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New Visualization Techniques for Cuneiform Texts and Sealings

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Abstract : This contribution presents insights into the ongoing evolution of new visualization techniques relevant for the fields of archaeology and, particularly, Assyriology. We focus on systems and methods facilitating the reading of texts and sealings impressed on clay tablets. Making high resolution 3D models of archaeological objects seems an attractive and fulfilling solution, but in most cases the acquisition of these models is complex and their manipulation is demanding for both computer and researcher. Research groups across the world are working on these issues. In the presented survey, special attention goes to the results developed by Ancient Near Eastern scholars and engineers of Leuven University - Belgium, who built a Portable Light Dome related to the PTM-technology, which supplies scholars with so-called 2D+ images of digitally recorded objects. These virtual artifacts allow a detailed dynamic study of a wide variety of archaeological finds. For the field of cuneiform studies, the outcome is revolutionizing the approach how in a combined way the tablet, the text or any other kind of impressions on its surface can be visualized all together. The new visualization techniques present themselves as excellent digital safeguards and have proven to be high quality aids when used during a study process as well as for consultation after publication.

Keywords : Cuneiform tablets, Seals, Digital Library, Imaging, 3D

INTRODUCTION

Even after the introduction of modern photography into the fields of Assyriology and archaeology, the accurate recording of archeological artifacts, which are by nature three dimensional, remains challenging. The incisions of cuneiform signs and the impressions of seals into clay tablets prove difficult to capture entirely in two dimensional images, whether drawings or pictures. The characteristics of a surface, with its changing relief of steep and gentle slopes, means that a single illumination might visualize the features at one location on the surface perfectly, while leaving other details shadowed or without contrast, and therefore unidentifiable. Examining an entire surface demands varying illumination angles to identify each individual cuneiform sign or iconographic detail. The established way of studying these archeological artifacts therefore consists of interacting with the object in hand, by tilting it in many directions to find the best lighting and viewing angles when investigating a particular detail. Skilled

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photographers can often limit the areas where an image does not convey enough information by searching for an optimal combination of light sources shining on each object. Completely removing the aforementioned problems, however, remains time-consuming, or even impossible, when trying to capture a tablet in a single image.

Many approaches have been devised over the years to address these issues. They range from low-tech solutions, such as enhancing the visibility and contrast of the surface before recording, to scanning the entire surface into three-dimensional models. The technical skills demanded of the user vary as widely as the range of methods employed. Thus the work requires well trained scholars for the acquisition of adequate images. It might even mean that the work can only been done by engineers.

Archaeological artifacts are stored all over the world in depots, museums, universities and private collections. The need to travel to many locations, restricted physical access and overall preservation issues are serious obstacles for scholars using any type of recording of artifacts. These problems are as old as the field itself, and the quest for solutions has led to the use of particular methodologies. Making archaeological finds available for the broader worldwide community of researchers is a concern of all involved. The main goal lies in finding solutions which deliver an objective result and make it available to a broad public, without losing vital information. Drawings made by specialists who follow a broadly accepted method have proven their value, but the outcome cannot be seen as objective. These are artistic or technical interpretations and their quality is limited by the professional abilities of their producers. Objective registration methods, such as conventional photography, also have limits, as discussed above. A good registration method minimizes these shortcomings and is able to render the artifact visible as accurately as possible. In addition, it makes it easier for researchers to study the objects, it allows the enhancement of details and produces high quality results that are easy to share.

Recording cuneiform tablets or sealings in collections or even during archaeological excavations in the field is a costly operation with regard to human resources, technical means and transportation, something that new visualization techniques have to take into consideration. In that regard, a system should be operational at any desired location, i.e. transportable, ready to be assembled on-site within an acceptable amount of time, easy to use and maintain, and, to make it practical in the field of archaeology and cuneiform studies, archaeologists or philologists should be able to operate it. The existing techniques (below) are numerous and in some circumstances they can meet the wide-ranging and challenging demands.

Traditional and Modern Visualization Techniques

The traditional registration of inscribed tablets and sealings is done with pencil, caliper and millimeter paper. Trained scholars meticulously measure and copy every detail of the original onto a line drawing ; a method whereby success is only achieved by those who have a thorough knowledge of the specific epigraphy of the script and/or iconography. These copies are then published. This method, which might seem archaic, has been used for the last 150 years and still proves its value today. The published results might not be objective, but they are certainly the result of intense scrutiny.

Photography, despite the disadvantages with regard to the sufficient readability of all details on the ultimate image, has since its invention also been a popular means of recording vast collections of archaeological artifacts, including cuneiform tablets and seals. Various solutions have been introduced to overcome some of the inherent disadvantages of this method. By the early 1970's, cuneiform tablets were sometimes coated with a thin layer of white ammonium chloride (NH_4Cl) to enhance the contrast on the pictures (OWEN 1975, 14). This technique has since been optimized to easily coat vast groups of texts (VANDECASTEELE 1996), but the materials used are toxic and thus only suitable to be handled by trained personnel. The whitened surface offers a much better contrast and partly solves the invisibility of some parts of the surface caused by the static illumination angle. By the 1990's, the introduction of digital photography provided new opportunities. Software applications allowed for a variety of post-recording manipulations to enhance the readability of the details on the images (WAMBACQ & MARIËN 1996 ; VAN LERBERGHE *et al.* 1997 and VANDECASTEELE *et al.* 2005). Since then, the arsenal of applicable enhancement algorithms has continued to grow and their outcome has become more accurate.

