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Looking both forward and back: imaging cuneiform*

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Imaging the three-dimensional cuneiform characters, written on clay, metal and on stone, has been a challenge since Carsten Niebuhr, Henry Rawlinson and Julius Oppert published the first of these inscriptions in the 19th century. Since then, hundreds of thousands of these inscriptions have been drawn, photographed, scanned, vectorized, hologramed. They have been included and assembled in printed publications, online databases and annotated media. Today, the importance of imaging these inscriptions is highlighted by the rapid destruction of this shared world heritage in the Near East, and an understanding that all inscribed objects from the ancient Near East are fragile. In our talk we want to ask what do specialists need; what are the requirements that both Assyriologists and colleagues from related fields expect from the visual documentation of ancient inscribed artifacts? In recent years, interactive 2D+ and 3D models of ancient inscriptions have been produced that conceal metric data which surpass the pure imaging purpose. But reliance on such cutting-edge technologies comes at a great increase in cost (equipment, capture and processing time), potentially limiting access to the data. Producing images of ancient inscribed artefacts, and making them available with searchable metadata, allows researchers to ask both traditional research questions as well as entirely new ones, in fact, we may not always know what questions researchers will ask of the data. In this paper, we will draw on our expertise in cultural heritage imaging built up over the past two decades in Leuven (portable dome project) and Los Angeles-Oxford-Berlin (CDLI), and suggest a sustainable path towards imaging any and all cuneiform documents.

A. Introduction

What constitutes an *ideal* representation of a cuneiform artefact? Mastery of the techniques necessary to achieve this goal have been a challenge for photographers, readers, and cuneiform scholars alike since the earliest days of photography. In this paper we will attempt to illuminate this issue from various angles and try to pave a trajectory towards future work. It is not our attempt to compare the various methods in terms of their technical specifics, but rather other aspects, such as gain, accuracy, and efficiency. In the early days of Assyriology, when the first large corpora of cuneiform tablets arrived at museums in the West, their imaging already led to important decisions: In 1866, H. W. Diamond stated in a short article about photographic reproductions of ancient artefacts as follows:

> *"In matters of such delicate rendering as Egyptian hieroglyphics, Sinaitic carvings, Cuneiform inscriptions, the question whether this or that mark upon the weather-worn stone shall be recorded as the remains of a line or a dot, or shall be overlooked as a defect produced by age, will be decided, in the work even of the most conscientious draughtsman, by the interpretation which he*

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> *places upon the symbols he is recording. Such inaccuracy in the observer generates a corresponding inaccuracy in the student who generalizes from his observations."* (Diamond 1864: 139)

But even prior to the onsets of photography the representation of cuneiform artefacts played an important role. Already in 1778 the Danish/German mathematician and cartographer Carsten Niebuhr produced hand drawings of the Persepolis inscriptions, which proved to be one of the key tools for the subsequent attempts to decipher cuneiform (e.g., Curtis and Tallis 2005: 26). Many scholars followed and cuneiform was represented in various ways, be it in the form of artistic drawings in the publications by the archaeologist Austen Henry Layard or the progressive use of types, most notably known from the publications of Henry Creswicke Rawlinson and other scholars (Layard 1949: 193-194, note 2; Adkins 2003: 177-178), and therefore early predecessors of Unicode. All these attempts lack the accuracy, which is needed for any further study, be it palaeography (Devecchi *et al*. 2015 (eds)), the identification for possible joins, or for the purpose to reconstruct seal impressions. One might think of the early days of Maya decipherment, whose progress was hampered, in particular, by the rather artistic renderings of Maya glyphic inscriptions by early travellers and hobby archaeologists. It was the extensive use of photography, first by Alfred Maudsley, who documented many sites in the area of the Maya empire, which eventually led to progress. This situation is not very dissimilar to early cuneiform research, although in Assyriology there is the certain luxury that a considerable amount of primary sources has been accessible in museums and scientific institute collections since the mid-19th century rather than in remote regions of tropical Meso-America.

