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TRACEABLE STORAGE AND TRANSMISSION OF 3D COLOUR SCAN DATA SETS

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ABSTRACT:

This paper describes a practical multidisciplinary approach to the traceable storage and transmission of 3D colour scan datasets using a combination of state of the art colour laser scanning technology, an e-Science developed data storage and retrieval solution (SRB) and an internet capable 3D visualisation tool which is being iteratively designed in association with a team of museum curators and conservators who are able to directly compare the handling of a range of original objects with their virtual copies.
Examples taken from a core object group from the world-class UCL Museums and Collections that have been recorded with a state of the art Arius3D colour laser scanner provide a demonstration of the developed 3D recording methodology and highlight how the developed system is capable of complementing traditional cataloguing methods for museum artefacts.

1. INTRODUCTION - THE UCL E-CURATOR PROJECT

The E-Curator project commenced in October 2007 at University College London (UCL) and is an interdisciplinary project which draws on UCL's expertise both in curatorship, in e-Science and the application of laser scanning technologies. Realising the importance of digital technologies and new interdisciplinary possibilities, the E-curator project is being undertaken by UCL Museums and Collections with the goal of applying two state of the art digital technologies: 3D colour laser scanning and e-Science.
This project captures and shares very large three-dimensional scans and detailed datasets of a variety of museum artefacts in a secure computing environment. The E-curator project presents an opportunity to exploit and analyse e-Science technologies and explore some of the opportunities they offer to museum practice in an increasingly virtual world. Such deployment will enable curators and conservators to compare records collected at different institutions, stored remotely, or collected over a period of time under different conditions, in order to assess and monitor change. Our complementary research aims to provide a useful user-friendly web-based shared platform for curators, conservators, heritage and museum specialists.

2. TRACEABLE COLLECTION OF 3D DATA SETS

A first aspect of our transdiciplinary approach is in the traceable collection, storage and sharing of data. The need for traceability (Cooper/Robson 1994), often termed provenance in the fine art domain, has necessitated the development of a general structure for scanned 3D colour data sets that can encompass not only the properties of the scanning system used, but also the chain of processing steps needed to develop a hierarchy of 3D data sets appropriate for viewing and analysis. We will detail the development of such scanning and post processing procedures in combination with a compatible set of metadata standards for 3D laser scan data. This area has been developed much more broadly in the form of the London Charter (Beacham/ Niccolucci 2006) to encompass themes of integrity, transparency, quality and community amongst a broad definition of interest of research and communication in cultural heritage.

2.1 Properties of the scanning system

The 'Arius3D Foundation Model 150' scanner (see Figure 1 and web reference 2) offers a detailed non-contact and non-destructive documentation and examination method which predetermines its use for conservation recording.
Surface scanning is carried out by a scanner head which emits a laser beam composed of three discrete red, green and blue wavelengths, which is focussed to deliver a spot diameter of the order of 100 micrometers within a 50mm deep scanning field. The scan head simultaneously measures surface reflectance at each of the three wavelengths and geometry by triangulation to record the laser reflection at each illuminated location. Every point for which a surface reflection is sensed by the scanning system has therefore a XYZ coordinate location and an RGB colour value. Given the illumination and collection angles at each point as well as at neighbouring points it is possible to also compute a surface normal at each illuminated point. The optical arrangement used is based on the National Research Council's patented auto-synchronized spot scanning principle (Taylor et al. 2003). A calibrated 'white cube' made of diffusely reflecting "Spectralon" (see web reference 4) is illuminated at the end of each scan line to provide a consistent reference surface enabling fluctuations in background illumination and laser output power to be corrected on a scan line by scan line basis. This correction is carried out as part of an off-line colour calibration process in combination with the scanning of a grey scale step series and planar and spherical Spectralon reference surfaces.
The Arius3D scanner head is mounted to a coordinate measuring machine which provides both the dimensional stability and the metrology level motion control necessary to repeatedly move the scan head over the object to be recorded

