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DO YOU LIKE OUR SHERD? – DIGITAL MEDIUM-COST ARTIFACT PROCESSING OF A CARROT AMPHORA FROM THE AUXILIARY CAMP OF AUGUSTIANIS/TRAISMAUER IN ROMAN NORTHERN NORICUM (AUSTRIA) BY USING 'SYNTHETIC MATERIAL CULTURE'

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Abstract: In this paper, we aim at the enhanced theoretical and methodological application of digital archaeological find processing using 3d-data, augmented and virtual reality, as well as synthetic data, particularly paying attention to the careful handling, virtual reconstruction, and scientific communication of the material culture. A carrot amphora served as an example for our case study: the fragments (partially assembled rim, handle, body, and foot) were excavated in 1973 at the vicus of the auxiliary camp of Augustianis (today Traismauer in Lower Austria/AUT) at the so-called Danube Limes in former Noricum. Three scaled 3d-models of the sub-objects were made using 3d-photogrammetry (image-based modeling/IBM), afterward virtually joined together, and missing parts were added digitally to obtain a complete reconstruction of the amphora. For this purpose, a Nikon DSLR, the proprietary IBM software Agisoft Metashape, and the free and open-source software (FOSS) Blender were used. The platform Sketchfab served as a medium for quick viewing, annotation, and sharing of the 3d-models. Furthermore, polymer 3d-prints were made of the amphora's rim using polylactic acid (PLA) as material and fused deposition modeling (FDM) as a rapid prototyping method. Our approach subsequently discusses the possibilities and limitations of working with such 'synthetic material culture' for daily archaeological work. The availability of multiple 3d-models, rendered images, and 3d-prints provide a real added value for research and science-to-science/public communication. Nevertheless, the total working time of > 8 hours makes the presented method currently not yet comparable to traditional analog find processing in terms of costs. However, the advancing technical development regarding smart devices and mobile apps could lead to the expectation that paper and pencil could soon be replaced by a digital documentation method for processing archaeological artifacts by default.

Keywords: digital archaeology; 3d-photogrammetry; photorealistic visualization; virtual sharing; additive replication

1. Introduction

Once an archaeological object is recorded in three dimensions ("3d") as a 3d-model, there are hardly any limits for further digital analysis and visualization of the archaeological record. A "3d-model" is a virtual (*i.e.,* not real but appearing like real) 3d-representation of any shape of a real-world object's surface. The computer-based reconstruction resp. "reverse engineering" of a real-world object is accomplished by dedicated 3d-software in the course of 3d-modeling, based on 'real-world data' derived from various recording methods; alternatively, a 3d-model is created entirely artificially in a virtual world (Cigola, 2015; Várady et al., 1997). The exploration of archaeological 3d-assets is, independent of location, easily possible by using various 3d-viewers in reality online within a browser tab (e.g., Sketchfab) or offline on a desktop computer (e.g., Microsoft 3d-Viewer), augmented or virtual reality (AR/VR) (Ellenberger, 2017; Hagmann, 2018). On the one hand, AR defines a fusion of our experience of the real world with a limited number of elements from a virtual world by using 3d-glasses or a smartphone's in-built camera and display as the user interface for the realtime-intersection of these two realms. Using a smart device's touchscreen and the camera-based live view, an interactive 3d-object, e.g., an archaeological artifact, can be shown within the viewer's real environment and moved, scaled, and rotated. Unlike a photograph or drawing, 3d-data allows a full real-time experience of an archaeological object, even though the original artifact is not physically present at the viewer's place but is stored in a museum archive on another continent or has long since been destroyed. On the other hand, VR describes an entire computer-generated and immersive world that can only be experienced virtually (Azuma 1997; Eve, 2017, 2018). While VR falls completely within a "virtual environment" (VE), AR belongs to the concept of "mixed reality" (MR). MR, in turn, denotes the intersection between the total VE and the total "reality environment" (RE) – this very concept is called "reality-virtuality-continuum" (Eve, 2012, 587 fig. 2). MR can be implemented in various forms such as virtually walkable worlds, and therefore offer extraordinary added value, e.g., compared to hand-drawn plans, because «[c]reating better facsimiles of ancient worlds certainly contributes to improved understanding of the past experience of landscapes, incorporating critical factors such as movement, lighting, and sound [...]» (Earley-Spadoni & Harrower, 2020, p. 185). 3d has long been part of numerous archaeological papers, be it, on a small scale, for recording individual features as textured surfaces or, on a large scale, as virtually walkable 'paleoscapes' reconstructions of archaeological building structures. 3d immensely expands the possibilities of archaeological work, which is also reflected in a wide variety of applications: recent studies address the potential of 3d-data for statements on pottery production, vessel reconstruction, automated find identification, reconstruction of ancient maritime marble sea trade, building archaeology, for collaborative online research activities, for archaeological project planning, for cultural mediation, and – particularly interesting in times of a pandemic – for virtual museums (Aiello et al., 2019; Badillo et al., 2020; Barrile et al., 2019; Bennoui-Ladraa et al., 2020; Borrero & Stroth, 2020; Cipriani et al., 2019; Ebolese et al., 2019; Ferrari & Quarta, 2019; Gugl & Trognitz, 2020; Harush et al., 2020; Lengauer et al., 2020; Magnani et al., 2020; Marshall et al., 2019; Paradis et al., 2019; Parizzi & Beltrame, 2020; Paul, 2019; Pérez-García et al., 2019; Proietti, 2020; Romanengo et al., 2020; Roussel et al., 2019; Spelitz et al., 2020; Unger et al., 2020; Verdegay & Rodríguez, 2020; Waagen, 2019; Wernke et al., 2020; Wilkins, 2020; Zotti & Neubauer, 2019).

