Advanced Documentation Methods in Studying Corinthian Black-figure Vase Painting

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Unwrappings are crucial in archaeological pottery studies. Within the study of Greek pottery, unwrappings of painted surfaces have a long tradition and their significance is still well-deserved. They show the depiction without photographic distortions or partitioning in multiple photographs, enabling archaeologists to analyse and interpret the image as a whole. This is especially true in the case of Corinthian pottery, where the poor preservation of the painting tending to flake off often results in unclear photographs. Nevertheless, traces of flaked off painting layers are still visible on the surface under specific illumination. Creating unwrappings manually is time-consuming. Manual acquisition with tactile tools like tracing paper is often not allowed due to the fragile nature of the surfaces. To facilitate this task for pottery archaeologists, a combination of 3D data derived by “Structure-from-Motion” (SfM) and “computed tomography” (CT) is proposed, where each technique can also be on its own. The fusion of these data sources to exploit their specific strengths is a new approach in the field of “Cultural Heritage” (CH): SfM with a high resolution in texture and CT with a high accuracy in geometry. The SfM and CT data are combined by transferring colour information to the vertices of the CT model. Afterwards, the GigaMesh Software Framework was used for enhancing geometric features in the surface data, in this study case, the fine incisions of the black-figure painting. With this approach, accurate and sufficiently detailed unwrappings aligned to the needs of pottery specialists can be created in minimum time.

Key words:
Computed tomography, Texture mapping, Corinthian pottery, Vase painting, Feature vectors, Unwrapping.

CHNT Reference:
Stephan Karl et al. 2018. Advanced documentation Methods in Studying Corinthian Black-figure Vase Painting.

INTRODUCTION

Unwrappings of curved painted surfaces are essential elements of a scientific documentation of an object in archaeological pottery studies. Within the study of Greek pottery, these unwrappings have a long tradition and a well-deserved high significance [Walter 2008]. They show the image without photographic distortions or partitioning in multiple photographs due to the partially or completely circumferential painting. This enables archaeologists to analyse the image as a whole in terms of style, dating and depiction. Additionally, such unwrappings transform the painting in a clearly legible graphic execution highlighting relevant details for the stylistic analysis. This is especially true in the case of the Corinthian black-figure pottery, where the poor preservation of the black glaze tending to flake off often results in unclear photographs. Black-figure describes in archaeology a Greek vase decoration technique, in which figures and ornaments were painted as silhouettes before a light background, using black glaze, whereas inner details were incised into the painted layer and specific areas were highlighted using added colours [Amyx 1988]. Thus, in computer science terminology the black-figure painting consists of texture and geometry data. In some cases of the Corinthian pottery where the painting is completely worn off, only the incisions are left. Nevertheless, traces of flaked off painting layers, like “shadows”, are mostly still

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visible on the surface under specific illumination. They allow archaeologists to reconstruct the painting and to perform unwrappings with reasonable certainty. The importance of unwrappings for stylistic analysis in Corinthian pottery, for identifying closely hands and workshops of Corinthian painters, is be underlined by recent works [Neeft 1998; 2013; 2017]. These are necessary stages to obtain a fine dating of the artefact and its context and for studying trade patterns or Corinthian craftmanship for example.

Although widely applied in archaeological pottery studies, there are barely any detailed descriptions of this process. A good example can be found in Hall [1936]. For making unwrappings one uses a tracing paper with highest possible transparency and with a rough surface for executing lines as thin as possible. The first challenge is to keep the tracing paper on the surface without displacements. This is achieved either by one hand whereas the other draws or by a strong band of elastic girdling the vase. If the surface is badly worn, which can be often the case in Corinthian pottery, only some glazed areas and some incisions can be seen accurately enough through the tracing paper. In such cases a careful examination must be made using a magnifying glass, while placing and removing the tracing paper several times and completing the tracing in front of the vase. The second challenge is to transfer a curved surface not based on a geometrical shape as cylinder or cone into the plane. In Corinthian pottery, the most emblematical and one of the most numerous vase shapes as aryballoi with a spherical shape and alabastra with an ovoid shape cause inevitably some distortions when projected to a plane. Such surfaces are called non-developable in mathematics. While unwrapping pottery surfaces, one principally avoids distortions of figures and tries to shift all necessary increases in the background (the area between the figures), making as little change in the composition as possible. This is done manually by shifting the tracing paper accordingly. However, there are scenes where single figures are linked together in close figural compositions, but also when the filling ornaments are tightly following the contours of the figures covering densely the background in a tapestry-like effect [Amyx 1988]. In these cases, one has to distribute the distortion even and reasonable. At the end, the tracing is transferred to a final drawing. The lines of the tracing, often feeble and inaccurate, must be strengthened and corrected in front of the vase.

The realisation of manually created unwrappings is a highly time-consuming task. A major obstacle is that using tactile tools like tracing paper is often not allowed by museum curators and conservators due to the fragile nature of the surfaces. Furthermore, one needs a trained person with necessary illustrative skills. An imprecise unwrapping is at least useless but can also be seriously misleading. Additionally, the manual drawings have to be digitised in an adequate way for the final publication, mostly using graphic programs, which also takes some time.

