3D-ACQUISITION OF ATTIC RED-FIGURED VESSELS AND MULTI-SPECTRAL READINGS OF WHITE GROUND *LEKYTHOI* IN THE *KUNSTHISTORISCHES MUSEUM* VIENNA

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Abstract: *Motivated by archaeological requirements we are developing an automated system using 3D-acquisition based on structured light for documentation of ancient ceramics. Furthermore we are developing a system for art-historic analysis of medieval paintings using multi-spectral readings of colour pigments. Documentation of polychrome pottery of the Collection of Greek and Roman Antiquities of the Museum for History of Art in Vienna (KHM) required the combination of both systems for documentation, classification and (virtual) restoration tasks. Therefore we show the combined methods of our systems for digital, contact-free, radiation-free acquisition of 3D-models including multi-spectral readings of painted ceramics.*

Keywords: *3D-acquisition, multi-spectral readings, pottery, 3D-model, Corpus Vasorum Antiquorum*

INTRODUCTION

As we all know, the analysis of ceramics reveals information about the age, trading relations, advancements in technology, art, politics, religion and many other details of ancient cultures.

Fig. 1 (a) Attic red-figured *chous* KHM IV 1043. (b) Attic white ground *lekythos* KHM IV 3745 (© KHM).

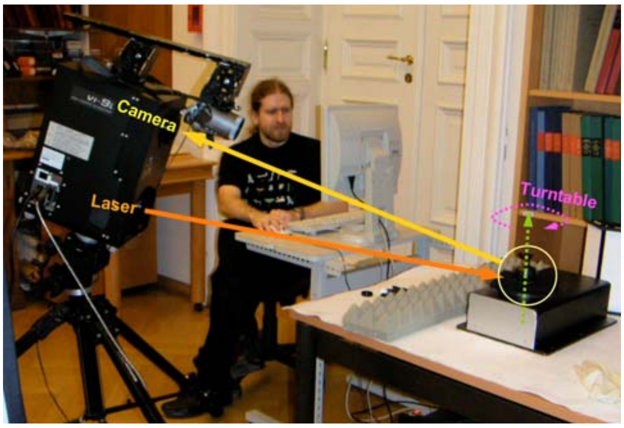

Fig. 2 3D-acquisition of a vessel in the *Kunsthistorisches Museum* Vienna.

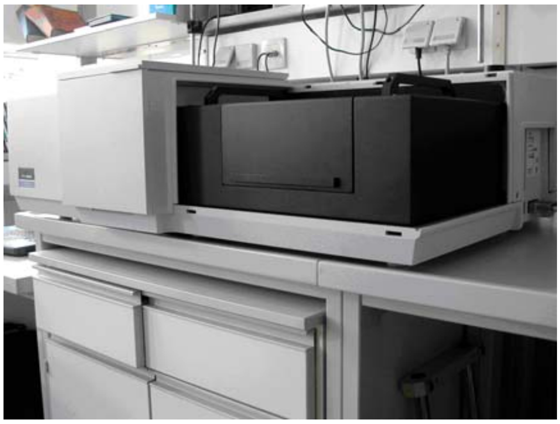

Fig. 3 UV/VIS/NIR Spectrometer (Perkin Elmer Lambda 900).

This is often a time consuming process and requires a lot of skill and manpower of experts. We are developing an automated system for documentation of pottery to help archaeologists to document their finds efficiently and accurately, one which can be used for further (computerized) research. The base of documenting pottery is a vertical intersection which is called a profile line. The intersections are usually drawn by hand. The PRIP-group provide a computer aided documentation method by using an automated system for acquisition and documentation of ceramics using a 3D-scanner based on the principle of structured light (*DePiero & Trivedi 1996; Liska 1999*). It was successfully tested on sherds as well as on unbroken vessels in interdisciplinary projects both in excavations and in museums (*Kampel & Sablatnig 1999; Cosmas et al. 2001*). In parallel the same group worked on a second system for analysis of medieval paintings in which pattern recognition techniques are used to detect and to classify brush strokes of under-drawings (*Kammerer et al. 2007; Asinger et al. 2005*).