along 3D paths determined by the user. The depth measurement capability of the scanning head in use at UCL has been proven to be better than 25 microns in depth following the scanning of several reference objects scanned for a range of engineering projects, for example in working with the UK Atomic Energy Authority and EFTA JET (Brownhill et al. 2007). The motion control system has been tested according to ISO 10360-2 (ISO 10360-2:1994) and is designed to deliver a minimum spatial sampling interval of 100 microns, commensurate with the laser spot diameter used to sample the surface within the field of view of the scanning head. To ensure consistent dimensional capability the unit has been installed in an air-conditioned room that maintains temperature at 20°C and can control relative humidity over a wide range to suit the requirements of the objects being recorded.

2.2 Scanning methods

Objects to be scanned with the system are supported either on a turntable or other rigid structure on the flat table beneath the bridge of the motion control unit. The scan head is then guided over the object by the operator in order to check appropriate surface reflection, assess best orientation between the scan head and the object for efficient scanning and to make sure that the combined RGB laser beam has an appropriate intensity to record the object surface. As with all scanning techniques, successful surface recording is heavily dependent on the optical reflectance properties of each individual object with diffusely reflecting surfaces, such as terracotta being relatively easy to scan whilst highly specular surfaces or very dark surfaces can severely test the capabilities of both the operator and capture technology to provide data that are fit for purpose.

Once appropriate scanner settings and an appreciation of the object properties and geometry have been gained by the operator scanning commences with the scan head being driven across the object surface, typically using both X (bridge) and Z (depth) driving systems of the scanner. Colour scan data are collected into Arius A3DScan software with data being collected in swathes 50mm wide at roughly 250mm per minute when scanning at the highest 100 micrometer point density. The A3DScan software environment allows the operator to visualise data, to assess overlap between component scans and to monitor live profile and colour data for example. On completing each group of scans the object or the scan head are manipulated to present a next set of surfaces to the user. At UCL object manipulation is carried out either by a curator or an approved and trained object handling specialist. Scan data collected during the primary recording process are archived to provide a raw data record before any further data processing is carried out.

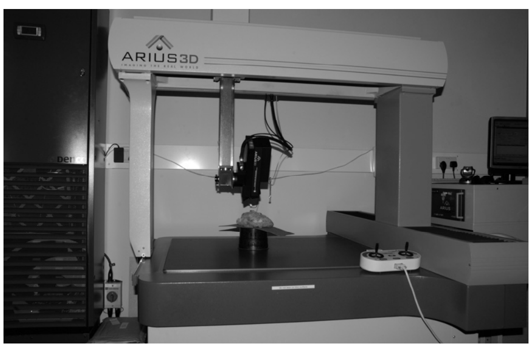

Figure 1: The Arius 3D scanner installed at UCL

2.3 Post-processing of 3D colour laser scan data

Before the scan data is ready for dissemination to an end user it must be corrected for colour recording differences due to imaging geometry and surface shape, registered to take into account arbitrary movements of the object and then cleaned and edited to provide consistent point spacing and colour. As a first step the raw scan data is imported into the proprietary Arius3D, Pointstream 3D Image Suite software (see web reference 3), which is specifically designed to process and visualize the densely sampled 'point cloud' data. The import function allows the user to set options for data smoothing, apply a geometry based colour correction based on data acquired from scans of colour and geometry reference objects and to optionally remove isolated data. The process also computes a normal vector per point to allow application of computer lighting models without the need to convert the data into polygons. This particular aspect takes best advantage of the very dense data produced by the system to visualise using point rendering graphics (Grossmann/Dally 1998) rather than having the overhead of generating polygonal meshes that are common in most other approaches.

The subsequent registration step controls the optimum alignment of the different component scan records in order to register them together using a 'point cloud to point cloud' iterative closest point procedure founded on the method described by Besel and MacKay (Besel/Mckay 1992). The point cloud data are then cleaned within the Pointstream application to remove overlapping geometry and balance colour acquired from different scanner head viewpoints using both manual editing and automatic filtering of multiple points based on combinations of geometry and colour content. After editing the geometry and colour information the component records are merged into a single scan data set.