Within the history of the "*Corpus Vasorum Antiquorum*" (CVA), the international standard publication of Greek pottery, there was an attempt in the mid-1960s to realise unwrappings using traditional photographical technology [Villard 1965]. For this, a special experimental camera was designed. Even if considerable distortions occurred around the upper and lower edges, it brought excellent results in case of the well-preserved vases. However, the technological difficulties prevented this slow and laborious method to be adopted by the scientific community.

Therefore, to facilitate this task for pottery archaeologists and to overcome the above-mentioned difficulties, we propose the application of already existing computer-assisted methods performing rollouts and to use these rollouts combined with feature enhancements to create a final drawing aligned to the archaeological purposes. Such rollouts obtained from a 3D model have two main advantages: (i) their acquisition is contact free and (ii) the results are verifiable and repeatable. A basic precondition is to capture the black-figure painting with its fine texture and incisions and to achieve a high quality for the post-processing and analysis. For this, we have chosen a fusion of 3D data derived by "Structure-from-Motion" (SfM) and "computed tomography" (CT). It exploits the specific strengths of these not-contact digitisation techniques: SfM with a high resolution in texture and CT with a high accuracy in geometry.

RELATED AND PREVIOUS WORKS

Technologies for acquiring 3D data, for performing geometric analysis and for visualisation in "Cultural Heritage" (CH) applications have become a broad research topic [Pintus et al. 2016]. Generating rollouts of rotation-symmetric objects represent an important computational tool for enhancing perception. It was applied on cylindrical seals [Pitzalis et al. 2008; Dahl et al. 2018] or on pottery with curved vessel profiles using frustum-shaped cones or clipped off spheres as proxy geometry [Bechtold et al. 2010; Mara and Portl 2013; Rieck et al. 2013]. The last-mentioned methods are implemented in the open access GigaMesh software framework[1], freely available with video

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[1] https://gigamesh.eu

tutorials[2]. Conical and cylindrical rollouts can also be created e.g. using CloudCompare[3] [Nocerino et al. 2018] or TroveSketch[4] [Hörr 2011; Hörr et al. 2011]. However, all these methods create rollouts which are still 3D models in contrast to a manually created unwrapping.

“Structure-from-Motion” (SfM) or “Structured Light Scanning” (SLS) are commonly applied in pottery research for obtaining 3D data. Alongside these optical methods also CT is used to create 3D representations of objects; of course, with a specific focus on the inner structures. In generally, CT has a significant impact on the methodology of object documentation, fabric analysis, and identification of manufacturing techniques [Karl et al. 2013]. In the last years an increase of CT and microCT applications in archaeological pottery studies are to be noticed. Normally, direct volume renderings coupled with CT slices are standard, e.g. for the investigation of manufacturing techniques [Sanger 2016; Kozatsas et al. 2018] or organic inclusions within pottery sherds [Barron and Denham 2018]. Based on the segmentation of the volume data, shape analysis of pores and inclusions within the ceramic fabric represent valuable first steps in analysing CT data quantified for comparative purposes [Kahl and Ramminger 2012]. The most significant drawback of microCT scanning in pottery research and its use as non-destructive method is its sample size limited on only few centimetres. Other approaches use CT volume data gained by industrial CT scanners to reconstruct surfaces after filtering and segmentation processes [Jungblut 2012; Jungblut et al. 2013]. Transferred to a 3D mesh the object can be analysed based on the surfaces of the matrix (the ceramic body) and of the inner inclusions, e.g. calculation of the filling capacity or the fabric density [Karl et al. 2013]. The knowledge of inner structures revealed by CT has also an impact on the study of vase paintings, as demonstrated in a specific case by visualising a hitherto unknown ancient repair on a Corinthian black-figure alabastron [Karl et al. 2018].

A combination of multiple data sources of different 3D acquisition techniques as X-ray tomography, optical micro topography and photogrammetry was demonstrated by Pitzalis et al. 2008 on a cylinder seal, whereby surface noise and the deformation of the final shape using X-ray tomography mentioning in this work are obviously results of a poorly adjusted, calibrated and/or suited device and reconstruction algorithm. Up-to-date CT systems deliver precise data for accurate surface determination which is nowadays an approved method in dimensional measurements [Buratti et al. 2017].

Fig. 1. Corinthian aryballos G 26 from the Archaeological collections of the University of Graz (KFU Graz)

MATERIAL AND METHODS

For this demonstration, a Corinthian aryballos from the Archaeological collections at the University of Graz (KFU Graz), inv. G 26[5] (Fig. 1) was used. This pottery object was published in the “Corpus Vasorum Antiquorum” (CVA) [Christidis et al. 2014]. This aryballos was primarily chosen because its background is densely filled in the way mentioned above. Vases decorated in this manner are frequent in the second half of the Early and first half of the Middle Corinthian period (c. 610–580 BC) [Amyx 1988]. The object is well preserved with only some parts of the black glaze flaked off. There were also archaeological reasons for this choice: during the research for the CVA

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[2] https://gigamesh.eu/youtube
[3] https://www.danielgm.net
[4] http://www.archaeologie.sachsen.de
[5] https://gams.uni-graz.at/o:arch.2478

publication, this aryballos could not be attributed to any already identified painter or workshop. Additionally, the uncanonical filling ornaments with parallel rows of connected short arches seems to be particular and very rare to the authors best knowledge. Therefore, an accurate unwrapping of this circumferential painting should serve as a reference for further comparative stylistic analysis.

