction tolerance of 0.01 was included in the merging process. The raw meshed file comprised 3.0 million polygons. The data set was decimated once by 50% in RF2006 prior to removal of overlapping data and merging with other data sets. Chiswick_7 – a reduction tolerance of 0.01 was included in the merging process. The raw meshed file comprised 5.2 million polygons. The data set was decimated once by 50% in RF2006 prior to removal of overlapping data and merging with other data sets. Chiswick_headresacnned - a reduction tolerance of 0.01 was included in the merging process. The raw meshed file comprised 0.4 million polygons. The data set was decimated once by 50% in RF2006 prior to removal of overlapping data and merging with other data sets. The complete data set (6.8 million triangles) was divided roughly in half using a geometry plane. Each half was decimated by 70% and then merged back together. This was because our computing power couldn't work on a data set this large. The final model comprised polygons 4.7 million polygons.
Processing procedure (if different from above), e.g. model split into separate parts, processed then re-merged):	While the complete data set was in two halves (see above) it was cleaned again and all holes with edges less than 50 were filled automatically again (RF2006). The areas documented in smoothing1.jpg and smoothing2.jpg were cut out (a hole created) filled, and then localised smoothing was applied using the smooth paint tool in RF2006. These are the areas where the data sets overlapped and any error was concentrated during merging.
Mesh watertight?	No.

Any other: (e.g. resizing, authentication mark added etc.)	No.
Finished filenames: (names, formats etc.)	Complete data: Complete_data.MDL Chiswick07_complete_data.STL Chiswick07_complete_data.OBJ Hole-filling: Face_beforeHF.OBJ Face_afterHF.OBJ/STL Leaves_beforeHF.OBJ Leaves_afterHF.OBJ/STL 1999 data meshed in PW: Face_1999_PWmesh.OBJ/STL Leaves_1999_PWmesh.OBJ/STL

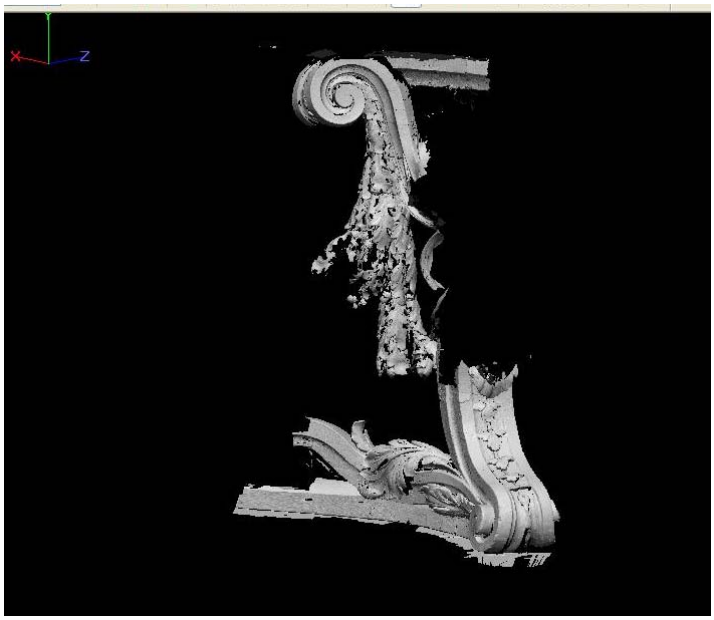
Data Supplied	
Notes:	'Left' table in separate room with large windows – may be problem with daylight. Table up against wall – cannot get back of carvings in present situation. Used lightweight tripod: test with glue gun left mark on floor, access via narrow winding staircase (15 steps). Would be possible to get heavy tripod in via doors from outside (still need to go up steps, but outside and not winding), but tripod may mark floor. Would probably want 1 week scanning time for each table. Laser power changed for different parts of surface. Table top obscures top of cherubs' heads.