2.4 File and metadata handling within E-Curator

Every three-dimensional record is annotated with metadata concerning its capture, the import and colour calibration filters used, and any particular scan process and post processing information (see
Table 1). This dataset provides the user with clear information about the production and the authorship of the 3D image.

The development of the metadata set has largely followed the recommendations of English Heritage for scan data (English Heritage 2006) and 'Big Data' project for Arts and Humanities (ADS and EH 2007). The metadata can be displayed alongside the 3D colour model in the prototype E-Curator application (see Figure 11).

For E-Curator these metadata guidelines have been extended to accommodate different sets of raw and processed data in order to provide traceability and transparency for the user, who is interested in examining the 3D images generated at different scanning and data processing stages. A hierarchy for these records has been established including the aligned 'registered' version of the point cloud without colour or point processing, a 'processed' version with cleaned colours and geometry, and a 'presentation' file with optimised colours and filled data voids. For the use of conservators and curators the second 'processed' model will be the most relevant since it encompasses the complete object in one data set but has undergone the least data alteration and processing.

Object information
Object_Dimension, Object_ID, Object_Descriptor, Object_LocationinMuseum, Object_LocationFound, Object_Period, Object_Owner, Object_Collector, Object_Description, Object_ModernLabel, Object_Inscription, Object_Material, Object_Category, Object_Name, Object_OriginalClassification, Object_Provenance, Object_ResearchQuestion, Object_LinktoWebDatabase
File information
File_NumberofPoints, File_ImportSettings, File_NumberofRecords
Scan information
Project_ID, Scan_Name, Scan_Hardware_used, Scan_Software_used, Scan_LaserSettings, Scan_Scandate, Scan_Time, Scan_Scanagent, Scan_Comments, Scan_Description, Scan_ColourCalibrationSet
Processing information
Process_ID, Process_Agent, Process_Software_used, Process_DateStartProcessing, Process_DateCompletionProcessing, Process_Time Process_Description, Process_Guidelines
Database information
Database_Added (to database), Database_Added by

Table 1: Metadata information for a single scan in the E-Curator prototype (July 2008)

It is also necessary to consider the technical challenges posed in maintaining quality in colour and geometry data collected with scanning systems, both of which must be carefully controlled to ensure that the collected record is fit for virtual heritage purposes. Whilst specifications for recording the position, size and departure from nominal form of geometric objects exist in the engineering domain (BS 7172: 1989) recording the geometry of free form surfaces to a similar level of best practice is in its infancy.
The situation is more complex for the recording of colour where knowledge and best practice is widely distributed amongst different user communities ranging from paint manufacturers through the digital imaging domain to surface finish specialisations. Most pertinent are models of Bidirectional Reflectance Distribution Function (BRDF) which can account for the variation in directional dependence of the reflected energy from a surface. Calibrated reflectance test charts, such as those in the MacBeth series, can of course be included in the process and are able to account for capture and viewing characteristics, but they are unable to correctly represent the surface characteristics of individual object to be recorded.
In the case of the Arius3D the system colour collection is reproducibly monitored for each scan pass and many of the key effects inherent in the imaging configuration are corrected, but there is no account made of viewing angle dependant colour surface properties. As a result the data produced following the editing process can be regarded as an operator's best attempt at a consistent and engaging 3D colour model rather than being consistent with an external colour standard.

3. EXAMPLES FOR 3D COLOUR LASER SCANNING FROM UCL MUSEUMS AND COLLECTIONS

A systematic approach and methodology for organic and inorganic materials is being developed within the project to

ensure repeatability of the scan process. The resulting coloured point cloud data available in the E-Curator application provide a highly accurate surface analysis tool.
As illustrative examples we would like to introduce a selection of outcomes from the E-Curator core object group, all from the world-class UCL Museums and Collections. The diversity of these collections, from archaeology, art and ethnographic to medical, provide an excellent 'laboratory' to apply and test the recording technique. All examples have been digitized with the Arius3D colour laser scanner at UCL.