Computed Tomography

The object was scanned using a Phoenix v|tome|x L 240 X-ray cone beam CT scanner at the Austrian Foundry Research Institute[6] at Leoben. The scanner consists of a 240 microfocus kV X-ray tube and a horizontal shiftable 1-megapixel (1000 x 1000 pixels) flat panel detector. This CT device is suitable for sample sized up to 335 mm in diameter and 550 mm in height which means that almost all vessel shapes of Corinthian pottery can be scanned. The pottery object was positioned on the turntable pivoted to his rotation axis in an angle of 35° and placed on a three-point mount of “extruded polystyrene” (XPS). A maximum X-ray energy of 180 kV, 220 µA current and a 0.5 mm thick tin filter was used to scan the object, which consists of each 1500 projection images acquired over a 360° rotation in four overlapping single scans. Each projection image was acquired by average 2 and skip 1 with a detector exposure time of 200 ms. The resulting pixel size of this object with a maximum high of 9.2 cm and a maximum diameter of 8.8 cm was 55 µm. The total scan time including calibration beforehand was 129 min. The reconstruction of the projection images was performed using the software datos|x to produce a 3D volumetric data set. The cubic CT volumetric data set with dimensions in x/y/z of 1850/1850/2108 voxels has a reconstructed isotropic voxel size of 55 µm. The total reconstruction time was 44 min.

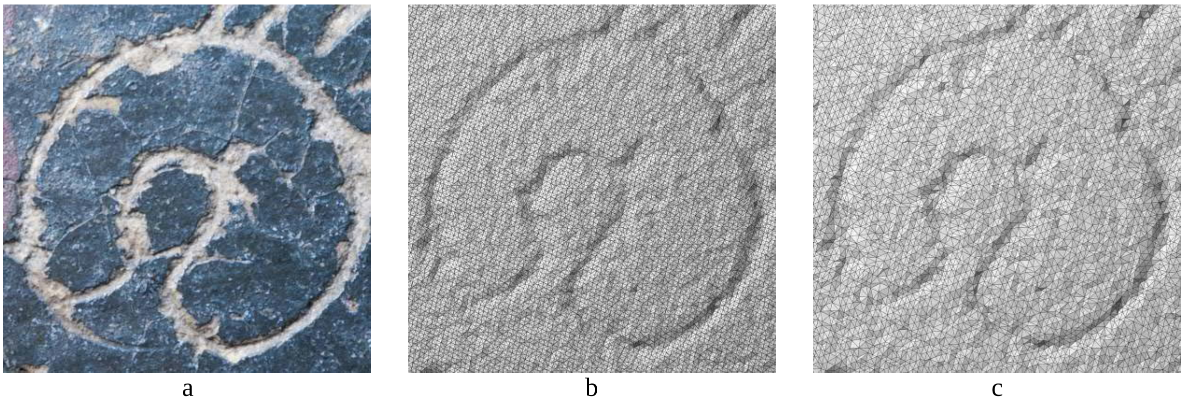
a b c

Fig. 2. Section of the aryballos KFU Graz G 26, size 5 x 5 mm: a) Photograph; b) CT surface in original resolution based on voxel size of 55 µm resulting in 564 points per 1 mm² in average (within this section); c) CT surface with point reduction within a tolerance of 0.01 mm resulting in 185 points per 1 mm² in average

The reconstruction of surface data from the volume data was performed using the commercial software VGStudio Max 3.0[7]. The surface was constructed using the local iterative surface determination implemented in this software [De Oliveira et al. 2016; Townsend et al. 2017]. It produces a material boundary based on local surrounding voxels. For compensating local deviations produced during the acquisition process, the search distance was adjusted to 7 voxels. The extraction of a surface polygonal mesh was performed using the surface extraction tool which samples the surface for the point creation using the ray-driven reconstruction modus. The resolution of the mesh was set to the voxel size. The result was exported as STL file. Reduced from some erroneous mesh parts of the supporting material and transformed to a PLY file, the resulting mesh has a point density of 499 points in average on 1 mm² of the object surface (matrix and pores), consisting of 30.742.039 vertices and 61.328.498 faces (Fig. 2b).