A fast, cheap and easy alternative to photography applied intensively for imaging cuneiform tablets in the recent past, is the use of flat-bed scanners. The recordings, made of all sides separately, give a good and objective view of the original. But as most surfaces are convex and were made irregular by the impressions of styli and seals, this scanning method with its nonadjustable lighting is unsuccessful in visualizing all indentations of the cuneiform characters properly and more dramatically, it mostly fails in imaging sealings and other features on the surface.

Based on hand copies, photography and flat-bed scans cuneiform texts have graphically been presented in paper prints by standardized signs since the very first text publications from the mid nineteenth century until the introduction of computerized abstractions of mostly late 4th or 3rd millennium BCE texts. For the former, publishers developed fonts in one particular paleographic style for each cuneiform character to allow publication with traditional printing presses. This method gave very legible reproductions, but all secondary information about the cuneiform text itself was lost and the published result offered no opportunity to check the interpretations made by the publishing author. New printing processes superseded this method, but a similar outcome was reintroduced in the field of Assyriology with the use of vector-based graphic applications on computers by the late nineteen eighties. Again, only the impressed signs are visualized in black and white with standardized plug-ins developed in a customized software package, giving an abstraction of the original impression (DAMEROW *et al.* 1989). The results are easy to review but by no means they visualize all characteristics of the surface or the shape of the studied object.

Cuneiform tablets, however, are three-dimensional objects with writing on all six sides. Ancient scribes traditionally continued associated writings on more than one edge. As a consequence, a single two-dimensional image often does not hold complete lines of cuneiform signs. In hand made copies, the associated signs of a line that is written on more than one side of the tablet are simply drawn on the millimeter paper beyond the boundary of the tablet. Another solution is the combination and correct compilation of photographed or scanned images of all sides, adjacent to each other.

It is therefore logical that, over the years, several solutions have been proposed aiming to obtain a complete 3D model of artifacts. Successful experiments by researchers at the University of Birmingham and Harvard University with 3D scans from a single viewpoint on cuneiform tablets demonstrated the potential (WOOLLEY *et al.* 2001). An initiative at Johns Hopkins University, known as Digital Hammurabi / iClay, took advantage of this method in producing high resolution 2D+ and 3D models of cuneiform tablets (COHEN *et al.* 2004 ; HAHN *et al.* 2006 and 2007). Their equipment has both stationary and moving components, with a fixed camera and a projector that can be moved along a circular path. The setup needs skilled engineers for calibration, but their excellent results proved the practical use of these new techniques. In 2009, The Max-Planck-Institut für Wissenschaftsgeschichte (Berlin) in cooperation with the Cuneiform Digital Library Initiative (Berlin - Los Angeles) and the Hilprecht-Sammlung (Jena) have at length presented and discussed their findings on the use of 3D-scanning techniques on cuneiform tablets. They tested several acquisition and viewing systems. In their report, one of the preliminary conclusions states that these methods, with the state of technology at that time, remain labor intensive and require experienced people during the post-processing phases (KANTEL *et al.* 2010, 49).

For scholars, the registration and visualization of archaeological objects using 3D-models is not necessarily the only or most appropriate technique to study the characteristics of interest on the surface of an artifact. To allow interaction with digitized objects, while staying within the framework of the common two-dimensional environment, modern approaches have developed other solutions. At Stanford University, Anderson and Levoy developed a labor intensive method by creating a full 3D model from several laser scans and fitting a low resolution surface to it. This allowed them to "unwrap" the scanned cuneiform tablet and present it in 2D to facilitate reading over the edges (ANDERSON & LEVOY 2002). At the same time, at Hewlett Packard Labs, Tom Malzbender successfully experimented with so-called 2D+ models (MALZBENDER *et al*. 2001), which can be thought of as interactive photographs. By placing objects, such as cuneiform tablets, under a hemisphere with flashbulbs and with a fixed digital camera mounted on top, a series of images with different illuminations of the same object (side by side) are recorded. From the collection of images, a Polynominal Texture Map (PTM) is built, containing the appearance of the object under varying lighting directions. Using a viewer application, the lighting can be interactively controlled in such a way that both the details of the seal impressions and the impressed wedges can be studied. Additional effects can be applied to render details more clearly visible. The PTM recording device and technologies are currently used by Cultural Heritage Imaging (CHI : http://c-h-i.org). In cooperation with the West Semitic Research Project at the University of Southern California and Cultural Heritage Imaging such a device controlling a set of 32 light sources has been used successfully for the registration and study of the Persepolis Fortification tablets at the Oriental Institute in Chicago (STOLPER 2009 & 2010). The authors of this contribution have also experimented with this technique at their home institute and have come up with a user-friendly setup and adapted software to make this technique as useful as possible for the field of cuneiform studies (see below). In addition, since Autumn

2010, the universities of Southampton and Oxford have been experimenting with this technique in a project called "*Reflectance Transformation Imaging (RTI) System for Ancient Documentary Artefacts*". A variety of inscribed documents, such as cuneiform tablets, have been tested (EARL *et al.* 2011).