In the context of the preparation of a Corpus Vasorum Antiquorum (CVA) volume of Attic red-figured vessels of closed shaped and white ground *lekythoi* (**Fig. 1**), today stored in the Collection of Greek and Roman Antiquities in the *Kunsthistorisches Museum* Vienna (KHM), both methods were combined: we acquired 3D-models of 128 vessels of various shapes. Especially for the polychrome *lekythoi* in the same collection, we chose to combine the experiences on the documentation of ancient ceramics and on the colour pigment acquisition and classification, used for medieval paintings. Related methods for the identification of pigments required the removal of a sample of the surface (*Wehgartner 1983, Koch-Brinkmann 1999*) while our method is based on contact-free measurements using a Spectrometer.

The following sections describe the 3D-acquisition, the multi-spectral readings and the combination (registration) of both methods followed by the results showing the profile line and top-views for the *Corpus Vasorum Antiquorum* (CVA).

The method which is used for the estimation of volumes and geometry will be of special interest for future work.

METHODS

3D-Acquisition and Processing

For acquisition we use a *Konica-Minolta* 3D-scanner based on the principle of structured light (*Tosovic 2002*) having a resolution of <0.1mm, which meets the requirements given by archaeologists for their documentation. Documentation using a 3D-scanner for ceramics consists of several steps. First the main part of the ceramic is acquired using a turntable to acquire the side views (**Fig. 2**). Therefore typically 4 to 6 3D-images depending on the complexity of the shape are acquired. Then the bottom and the mouth of the vessel are acquired using typically 4 to 8 3D-images. Finally the 3D-images are registered and background objects supporting the ceramics are removed (*Mara 2006*). The result is a 3D-model describing the surface of the ceramic.

For archaeological publication and further analysis, we have to estimate a profile-line. This is the longest elongation around – or cross-section through – the wall of a vessel defined by the rotational axis (also called axis of symmetry). The term rotational axis relates to the fact that rotational wheels (plates) have been used for thousands of years for manufacturing ceramics. Therefore we base our work on using the rotational axis to orient a vessel (or its fragment) to estimate the profile line as it is done manually in drawings. Therefore we use the principle of fitting circle templates (*Gander et al. 1994*), which was inspired by manual documentation.

Furthermore the creation of such manual drawings is a time-consuming task requiring expert-skills. Our system helps to dramatically reduce the time for documentation.