To make this data easier to process, the point reduction tool was used. The original point cloud was reduced by the elimination of points lying within a distance of 0.01 mm to a plane build by their neighbourhood points. This means that the resulting reconstructed surface has a reduced degree of details: it gives no further information about the original object’s shape within the given tolerance of 0.01 mm. The mesh gained from this process has a point density

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[6] http://www.ogi.at

[7] https://www.volumegraphics.com

of 218 points in average on 1 mm² of the object surface, consisting of 13.408.753 vertices and 26.674.008 faces. On the outer surface of the ceramic body (the matrix) the point density is lower, in average 186 points per 1 mm², whereas the surfaces of the inner pores or air voids have a higher point density due to their stronger curvatures, in average 344 points per 1 mm². The reduced mesh preserves the features as the fine incisions of the black figure technique (Fig. 2c).

To capture the geometry of the incisions of this black-figure aryballos having a wide of 0.2 to 0.4 mm, a spatial resolution of at least 1/2 of the wide is required [Mara 2012; Dahl et al. 2018]. But to represent these features with uneven, irregular edges sufficiently precise, a resolution of 0.05 to 0.1 mm or lower is needed. As known, the resolution is not the only factor determining the quality of a 3D mesh [Moitinho de Almeida et al. 2017; Moitinho de Almeida and Rieke-Zapp 2017]. To capture the fine incisions sufficiently, one needs also a high accuracy which should be considerably lower than the spatial resolution. The knowledge of such accuracy is essential, but normally difficult to gather [Dahl et al. 2018]. As mentioned above, the high accuracy is one of the strengths of CT. Current methods representing the state-of-the-art for segmenting CT volume data allow to reach about 1/10 of a voxel in terms of measurement uncertainty [Karl et al. 2013; De Oliveira et al. 2016]. In this case, it means 5.5 µm.

Fig. 3. The fusion of SfM texture and the CT data in the case of the aryballos KFU Graz G 26

Texturing CT

In addition to the CT model, a Nikon D3X (full frame camera, 24.4 megapixels) – and an electric turntable – was used to create 126 images as input for SfM. The images were processed in the commercial software Agisoft PhotoScan 1.4.3 Standard[8] to create a model with a high-resolution texture map (9999 x 9999 pixels). In MeshLab[9], the roughly scaled SfM model was scaled and aligned to fit the CT model with its absolute measurement. Then the texture of the SfM model was transferred to the closest vertices of the CT model. Of course, only the visible outer surface of the aryballos was captured with SfM, so only the outer surface of the CT model was coloured (Fig. 3).

Although the overall geometry of the scaled SfM model computed with high and very high settings fitted the CT model very well, fine details were missing or roughly visible in the mesh. Looking closer on a small surface section of this aryballos, the high accuracy of CT technology towards SfM is evident (Fig. 4).

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[8] since Version 1.5 Agisoft Metashape

[9] http://www.meshlab.net

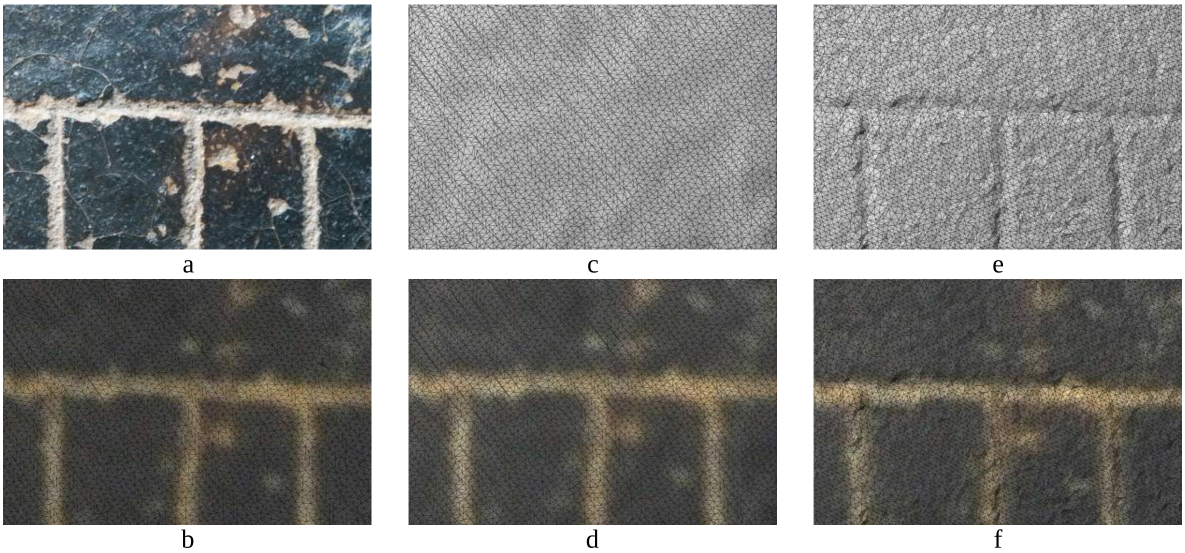

Fig. 4. Section of the aryballos KFU Graz G 26, size 4 x 6 mm: a) photograph; b) SfM mesh with 3949 vertices, in average 164 vertices/mm² (in this section); c) SfM mesh without texture; d) texture transferred to SfM vertices; e) CT surface with 4950 vertices, in average 202 vertices/mm²; f) texture transferred to the CT vertices

Rollouts and Feature enhancement

The fused dataset was processed with the GigaMesh Software Framework, which was used to unroll the body of the aryballos. The latter can be approximated by a sphere, which is defined by four points selected from the surface. The axis of rotation is defined by the orifice plane. Selecting the sphere and the orifice plane requires a minimum of user interaction of a few seconds. As any rollout leads to cutting the surface, an intersecting half-plane was chosen, defined by the axis and a point of low importance to the depiction of the motif.