Owing to the new possibilities technology offers, projects to digitize ancient artifacts around the world are motivated on well-considered grounds : unlocking hard-to-access public or private collections, facilitating study and consultation of artifacts kept around the world, digital safeguarding against limited preservation, making entire collections – including less "spectacular" items – systematically available, or virtually unifying geographically dispersed collections and artifacts. Driven by these benefits the digital library initiatives are numerous throughout the heritage sector, including within the field of Assyriology. Some of them are of limited scale, such as the 3D-scans of the small collection of Kültepe tablets at the Universitätsbibliothek Gießen, published online ; others have a worldwide scope, such as Inscriptifact or CDLI (Cuneiform Digital Library Initiative). New visualization methods will optimize the readability of all these cataloged texts and will provide welcome improvements in the future.

The application of the new techniques opens up new areas of research. Besides the purely visual characteristics of the recorded artifacts, extremely accurate metric data is stored as well. Recently, 3D scanning has been used at Brooklyn College (City University of New York) to study the culture of production and use of cuneiform tablets, which allows detailed forensic research to track human behavior (Cuneiform Forensics Project). Varying handwriting on tablets makes identification of cuneiform signs challenging. Using the vector characteristics at the surface of the tablets, a team working at Heidelberg University employs the so-called *GigaMesh* system to search for solutions to automate the extraction of cuneiform characters based on 3D models (MARA *et al.* 2010). Alongside these benefits, including the inherent objectivity of the technique and the potential for the full registration (all details) of artifacts and the ease of distribution of images, the new technologies also have the potential to give new impulses to traditional areas of research, the most prominent being paleography.

THE 2D+ TECHNOLOGY AND THE PLD-SYSTEM

It follows from the statements above that a visualization technique needs to be practical. An appropriate method is that of the 2D+ models based on PTM technology, which several teams from around the world have experimented with. Below, the focus is on a system developed at the Katholieke Universiteit Leuven in Belgium where the Portable Light Dome system[1] (WILLEMS *et al.* 2005) was developed and improved for the field of cuneiform studies. This Leuven system consists of a hemisphere with light sources that recreates 2D+ models from a series of photographs. In contrast to the PTMs mentioned earlier, the goal is to model the appearance under different illumination directions and to reconstruct the surface orientation and color of the object as well. Once these have been computed, the virtual artifact can be relit in real-time together with several effects to enhance the detail. The acquired

[1] The Portable Light Dome has previously been called the Leuven Camera Dome, WILLEMS *et al*. 2009 and VAN LERBERGHE & VOET 2009, viii, 161-162.

data are presented in 2D, but in a interactive way through a viewer application. Based on the source data, the filters enhance exactly what the researcher wants to focus on. One of the visualization filters gives automated objective line drawings. By using the dynamic tools in the viewer application, it is the researcher's choice to focus on the incised writing or the impressed seals with such a filter. A partial 3D model can also be obtained from the same data.

To record an artifact, the Portable Light Dome kit, which fits inside a suitcase, makes use of a FireWire camera, four partial shells of the hemisphere containing the light sources and a USB controller to connect to a laptop (Fig. 2). All the components were developed by the ESAT-PSI-engineers of Leuven University. A few of these domes have subsequently been used in operation by scholars of the university's Ancient Near Eastern Studies Department. To use the dome, the four shells are snapped together and fixed onto a table, after which the camera is positioned on top. By connecting the cables, the system is ready for image acquisition (Fig. 1).

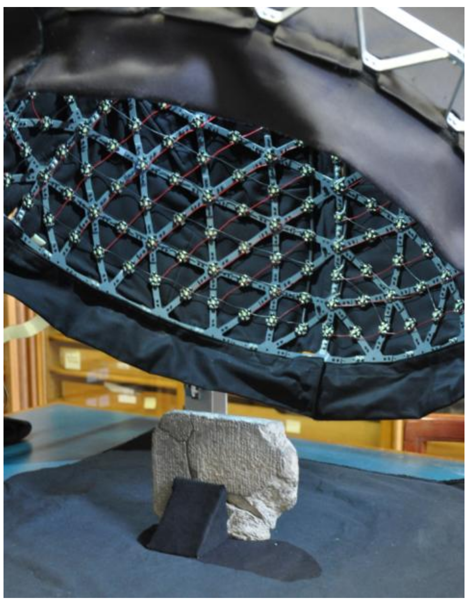

Fig. 1. Recording of a large tablet with the PLD.

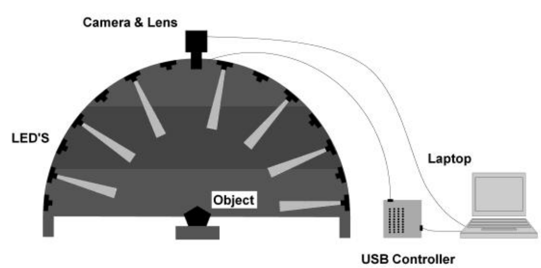

Fig. 2. Scheme of the PLD-system.

When examining the surface of an artifact, an expert uses different lighting and viewing angles to study the steep ridges of the wedges as well as the subtle relief of the sealings. By moving the position of a light, some parts will become brighter while others become darker or are occluded by shadows. The change in object appearance gives the expert an idea of the three-dimensional structure of the artifact and the details in particular. The 2D+ technology of the Leuven system uses a similar process, taking images from a single fixed camera while the position of the light changes. However, instead of moving a light to a different position, a different LED is lit each time a picture is taken. From the combined set of images, the surface orientation and color can be computed for each pixel using a technique called Photometric Stereo (WOODHAM 1989).