3.1 Example 1 – a painting from UCL Art Collections

We chose a very rare example of British Impressionism by outdoor painter Walter Westley Russel. The 'Beach Scene' (ca. 1890) is part of the Paintings Collection in UCL Art Collections.

Figure 2: Three-dimensional colour laser scan of Russel 'Beach Scene' painting. Brush strokes and surface features are clearly visible due to adjusted artificial light settings.

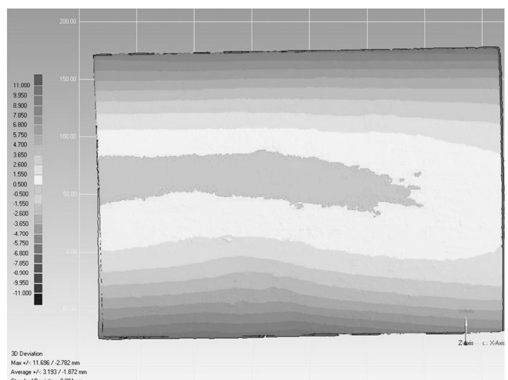

Figure 3: Geometric evaluation of the Russel painting. The convex deformation is now quantifiable from the 3D model.

The lightweight wood used as a sketching panel, possibly deal or mahogany, played an important role in the painting process. Not only did the paint dry rapidly on the unprepared surface but the painting also profits from a warm tonality within its coloration (Strang Print Room UCL 2007). The painting shows some serious conservation problems.
Detailed conservation science analyses (X-ray, pigment analysis) have been done on the painting by the UCL Art History Department and the 3D colour laser scan hopes to complement the results.
The goal is to produce a virtual three dimensional archival document that widens our knowledge of the object.

The scan product is a coloured point cloud with the density of 100 µm per 100 µm; such a detailed survey of the painting has not been delivered before. Brush size, paint direction and structural surface anomalies can be visualised by using the options of artificial raking light settings. The 3D scan, stripped of its colour information, makes surface features more visible to analysis (see
Figure 2 and Figure 4). The now perceptible impressionistic paint structure could lead to knowledge about an artist's personal style - his 'handwriting' - and could help to identify authenticity of a painting.
The 3D colour scan is not only documenting the brushwork of the painting. But also the warping deformation of the wooden panel is recorded, which provides an ideal starting point for detailed surface measurements and further monitoring over time. Sections and evaluations of geometric deformation can easily be derived from the 3D point cloud (see
Figure **3**).

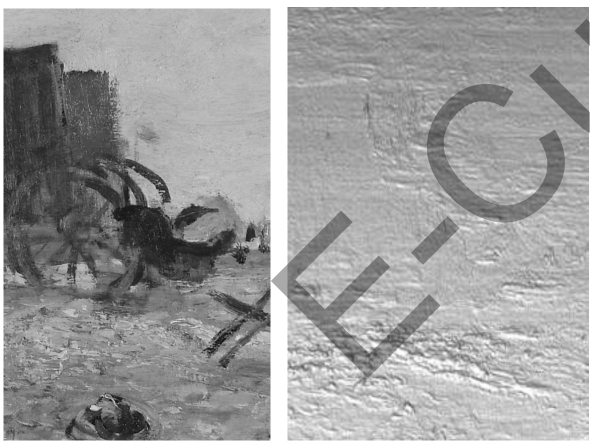

Figure 4: Photographic detail versus 3D laser scan: detail of the Russel painting. The X-ray of the painting gave evidence of earlier additions, maybe more 'bathing machines', in the background. They were later painted out with lead white. A fact that can be also be confirmed by the scan image.

The results suggest that the technique can complement traditional conservation analyses methods.