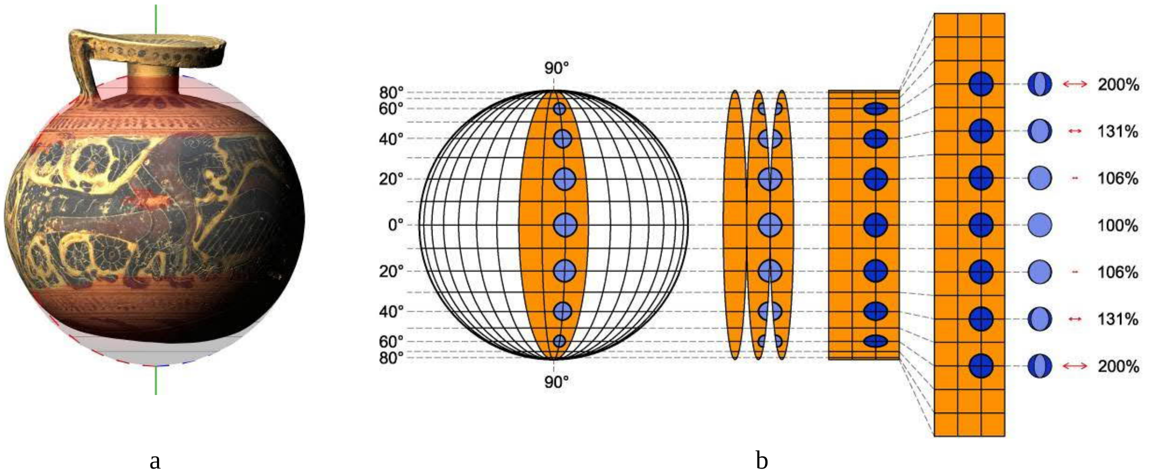

Fig. 5. The used equirectangular projection of a sphere for unwrapping: a) setting in GigaMesh; b) showing the increasing distortions to the poles only along the latitudes

The equirectangular projection is shown in Figure 5 and has proven most suitable for painted pottery among the rollouts using cones and cylinders as well as their combinations [Bechtold et al. 2010; Rieck et al. 2013]. It has no distortions along the longitudinal lines. As the sphere is a non-developable surface, the factor of the distortions along the latitudes can be computed by

$$s_{lat}(\theta) = \frac{1}{\cos(\theta)}$$

whereby θ is the angle formed by the normal at this point to the equatorial plane, similar as in geography.

These rollouts of 3D models are actually an umbrella transformation which deforms the 3D space using the coordinate system of the selected primitive [Apostol and Mnatsakanian 2012]. Such cone-based rollout unfolds like an umbrella which also has to be cut to become flat. The rollout of spheres follows the same principle. This allows the rendering of images with and without texture maps as well as high-contrast renderings based on the MSII filter result highlighting faint and small details. As the umbrella transformation is global, it strongly tends to preserve local i.e. small details like the fine incisions of the Corinthian black-figure pottery. The computation of the Multi-Scale Integral Invariant (MSII) filter of GigaMesh [Mara et al. 2010] was done before unrolling to avoid unwanted artefacts from the deformations of the spherical rollout within the final image. Figure 6 shows from top to bottom the aryballoi after the umbrella transformation with and without texture map. The latter demonstrates that the result of the transformation is still a 3D model, because a shading using virtual light source could be applied. The bottom rendering shows the pre-calculated MSII filter response highlighting the incision.

Fig. 6. Rollouts of the painted and incised surface of the aryballos KFU Graz G 26; a) texture; b) surface with shading; c) surface with MSII filtering

Archaeological Drawing

The unrolled MSII filtering and texture layers were used for a detailed graphical annotation aligned to the demands in Corinthian pottery research. This archaeological interpretation task is important in two aspects: (i) distinguishing the incisions of the black-figure painting from other features like scratches or fractures; (ii) recognising the contours of the black glazed and added red areas, also if only traces of flaked off painting layers are left. With the words of Michael Shanks, one has to "distinguish signal from noise" [Shanks 2012]. The drawing was executed and finished as “Scalable Vector Graphic” (SVG) using Inkscape[10] in front of the physical object to verify each line, together with a magnifying glass (Fig. 7). Additionally, the polylines and polygons were separated in different layers relating to incisions of ornaments or figures, contours of ornaments or figures, added red and dividing lines between figures

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[10] https://inkscape.org

and ornaments. The working time for the archaeological drawing of the aryballos, which is able to be published in this execution, was 5 hours in total (in this detailed demonstration of 922 lines with 18.610 nodes) (Fig. 8).