To acquire the image the researcher places the artifact under the dome and an application on the laptop shows a live view from the camera, to enable the object to be centered exactly beneath the camera and to determine the correct focus. After specifying the object's metadata and which side of the object is facing the camera, the recording is started from the laptop. There are 264 LED light sources installed in the hemisphere. During the automated recording sequence each LED lights up and a total of 264 images with different illumination directions are taken. The recording phase of one side takes less than 4 minutes depending on the characteristics of the artifact. Next, the surface properties, the orientation and color of the surface at each pixel, of a side is calculated from the recorded image sequence. Finally, the obtained data of all recorded sides of an artifact are stored together in a single Virtual Artifact File, the size of which varies between 10 and 30 MB.

This file can be opened in a viewer application that shows five of the six sides simultaneously together with the metadata of the object. For the presentation of cuneiform tablets, the different sides are positioned in such a way that the inscriptions can be read "across the edges". Within the viewer, the artifact can be studied by moving a virtual light over the object (relighting), as would be done when inspecting the real artifact, i.e. by tilting the object in front of a light source.

Short excursus on the technology

The basic idea of the dome structure and software is based on the following. It is assumed that the light, reflected from the surface into the camera, depends only on the color of the surface and the angle between the surface and the direction of the light source. Such a surface is called "Lambertian". In this ideal case, only 3 light sources (and images) are needed to compute the surface orientation and its color. In reality, however, most surfaces are not purely Lambertian. A metal object, for example, behaves partly as a mirror. Lit from certain directions, its apparent brightness changes with the varying viewing direction and the images will contain specular highlights ; on a picture these specular highlights appear as bright, almost white, spots on a shiny surface when illuminated. A second problem occurs with objects with large indentations. As a result certain parts of the surface can become shadowed as the light is blocked by another part of the surface. These spots will show up in the pictures as too dark and do not convey any useful information.

For each pixel, the system therefore iteratively selects a subset of the 264 samples that exhibit pure Lambertian behaviour by removing those recordings for the specific pixel whose brightness is too high (probably a specular highlight) or too low (probably a shadow). From this subset the direction perpendicular to the surface (the normal) and the color (the albedo) are computed at that pixel. The result is a digital file which holds the normal and albedo information of every pixel. This information is enough to relight the object from any direction virtually. The created Virtual Artifact File stores this information for every part of the surface of the object and thus contains the surface orientation and color of every detail. In addition, besides photorealistic rendering, this information enables several non-photorealistic visualizations, an approach not available when studying the actual object. In the viewer application, several filters are available to display these photorealistic and non-photorealistic visualizations in real-time (Fig. 3).

The **color filter** renders the artifact with the color information obtained during the recording phase, based on the principles of photometric stereo explained above. The results in this case look very similar to viewing the physical object, although without the hindrance of specular highlights and shadowed areas.

The **shading filter** shows the object without its color and makes the object look as if it were chemically bleached. Advantage of the filter : This can significantly enhance the visibility of the relief as certain intensities and contrasts of color can obscure graphical details of importance on the surface of the object.

The **exaggerated shading filter** enhances the surface indentations by rendering the ridges more steeply than they are in reality. The result obtained is thus not physically correct. Advantage of the filter : some details, more in particular shallow relief, tend to show more clearly with this filter.

The **line drawing filter** uses the surface information to extract the indentations of the impressions from the rest of the surface. These grooves in the surface are detected by searching around each pixel for rapid changes in the surface orientation that signal a local concave surface (a thin, steep indentation). Each pixel is assigned a color based on how much the distribution of the normals around the pixel correspond to a concavity. Pixels in which the surface is flat are shown in white while a highly concave surface pixel is shown in black. As such, the filter generates accurate black-and-white line drawings in an objective way. Advantage of the filter : an easy to consult (with black-and-white contrast) image gives a fast interpretation of the relief on the surface. As the filter focuses on the concave shaped features, it is the cuneiform impressions that are visualized most clearly on clay tablets.

Thanks to the 2D+ technology, objects are represented in a user-friendly way ; at any time a chosen view can be selected for print publication. For the visualization of incised cuneiform characters and sealings this approach proves most effective, especially with the line drawing filter, which gives a fast, accurate and easy to interpret representation of the features to study.

It is in the 2D+ viewer application that the interactive filters can be used and where the actual potential of the system is demonstrated. The images below, i.e. static visualizations in two dimensions, illustrate the described technologies.

Fig. 3. Reverse of *OLP* 4 : 11 (NP 2 ; 4,5 x 4,5 cm).
Visualization filters in the PLD-system - Left to right : 1. **Color filter** with lighting from directly above ; 2. **Color filter** with lighting from the top right ; 3. **Shading filter** ; 4. **Exaggerated shading filter** ; 5. **Line drawing filter**.

