

Considerations on Technical Sketch Generation from 3D Scanned Cultural Heritage

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Abstract

Drawing sketches is certainly one of the most important but at the same time elaborate parts of archaeological work. Currently, 3D scanning technology is affording a number of new applications, and only one of them is using virtual copies instead of the originals as the basis for documentation. Our major contribution is methods for automatically generating stylized images from 3D models. These are not only intuitive and easy to read but also more objective and accurate than traditional drawings. Besides some other useful tools we show several examples from our daily work proving that the system accelerates the whole documentation process considerably.

Keywords

automated documentation, non-photorealistic rendering, 3D scanning

1. Problem statement

Due to the increasing number of large-scale excavations, every institution concerned with cultural heritage is faced with an enormous amount of finds. In the federal state of Saxony alone, the archaeological archive is currently containing almost 20,000,000 objects, mostly pottery from the Neolithic to modern times, and their number is annually increasing by another 700,000. All these objects are of little use if they are only put into storage instead of being prepared for scientific evaluation and interpretation.

Only material that is published can finally contribute to archaeological knowledge.

Within the documentation process, creating graphical illustrations is certainly one of the most laborious tasks of archaeological work, and it consumes the major part of the available, but always precious time. For drawing ordinary objects about an hour of work can be assessed, and the effort can quickly increase up to several days for really complex ones, such as the beaker in *Fig. 1*. Our aim is therefore to accelerate the whole workflow by deriving measures and illustrations directly from the geometry of 3D scanned models.

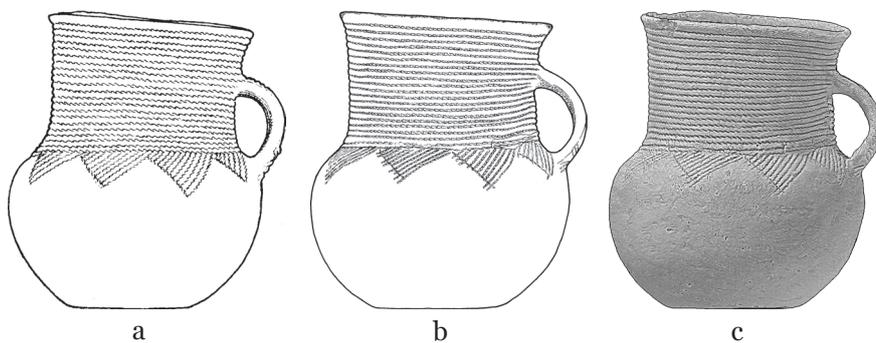


Fig. 1. Comparison of (a) traditional drawing, (b) revised drawing, and (c) non-photorealistically rendered image of a Corded Ware beaker. The latter was used as a template for (b), but still the differences among the images are striking, particularly concerning the rim part, the decoration, the silhouette and the overall plasticity. While (a) and (b) took hours to be drawn, the rendered image was generated within a few seconds and many more of them could be added if necessary.

This not only shortens the time usually spent on the publication of archaeological finds dramatically, it even improves the quality of the documentation results in terms of accuracy and objectivity.

The paper is organized as follows: First, we briefly summarize the requirements of conventional drawings, their benefits and deficiencies. Afterwards, we discuss some practical aspects of the scanning process for achieving the best results. Section 4 is dedicated to several applications arising from the

existence of virtual copies, including automated measurement, photorealistic and non-photorealistic rendering, vessel unrollings and profile generation. Giving some exemplary results in section 5, we show advantages and limitations of the presented system.

2. Traditional documentation

Among the different techniques for the documentation of archaeological finds, without doubt manually drawn technical sketches are most prevalent. At the same time they convey information about many different properties such as shape, manufacturing process, surface treatment, ornamentation, and state of preservation. These images are intended to be read easily and quickly and are therefore highly abstracted. Usually only as little time as necessary is spent on their production, which is often another source of loss of information.