Hence, one prominent field is digital artifact processing (Di Angelo et al., 2022): for instance, the running Arch-I-Scan project (Tyukin et al., 2018) and the recently finished ArchAIDE project (Anichini et al., 2020) both seek to recognize and consequently classify archaeological artifacts using artificial intelligence (AI) and image recognition. Further initiatives, like the Presious project (Papaioannou et al., 2017), apply automatic sherd reassembling, completion, classification, and questions related to the production processes based on the artifacts' overall shape and decoration (Harush et al., 2020; Lengauer et al., 2020; Romanengo et al., 2020). Other projects keep track of the digital record of specific geographic areas and certain types of archaeological finds (Allen et al., 2015; Keay & Williams, 2014; Richards, 2017). Further, working groups use Light Detecting and Ranging (LiDAR) and 3d-photogrammetry for automatic profile drawing of archaeological sherds and managing 3d-models in specialized applications (Demján & Držík, 2021-ongoing; Di Angelo et al., 2021; Frisky et al., 2020; Kingsland, 2020; Spelitz et al., 2020; Wilczek et al., 2018). Based on digital data, all projects want to significantly speed up data recording and querying for analysis, in parallel providing better reproducibility. This trend can be similarly observed elsewhere in other archaeological branches (Schmidt & Marwick, 2020). More specifically, digitizing the archaeological record results in virtual archaeological objects (Gualandi et al., 2021; Núñez Jareño et al., 2021). These may be if one continues working with such virtual data classified as artificial or "synthetic material culture". The latter term used here was adopted, for archaeology, from Holly Wright's and Gabriele Gattiglia's (2018, p. 63) virtual "synthetic sherds". When we talk about the underlying "synthetic data" (Dankar & Ibrahim, 2021) that conceptually originate from the wish for anonymization measures for statistical datasets (Rubin, 1993), we refer to the definition by Gartner where such data are «[...] generated by applying a sampling technique to real-world data or by creating simulation scenarios where models and processes interact to create completely new data not directly taken from the real world» (Gartner, Inc., 2022). By generating digital derivations, interpolating or decreasing densities of points and vertices, adding entirely new elements such as digital supplements of missing parts, manipulating the virtual appearance by applying shadings, exposures, and filters, and producing replicas using additive processes, we may no longer work with the immediate reverse-engineered digital representations of archaeological objects, but with entirely artificial and therefore entirely digital-born "synthetic" replicas, nevertheless of highest similarity to the original. Suppose one records an archaeological object by applying 3d-photogrammetry. In that case, the archaeologist may most likely obtain a sparse point cloud in the first place, which can be seen as the reverse-engineered virtual representation of the original object. However, these "original data" will be further processed in other steps. In the end, the archaeologist may use a textured mesh dataset for archaeological interpretation, which may be itself – at least partly – based on interpolated and "synthetic" derivations of the original sparse cloud. Following Wright and Gattiglia, "synthetic material culture" may therefore refer specifically to «3d-shapes available on the computer» (2018, p. 63) as well as to 3d-prints, referring to "virtual" and "additive synthetic material culture."

2. Materials and Methods

The study presented in this paper involves the fragments of a carrot amphora from today's *Traismauer* in Lower Austria/AUT, located along the "Danube *limes*". The Roman site (dating to c. 2nd half of the 1st cent. AD-2nd half of the 5th cent. AD), including an auxiliary fort and a vicus as well as various necropoleis, is commonly identified with ancient *Augustianis* (or *Augustiana*) mentioned in the *Notitia dignitatum* (*occ*. 34, 35). Especially brick stamps and inscriptions (e.g., CIL 03, 05654; CIL 03, 11795; http://lupa.at/4805) prove this interpretation and further provide information on the military occupation history. 'Roman *Traismauer'* lies below the entire present-day city area, and medieval buildings completely overlay the fort (fig. 1).

Carrot amphoras differ in fabric and are typologically classified into different types; they are commonly designated as Camulodunum 189, Augst 44, Pompeii 15, Schöne-Mau 15, and Peacock-Williams 12 (Williams, 2014). A rim without a neck, small handles, and a tapered body with horizontal grooves characterize the relatively small amphorae, which, according to P. Vipard, can be divided into three basic types (A, B, C) with different rims (Vipard, 1995, pp. 52-54). They originate from the Greek East, probably from the Levant or Egypt, and probably reached *Traismauer* via the Adriatic Sea and Aquileia. (fig. 2) The contents were presumably (dried or pickled?) dates, figs, plums, or olives (Schindler-Kaudelka & Ruprechtsberger, 2012, pp. 261-262). Carrot amphorae usually occur in the Rhine-Danube provinces on early military sites in Britain, the Rhine Limes, and the Pannonian provinces (*Vindobona*, *Carnuntum*, *Aquincum*). However, numerous specimens are also known from present-day France, Spain, and Italy. For carrot amphoras in Noricum, H. Sedlmayer generally dated the type from the last decade BC to the 1st quarter of the 2nd century AD (Sedlmayer, 2006, p. 278). An assemblage of carrot amphoras from a ruined earth cellar of the nearby (and for

fig. 1. Archaeological map of all spatially recorded archaeological features of the Roman auxiliary fort, vicus, and necropolises of Augustianis compared to today's land-use/land cover of Traismauer. The fort is located at the river mouth on the right bank of the river Traisen, a tributary of the Danube (Hagmann, 2022; cultural heritage data: Bundesdenkmalamt, ARDIG – Archäologischer Dienst GesmbH, Novetus GmbH; geodata: base map.at, Land Niederösterreich; Google Earth).