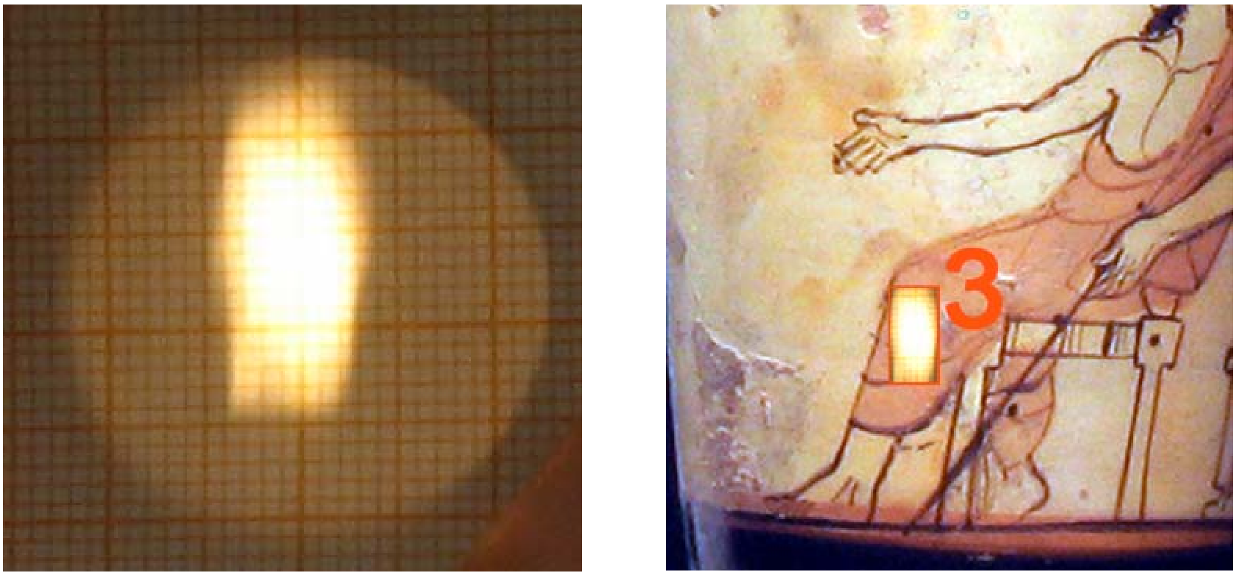

Fig. 4 Measurement slit at the exit point of the Spectrometer projected at (a) a graph paper with a mm scale. The 'ideal spot' is marked as a square of 5 x 8mm (b) Measurement slit projected on a real object (photo composition based on our proposed method).

Multi-Spectral Readings

For the research on the pigments we acquired 105 multi-spectral readings of 17 *lekythoi* and vessels with additional paint. The surfaces of these vessels have been measured on a *Perkin-Elmer Lambda 900* UV-VIS-NIR (UltraViolett, VISible Light, Near InfraRed) Spectrometer (**Fig. 3**) applying the diffuse reflectance technique using a *60 mm* integration sphere. The reflectograms have been measured from *190 nm* up to *2500 nm* in *10 nm* steps. Initial experiments regarding pottery showed that decreasing the step width below *10 nm* dramatically increases the acquisition time, while – due to noise – no gain of information is gathered. The data has been rationed versus a pure *Spectralon*™ background. The surface of the vessels are placed near the slit as close as possible, in order to reduce the loss of reflected radiation. A black box was put over the object in order to eliminate external radiation. The ideal measured area covers 5x8 mm, at zero distance (**Fig. 4**).

The chosen method has some limitations concerning the evaluation of the intensity of the measurements: due to the restricted setup and the varying size of the objects, the distance between object and slit could not be kept constant; since the objects are not flat, different curvatures also result in a variation of the measured intensities; due to the fixed size of the measurement area given by the slit of the Spectrometer in certain cases the pigmented area is smaller than the measurement area which results in a measurement of a mixture of background and pigment.

These limitations do not allow an exact measurement of the absolute reflectance. Still the measured curves can be evaluated, since the relative reflectance at a different wavelength can be used to identify pigment specific characteristics without any post-processing. As this is not satisfactory for future analysis and especially not for automated analysis we decided to determine the geometry of the setup by 3D-acquisition of the setup for each multi-spectral reading of every vessel. Therefore we have to register and estimate the location of the measurement area on the 3D-models.

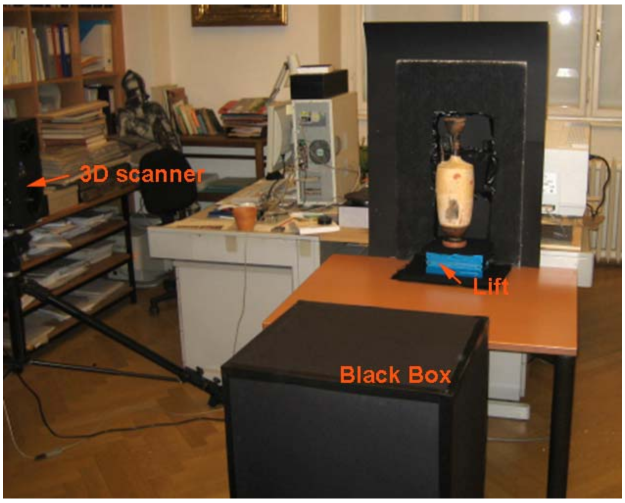

Fig. 5 Acquisition setup: 3D-scanner (left), vessel placed on a lifting platform, Spectrometer (background) and black box (front).