In order to keep printing costs low the images are generally restricted to black-and-white, and of course, they need to be undistorted and true to scale. Even if the sketches are drawn as fast as possible, before being ready for printing there are many different steps of work to each of them:

1. The object outline is drawn with a pencil. If present, paintings, ornamentations and breaking edges are added.
2. The image is copied with ink and is also given a plastic impression by schematic shading of the object surface (stippling, pointillism, hatching, etc.).
3. The scientific editor revises the image and if necessary, corrections are made.
4. The ink drawing is digitized with a flat-bed scanner.
5. The image is post-processed and possibly vectorized.

However carefully the sketches are drawn, they are still drawn by hand and are thus susceptible to the illustrator's individual skill. If one same object was to be drawn by several illustrators, the results would exhibit not just negligible but striking differences (cf *Fig. 1* and e.g. Orton *et al.* 1993, 93, fig. 7.3). While sketching, the draughtsman has to decide which properties of an object are important to depict and which are dispensable information. Of course, this process of abstraction and simplification remains untraceable to the viewer and can easily convey an impression different from that of the original find.

So far, there has been no comprehensive rules or conventions that apply to technical illustrations in archaeology in general, although this would simplify the understanding of the sketches a lot and therefore would be of great importance. If there are any conventions at all, they are usually restricted to single research institutions or publication series (cf. e.g. Czysz *et al.* 2007). Hence, a lot of different drawing styles evolved in the past that are almost impossible to make consistent. The helplessness of some major institutions faced with this situation is for example clearly displayed in the vague illustration guidelines of the Roman-Germanic Commission (RGK 1990).

There are hardly any alternatives to technical illustration. In order to rule out subjectivity, photography might serve as a convenient option. It is used for documenting selected finds such as elaborately decorated, uniquely painted vessels where a manual sketch would take even longer to create than usual. Still, there are several disadvantages to photographs: Depending on the shape of the object and the focal length of the lens, the image can be strongly distorted. Additionally, illumination often causes highlights on polished or glossy surfaces so that details in these parts may disappear. Finally, the virtual reconstruction of complete vessels out of single fragments, which is comparatively easy in an illustration, is hardly possible to achieve by means of photography.

2.1. First approaches towards automation

A new device called "profilograph" has been developed by Smilansky *et al.* (Watzman 2004). It allows the user to digitize profile lines of single sherds by pointwise mechanical or optical measurement. If the sherds have been correctly aligned with respect to the rotational axis previously, a highly stylized 2D sketch can be computed. Though the method has successfully contributed to the development of vessel typologies on the basis of the profiles of rim sherds (Gilboa *et al.* 2004), it is questionable if it can really accelerate traditional documentation or even replace it completely. According to Karasik and Smilansky (2008) in the meantime this research group switched over to 3D scanners as well.

Another application has recently been presented by Mara *et al.* (2007), where painted Attic pottery is captured with a 3D scanner and the surface colour is analyzed by a multispectral camera. Profiles and

silhouettes are directly extracted from the 3D meshes and serve as templates for the generation of figures meeting the requirements of the *Corpus Vasorum Antiquorum* series. However, this approach is not yet able to also display surface structure.

3. Data acquisition: practical issues

During the past years, several range scanning techniques have conquered archaeology. Terrestrial scanners have been followed by object scanners, and for both a multitude of applications have emerged. Current devices are able to measure objects with a point distance of less than 0.2mm down to a few microns, finer than what a human eye is able to resolve (cf. Hörr 2009). In this respect, their quality has become good enough to use the virtual copies instead of the originals as the basis for documentation. The advantages coming along with this approach are numerous: The original objects are protected by minimizing physical contact, they become spatially independent, and reconstructions can be carried out completely in virtual space saving physical storage capacities too.