VISUALIZATION AND RESEARCH

The efforts to record the vast collections of ancient artifacts with the help of new technologies have well considered purposes, varying from introducing the broad public to cultural heritage to making available to scholars spread around the world complete collections for detailed study. For the former, a spectacular visual appearance might be satisfying but for the latter the outcome has to be detailed, intelligible and if possible it should offer additional benefits for the study of the artifacts. Therefore the above discussed 2D+ system was applied to collections of previously published and unpublished cuneiform tablet collections. As such, the results of the old and new techniques could be compared. Below, two examples (Fig. 4 & 5) of hand copies (NP 3 and NP 10), both tablets from the Leuven collection (NASTER & SAUREN 1973 and SAUREN 1974), are placed alongside the new recordings of those same tablets.

The representations in the line drawing modus in figures 4 and 5 demonstrate the potential of the 2D+ technology. They display in two dimensions the recorded virtual 3D tablets alike the standard method of publishing cuneiform texts, i.e. by easy to consult black and white hand copies. For study purposes this fast, objective and clear visualization enables the examination of the tablet’s surface. Besides that, and with the same effort, the tablets themselves are visualized as well. They are not simplified as is the case with the hand copies on the left of both figures. One and the same recording presents the cuneiform signs, the shape of the tablet, any additional characteristics the tablet has, and the exact composition of all the features on its surface, such as seal impressions. In traditional publications some of this information is lost, ignored or is only partially depicted.

Even though the elimination of an intermediate copyist-interpreter might remove the potential for human error, the objective virtual recordings have their disadvantages as well. As illustrated by the examples below, each researcher using the 2D+ line drawing has to act as the initial interpreter, unguided by a well-considered drawn interpretation by a specialist who studied the original. Accordingly, a hand copy can for instance show hard to interpret sections on the surface with greater clarity, or even reconstruct details in damaged sections based on secondary information. Unfortunately, this same mechanism can also be responsible for misleading results. Via the 2D+ visualization, which is a presentation of a 3D-object, the different sides are organized next to each other and the researcher has to link the features depicted and visible on two recorded edges himself. A hand copy can overcome this by unwrapping the feature and draw it in two dimensions. If no human error is involved, hand copies have the potential to be better than the original. Unfortunately, mistakes are made and producing hand copies is time-consuming. Without any additional effort, the 2D+ line drawing can be extracted for tablets with few or many lines of text and for sealings with any degree of complexity. In an overall comparison the line drawing is accurate, complete and fast in acquisition ; the hand copy has the benefit to provide the clearer result with its pure black and white outline.

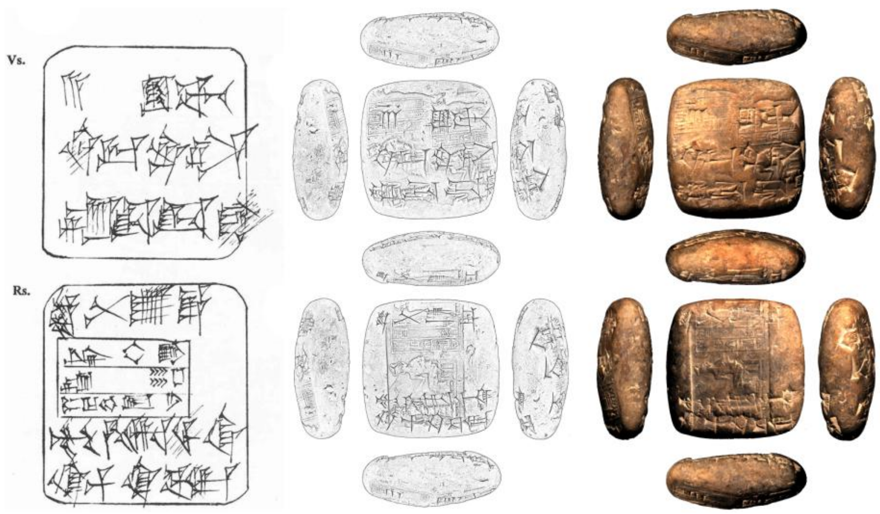

Fig. 4. *OLP* 4 : 12 (NP 3).

Fig. 5. *OLP* 4 : 51 (NP 10).
For both examples above : Left : Subjective hand copy by H. Sauren as published in *MVN* II (1974) ; Middle : Objective extraction with the line drawing filter based on a recording with the 2D+ system of the PLD ; Right : PLD recording with the color filter and a particular lighting angle applied.

Based on the same source-data as the 2D+ technique, the Virtual Artifact File, 3D images of artifacts can be modeled in the viewer program in a matter of seconds (Fig. 6). As such, these high resolution models do not need to be stored. If needed, the viewer can calculate them from the archived Virtual Artifact File. Normally, high resolution 3D-models demand large amounts of storage. However, utilization of the PLD-technique permits all the data for both the 2D+ and 3D visualization to be saved within one Virtual Artifact File of 10-30 MB.

In the test cases (see below) 3D visualization only occasionally proved beneficial for the study of cuneiform inscriptions in comparison to the 2D+ images, especially when the line drawing filter was employed. On clay tablets the cuneiform signs are indentations, incisions in the surface. The 2D+ line drawing tool visualizes these features of the relief the best. If the details of interest lie on top of the main surface in low relief, as is the case for sealings, a 3D model does improve the study of such type of features.

Handling 3D models is demanding for computers, and hard-won information is lost in traditional publications, because the third dimension disappears when the image is printed on paper. When the models can be consulted in a 3D viewer, 3D has the overall visual superiority over 2D pictures and even 2D+ images. But as stressed above, any visualization technique has its benefits and disadvantages with regard to what is being studied.