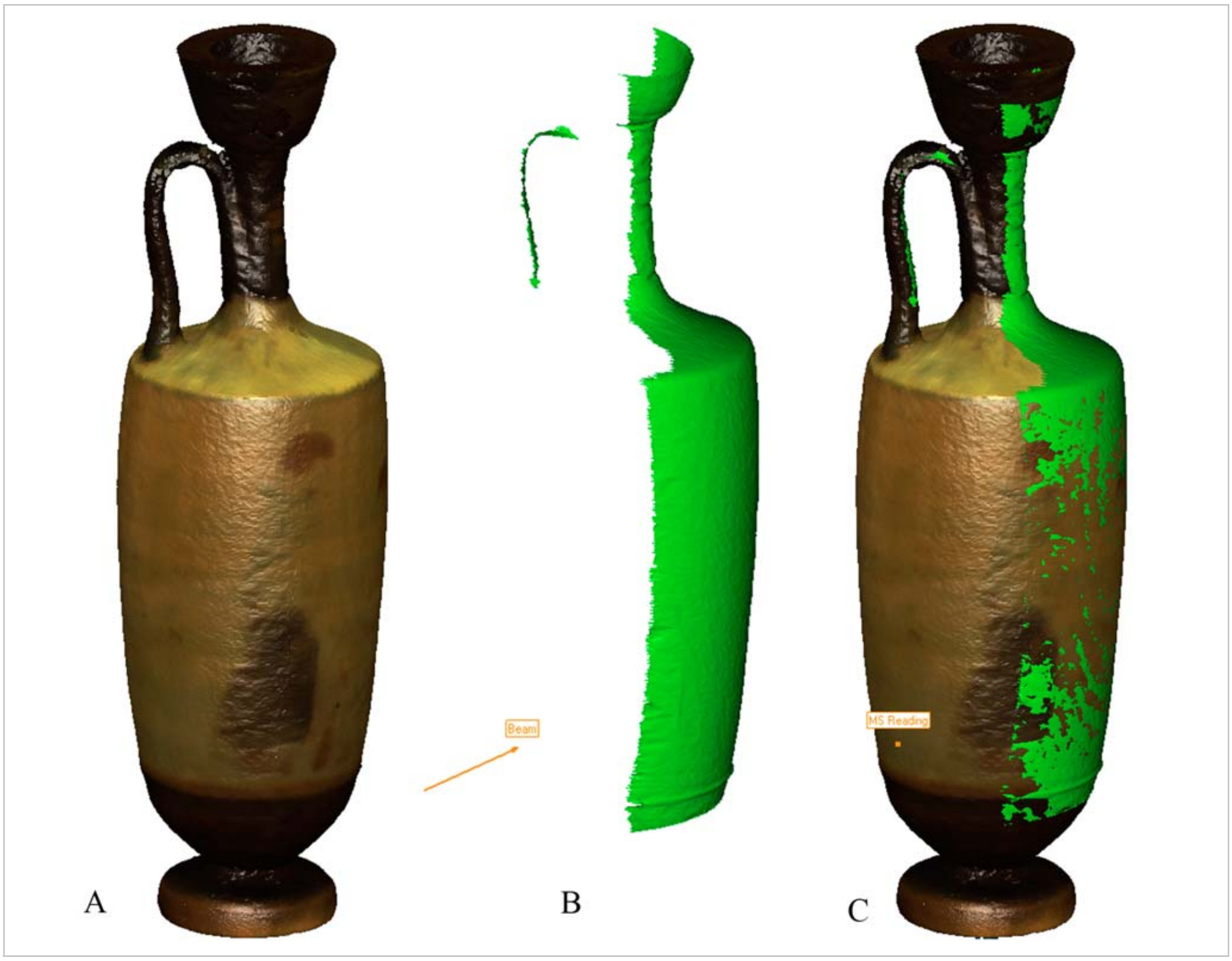

Fig. 6 (a) Complete '3D model' of a vessel (KHM IV 143). (b) Vector of the beam registered with a part of the vessel at acquisition of a measurement (No. 4). (c) Registered 3D-Model having the complete 3D-model including the position of the measurement described by the intersection of the beam and the 3D-models surface.

Registration of the Multi-Spectral Readings within the 3D-Models

To register (combine) the spot measurement of the Spectrometer we used the same techniques and the same 3D-scanner as for the acquisition of the 3D-models. Having the 3D-models of the vessels already available which were acquired in an earlier documentation phase, we needed only one 3D-scan per multi-spectral reading (**Fig. 5**).