In our laboratory we are currently employing the Konica Minolta VI-910 laser scanner which was one of the first to also capture the colour of the surface. Compared to some newer devices, its optical and texture resolution are rather low, but for the majority of objects it is still sufficient. In order to ensure constant and optimal lighting conditions, we illuminate the object to be scanned with two diffuse daylight bulbs. To rule out any influence of stray light, we first shielded the whole set-up with a box of black molleton as it is commonly done by photographers. Experience showed however, that this enhances shades on the object, which makes the registration of colour values difficult. Because of this, we decided to line the box with white sheets that give a soft reflection of light all over the object surface. Anyway, a genuine rendition of colour cannot be guaranteed by any device and so the aim should be at least to establish uniform lighting conditions rather than trying to capture the actual colour. One of our major concerns on this topic is that comparability gets lost, which is probably even more important than accuracy. Moreover, as the colour of unpainted objects is rarely of interest and not depicted in technical illustrations, this does not pose a real problem. In the few cases in which the surface colour was needed, we texture

mapped the 3D model with a high resolution, true-to-colour digital photo by using a colour chart as well.

For our work, aside from closing small holes in the triangular meshes any attempts to improve the 3D models after the scanning process, in particular by smoothing the surface, have proven to be of no or only little use. Additionally, any subsequent changes only affect the scanning result as they remain untraceable – a matter being also discussed in the London Charter (www.londoncharter.org). Nonetheless, we can state that the better the data, the better the documentation results. However, data quality also depends highly on the object texture and material. We got the best results on non-shiny, moderately bright materials, e.g. unglazed ceramics, organic materials such as wood and bones, many kinds of rocks and corroded metal (see section 5). At least in some cases a matting spray can be applied, provided that it is chemically harmless and the surface colour is of no interest.

In order to accelerate the scanning process we also employ a motorized turntable, which enables us to produce entire series of scans that are already correctly aligned in one step. This shortens acquisition time a lot, and so up to 30 pots can be digitized within an eight hour working day. For the quick scanning of a few single sherds at once, Karasik and Smilansky clip them on a framework mounted to the turntable (2008, 115of). Thus, according to them, actually several hundred sherds can be scanned per day.

4. Using 3D models for automated documentation

Since our focus of interest is currently on ancient ceramics, the following presumptions and prerequisites are derived from the specific demands of pottery documentation. However, most of the proposals apply to other types of artefacts as well.

4.1. Measures

Once having a digital surface model of an object, taking measures is relatively simple. Within seconds many measurements can be computed by just clicking on two points on the object surface. Depending on the point cloud density and the sensor resolution of the scanner, usually a much higher accuracy compared to manual measurement by rulers and calipers can be achieved.

In the special case of vessels we can introduce some automation by making use of their rotational symmetry. Estimating the rotational axis has previously been tried by several research groups (e.g. Karasik and Smilansky 2008 and references therein), but here, objects are rather put upright onto their base surface in cases where it is preserved. We therefore developed a specific algorithm detecting the base plane which we leave out here for lack of space. As soon as the vessel (or sherd) is correctly aligned, several heights and diameters can be extracted either directly from the 3D mesh or from some selected profiles. As we have already shown in recent publications, measuring vessels automatically can particularly contribute to similarity estimation (Hörr and Brunnett 2008) and automated classification (Hörr *et al.* 2008).

4.2. Stylized figures

4.2.1. Limitations of line drawings

When creating stylized drawings directly from 3D models, the question is raised, how accurately the traditional sketches could and should be emulated. In the computer graphics literature, recently many proposals for line drawings have been made, e.g. suggestive contours (DeCarlo *et al.* 2003) which, according to Ma and Zha (2006), do not meet the requirements of archaeological drawings yet, as well as highlight lines (DeCarlo *et al.* 2007), apparent ridges (Judd *et al.* 2007) and lines from diffuse shading (Lee *et al.* 2007). But as it is shown in an interesting study by Cole *et al.* (2008), none of them regards all aspects of human drawings. Basically, the main issue in this topic is, when is a feature considered significant enough to be emphasized by a line. Without doubt, this is a matter of subjectivity. Furthermore, since there are so many different drawing conventions in archaeology, it seems nearly impossible to create a style that is common to everyone. Consequently, we came to the conclusion

that if a new technique has to be developed anyway, there is no need to intentionally simulate the loss of information inherent with abstracted line drawing. Nevertheless, at least the object silhouette should be depicted, since it is probably the most important element to convey shape. For its computation we refer to the overview paper of Isenberg *et al.* (2003).