integration of the population of Augustianis into the common Roman transregional and intercontinental trade and the empire-wide availability of typical Mediterranean products such as dates or figs even at the peripheral northeastern Norican frontier; ergo, the supply depended not only on regional products but also on imported goods from considerable distances (Reynolds 2018; Reynolds et al. 2008-2009).

The fragments discussed here come from an assemblage of artifacts («*Fundkonvolut*») excavated in 1973 in the eastern *vicus* of the camp. Based on the report published and according to the analog-descriptive excavation documentation (file [«*Akte*»] 153/73) made by the excavator Alois Gattringer, the site can be located precisely to today's plot no. 996/1 (coordinates – longitude: 15°44'54.19"; latitude: 48°20'58.279" [EPSG:4326 WGS 84]); the objects originate from the western part of a large waste pit ([«*Grube*»] 06). The 'grooved amphora remains' («*gerillte Amphotenreste*») belong to the artifact assemblage «FNR 06», found at the oldest stratification unit, a 'gravelly' stratum at planum 5, directly above non-archaeological, naturogenic geological sediments («*Schotterstratum über [dem] Gewachsenem*») in quadrant 6. Several different carrot amphoras belong to FNR 06, whereas from this site, even more amphora remains are known, e.g., from quadrants 8, 9, and 23 (Gattringer, 1974).

Specimen "carrot amphora 02", an ensemble of associated sherds of one of the best-preserved carrot amphoras of FNR 06, and therefore our object of interest in the paper, is of type "Bb" with a rim "3b1" after Vipard (1995, 53 fig. 1 Bb and 3b1) (figs. 3 and 4). For this (partly) assembled specimen (corresponding inventory numbers of *Traismauer*'s municipal archaeological collection: 3570-3572), a virtual reconstruction attempt was made based on

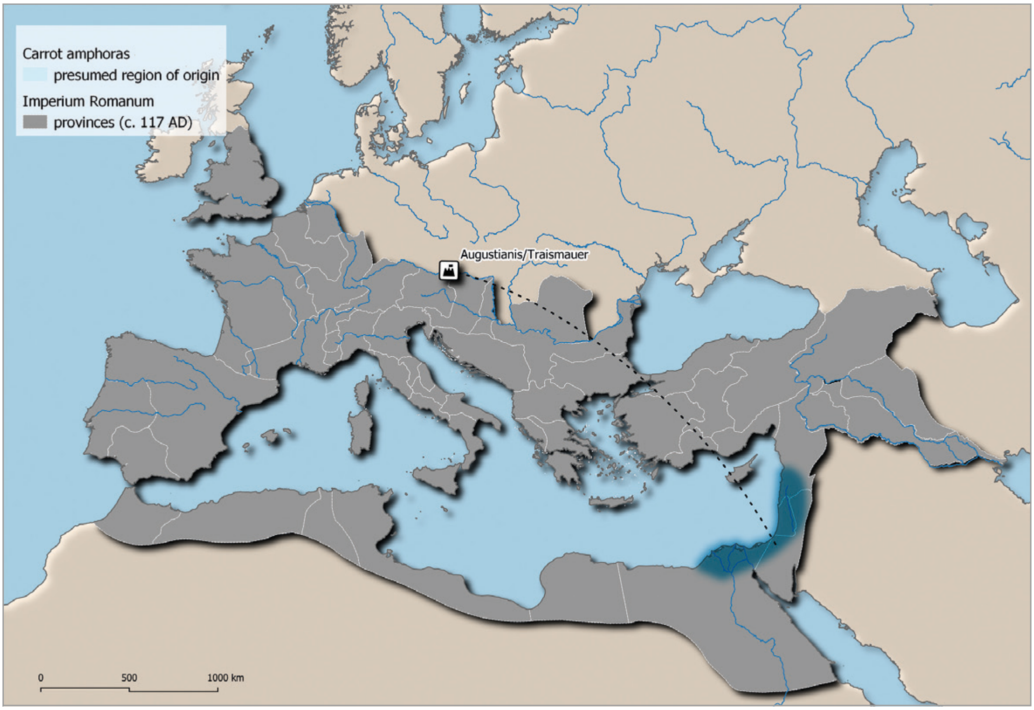

fig. 2. Geographic location of Augustianis/Traismauer within the Roman Empire (c. 200 AD) and presumed carrot amphoras' area of origin (Hagmann, 2022; cultural heritage data: Ancient World Mapping Center; geodata: Natural Earth).

fig. 3. Sample of carrot amphora fragments (1973's FNR 06) from the *vicus* of *Augustianis/Traismauer*. Individual matching fragments have already been partially assembled by the excavator A. Gattringer (photos: V. Böck & K. Klein 2020).