The following steps are performed for determining the geometry of the scene (**Fig. 6**):

1. Acquisition of a complete '3D' model as shown previously.

2. 3D-acquisition of the 'beam' and object at measurement position. The beams position was estimated by placing an elongated calibration object with prismatic shape into the beam, and marking the position of the Spectrometer slit. The 3D-scanner setup must not be changed between the acquisition of the beam and the acquisition of the measuring scene.

3. Registration of vessel 3D-model with vessel and beam, calculate the intersection between beam and object in order to determine the measurement position.

As a 3D-scan is performed within less than 30 seconds and the fact that a multi-spectral reading requires up to 10 minutes, we could gain an accurate (<1mm) location of the multi-spectral reading on the vessels surfaces without any noticeable increase of working time for multi-spectral readings solely.

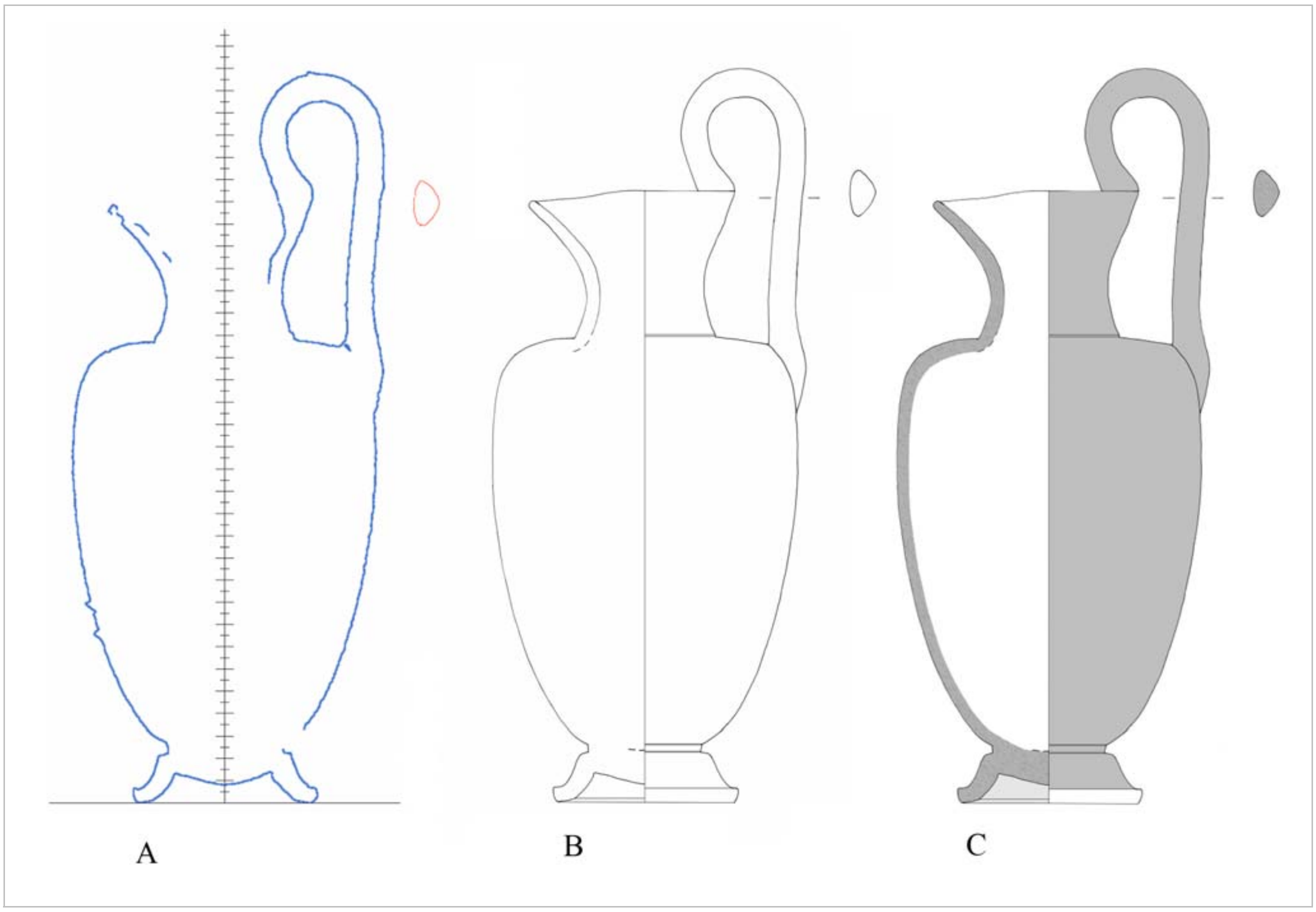

Fig. 7 (a) Automatically estimated profile line of vessel KHM IV 350 leading to the (b) edited drawing, which is extended to the (c) pre-final drawing by adding artistic features.

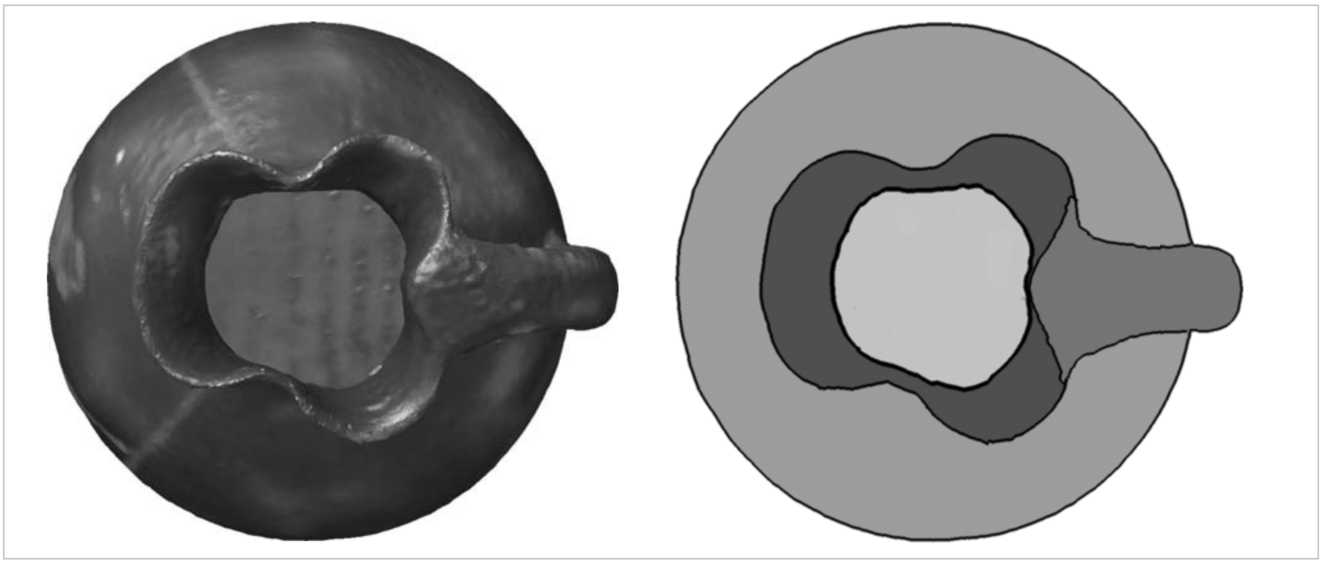

Fig. 8 (a) Top-view of the '3D-model' of KHM IV 352 and (b) the related, estimated line drawing.