An intuitive rendering style being not too far away from pencil drawings should at the same time convey a high level of detail and a plastic impression caused by a lightsource placed in northwestern direction. In the next two sections we discuss both issues separately.

4.2.2. Lighting models

For the sake of simplification, in the following we assume to illuminate a sphere with poles being defined by the lighting direction and the equator being defined as the set of points whose surface normals are perpendicular to the lighting direction. The lighting direction splits the sphere into a frontfacing (“dayside”) and a backfacing hemisphere (“nightside”). Unless otherwise stated, we place the lightsource at an azimuth and zenith of both 45°, simulating the traditional over-the-shoulder lighting.

Probably the most employed lighting model throughout computer graphics was introduced by Phong in 1975. He splits the light reflected by a surface into an ambient, diffuse and specular term. While the ambient light causes an omnipresent, but usually moderate basic luminance by simulating perfectly diffuse lighting from all directions, the diffuse term is responsible for the basic lighting gradient on the frontfacing hemisphere according to the Lambertian cosine law. Additionally, for objects with very smooth materials such as polished metal the specular term causes view-dependent highlights (*Fig. 2a*). In technical sketches however, these would only distract the viewer from interesting details and should therefore be avoided.

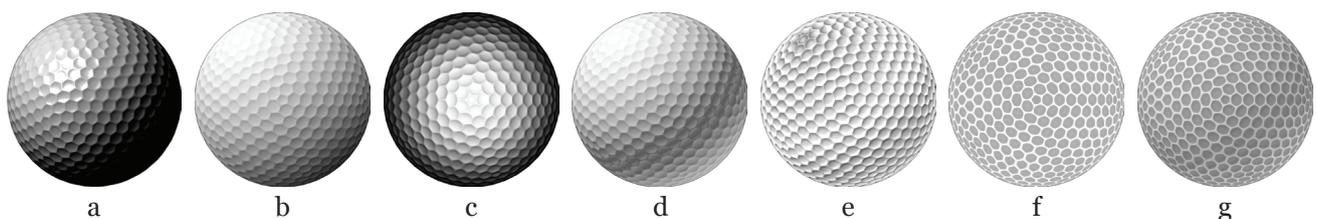


Fig. 2. Different rendering styles: (a) Phong lighting model, (b) smooth diffuse shading, (c) sharp diffuse shading with headlight, (d) cartoon-like shading, (e) shaded by local light adjustment, (f) shaded by local surface analysis, (g) composite view of (d) and (f).

In Phong's lighting model the backfacing hemisphere is brightened up only by the ambient term. In order to simulate a more balanced lighting situation we extend the lighting gradient so that it is ranging from pole to pole (Gooch *et al.* 1998). This lighting model is still artificial but it gets much closer to reality, where indirect lighting is the much more frequent case than direct lighting. As it can be seen from *Fig. 2b*, two disadvantages of this approach are the very low local contrast and the overexposure around the lit pole.

An enhancement of contrast could be achieved by simply squaring the intensity either of the Phong model or the smooth diffuse gradient. In both cases lighting from northwest causes a very dark area in the lower right part of the sphere, and this would also apply for bellied vessels. Therefore, only a headlight from the viewer's position illuminates the object strong enough. The result is an unfamiliar, but kind of dramatic view (*Fig. 2c*) which may have applications in some niches. At least, it underlines the object silhouette and some surface details.

In order to enhance the local contrast but still to convey information about the lower right part, we tried to place a second, slightly weaker light source opposite to the first one (Gooch *et al.* 1999). This yields a shading that is sometimes used in cartoons, but at the same time it causes cords near the equator (*Fig. 2d*).