Fig. 6. Reverse of *OLP* 4 : 12 (NP 3).
Two views of a 3D model based on the PLD-source data enhanced with the 'Radiance Scaling tool' from MeshLab v1.3.0b.

The main goal for visualization systems is to facilitate future research. Above, mention was made of the use of the 2D+ technology on the Persepolis Fortification Archive by the team of M. Stolper at the Oriental Institute of the University of Chicago. With the Leuven system, experiments were also undertaken within several research projects working on cuneiform texts and sealings. Because this system is easy to deploy on location it was used by K. Van Lerberghe and G. Voet at the Cornell University Department of Near Eastern Studies (USA) to digitize a hitherto unstudied portion of the CUNES collection (VAN LERBERGHE & VOET 2009). A. Goddeeris has satisfactorily used the technology at the

Friedrich-Schiller-Universität Jena (Germany) on a section of the Old Babylonian tablets of the Hilprecht collection (publication forthcoming). E. Devecchi recorded for study and publication the large tablet of the Aleppo Treaty at the British Museum (DEVECCHI 2010 and Fig. 1) and H. Hameeuw recorded all cuneiform documents in the Katholieke Universiteit Leuven as well as the bilingual Neo-Assyrian archive of northeast Syrian origin kept at the Royal Museums of Art and History in Brussels. As a result of this work, a large portion of these recordings can be consulted online via the website of the Ancient Near Eastern Studies department at Leuven University. These tests, along with other completed and still ongoing research projects, have made it clear that the virtual artifacts allow excellent readability of the texts and greatly improve the visibility of the sealings on the surface. To further explore the potential of the latter, the opportunity was taken to register with the PLD system clay jar stoppers with seal impressions at the excavations of H. Willems at Dayr al-Barsha in Middle Egypt. As expected, these impressions, which are hard to draw from the original stoppers, were easy to study on their virtual counterparts (WILLEMS *et al.* 2009, 330).

The new technologies are used interactively, operated from viewer-programs on computers. As a consequence, researchers can choose to apply whatever views or enhancement filters they need for the specific feature of interest. They can zoom, rotate and save specific views at any time. The examination of sealings on cuneiform tablets demonstrates this dynamic process perfectly. The study of the iconography and inscriptions of seals has always been difficult, not least due to the Ancient Near Eastern practice of writing on top of the previously impressed seals, thus partially obscuring the impressions in the process. The combined use of various visualization filters on 2D+ and 3D virtual artifacts renders them more visible than ever before. With one view or filter the incised cuneiform characters are visualized prominently, with another the impression of the seal can be viewed instead. (Fig. 7).

Fig. 7. Detail on the reverse of NP 3.
Seal impression beneath inscribed cuneiform signs, Above left : with shaded filter of 2D+ (PLD), Above middle : with line drawing filter of 2D+ (PLD) low threshold, Above right : with line drawing filter of 2D+ (PLD) high threshold, Below left : with color filter of 2D+ (PLD), Below right : 3D representation based on PLD-source data enhanced with 'Radiance Scaling tool' from MeshLab v1.3.0b.

Altogether, new visualization systems provide efficient and objective results to facilitate transliteration and translation processes for cuneiform texts. They open new opportunities for research thanks to the objective registration and increased visibility of the object surface. As such, they will contribute to the study of artifacts archived in digital libraries. Three-dimensional models give an accurate representation of the artifact's dimensions, but do not necessarily facilitate the study of the artifact's surface better than 2D+ technology. In fact, the available tools of visualization filters in the 2D+ viewer-programs are the most appropriate for the correct reading of cuneiform texts, especially with applications such as the above demonstrated 'line drawing filter'. The recording method is complete and objective, which allows, even when focusing only on the field of cuneiform studies, an enormous potential such as accurate paleographic studies, morphometric studies to analyze the shape of signs written by different scribes or as they were used in varying genres, discerning scribal hands, establishing the provenance of tablets, or to investigate the type of stylus and the way a stylus was handled to impress the cuneiform signs (Fig. 8).

Photograph	Hand copy	2D+ Line drawing	
			Imprints of the sign 'bu' on an Old Babylonian tablet from Nippur with a decayed stylus. (HS 2074)
			Accurate paleography of the sign 'um'. (CUNES 51-01-090)
			Deformation of previously incised imprints within one particular sign, giving information on the order of imprints in composing the sign. Indentation 2 was pushed down by impressions 3 & 4. (HS 2074)

Fig. 8. Some examples of observable details when applying the objective 'line drawing filter' on 2D+ recordings in comparison to the subjective published hand copies and official reference photographs of cuneiform tablets of the collections of the Cornell University (with ammonium chloride coating) and the Hilprecht-Sammlung.

FUTURE CONCERNS

Overall, the new recording techniques have the main disadvantage of requiring the use of computers with specialized software. Digital photography in contrast, produces tiff- or jpegfiles, formats supported by most graphic software packets and they are easily printed or inserted into digital documents or online databases. 3D and certainly 2D+ images do not benefit this wide support and require specific software. For both 2D+ and 3D such software is available as freeware[2] or in several occasions even incorporated in

[2] The authors used for 2D+ the at the K.U.Leuven developed PLD-viewer (available via the website of the Ancient Near Eastern Studies department) and for 3D the MeshLab software package, freeware available on the internet.

browser applications. To make these new technologies effective and user-friendly further investment is needed.