that region early) Norican *limes* settlement of *Linz-Kepplerwiese* from 2008 is dated around the middle of the 1st cent. AD (Ruprechtsberger, 2015, pp. 160-161). For the nearby *Vindobona*, carrot amphoras are dated by K. Adler-Wölfl to Tiberian/early Claudian times until the early 2nd century AD (Mosser et al., 2010, p. 338). Such amphoras testify to the already early

fig. 4. Significant carrot amphora specimens (1973's FNR 06) from the vicus of Augustianis/Traismauer. Individual matching fragments have already been partially assembled by the excavator A. Gattringer (photos: V. Böck & K. Klein 2020).

the 3d-recordings of the corresponding object parts. We aimed at the contactless generation of scaled 3d-models applying a tailored workflow using "image-based modeling" (IBM) by applying "structure-from-motion" (SFM) and "multiple-view-stereo" (MVS) algorithms to a set of photos of the carrot amphora's sub-objects. Thus, the objects were subject to minimum physical stress by our workflow. Since we were following a hybrid-asymmetric technical approach to get the best out of two worlds, we pragmatically used proprietary programs as well as free and open-source software (FOSS) (Hagmann et al., 2016). Photogrammetry-based reconstruction of full 3d-shapes by IBM is not new, nevertheless, nor a trivial task and generally requires a set of high-resolution (> 10 MB), non-blurred photos capturing the whole surface of the motif from different angles. At least two photos each must overlap to a certain degree (c. 70%) to cover the same respective area of the motif's surface. The SFM algorithm analyzes the set of photos and reconstructs the relative camera positions by tracing corresponding feature points on each photo pair. Therefore, a sparse point cloud of the recorded object's surface is created. In the next step, MVS can be used to 'densify' the sparse cloud into a dense cloud (Verhoeven, 2018; Hafeez et al., 2020; for other recent approaches, see, e.g., Göldner et al., 2022). The method presented in this paper corresponded with comparable procedures for digital 3d-model-generation of cultural heritage objects (Bischoff, 2021; Göttlich et al., 2021). For the 3d-reconstruction of the study objects, photos recording the fragments from different angles were taken in a photo tent under constant lighting, provided by two headlights. A standardized, pre-printed, self-sticking and removable 1-cm scale on a special label ("HERMA 10000" universal labels, 17.8×10 mm) was temporarily affixed directly to each recorded carrot amphora sub-object, allowing everyone to scale the object visually. After photography, the label was removed without leaving any residue. The respective object was then scaled in a local coordinate system using a virtual 1-cm-scale in Metashape (no control points were used), though scaling results in significant error estimates within Metashape. A NIKON D610 full-frame *digital single-lens reflex* (DSLR) camera with a CMOS FX-format image sensor (35.9×24.0 mm) with a resolution of 24.3 MP and a non-precalibrated NIKON PC-E 45 mm 2.8D ED tilt/shift lens was used for the photographs. The tilt/shift lens helped enlarge the imaged plane of focus, which benefited the overall quality of the 3d-model by avoiding poor depth of field in the photographs. The subsequently not further processed photos were saved in JPEG format (6.016×4.016 px, with a px-size of 5.98×5.98 µm) to keep the required file storage space as small as possible. Every amphora sub-object was individually recorded. The image dataset of each sub-object was then used to reconstruct the sparse cloud. Based on a static background, all photos were automatically masked in the software Agisoft Metashape (1.8.x; https://www.agisoft.com/) using "background subtraction" resp. "suppression" as a method (Bouwmans, 2014, p. 32; Garcia-Garcia et al., 2020, p. 5; https://agisoft.freshdesk.com/support/solutions/articles/31000158967-aligning-photos-with-background-suppression-from-single-mask). Consequently, we manually rotated the respective sub-object in approx. 5 cm steps in the horizontal plane for image capturing of different views necessary for IBM while the background remained static for every photo, meaning we waived the use of a turntable. After the camera, mounted on a fixed rig, was focused on the sub-object, photos were captured using a continuous time interval of 1 photo every 5 seconds from an angle of approx. 45 degrees, and we thus rotated the artifact itself manually, a total of 360 degrees in the horizontal. After completing this first round, the camera was pointed at the artifact at a different approximate angle of 10 degrees. Another set of photos was taken in another round by manually rotating the find 360 degrees in the horizontal again, using the same time interval of 5 sec./photo. After the second round, the artifact was approximately rotated once in the vertical plane 180 degrees, followed by two other rounds of shooting images by manually rotating the sub-object in the horizontal plane from different angles of approx. 45 and 10 degrees again. On occasion, depending on the geometric complexity of the sub-object, e.g., in the case of the rim with one handle attached, further rounds were