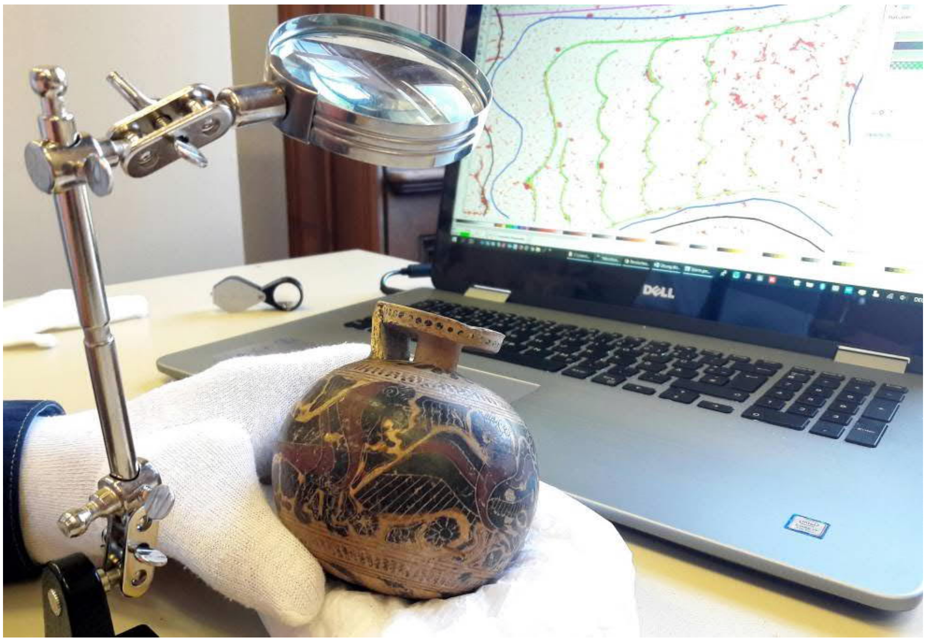

Fig. 7. Archaeological interpretation in front of the original, the aryballos KFU Graz G 26

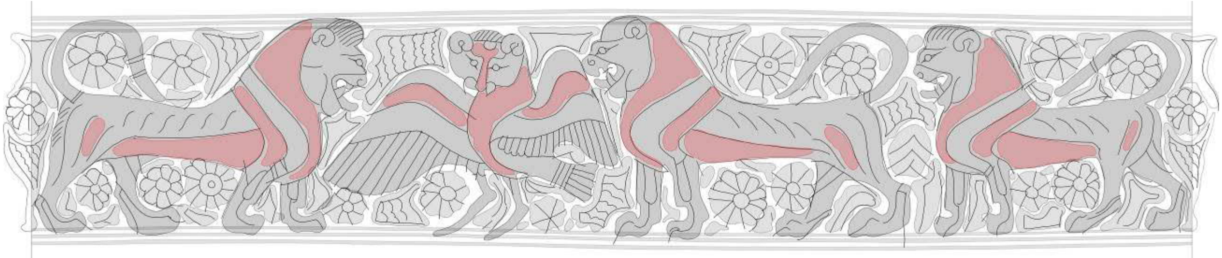

Fig. 8. Archaeological drawing of the black-figure frieze of the aryballos KFU Graz G 26

RESULTS

This non-contact method offers a highly efficient and precise way for executing drawings of Corinthian pottery. Compared to manual drawings, the computed rollout is repeatable by knowing the projection parameters and most important, independent of human skills. The height of the painted frieze on the aryballos ranges between 34° north latitude and 27° south latitude, which means that by using the equirectangular projection the maximal distortion has a scaling factor of 1.21 at the upper border of the frieze, and 1.12 at the lower border. As mentioned in the previous section using this projection method the longitudes are projected in scale 1:1. The occurring distortions are justifiable, the changes within the proportions of the figures and ornaments are neglectable. However, projecting a curved surface to the plane causes mandatorily distortions. In the field of cartography, the challenge of minimising distortions has been tackled since more than two thousand years [Snyder 1993] using different possibilities of unwrappings of the Earth's surface [Van Wijk 2008]. In general, the chosen projection depends on the purpose of the unwrapping. In archaeology, projections with no interrupts are preferred. Relating to Corinthian aryballoi with their painted friezes, which are situated normally within the 40° latitudes (i.e. having a distortion of 131 % at the furthest away latitudes), the equirectangular projection is most suitable. Additionally, using computed rollouts based on 3D models enables to quantify the scaling of the resulting unwrappings.

The projection of a surface of a sphere to a plane is also affected by the topological characteristics of spaces. A sphere in mathematics is a 2D closed surface, i.e. it is without a boundary. Using it for a projection, one has to cut the sphere. This will be done along a meridian in the simplest case. In case of the Greek vase shape, the aryballos, it is appropriate to cut the surface on the vase's backside along a meridian. With densely painted surfaces as on the example KFU Graz G 26, it separates ornaments arbitrarily. To solve this visual constraint, the affected ornaments were manually duplicated on both sides.