3.2 Example 2 – a mask from UCL Ethnographic Collection

UCL's broad range of collections includes a Sepik Yam Mask from Papua New Guinea. This fragile mask is woven from natural fibres and decorated with coloured pigments, shell valuables and some feathers. A 3D scan should reveal greater surface detail of the mask, pigmentation loss and deterioration of the woven fibres.
The fragility of the mask prohibits a too frequent lifting and turning upside down. Students of conservation and anthropology could now browse the digital object to find out more about the weaving pattern of the mask without increasing its deterioration by handling.

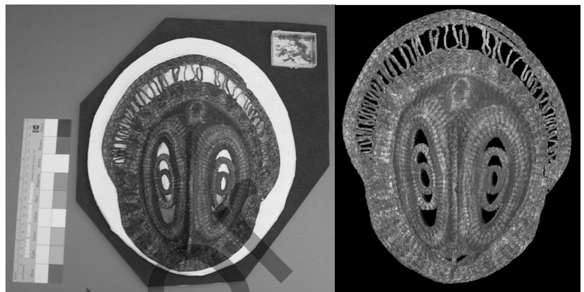

Figure 5: Sepik Yam Mask: photograph versus 3D colour scan.

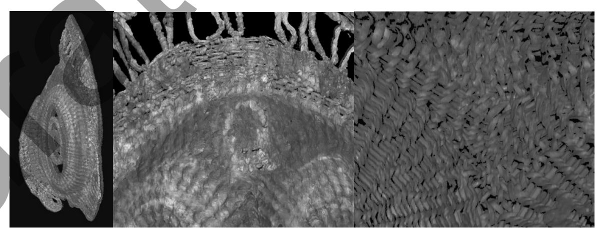

Figure 6: Details of side, front and back of the New Guinea Mask. The front detail is showing pigment and surface loss, whereas the back detail reveals an intricate weaving pattern.

Further distribution methods of this digital model to enhance knowledge about this type of object can be considered now: virtual reconstructions, animations and films for multimedia and education (e.g. in e-learning).

3.3 Example 3 – The Petrie Quartzite: an incised and inscribed stone from 1500 BCE

This object from UCL Petrie Museum is described as an irregular carved slab of quartzite, orange-brown colour, with black-outlined incised cartouche of throne-name of Hatshepsut, Maatkara on the convex side. A line of largely effaced hieratic in black colour runs along the left side of rectangle framing of the cartouche. It is dated into the period of dynasty 18 (1295BCE-1550BCE).
The Petrie Quartzite is frequently loaned but has recently failed a conservation test. The curators hope that a digital image of the stone helps distinguish tool marks from erosion without direct contact with the object surface and facilitate a better reading of the fading carbon-black cursive inscription line.

Figure 7: A catalogue photograph next to a 3D colour laser scan of the namestone aka Petrie Quartzite, UCL Petrie Museum collection number UC 55606.

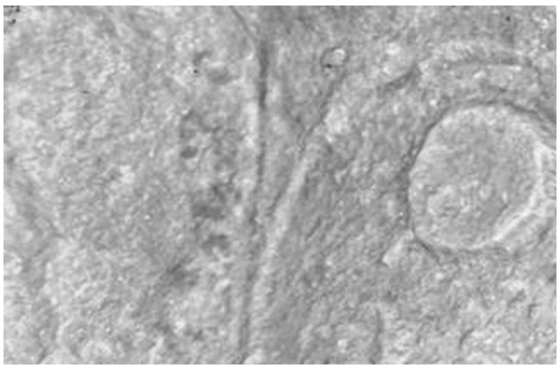

Figure 8: A detail of the colour laser scan which enables the conservator and curator to see fine ink writing as well as surface geometry, geological formation and coloration of the stone.

A 3D colour laser scan documents the object in the round in high resolution. It also reveals almost indiscernible surface incisions and features on this namestone (see Figure **9**).

Further research on the digital image is now possible without endangering the surface by abrasion through manual handling. External researchers could be invited to give their comments remotely and compare it to similar objects.