Amid a few exceptions it can be undoubtedly stated that early attempts to sketch cuneiform artefacts widely ignore the physicality of the artefact, such as its true shape, dimensions, clay type, condition, and colour. Frequently, early hand copies pay little attention to dilapidated surface and half-broken signs (Taylor & Cartwright 2011; Taylor 2011; Lewis *et al*. 2015: 157). Nevertheless, line drawings have always had a major advantage compared to photographs. Firstly, they reduced printing costs immensely, since a single photograph of one vantage point cannot depict the whole object and therefore several full raster images are needed in order to achieve a more complete coverage. Beside the expenses for printing, early photography throughout the 19th century was the exclusive field of technically specialized photographers who were skilled in working with toxic chemicals, glass negative and heavy equipment; all this led to an additional high production cost. Thus, the economic reason is an undeniable factor for the extensive use of hand copies in scientific publications. But obviously, hand copies serve another, more scientific, purpose. They draw the attention to those features, which are of interest for the intended study by only highlighting the inscription or seal impressions and as such, usually ignoring all other features. Hand copies therefore reduce the necessity to hold the original document, rotate or slant it and adjust the light angle in order to approach better visibility and subsequently reach an identification. From this point of view, the photographic visualisation (which includes all other comparable real reproductions of artefacts such as 3D models, holograms, flatbed scans, and so forth) has the disadvantage that they offer its end user an undigested perception, namely uninterpreted raw data. Hand drawings, on the other hand, despite the grade of their accuracy, trace the cuneiform characters impressed onto the clay surface, and therefore never can reach the level of objectivity of photographic representations. They represent interpretations of the cuneiform scholar and subsequently their producer. Cuneiform wedges are usually represented by their characteristic triangular shape, which make more complex configurations of wedges more accessible (Cammarosano et al. 2014; Bogacz et al. 2015). They therefore normalise what is in fact visible on an inscribed object; the threedimensionality is simplified and transposed onto two dimensions. In addition, the way the stylus left its imprint into the wet clay is standardised by which the 3D triangular impressions of the stylus are transformed into a familiar 'head + tail' representation. Many producers of hand copies follow a rather minimalist approach, most have even developed a personal ductus, and in many cases ignore the intricacies of cuneiform script in certain periods, when wedges *interact* with each other and so forth. Hand copies usually do not pay any attention to the writing material itself. Cuneiform styli usually were made of reed and the reed's texture appearing on the original artefact never features in a hand drawing (Hameeuw and Willems 2011: Fig. 8). Introducing all this kind of information into a hand-copy quite certainly diverts the attention from the actual inscription and is therefore in most cases intentionally ignored.

A further layer of complication is the capture of sealings on inscribed artefacts. From the physical point of view, the cuneiform inscription written by the scribe is impressed into the surface and thus forms a recession; seal impressions create a new surface of which the impressions, the depicted features, protrude from the surface. If seal impressions are registered together with the cuneiform text on a drawing, the sealing which sometimes appear rather prominent, need to be represented separately on a different level as the inscription. In order to achieve higher clarity and in such cases, in which a seal image is reconstructed from various partial impressions, the sealing should be given separately as well, since impressions often superimpose each other.

In the past, seal impressions, in general, and their iconographic data, in particular, was simply neglected, put aside for an art-historical analysis of seal imagery. Sealed documents were frequently deprived of their sealing or text publications only very exceptionally include information on the way a seal was impressed. If seals are copied, many hand drawings omit any reference to the iconography of the impressed seal. As such, in numerous Assyriological publication only the inscriptions on seal impressions are copied; the iconography is not. Although occasionally some publications in the past have dealt with this issue and the situation has improved in recent times,[†] this approach has done much harm to the archival context of the documents. Even if both text and seal are treated in one and the same publication, only in very rare cases there is additional data on the physical aspects. This lack of information limits many potential research axes.

Up until now, hand drawings of cuneiform artefacts are widely used, they have rightfully a long tradition in Assyriology. A hand-copy can perfectly highlight the features of interest in support of the published research. This transposition allows a swift insight into the study object; a key benefit in the examination of large numbers of documents. But again, herein lies also the main pitfall, a hand-copy is an interpretation by its producer. A drawing facilitates research questions, but these are highly dependent on its accuracy and mode of representation, in particular of eroded, hard to interpret and broken areas.

Early photographic attempts yielded high quality images, which are by modern standards still remarkably elucidating.[‡] It demonstrates that these imaging exercises were, in the first place, the work of professionals. Today, we all handle camera's, equipped with expensive lenses and manufactured with high definition light sensors; but because of the physical

[†] A good approach on how a hand-copy can successfully combine both incised cuneiform signs as impressed seals is achieved by attributing different grayscales to these diverse features, Nikol'skij 1915; Mayr 2012; Wagensonner (forthcoming).

[‡] For this, one can even refer to one of the earliest publications of oriental seals which gives very sharp photographs (*héliogravures*) with a good contrast, i.e. de Clercq 1888.