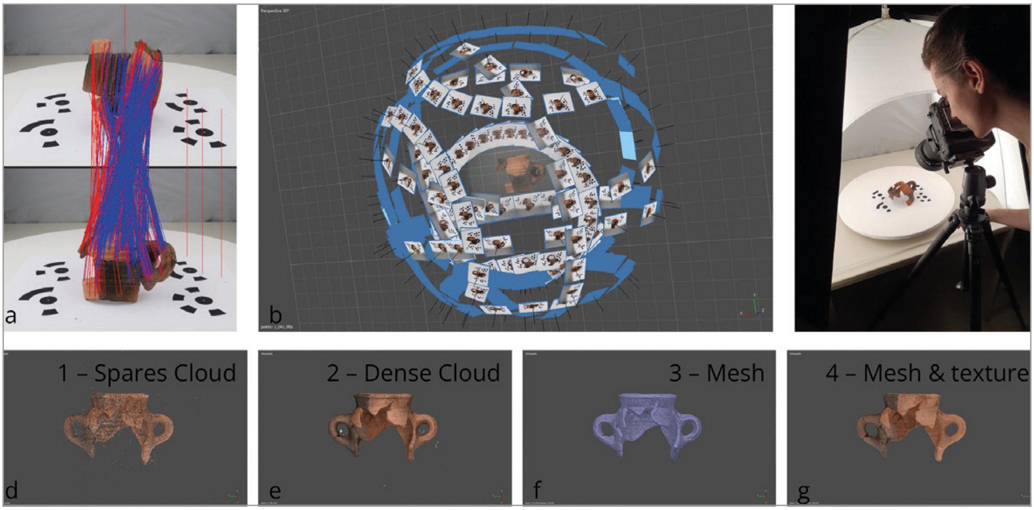

fig. 5. Rim-and-handle sub-object of specimen 02 – a: exemplary matches (632/valid: 403/invalid: 229) of two images (DSC_6470 and DSC_6568) used for IBM; b: camera positions and points of the dense cloud; c: photographer K. Klein during the recording of the object; d-g: The main processing steps (1-4) of the carrot amphora 3D model. (photo[grammetry]: Hagmann, 2019).

photographed by rotating the artifact again in the vertical and then taking photographs in the horizontal as described in two more passes. Additionally, the static background was recorded each time the camera position on the rig was changed before starting a new round. Subsequently, the sparse cloud was calculated for each photo set, which enabled a relatively fast generation of each sub-object's initial sparse point cloud models. Separate, extremely time-consuming manual masking of all photos was unnecessary. Nevertheless, using Metashape, one can apply masks based on a (rough) model after quickly generating a sparse cloud and mesh in low to medium quality alternatively.

Aside from an Acer Aspire V 17 Nitro Black Edition notebook (Windows 10; CPU: Intel Core i7-6700HQ CPU @ 2.60GHz; GPU(s): Intel(R) HD Graphics 530, NVIDIA GeForce GTX 960M; RAM: 15.91 GB), cloud-based computing offered by Agisoft was used, which allowed access to powerful hardware (CPU: 32 vCPU [Intel Xeon E5 2686 v4 up to 2.7 GHz], GPU: 2 x NVIDIA Tesla M60; RAM: 240 GB) and therefore the further acceleration of computing time (https://www.agisoft.com/features/cloud/). The remaining processing tasks were based on established workflows (cf. Agisoft's helpdesk portal at https://agisoft.freshdesk.com/). They included the cloud-computing-based generation of a dense cloud (alternatively, in Agisoft Metashape, this step can be skipped by using depth maps exclusively), a mesh based on the densified point cloud, and the subsequent texturing of the mesh based on the images initially used for SFM-MVS (Bedford, 2017; Doneus et al., 2011). In the end, the models were virtually referenced using the scales (fig. 5). All three sub-objects' models were processed, referenced, and managed centrally in the software Metashape; a processing report was generated in terms of meta- and paradata recording for every 3d-model (Huvila, 2022).

After finishing the 3d-modeling process, the following task was an export of the scaled and textured 3d-models to the FOSS Blender (2.92.0; https://www.blender.org/) as OBJ-files (for the 3d-meshes) and texture files (JPEG-format), in which the individual models of the original sub-objects were arranged accordingly to a type table (Vipard, 1995, 53 fig. 1 Bb). In a final step, the parts missing from the original piece were added virtually in Blender, following the type table as the underlying 'blueprint'. Blender was also used to visualize the result by exporting a rendering image. The whole dataset was stored locally on a notebook and, in parallel, using a cloud storage service (Google Drive; https://www.google.com/intl/en-US/drive/). According to the FAIR principles (findability/accessibility/interoperability/reusability) for long-term archiving and- access, the whole data set was uploaded to the Open Data MOD archive. Using the respective APIs integrated into Metashape and Blender, we uploaded the (sub-)objects for easy access and sharing to the online platform Sketchfab (https://sketchfab.com) (Ulguim, 2018). Aside from assigning keywords and providing short descriptions of the objects, we used Sketchfab's inbuilt visual optimization functions. We also annotated the 3d-models with additional qualitative information, including linking them to each other, ensuring availability of the whole dataset on Sketchafab is also possible if only a link to a submodel or so is available.

Regarding rapid prototyping and additive archaeology (Reilly, 2015; Barbieri et al., 2022), we collaborated with Torhoff 3d and submitted them a 3d-model of the rim as an SLT file online for 3d-printing. Polylactic acid (PLA) with 50% stone powder content (FormFutura StoneFil Filament granite; https://www.formfutura.com/) was chosen as printing material using "fused deposition modeling" (FDM) as a method for additive manufacturing. PLA and FDM are inexpensive and simultaneously well established in rapid prototyping (McCarthy & Brabazon, 2021; Pramanik et al., 2021). PLA enhanced with stone powder has haptically a more realistic effect concerning archaeological finds than regular PLA due to a certain perceptible heaviness due to adding stone powder. The matte, rough surface also creates a further 'ceramic-like' tactile, haptic impression. However, due to the choice of material, a less clean printing process was present as opposed to regular PLA. For rapid prototyping, an Ultimaker 2+ was used printer (https://ultimaker.com/). It is foreseeable that the material used has quite a good durability (> 10 years of life per replica). The material used is also biodegradable and utterly recyclable under certain conditions. The finished replicas were not colored because, in addition to cost- and time-saving, the omission of coloring emphasizes the difference from the original. Anyway, the 3d-models provide a high-resolution and photorealistic texture.