All the lighting models mentioned above compute luminance only as a local property. As a result, global influences, particularly indirect lighting are only approximated or not considered at all. In cases where a photorealistic image rather than a technical sketch is wanted, but photography is



Fig. 3. A rendered picture using POV-Ray with radiosity enabled. Computation time was approximately 37 minutes.

unsuitable due to the mentioned shortcomings, more sophisticated rendering techniques such as raytracing or radiosity could be a way out (*Fig. 3*). Because of their algorithmic complexity these methods do not allow real-time interaction, but the results speak for themselves. Although they might not be suited for scientific documentation purposes in general, they could at least give some new impulses to illustrations in popular science.

4.2.3. Stressing surface details

From the above it becomes obvious that lighting models alone are not sufficient enough to convey all parts of a traditional sketch. We therefore need methods that emphasize surface details better but still match human perceptions. We observed that again simply composing a shaded view and a line drawing is unsatisfactory, because mixing a grey-scaled and a black-and-white view is very uncommon in scientific illustrations.

Within photography surface details are commonly stressed by putting the object into a grazing light. Indeed this works well for relief-like objects like coins or tiles, but it leads to problems on spherical or cylindrical pieces, because the grazing light can only point in one direction at once. What may be difficult in reality, is rather easy to implement in virtual space: Rusinkiewicz *et al.* (2006) propose an approach in which a principal lighting direction is still prescribed but locally modified, so that the grazing light is present everywhere on the surface (*Fig. 2e*). This creates a situation where especially ridges and valleys are clearly exaggerated, but unfortunately this also applies for smallest bumps and noise. The algorithm therefore provides additional parameters to control the level of detail as well as the strength of their emphasis. Although this idea is comprehensible, we observed that it is suited for our purposes only to a limited degree. Firstly, such a modified grazing light does not occur in reality and is therefore not very natural. Secondly, it is difficult to find an acceptable trade-off between emphasizing details (then the surface gets the impression of being kind of scarred) and too much smoothed shading (then unfamiliar cords appear). Hence, the approach is suited for smooth, manually modeled objects rather than 3D scans.

Among all ideas it seems to be most appropriate to simply shade concave areas such as rills, cracks or grooves darker than the rest. If furthermore grey instead of white is used as the basic colour, convex

areas such as bumps and ridges can be highlighted by a brighter shade as well. At least, the former is tried by algorithms computing the accessibility (Miller 1994) or the ambient occlusion (Landis 2002) at a surface point, but these create soft local shadows rather than sharp edges. We therefore computed the local surface curvature (e.g. Rusinkiewicz 2004) and used the amount of the first principal curvature as intensity value (Fig. 2f). By this means, we achieve the highest level of detail that is possible from a point cloud.

For documentation, in most cases we are currently using a combination of the cartoon shading (Fig. 2d) and the curvature image (Fig. 2f), whereas sometimes the smooth diffuse gradient (Fig. 2b) is also used. In our opinion this rendering style exhibits the best compromise between detail emphasis and plasticity.

Another popular drawing style is hatching. It is used with many different textures, e.g. stippling, charcoal strokes, pencil strokes, crosshatches and many more. On the one hand, hatching tends to achieve a better plasticity by varying shades, but often also material properties are conveyed by the type of texture. For 2D images hatching filters have already existed for a while. Photoshop for example is offering several series of them. The problem of image space hatching is that it usually does not follow the object shape as it is known for example from copper engravings. Praun *et al.* (2001) presented a method that is able to map arbitrary hatching textures onto a parametrized surface in real-time. This approach was extended by Vix (2008) where the hatching strokes are oriented towards a homogeneous field of the principal curvature vectors. Consequently, the object shape is conveyed much more intuitively. Some examples for automatically hatched objects are to be seen in Fig. 4.