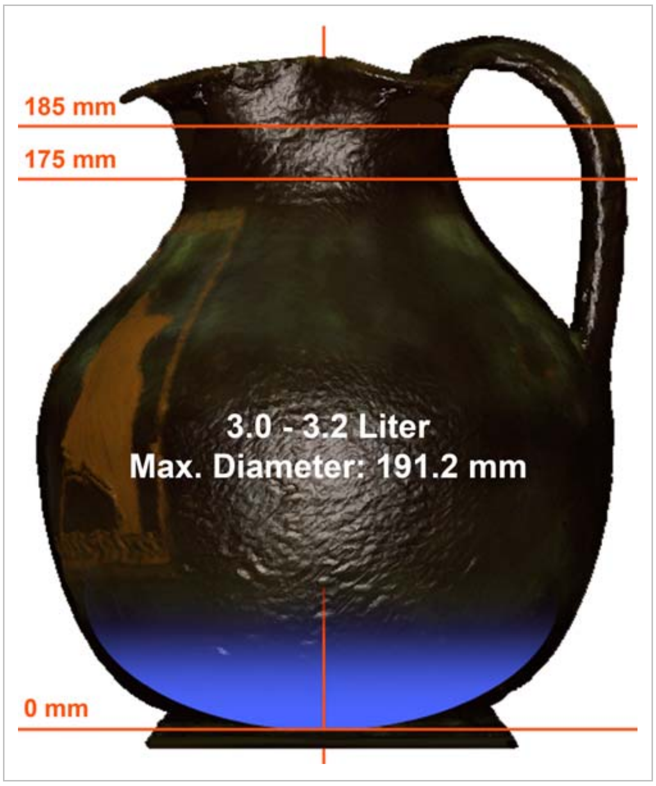

Fig. 9 Volume estimation of *chous* KHM IV 1034 which was – because of its shape – supposed to be used for measuring liquids.

FINAL DOCUMENTATION AND OUTLOOK

The final documentation of the vases in the project consists of two parts. The first part is based on the 3D-models and will be used immediately. The extracted profile lines will be published within a new volume of the CVA. In the same volume top-views and unwrapped vessels will be shown. Due to the limits of publication costs and the general goals of the CVA the results of the multi-spectral readings will be published as technical report separately.

Both measuring methods, 3D-acquisition and spectral readings, are optical methods. They are radiation-free and non-invasive. They can be done in any location.

3D-Models: Profile Lines, Top-Views, Unwrapping, Volumes

The estimation of the profile line is the most fundamental mean of archaeological documentation. In our work the profile lines are automatically estimated from the acquired '3D models' (**Fig. 7a**).

The profile line can be exported as an AutoCADTM dxf and other common file formats. Various post processing steps follow: removal of distortion, completion of the inner part of the profile line (compensation of shadowing effects), and addition of further geometric information of other parts of the vessel, like the cross-section of the handle (**Fig. 7b**). The addition of the surface decoration to the profile drawing is the last step to the ready-to-print drawing (**Fig. 7c**). It is available in each scale as may be necessary.

Further benefits occur from using a 3D-model: Top-views can be generated without the loss of accuracy (photographs have perspective distortion!) and may be adopted for a publication as easily as the profile lines (**Fig. 8**). To provide the unwrapped surface based on a 3D-model will improve especially the documentation of figured vases. The estimation of the volume (**Fig. 9**) or the analyses of the symmetry of a sample of vessels (*Mara & Sablatnig 2006*) are optional areas of research based on a 3D-model.

Multi-Spectral Readings

As the Spectrometer can only acquire multi-spectral readings at certain spots (points) and due to time constraints (10min/reading) we selected points of special interest. It turned out that even samples which appear the same for the human eye can show a significant difference in the reflectograms, e.g. the red colour used for the depiction of hair on white ground *lekythoi* between 1400 and 1500 nm (infrared) (**Fig. 10**). This indicates that different ingredients have been used. An application of this analysis can help to determine fake objects without taking samples.

In general the acquired data and this technique in combination with a pigment database will assist in further analysis. We planned to set up a database of colour pigments in collaboration with experts of chemistry, similar to the work done within the project *Casandra* (FWF-Project P15471-MAT, *Asinger et al. 2005*).

CONCLUSION

Summarizing the results of our interdisciplinary, cooperative project, we could show that 3D-acquisition is an eligible tool for acquisition and documentation of pottery, from the masses of daily finds on excavations up to unique objects of museums collections. We could show that we could decrease the time and costs for documentation for such objects. It must be stressed, that even more time and costs can be saved because the digital drawings can be easily adopted for different purposes, e.g. publication in different scale, and may be used within digital libraries. Especially the use within such libraries will enable experts to digitally analyze and compare vessels stored in various places, often not accessible to the public. A 3D-model of a sherd or a vessel gives a 'copy' of the whole object of which future research work may draw detailed information without handling the object again, e.g. estimation of the volume, various sections, unwrapped figure scenes etc.