3. Results

Our method generated three scaled, textured 3d-models of the carrot amphora's rim, body, and foot. We recorded 399 images (including background photos): For the rim's sub-object, 208 out of 228 recorded images were aligned, with a ground resolution of 0.0492 mm/px. 84,511 sparse cloud tie points and 1,041,956 dense cloud points were calculated, resulting in a mesh with 69,464 faces and 34,728 vertices. We assembled virtually all 3d-models, completed missing parts, and thus generated a virtual reconstruction of the original amphora. Based on the 3d-model of the rim of the carrot amphora, an identical 3d-print was also created (figs. 6, 7) Thus, until completion of the model,

- approx. 2.5 hours for taking all photos,
- approx. 3.5 hours of processing time for IBM 3d-model generation (not including the connection-dependent upload and download of the data to/from the cloud infrastructure), and
- approx. 2 hours for the virtual composition of the fragments with subsequent reconstruction as well as the rendering of views, and then upload to the distribution platform were required. All models, as well as the reconstruction, can be explored interactively on the platform Sketchfab:
- **Rim**: https://sketchfab.com/3d-models/carrot-amphora-rim-from-traismauer-v-100-6ba38df0c9574d65b533e1470771ad86
- **Body**: https://sketchfab.com/3d-models/carrot-amphora-body-from-traismauer-v-100-7ed32e39a90a4d99a2379bc122c8ae14
- **Foot**: https://sketchfab.com/3d-models/carrot-amphora-foot-from-traismauer-v-100-7c912cc6484344caacb583ef4cc2c2bf
- **Virtual reconstruction**: https://sketchfab.com/3d-models/carrot-amphora-from-traismauer-v-100-bb7ad11310a44021a3b7611547a81eca
- Further, the 3d-models are saved to a **collection** on Sketchfab: https://sketchfab.com/dominik.hagmann/collections/carrot-amphora

fig. 6. a: textured 3d-model of carrot amphora 02's rim sub-object; b: 3d-print of the same object; c: original; d: textured 3d-model of carrot amphora 02's body sub-object; e: textured 3d-model of carrot amphora 02's foot sub-object; f: virtual reconstruction of carrot amphora specimen 02; c.f. fig. 7; the QR codes are linked to the models on Sketchfab (Hagmann, 2022).

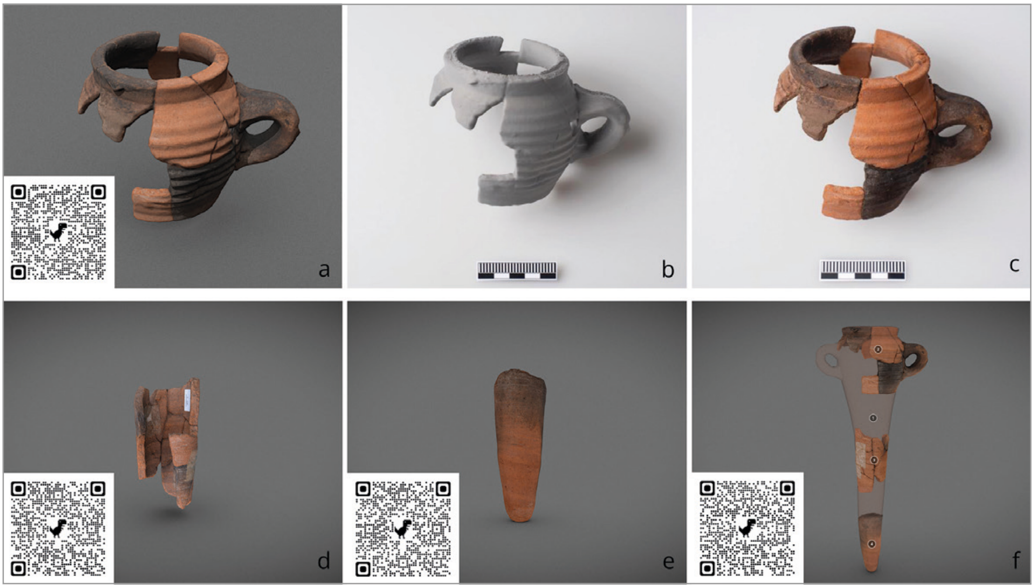

fig. 7. Virtual reconstruction of carrot amphora specimen 02; the QR code is linked to the models on Sketchfab (Hagmann, 2022).

fig. 8. a & b: 3d-model of a Roman portrait head (Constantius I Chlorus or Constantine the Great [?]; c. 1st quarter 4th century AD) from a (presumed) *villa* at *Trasdorf* (c. 10 km east of *Augustianis/Traismauer*) made using 3d-photogrammetry and the app Polycam on an iPhone SE2020; c: UV mapping; d: model's wireframe; the QR code is linked to the models on Sketchfab (Hagmann, 2022).