In our opinion, for scientific purposes this style is applicable only to

a limited degree and the above composite view is to be preferred. For popular scientific figures however, it may provide a serious alternative.



Fig. 5. Conical unrolling of the lower part of a Terra Sigillata bowl shaded by the composite view (Fig. 2g).

4.3. Unrollings

In the case of intricately decorated pottery it is often difficult to give a representative impression of the ornamentation by a single sketch only. Hence, unrollings that show the entire decorated part of the vessels are added to the front view illustrations. According to the form of the vessel and the location of the ornamentation, an unrolling can be either cylindrical or conical. Unrollings are very difficult to draw and sensitive to measurement errors and

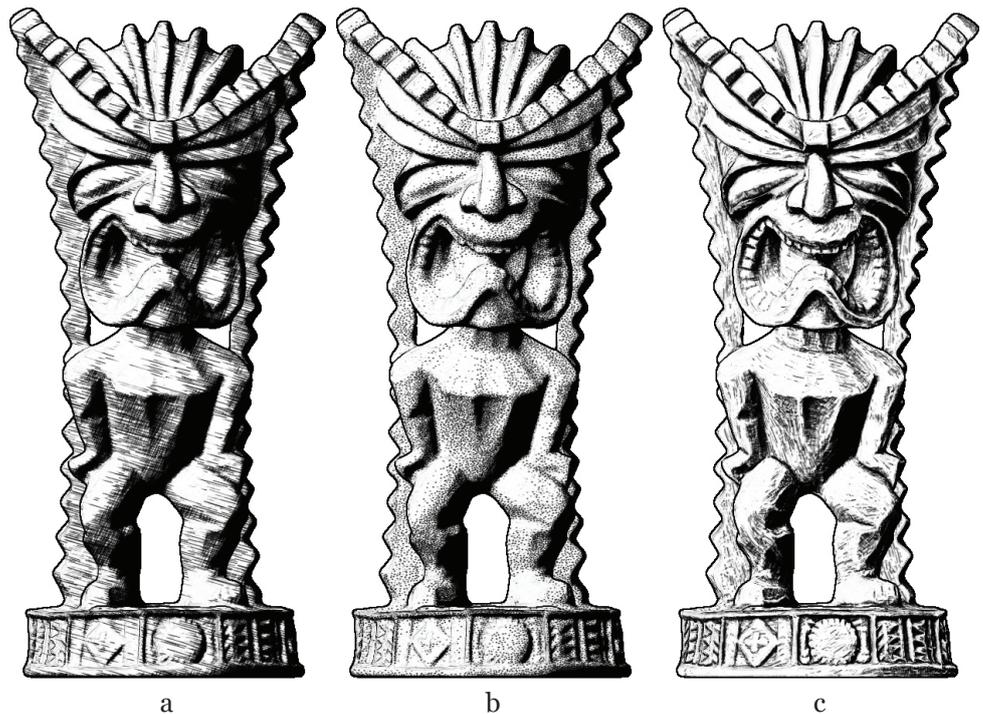


Fig. 4. Different hatching styles on a modern Hawaiian Tiki figure: (a) strokes in image space, (b) dots in image space, (c) strokes in object space including curvature shading.

perspective distortion. In addition, they are costly in terms of time. Therefore, they are only prepared for selected objects, although they would also be useful for a much larger number of objects. This situation may change in the future, because unrollings of 3D models can easily and quickly be created by simple coordinate transformations. Of course, distortions still occur if the object is not exactly cylindrical or conical, but they can be minimized with respect to the specific needs of the image.

4.4. Cross sections

In archaeological documentation in many cases a cross section is depicted besides the object illustration. Once the 3D model has been created, this step is rather simple and comfortable because intersecting a mesh can be quickly performed with arbitrary planes. However, a frequent question is how to handle objects that could not be scanned everywhere, such as the inner walls of narrow-necked vessels for example. Consequently, we designed our system in a way that should be common to most archaeologists. Normally, a caliper is used to measure the wall thickness at some few points and the profile is manually completed in between. The same applies to the digital method where the measured points are added to the profile and the section in between is smoothly interpolated. Moreover, we designed a tool that automatically completes missing parts of the profile curve by an equidistant line. Daily practice has shown that it is often easier to post-process this extrapolation by simply adjusting some data points instead of completing the profile by oneself.