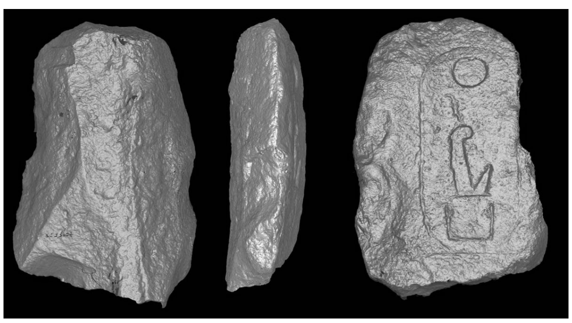

Figure 9: 3D laser scans of the Petrie Quartzite 55606.

4. TRANSMISSION OF 3D DATA SET

A facility for the inter-institutional exchange of the collected data scans and related metadata is being developed to provide a shared platform accessible by museum specialists on low cost computing hardware. The E-Curator application prototype is an e-Science developed data storage and retrieval solution and an internet capable 3D visualisation tool. It is being iteratively designed in association with a team of museum curators and conservators who are able to directly compare the handling of a range of original objects with their virtual copies.

4.1 Data sharing and real time interaction with 3D colour laser scan data

For 3D colour scans to be of practical use, robust means of sharing and validating the data obtained need to be established. High resolution colour scans of one object can require hundreds of megabytes of storage space, and can only realistically be shared using the distributed file systems such as Storage Resource Broker (SRB) being widely deployed in the e-Science environment.

SRB is a data grid middleware software system produced by the San Diego Supercomputer Centre (SDSC). The system implements logical namespaces (distinct from physical file names) and maintains metadata on data-objects (files), users, groups, resources, collections, and other items in an SRB Metadata Catalogue (MCAT), which is stored in a relational database management system. The SRB has features to support the management and collaborative (and controlled) sharing, publication, replication, transfer, and preservation of distributed data collections.

The E-Curator prototype currently enables an external user to access and search different objects across UCL Museums and Collections. The following categories are displayed and can be browsed: Catalogue Information, Conservation Information, Exhibitions & Displays, References, 2D images, related objects in the E-Curator application and 3D images with its scan metadata information.

SRB allows data to be replicated from remote into local databases to allow fast access. Further development will automatically connect E-Curator users to such local versions when available, reducing the time taken to retrieve commonly-accessed objects and also minimising bandwidth demands on remote connections.

4.2 Software architecture of the E-Curator application: e-Science technology (SRB)

The E-Curator application is middleware software that provides user access via a web browser to 3D colour scan data and relevant catalogue and metadata information. It is written as Java servlets running on a Tomcat server (see web reference 1), and interacts with the Storage Resource Broker using the JARGON library (see web reference 5). Users access this software using their web browser (see Figure 10).

Metadata about the scanning process is stored in SRB alongside each scan. Cataloguing information about each object is stored using SRB's Metadata Catalogue. This information is displayed alongside object scans within Internet Explorer (see Figure 11).

3D scans of objects in Arius3D Pointstream format are stored on the SRB server as a collection hierarchy. A web-based interface has been developed to allow users to access the 3D images, using an Arius ActiveX plugin to visualise and manipulate scans in Internet Explorer (see Figure 12).

Institutions wishing to provide access to scans of their own objects will have the choice of installing this software for themselves (which is being released under an open source licence), or alternatively partnering with an organisation that provides this type of functionality – such as in the UK the National Grid Service funded by the UK Research Councils.

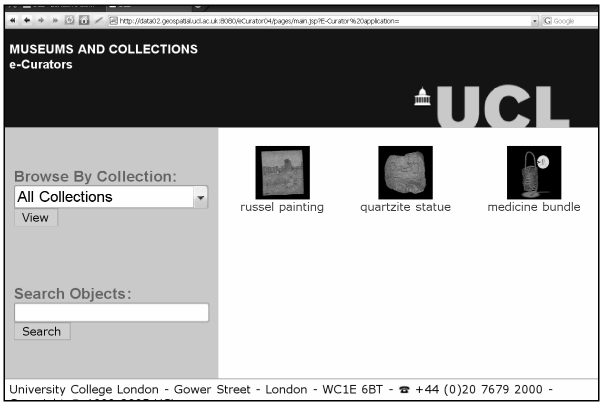

Figure 10: E-curator application prototype (June 2008).