Due to the more or less well-preserved surface of archaeological pottery objects, a drawing aligned to pottery standards is mandatory. Despite all developments in computational sciences, this step is performed manually most effective, especially in regard to objects of Corinthian pottery with their typically worn-off surfaces. Anyway, based on the textured and feature enhanced computed rollouts, such drawings are easy and fast to create with basic knowledge in graphic editors. Within this procedure, the separating of all lines in different content layers helps to extract very quickly specific details (Fig. 9). This can be used for rendering details in a painter's oeuvre and its periodisation [Neeft 1998].

However, detecting the incisions and contours in the black-figure painting appropriately, requires a minimum resolution in CT and photogrammetry depending on the fineness of the painting. For the Corinthian black-figure painting a spatial resolution of 0.05–0.1 mm or lower based on an adequate accuracy are recommended.

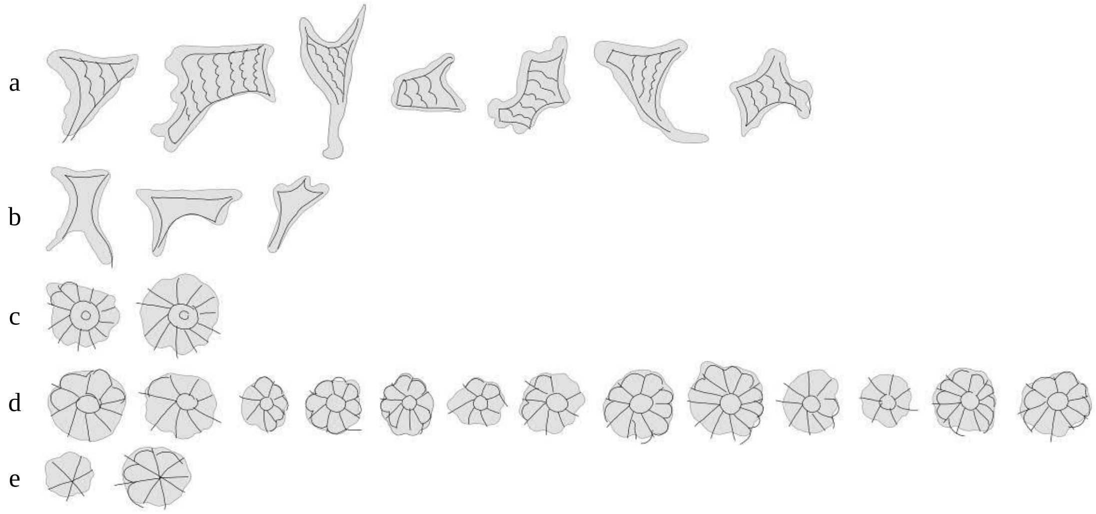

Fig. 9. Selection of specific filling ornaments on the aryballos KFU Graz G 26: a–b) amorphous fillers within an incised frame and with and without wavy incisions formed by interconnected separately drawn arches; c–e) rosettes with and without central heart and petals closed not entirely consistently by semi-circular incisions

This new accurate unwrapping of the aryballos KFU Graz G 26 allows us a fine analysis of the decoration and its style and recognise the painter's hand on another vase: Paris, Louvre, inv. Cp 12420, reconstructed from the so-called Campana fragments coming possibly from Cerveteri (Fig. 10). The decoration of the mouth-plate and the bottom repeats the syntax of the Warrior Group [Amyx 1988]. The extra decorative band above and below the main decoration of the body is rare, but not unheard on the vases of the Warrior Group, see in particularly the vases of the Sydney Cluster and the Equine Constellation [Amyx 1988]. However, the vase's size is bigger than the aryballoi of the Warrior Group and its style is different to the live and neat, sometimes archaistic decoration of the Warrior Group. The painter uses particular decorative motifs, such as the amorphous filling ornament divided by wavy incisions formed by interconnected separately drawn arches within an incised frame (Fig. 9a) and the rosettes with incised central heart and radiating incisions forming the petals that are closed not entirely consistently by a semi-circular incision (Fig. 9c–d). The filling ornaments of the bands framing the frieze, like the reversed Zs and the undulated diagonal lines, appear on aryballoi and alabastra dating from the later part of the Early Corinthian and the first half of the Middle Corinthian, meanwhile the row of double dots continued at least to the end of the Middle Corinthian. The panther and the lion show an advanced version of the Early Corinthian type with some touches announcing the Middle Corinthian style. The framed amorphous filling ornaments appeared on alabastra and aryballoi in the advanced stage of the Early Corinthian and remained in use in the Middle Corinthian [Lawrence

1998]. The Graz aryballos thus can be dated to the Late Early, or to the Transition from Early to Middle Corinthian. The Louvre vase is a little bit coarser and less careful work comparing to the aryballos in Graz. The filling ornaments are simpler and the large sized amorphous filling ornaments with this special kind of wavy incisions (Fig. 9a) seem to be omitted. It may point a later date in the painter's career and may be tentatively dated to the Transition from Early to Middle Corinthian, or the beginning of the Middle Corinthian period. In absolute dates, the painter activity can be symbolically situated between 600/590–585 BC.