5. Discussion

Up to now, 3D scanning technology has been primarily applied in archaeology for the documentation of prestigious finds in spectacular projects and to make them available to the public in virtual museums. Apparently for the first time, we use this technology as an everyday tool in all fields of archaeological work. Within one year we scanned the 1500 vessels of a Bronze Age cemetery in order to publish it as soon as possible. Since the majority of ceramics had additionally already been drawn, the enormous savings of time was revealed. For simple artefacts the speed-up amounts to a factor of 5, in case of elaborately decorated finds even to a factor of 10 or more. Once an object is scanned, the additional effort

to create further images, unrollings and profiles is very low compared to traditional documentation. Thus, objects can now be illustrated much more extensively than time has permitted so far.

The surface structure, which is depicted in the sketches only in exceptional cases, is now clearly visible (cf. *Figs 1* and *6*), and in contrast to the very schematic designations of rough structures even more objective. Comparing the traditional sketches and the computer-generated images directly, we can observe that sketches in fact convey a similar impression, but particularly in areas with high perspective distortion they can display a deviation of several millimetres towards the original.

We arrive at the borders of computer-supported documentation if the scanner cannot provide satisfactory results. Especially filigree structures or faint decorations may not be captured if the sensor resolution is too low and as long as they are not reflected in the geometry they cannot be pictured at all. While such properties are simply exaggerated in manual sketches, computer-generated images offer the opportunity to depict post-processed images with enhanced details beside the objective illustration. Since with the scanner only the as-is state of an object is captured, it is not possible to illustrate artefacts according to the original state of preservation. In this case a post-processing is necessary as well and the manual sketch is advantageous. However, the reconstruction of ceramic vessels out of single sherds does not pose a big problem. If the sherds are correctly aligned, we can choose arbitrary profiles or even a median profile (Karasik and Smilansky 2008; Hörr and Brunnett 2008) in order to complete the rotationally symmetric reconstruction. From that it is easy to distinguish the reconstructed part from the original one by a much brighter shading and thus it is clearly visible as a possibly interpretative extension (*Fig. 6b*, items 4 and 8). In contrast, often it is not possible to identify parts in the rendered view that have been plastered in the original, and therefore the actual state of preservation cannot be concluded from the image itself.

Sometimes we use the rendered images as a template for manual sketches (*Figs 1* and *7b*), particularly for really complex artefacts that are difficult to draw by hand. This apparent step backwards is necessary in order to keep the illustrations in running projects and publications uniform, but the additional amount of work is justified by the impressively accurate results.

Finally, huge artefacts that are even more difficult to draw can be documented this way as well. Since the scanners are usually portable, it is possible to scan whole tombstones (Fig. 7b) or architectures being increasingly damaged by environmental influences. Creating high-resolution replicas out of 3D models has already become a standard technique in today's restoration; further impressive applications will emerge in the future.

6. Conclusions and outlook

In this work we proposed several attempts towards a highly accelerated but at the same time objectified documentation process for cultural heritage. These include but are not limited to the generation of non-photorealistic images of scanned 3D models. In combination with the presented tools for measurement, unrollings and profile generation we achieved a remarkable speed-up and a significant improvement of accuracy compared to the traditional method. Although the prices of 3D scanners are still an obstacle for many institutions, we believe that acquisition costs have amortized after less than two years and digital documentation soon becomes profitable.

Currently we are promoting the system in order to get feedback on usability and applicability. One of our major concerns is to establish a quasi-standard for drawings in archaeology, no matter how it might look like, in order to make images finally comparable.

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