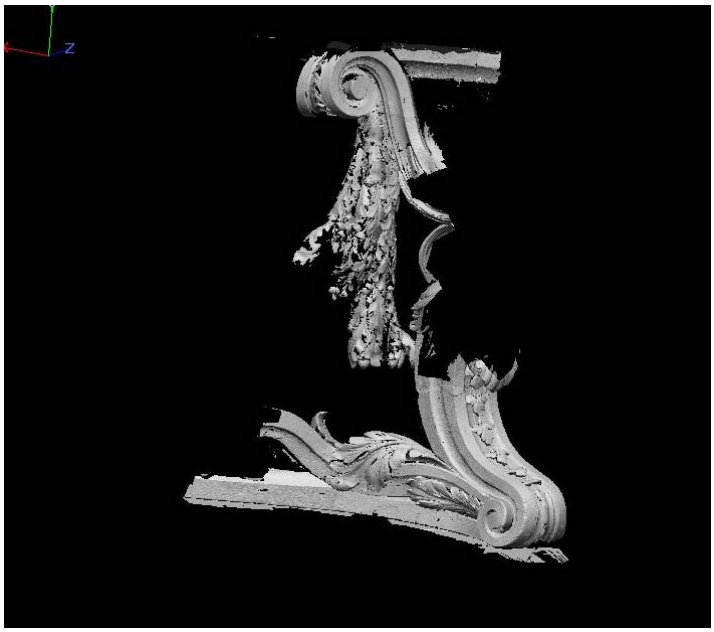
7.2 Raw data screenshots

The following images are screenshots showing the raw point cloud data captured in each file (2006 data).