4. Discussion

By using synthetic material culture, it is possible to go beyond the existing limitations of artifact recording: instead of simply working with traditional (retro-digitized) hand-drawn 2D sections of an artifact, e.g., by viewing a PDF printout or a PNG-file on a screen, 3d-model viewing, and MR using suitable apps on any (bowser-enabled) device can be used to literally digitally *experience* an archaeological object as digital 3d-asset completely autonomously as well holistically at any time in astonishing detail. Such an experience can always happen in addition to a physical drawing – working with synthetic material culture has to be seen as inclusive rather than an exclusive approach. Employing 'virtual clones' enables a significantly expanded cognitive experience of the artifacts in full detail, based on grasping the overall artifact in great detail, independent of the location (Eggert et al., 2014). Even if the original object is no longer physically existing due to, e.g., loss, its shape is preserved as a virtual replica by a point cloud/textured mesh volume (Doneus et al., 2003; Doneus et al., 2011; Doneus & Neubauer, 2005, 2006). We see the presented approach (photography/processing/virtual reconstruction/uploading to distribution platform) as an alternative to conventional analog find processing. However, the time and technological equipment required are likely to be (still) inferior/more expensive to that of a hand drawing (graphic recording using paper and pencil/scanning the drawing/retro-digitizing) (Anderson, 2020). In total, > 8 hours (or a whole working day of working time without breaks) to complete a full 3d-model were necessary. Archaeologically defining the type or time losses due to processing errors are omitted. Our result is, in terms of time and costs, clearly behind the traditional analog graphical drawings of sherds, although these are interpretative 2D abstractions mostly. Another crucial methodological drawback is the sensitive reactions of IBM to strongly varying exposures of the recorded object and to artifacts with shiny or reflective surfaces (such as, in some instances, *terra sigillata*), which can result in faulty 3d-models (Bayer, 2021, p. 1).

Smart-device-based photogrammetry is an attractive alternative that can bypass the high amount of time for 3d-model-building. Inbuilt smartphone or tablet cameras and mobile, primarily proprietary or cloud-based, apps (e.g., Polycam by Polycam Inc. [https://poly.cam/], 3D Scanner App from Laan Labs [https://3dscannerapp.com], Scaniverse [https://scaniverse.com] by Niantic, Inc. or Epic Games/Capturing Reality‘s RealityScan [https://www.capturingreality.com]) provide promising results and various export possibilities for 3d-photogrammetry and subsequent processing (cf., e.g., Hagmann, 2022). (fig. 8) Such apps are currently often highly tied to a proprietary ecosystem with little to no insights regarding the overall 3d-model reconstruction process. Nevertheless, proprietary desktop software like Agisoft's Metashape or Epic Games/Capturing Reality‘s RealityCapture (https://www.capturingreality.com) must also be considered 'black boxes' regarding overall photogrammetry processing. Further, such applications sometimes require a purchase using different payment models and are currently unavailable as FOSS. Another future development that may eradicate the disadvantages is also the increasing price drop and the growing use of LiDAR scanners, which are already installed in commercially available high-end tablets and smartphones, also capable of considerable hardware: e.g., Apple iPad Pro 2020 and 2021 and iPhone 12 and 13 Pro /iPhone 12 and 13 Pro Max, each with Apple silicon system on a chip (SoC) (Gollob et al., 2021; Luetzenburg et al., 2021; Spreafico et al., 2021; Vogt et al., 2021). Should 'smart and mobile' LiDAR-technology further increase in terms of accuracy and precision (as it seems at the moment primarily suitable for quick and easy 3d-feature than artifact-recording) to become as widespread as standard high-resolution smartphone cameras in the future (e.g., by being also used on Android-based devices for further democratizing 3d-find processing), we can expect a further boost in methodological innovation for 3d-recording of archaeological finds and excavations. Such a future development, as well as hybrid approaches, does not seem to be entirely out of the question since apps like 3D Scanner App or Scaniverse already offer both pipelines for 3d-model generation, or, as apps like Polycam, at the time being (2022) even combine LiDAR and 3d-photogrammetry in specific modes.

Another major drawback of virtuality is the requirement of an interface provided by a dedicated device for viewing and interacting with synthetic digital artifacts: although much has already been said about 3d, widespread usage is likely to remain limited. Alternative devices like next-generation and cost-effective smart data glasses (cf., e.g., as of 2022, VPS 19 glasses – https://viewpointsystem.com/) may soon perform as game-changers. They may go beyond touchscreens and integrate vast MR usage, as smartphones changed our daily lives several years ago.

The actual step out of the MR-realm (although it may sound paradoxical) back into the RE-realm, i.e., our physical reality, can be taken by additive (and also subtractive) processes (Sargentis et al., 2022). Like a cycle, the archaeological material can be 'resurrected' as 3d-printed replicas without needing an additional device for cognitive and tactile interaction with an object, not even the original object itself (Cooper, 2019). Synthetic material culture can also be proposed to solve the problematic and controversial issue of exporting or returning finds from one region to another for archaeological study or exhibition. Further, virtual and additive synthetic material culture can serve as valuable training materials for photography or analogous drawing. The printed replicas can be physically used (despite the original's unavailability) and handed out to interested people with and without visual impairments, contributing to an 'inclusive archaeology.' (Díaz-Navarro & Sánchez De La Parra-Pérez, 2021; Butler & Kwan, 2018) The well-known, so-called Hadrian's Gate from Palmyra/SYR (a monumental arch of Septimius Severus) serves here for exemplification since the building was restored as a 3d-print and presented, among other places, in London and New York after its destruction by what was then known as ISIS (Islamic State of Iraq and Syria) in 2015. This example impressively shows that it is possible to physically replicate and further use synthetic material culture regardless of location, provided that an appropriate data basis is available. For artifacts, this can mean that archaeologists can produce 3d-models at the excavation site, share them over the Internet, and have them analyzed by others virtually and even physically at a completely different location. Adverse effects such as loss, theft, or damage remain of secondary importance since only the replica is affected in an incident, not the original. Additive archaeology has considerable potential, although there are also important factors such as 3d-data quality, scaling, and used materials for printing to be taken into account to avoid problematic consequences (Khunti, 2018). Nevertheless, the presented low-cost production process regarding rapid prototyping also has disadvantages through limitations in 3d-printing: assuming a flat starting surface, FDM does not allow any shape to be printed, so the 3d-models were adapted for printing by being divided into at least two parts, and which were printed and then glued together manually. Furthermore, the material is not insensitive to UV light, mechanical effects, and 3d-print support structures inherent to the additive manufacturing process must be removed too for completion of the task. The environmental impact of the transport route can only be considered a disadvantage to a limited extent, as the goods were shipped together with other products via a transport service provider, saving as much CO2 as possible.