Hand copies or photography register objects with any reasonable dimensions. Many 2D+ and 3D acquisition systems have limits in that regard and to overcome them, the recording phase becomes complex or the result less detailed. It is therefore problematic when attempting to capture images of large objects. Today, the best technique to resolve these problems within the concept of 2D+ (PTM) images is the technique of Highlight RTI image capture using reflective spheres, a technology used on subjects ranging from coins to large surfaces with rock-art (MUDGE *et al.* 2006). In the field of Assyriology itself, bearing the sizes of cuneiform documents in mind, the above solution using the Portable Light Dome is applicable. By selecting the appropriate lens - wide angle or macro/micro - only the largest type of tablets has to be excluded from the current PLD-hardware.

A main problem with recording systems using one fixed camera position, as is the case for the PLD-system, is the correct visualization of strongly curved surfaces, such as the edges of clay tablets. This approach leads to distortions. Future research has to take this into account. Introducing more camera positions could be one way to eliminate this problem.

The 2D+ and 3D visualization techniques used today can only be fully reviewed with the aid of computers and therefore create tension with regard to printed publications. The added value comes from the interactive nature of working with these images, a facility unavailable when printed. Cuneiform documents, the inscriptions and the sealings, are traditionally published as hand copies or photographs ; and in fact, despite all new visualization techniques, this approach suits this type of publication best. So where does the use of 2D+ and 3D images stand in the field of Assyriology ? Their significance reveals itself in several directions. In the first place, the various ways of displaying the tablets act as an aid during the research phase ; those who used the Virtual Artifact Files for their ongoing work in the recent past have proven this function with great satisfaction (see above). Secondly, images based on the 2D+ and 3D models can accompany printed publications ; the line drawing tool based on the 2D+ images with the PTM-technique manifests itself most prominently in this practice. Furthermore, once the basic edition is published and taking the objective nature of the new techniques into consideration, the images can play their role as means to verify or elaborate upon features discussed in that publication. To make this possible, the recordings should be made available via online accessible digital libraries. An additional significance, and becoming more and more relevant, is the potential to incorporate these interactive images in digital publications. Beside these, the recordings act as perfect digital safeguards of the original artifact stored around the world frequently in substandard conditions.

BIBLIOGRAPHY

ANDERSON, S. and LEVOY, M., 2002 : «Unwrapping and Visualizing Cuneiform Tablets», *IEEE Computer Graphics and Applications* 22/6, 82-88.

COHEN, J., DUNCAN, D., SNYDER, D., COOPER, J., KUMAR, S., HAHN, D., CHEN, Y., PURNOMO, B. and GRAETTINGER, J., 2004 : «iClay : Digitizing Cuneiform» *in* CHRYSANTHOU, Y., CAIN K., SILBERMAN, N. and NICCOLUCCI, F. (Eds.), *The 5th International Symposium on Virtual Reality, Archaeology and Cultural Heritage (VAST 2004)*, Brussels, 135–143.

DAMEROW, P., ENGLUND, R.K. and NISSEN, H.J., 1989 : «Zur rechnergestützten Bearbeitung der archaischen Texte aus Mesopotamien», *Mitteilungen der Deutschen Orient-Gesellschaft* 121, 139-152.

DEVECCHI, E., 2010 : «"We are all Descendants of Suppiluliuma, Great King" The Aleppo Treaty Reconsidered», *Die Welt des Orients* 40, 1–27.

EARL, G., BASFORD, Ph., BISCHOFF, A., BOWMAN, A., CROWTHER, Ch., DAHL, J., HODGSON, M., ISAKSEN, L., KOTOULA, E., MARTINEZ, K., PAGI, H. and PIQUETTE, K.E., 2011 : «Reflectance Transformation Imaging Systems for Ancient Documentary Artefacts», *Electronic Visualisation and the Arts (EVA 2011)*, 147-154.

HAHN, D., BALDWIN, K. and DUNCAN, D., 2007 : «Non-Laser-Based Scanner For Three-Dimensional Digitization of Historical Artifacts», *Applied Optics* 46, No. 15, 20 May, 2838-2850.

HAHN, D., DUNCAN, D., BALDWIN, K., COHEN, J. and PURNOMO, B., 2006 : «Digital Hammurabi : Design and Development of a 3D Scanner for Cuneiform Tablets» *in* CORNER, B.D., PENG, L. and TOCHERI, M. (Eds.), *Three-Dimensional Image Capture and Applications* VII, *Proceedings of SPIE 6056*, Bellingham, 130-141.

KANTEL, J., DAMEROW, P., KÖHLER, S. and TSOUPAROPOULOU, Ch., 2010 : «3D-Scans von Keilschrifttafeln - ein Werkstattbericht» *in* ASSMANN, W., HAUSMANN-JAMIN, Ch. and MALISIUS, F. (Hrsg.), *26. DV-Treffen der Max-Planck-Instituut, 22.-24. September 2009 in Berlin* (= *GWDG-Bericht* 76), Göttingen, 41-62.