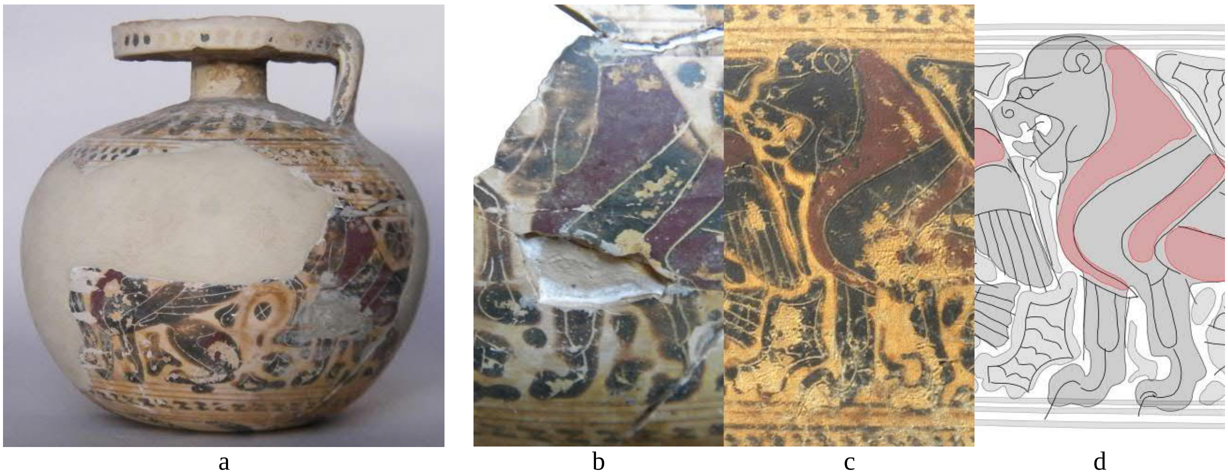

Fig. 10. A comparison of the lion on the aryballos Louvre Cp 12420, © musée du Louvre / András Márton (a–b) and KFU Graz G 26 (c–d), showing the characteristics of the painter's hand

CONCLUSION

One of the main objectives of the first edition of a vase or a reference publication, such as the *Corpus Vasorum Antiquorum*, is to provide a high-quality visual documentation for everybody who needs to work with the vase. Computed rollouts coupled with an accurate and sufficiently detailed archaeological drawing provide a sound basis for the stylistic analysis of painters and workshops. Only a meticulous fine documentation can reveal the particularities and characteristics of a painter and can help to recognise these on other vessels.

Constraints from the museum regarding CT – mainly because the object has to go to the CT laboratory and not vice versa – "Structured Light Scanning" (SLS) is an adequate alternative for capturing high-resolution models, at least of the visible surface. Of course, the usage of appropriate small measuring fields is necessary to achieve the required resolution in geometric data for detecting the incisions.

The minimisation of distortions for rollouts of high-resolution 3D-measurement data is an interesting challenge for algorithm development in the domain intersection of human perception and computer vision. Rollouts with visual correspondences showing longitudes and latitudes or visualisations of the scale of the incurred distortions, e.g. as stress map will improve the scientific documentation. Regarding the question for a proper segmentation, how do cut a sphere without dividing ornaments or – worse – figures, is an additional challenge in computer graphics.

Of course, the peculiar added value of CT is its ability to look into a closed vessel or into the material ceramic itself. This allows the computing of profile sections as well as visualisations and rollouts of the inner surface, as shown in an accompanying video[11]. Additionally, pores and inclusions in the ceramic fabric can be analysed according to amount, size, shape and orientation. CT shows and unveils significant details of the manufacturing process and of the fabric.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Univ.-Prof. Dr. Peter Scherrer, Head of the Institute of Archaeology and Vice-

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[11] DOI: 10.11588/heidok.00025189; http://www.ub.uni-heidelberg.de/archiv/25189

Rector for Research and Junior Researchers' Promotion at KFU Graz, for the financial support of this work, and Dr. Anne Coulié, Conservateur en chef, AGER, musée du Louvre, for her kind permission to illustrate the Louvre aryballos. A special thank goes to Dr. Johanna Kraschitzer, member of the Institute of Archaeology at Graz, for the close-up photographs of the aryballos KFU Graz G 26.

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Imprint:
Proceedings of the 23rd International Conference on Cultural Heritage and New Technologies 2018.
CHNT 23, 2018 (Vienna 2019). http://www.chnt.at/proceedings-chnt-23/
ISBN 978-3-200-06576-5

Editor/Publisher: Museen der Stadt Wien – Stadtarchäologie
Editorial Team: Wolfgang Börner, Susanne Uhlirz