Ultimately, everyone can obtain a virtual and a physical replica of an artifact at low to medium costs by generating, viewing, or downloading open synthetic material culture data (Opgenhaffen, 2021). It is then possible to use them for further analysis by applying on-/off-line 3d-viewers or scientific FOSS like CloudCompare (https://www.danielgm.net/cc/) or Meshlab (https://www.meshlab.net). For 3d-printing, everyone can (if no own 3d-printing equipment is available) upload a model to a dedicated platform (e.g., https://www.hubs.com or https://www.treatstock.com) for ordering replicas there, which may then be delivered as ‘hardcopies’ by mail within a few days.

5. Summary and conclusion

With a specific emphasis on the careful management of the artifacts, digital reconstruction, and scientific communication, our goal in the study presented was to improve the use of medium-cost digital processing for synthesizing material culture. In our case study, we used a carrot amphora. The study object’s rim, body, and foot fragments were discovered in 1973 in the vicus of the auxiliary camp *Augustianis*, which is now *Traismauer* in Lower Austria/AUT, at the “Danube *limes*” in Roman Noricum.

Three scaled 3d-photogrammetry-based models of the fragments were brought together virtually to create a virtual reconstruction of the original amphora, and missing pieces were inserted. The tools used for this project included a Nikon DSLR, a photo tent, commercial software (Agisoft Metashape), and FOSS and (Blender). 3D models could be quickly viewed, annotated, and shared via Sketchfab. Additionally, the rim of the carrot amphora was 3D printed. For daily archaeological work and science communication, static renderings and interactive 3d-models on Sketchfab (also linked in published papers or on social media; see https://www.facebook.com/1983945428325085/posts/5159765264076403/), as well as 3d-printed physical objects, offer a variety of added values.

However, the discussed method is currently not yet quite comparable to traditional analog find processing in terms of time and costs, whereby the digital processing of finds is becoming more and more popular in research (cf., Di Angelo et al., 2022; Grosman, 2022). Soon, we could see even more improvements in digital find processing thanks to mobile apps. The original artifact can be immediately replaced by copies manufactured utilizing additive methods, which can then be professionally kept as a cultural asset in a secure location.

Our method can reduce the need for unnecessary visits to and from a depot (and the accompanying costs for budget and climate concerns) while improving artifact processing with great flexibility. Findings are to be seen, handled, and processed remotely in the home office virtually in 3d without even touching the actual physical items (!) if the required digital data set is provided. This approach is perfectly suitable for times of crisis with closed borders or rampant destruction by barbaric acts of war like during the Russian invasion of Ukraine started in 2022.

To come at the end of this discourse to the inspiration of the paper's title, the 1982's movie “Blade Runner,” Ridley Scott's influencing science fiction blockbuster about various astonishing as well as problematic aspects of artificially replicating living beings by sophisticated technologies, based on the novel «Do Androids Dream of Electric Sheep?» by Philip K. Dick's from 1968: During a dialogue of two of the main protagonists, the artificially made being (so-called replicant) Rachael, portrayed by Sean Young, asks Rick Deckard, portrayed by Harrison Ford, while watching a completely authentic looking but replicated owl: «Do you like our owl?», alluding to the impressive perfection of their artificially made, deceptively real-looking and actually ‘living’ but artificial products. In that sense, another protagonist, Dr. Eldon Tyrell, head of the Tyrell Corporation that produced the replicants and portrayed by Joe Turkel, states elsewhere in the movie: «*More human than human* is our motto.» Obviously, animals or humans are not to be reproduced in archaeology, but in terms of applying information and communication technologies for enhanced work with archaeological finds, it is feasible to synthetically reproduce material culture heading to a Tyrell-esque scenario close to a ‘more real than real’-motto. Consequently, the advancing technical development could lead to the expectation that paper and pencil could be replaced by an alternative holistic digital method for processing finds. Until then, like Rachael in “Blade Runner,” all that remains is for us to ask the gentle reader: ‘Do you like our sherd typo?’

Authors' statement

Conceptualization and methodology: D. Hagmann, K. Klein, A. Langendorf; Data collection and curation: D. Hagmann, K. Klein; Data analysis: D. Hagmann; Writing and review of the original draft: D. Hagmann, K. Klein; Visualization: D. Hagmann, K. Klein, A. Langendorf; Supervision: D. Hagmann; Project administration: D. Hagmann; Funding acquisition: D. Hagmann.

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