MALZBENDER, T., GELB, D. and WOLTERS, H., 2001 : «Polynomial Texture Maps» *in* POCOCK, L. (Ed.), *SIGGRAPH '01 : Proceedings of the 28th Annual Conference on Computer Graphics and Interactive Techniques*, New York, 519–528.

MARA, H., KRÖMKER, S., JACOB, S. and BREUCKMANN, B., 2010 : «GigaMesh and Gilgamesh - 3D Multiscale Integral Invariant Cuneiform Character Extraction» *in* ARTUSI, A., JOLY-PARVEX, M., LUCET, G., RIBES, A. and PITZALIS, D. (Eds.), *The 11th International Symposium on Virtual Reality, Archaeology and Cultural Heritage (VAST 2010)*, Paris, 131-138.

MUDGE, M., MALZBENDER, T., SCHROER, C. and LUM, M., 2006 : «New Reflection Transformation Imaging Methods for Rock Art and Multiple-Viewpoint Display» *in* IOANNIDES, M., ARNOLD, D., NICCOLUCCI, F. and MANIA, K. (Eds.), *The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2006)*, Nicosia, 195-202.

NASTER, P. and SAUREN, H., 1973 : «Textes cunéiformes conservés à Louvain», *Orientalia Lovaniensia Periodica* 4, 17-70.

OWEN, D., 1975 : *The John Frederick Lewis collection I* (= *Materiali per il Vocabolario Neosumerico* 3), Rome.

SAUREN, H., 1974 : *Wirtschaftsurkunden aus der Zeit der III Dynastie von Ur im Besitz des Musée d'art et d'histoire in Genf und kleinerer Sammlungen* (= *Materiali per il Vocabolario Neosumerico* 2), Rome.

STOLPER, M.W., 2010 : «Persepolis Fortification Archive Project», *The Oriental Institute 2009-2010 Annual Report*, 83-91.

STOLPER, M.W., 2009 : «Persepolis Fortification Archive Project», *The Oriental Institute 2008-2009 Annual Report*, 104-111.

VANDECASTEELE, C., 1996 : «Deposition of Ammoniumchloride on Cuneiform Tablets» *in* ISMAIL, F., SALLABERGER, W., TALON, Ph., VAN LERBERGHE, K. and LEBEAU, M. (Eds.), *Administrative Documents* *from Tell Beydar (Seasons 1993-1995)* (= *Subartu* II), Turnhout, 193-194.

VANDECASTEELE, C., VAN LERBERGHE, K., VAN ROMPAY, J. and WAMBACQ, P., 2005 : «Digitizing the Cuneiform Tablets from Beydar» *in* BOWMAN, A. and M. BRADY (Eds.), *Images and Artifacts of the Ancient World*, London, 85-96.

VAN LERBERGHE, K. and VOET, G., 2009 : *A Late Old Babylonian Temple Archive from Dur-Abieshuh* (= *CUSAS* 8), Bethesda.

VAN LERBERGHE, K. and WAMBACQ, P., 1997 : «L'épigraphie, quelles perspectives ?» *in* TALON, Ph. and VAN LERBERGHE, K. (Eds.), *En Syrie, aux origines de l'écriture*, Turnhout, 97-102.

WAMBACQ, P. and MARIËN, D., 1996 : «Enhancement of the Quality of Photographs of Tablets Using Digital Techniques» *in* ISMAIL, F., SALLABERGER, W., TALON, Ph., VAN LERBERGHE, K. and LEBEAU, M. (Eds.), *Administrative Documents from Tell Beydar (Seasons 1993-1995)* (= *Subartu* II), Turnhout, 195-198.

WILLEMS, G., VERBIEST, F., MOREAU, W., HAMEEUW, H., VAN LERBERGHE, K. and VAN GOOL, L., 2005 : «Easy and Cost-Effective Cuneiform Digitizing» *in* MUDGE, M., RYAN, N. and SCOPIGNO, R., (Eds.), *The 6th International Symposium on Virtual Reality, Archaeology and Cultural Heritage (VAST 2005),* Pisa, 73-80.

WILLEMS, H., VEREECKEN, S., KUIJPER, L., VANTHUYNE, B., MARINOVA, E., LINSEELE, V., VERSTRAETEN, G., HENDRICKX, S., EYCKERMAN, M., VAN DEN BROECK, A., VAN NEER, W., BOURRIAU, J., FRENCH, P., PEETERS, Ch., DE LAET, V., MORTIER, S. and DE KOONING, Z., 2009 : «An Industrial Site at al Shaykh Sa'id/Wadi Zabayda», *Ägypten und Levante : Zeitschrift für Ägyptische Archäologie und deren Nachbargebiete* 19, Wien, 293-331.

WOODHAM, R.J., 1989 : «Photometric Method for Determining Surface Orientation from Multiple Images» *in* HORN, B.K.P. and BROOKS, M.J. (Eds.), *Shape from Shading*, Cambridge (MA), 513531.

WOOLLEY, S.I., FLOWERS, N.J., ARVANITIS, T.N., LIVINGSTONE, A., DAVIS, T.R. and ELLISON, J., 2001 : «3D Capture, Representation, and Manipulation of Cuneiform Tablets» *in* CORNER, B.D., NURRE, J.H. and PARGAS, R.P. (Eds.), *Three-Dimensional Image Capture and Applications* IV, *Proceedings of SPIE 4298*, Bellingham, 103–110.