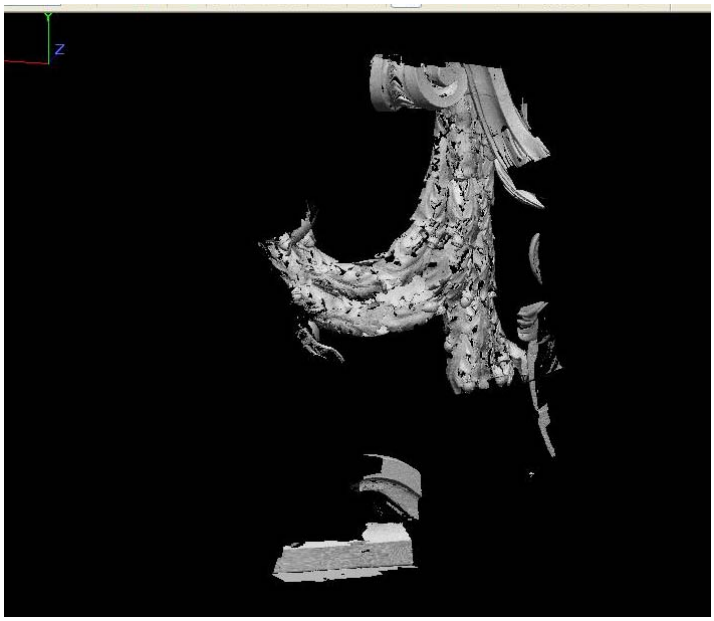


Chiswick2.sab2

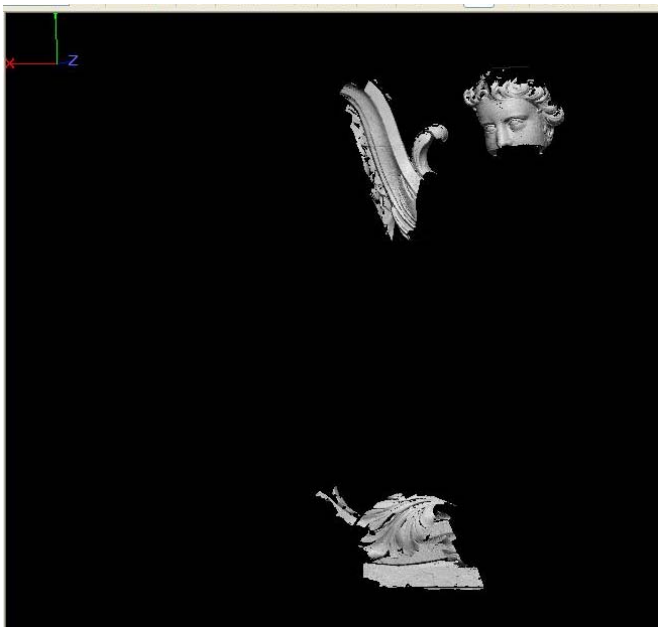


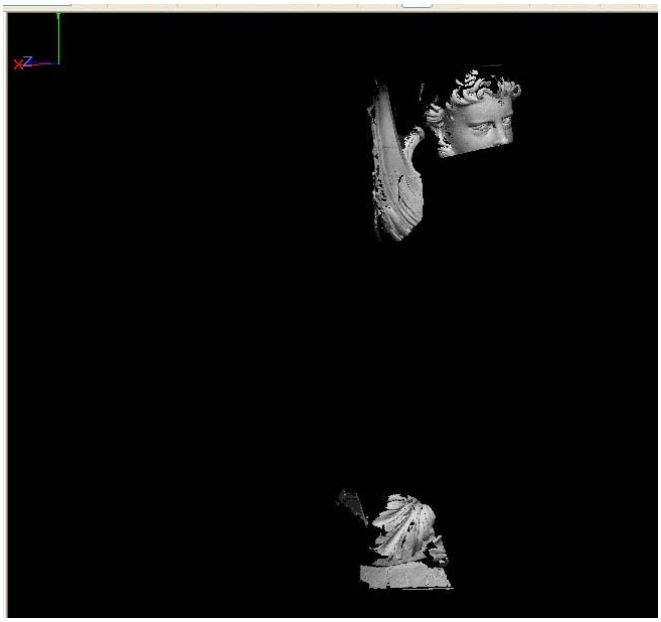


Chiswick 3b.sab2

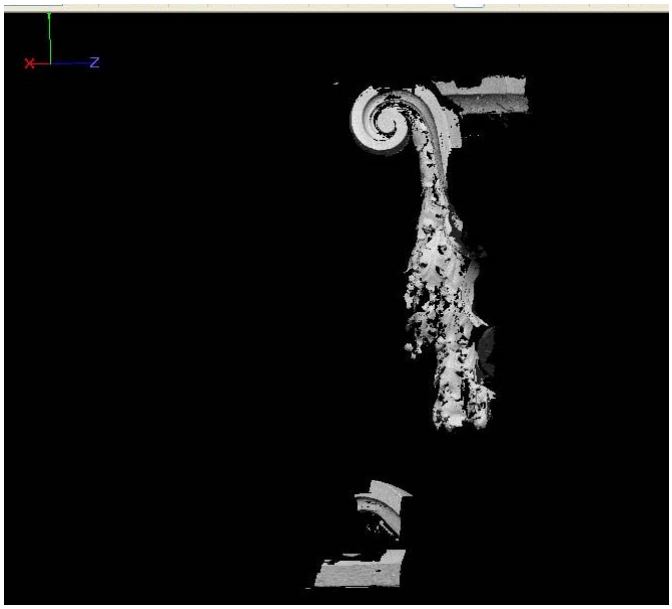


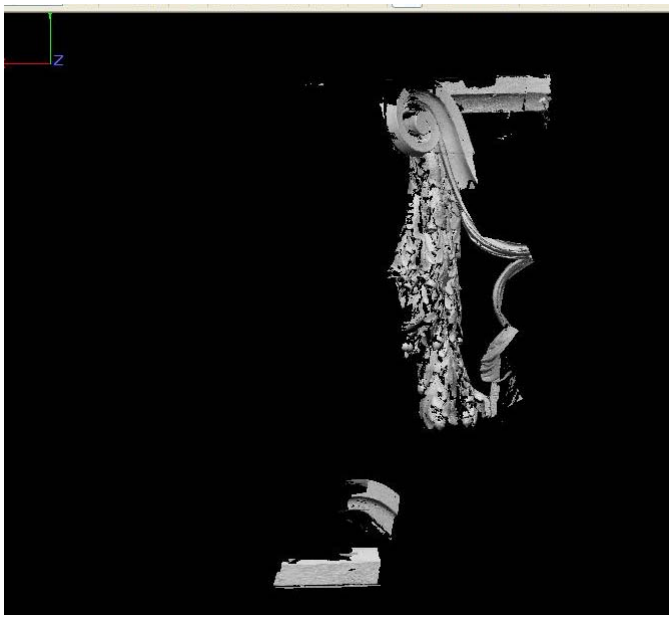
Chiswick4.sab2





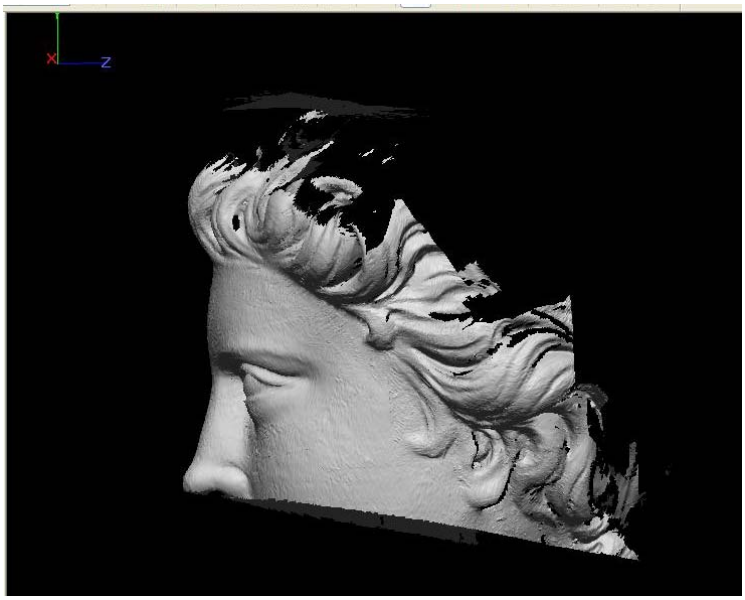
Chiswick5.sab2

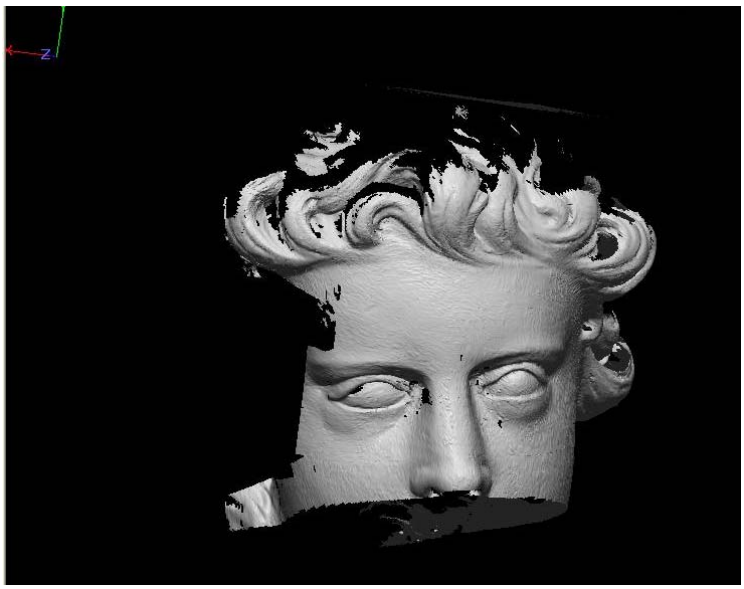




Chiswick6.sab2

Chiswick7.sab2

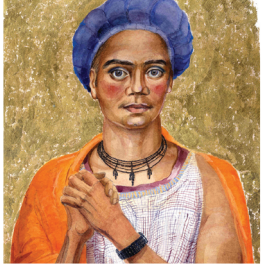




Chiswick_head_rescan.sab2

7.3 File names

File name	File extension	Description
Chiswick_2 Chiswick_3b Chiswick_4 Chiswick_7 Chiswick_head_rescan	SAB2/ASC	Raw point cloud data from 2006 tests in scanner's own format (SAB2) and ASCII
Chiswickface Chiswickleaves	CTA/ASC	Raw point cloud data from 1999 tests in scanner's own format (CTA) and ASCII
Chiswick07_complete_data.OBJ	OBJ	Raw mesh of laser scanned area
Face07_beforeHF.OBJ	OBJ	Raw mesh of face
Face07_afterHF.OBJ	OBJ	Mesh of face after hole-filling
Leaves07_beforeHF.OBJ	OBJ	Raw mesh of section of leaves/acorns
Leaves07_afterHF.OBJ	OBJ	Mesh of leaves/acorns after hole-filling (partial)
Face_1999.OBJ	OBJ	Original mesh of face from 1999 scan data
Leaves_1999.OBJ	OBJ	Original mesh of leaves/acorns from 1999 scan data
Face_1999_PWmesh.OBJ	OBJ	Mesh of face from 1999 scan data using Polyworks software
Leaves_1999_PWmesh.OBJ	OBJ	Mesh of leaves/acorns from 1999 scan data using Polyworks software



ENGLISH HERITAGE RESEARCH DEPARTMENT

English Heritage undertakes and commissions research into the historic environment, and the issues that affect its condition and survival, in order to provide the understanding necessary for informed policy and decision making, for sustainable management, and to promote the widest access, appreciation and enjoyment of our heritage.

The Research Department provides English Heritage with this capacity in the fields of buildings history, archaeology, and landscape history. It brings together seven teams with complementary investigative and analytical skills to provide integrated research expertise across the range of the historic environment. These are:

* *Aerial Survey and Investigation*
* *Archaeological Projects (excavation)*
* *Archaeological Science*
* *Archaeological Survey and Investigation (landscape analysis)*
* *Architectural Investigation*
* *Imaging, Graphics and Survey (including measured and metric survey, and photography)*
* *Survey of London*

The Research Department undertakes a wide range of investigative and analytical projects, and provides quality assurance and management support for externally-commissioned research. We aim for innovative work of the highest quality which will set agendas and standards for the historic environment sector. In support of this, and to build capacity and promote best practice in the sector, we also publish guidance and provide advice and training. We support outreach and education activities and build these in to our projects and programmes wherever possible.

We make the results of our work available through the Research Department Report Series, and through journal publications and monographs. Our publication Research News, which appears three times a year, aims to keep our partners within and outside English Heritage up-to-date with our projects and activities. A full list of Research Department Reports, with abstracts and information on how to obtain copies, may be found on www.english-heritage.org.uk/researchreports

For further information visit www.english-heritage.org.uk

ENGLISH HERITAGE