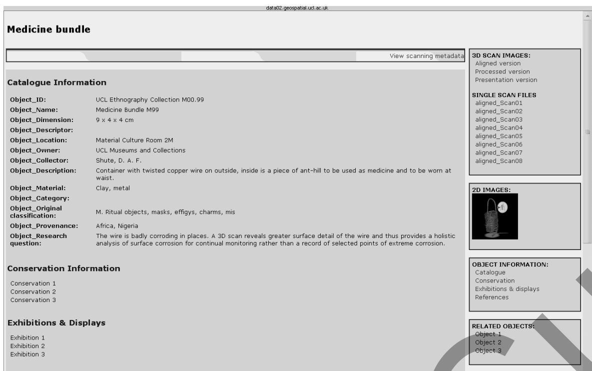

Figure 11: E-Curator application prototype while browsing the metadata of the object and 3D scans (June 2008).

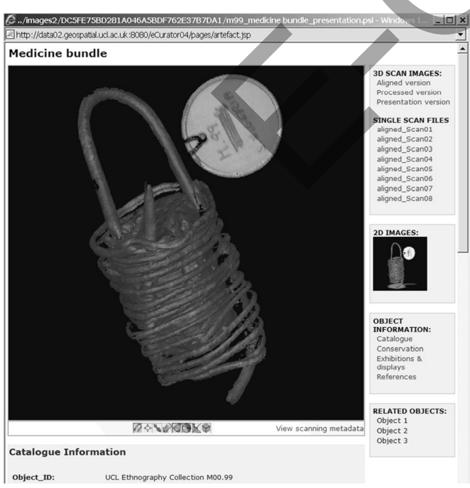

Figure 12: Browsing the 3D model of a Medicine Bundle from West Africa (UCL Ethnographic Collection) in the E-Curator application.

4.3 Metadata and catalogue information for 3D scan data

3D representations of heritage objects and museum artefacts need to have a clear 'provenance'. This includes both a description of history and ownership of the object and a clear set of data that describes the production of the digital 3D scans of the object.

The E-Curator team has developed a specific metadata set for the E-Curator application that includes UCL Museums and Collections catalogue entries. The metadata used to describe the 3D images is based on SPECTRUM (1996), the UK Museum Documentation Standard for catalogue entries. These metadata include information about the object ID, physical description, location, historical facts, condition, exhibition and conservation information. The metadata provides a relevant framing for artefacts such as historical and archaeological facts, conservation information, exhibition and display information. The data is collected from local databases and paper documentation currently kept at UCL museums.

5. CONCLUSIONS

The examples given in this paper provide a demonstration of the developed 3D recording methodology and highlight how the developed system is capable of complementing traditional cataloguing methods for museum artefacts. The availability of complete data sets from raw scan data to final edited models allows users to interrogate the available 3D content from a range of standpoints. On a basic level simply to gain an appreciation of the overall appearance of an object from its final edited record and for a more scientific enquiry to access constituent data at a range of defined levels that reflect the data processing regime developed for the Arius 3D scanning system deployed within the project. The hierarchical system has the capability to be expanded to accommodate data from other scanning systems, photogrammetric imaging and Polynomial Texture Mapping (PTM) which are also deployed at UCL.

The utilisation of Grid technology through SRB and an allied web based interface is expected to prove extremely useful in providing a scalable solution for the dissemination of information from the E-Curator project to a multitude of users. Currently the user group is limited to a museums and collections community who are involved with project assessment and the development of further E-Curator capabilities, but the system will be made available to external users on both real and virtual visits to UCL Museums and Collections sites in the near future.

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