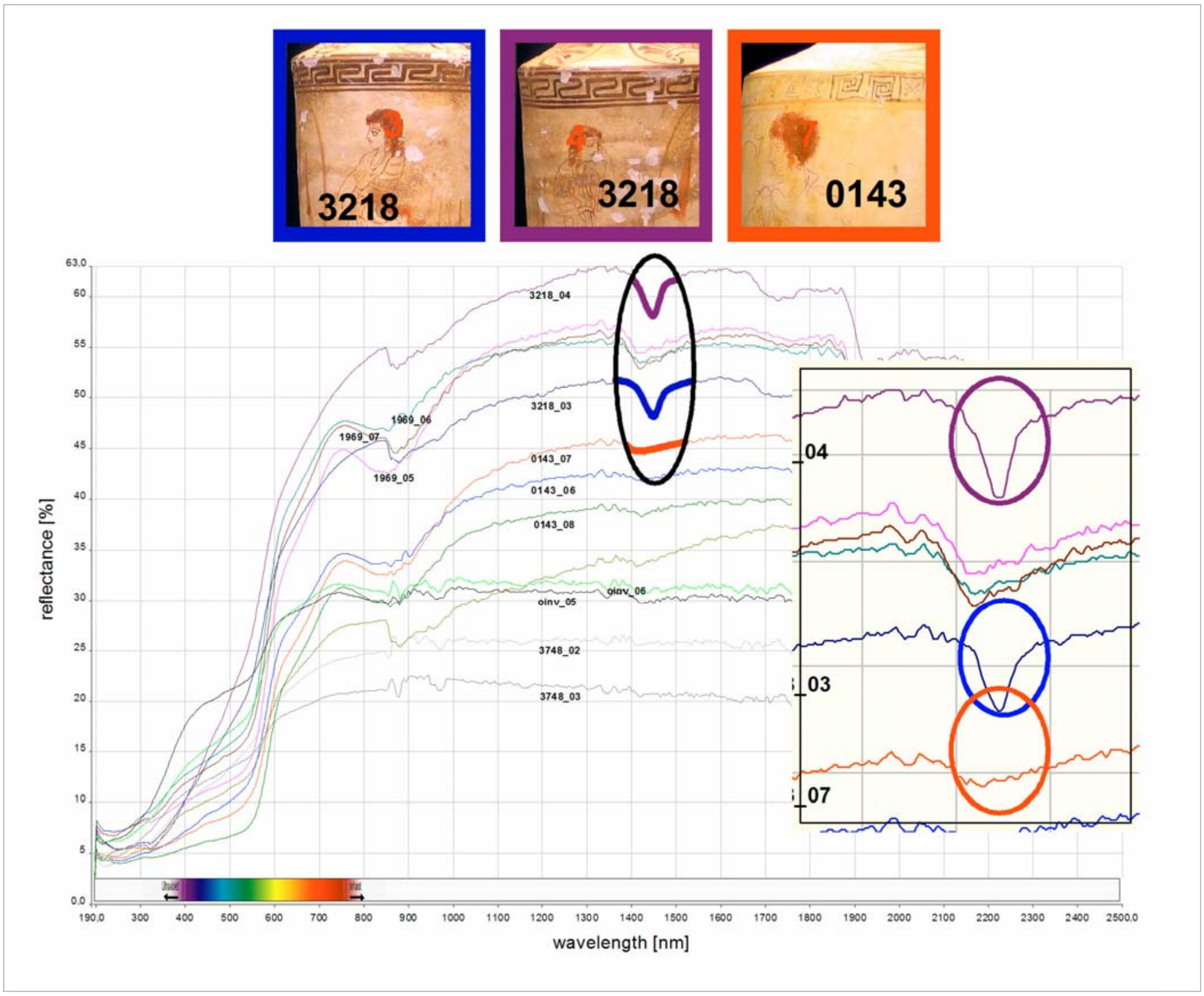

Fig. 10 Comparison of reflectograms of the colours used to paint red hair. The ellipses mark a significant difference for red coloured hair at a wavelength between 1400 and 1500nm (infrared).

Future work will be the adoption of digital libraries for textured 3D-models including registered multi-spectral readings of ceramics.

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