characteristics of an inscribed or sealed surface the imaging will always come up against a number of restrictions. Any image of a cuneiform tablet is a representation or an interpretation by the human who made it or the result of the applied technical approach; they all have their benefits or disadvantages (see the table below). For photographs the number one hazard is the lighting condition. It is practically close to impossible to perfectly illuminate, on a curved and irregular surface, all features to allow their identification. Some zones will be shadowed, others over-exposed. A solution for this has been found by coating the surfaces just before imaging with a thin layer of white ammonium chloride (NH_4Cl) to enhance the contrast on the pictures (Owen 1975: 14; Vandecasteele 1996). Worldwide, several research groups in cuneiform studies have specialised themselves in this technique; but most collection holders refuse this approach as it uses toxic products for which the effect on the ancient artefacts nor on the people who handle them is sufficiently understood. In order to improve results compared to conventional photography and reduce the risks that may arise using such chemicals, in the last couple of years some automated methods with photography have been used for capturing and processing cuneiform artefacts (Vandecasteele et al. 2005; Wagensonner 2014). Most promising in this respect is High Dimension Range photography, short HDR. HDR photos, which are usually merged from three different exposures, result in a representation containing more detail. Of course, this method uses a static light source as well. Therefore, the lighting is crucial, but in general HDR photography helps to compensate for either dark or over-exposed areas. Nevertheless, this method does not produce a dynamic image, in which certain features can be adjusted.

Capturing a nicely preserved artefact inscribed with clear cuneiform characters is no big challenge. However, collections in general and those in museums, which often derive parts of their objects from excavations, hold much more than just well-preserved text artefacts. In the past, many publications of cuneiform documents have too often focussed on objects whose state of preservation is comparatively good. Heavily damaged, deteriorating or hugely fragmented exemplars are often ignored or left aside for future research and eventual publication. Although this practice is understandable, thus neglecting certain collections by depriving them of a thorough and visual documentation, is not. Cuneiform signs, as well as iconography on seal impressions, are often difficult to capture in a hand-copy, even more so, when they are obliterated by surface damage or the build-up of salt crystals. The firing of unbaked clay artefacts (Thickett et al. 2002) was for a long time, and is still by some, believed to put a halt to further deterioration of such objects, but preserving inscribed artefacts heavily relies on a wide range of factors such as handling, storage conditions, and frequency of consultation. All these factors influence the state of preservation. Many clay artefacts deteriorate over time especially due to the amount of salts and the chemical reaction with the minerals in the clay fabric leading towards a weakening of the entire body of the tablet. Clay objects, which are left in such a state, will crumble over time. Bigger collections of cuneiform artefacts have been baked and fired. This rather invasive treatment of firing a tablet is irreversible and may lead to rather significant alterations in the body of the tablet. Often a clay artefact has been studied and photographed before firing. Easy to apply imaging technique can be the solution for this group of objects.

It is well known, that although the process of baking tablets makes the salt crystals fall off, the same process can also occasionally make tablets crack or even deteriorate. Thus, each imaging effort, whether a drawing, photograph, flatbed-scan or 3D modelling technique is a documentation of the artefact at that moment in time. It captures the respective condition of an object, but it might also visualise additional or fewer features compared to earlier attempts. Any effort can be the first, but also the last chance to document the artefact. Both publications and databases aim for a complete registration, which will allow for the highest amount of research avenues in the future. Excluding artefacts from a full registration might bear the risk that those objects are not available anymore in the future because of advanced deterioration.

The effort of imaging has in Assyriology a long-standing tradition. Some important or highlight tablets and monuments have been drawn, photographed and 3D lasered a dozen times. Others are slowly crumbling away; being neglected since the day they were unearthed. The challenge to image them all seems out of reach, but is secretly the wish of everyone in the field. When representations of these artefacts are being created; they mostly serve a purpose; but what is *this* purpose? What makes an image good? Is a high-quality textured 3D model truly superior to a hand-copy? Is an image without additional information desirable? And if we have all that data, what should we do with it?

B. What is an image

Before discussing what makes an image appropriate for the field of Assyriology one point should be stressed firmly. Any image of a cuneiform artefact is merely a model and therefore can never be better than the original object. So far it is not possible to handle the representation of a cuneiform artefacts in the same way as a researcher handles the original artefact. It is, nevertheless, possible to facilitate this discrepancy and even go beyond the visual aspect of an artefact and highlight features, which elude the work with an original object. A cuneiform tablet, its inscription, as well any seal impression carries 3D information. Due to this 3D nature, all its surface characteristics can only be observed and recognised if variables can be controlled with or around the physical object. While handling a clay tablet, for instance, the three dimensions are only perceived correctly by altering the vantage point, by moving, slanting and rotating the object as well as by changing the light angle cast onto the surface of the object. Only then is the human brain capable of understanding its actual shape and physical characteristics. In the real world a researcher has control over all of these parameters. Both the head as well as the object can be tilted in any direction. The use of two eyes and thus two viewpoints adds additional stereo perception of all three dimensions.

A lithographic representation as a conventional photograph or any representation in print will not allow for any modification of the three parameters mentioned above. In print publications such a representation can approach such 3D characteristics only if multiple images are used, which portray an object from various viewing angles. Hand drawings compensate for the shortcomings of this kind of visualisation, because they flatten the curved surface and therefore normalise the inscriptions by putting it onto a two-dimensional plain.

Modern imaging techniques frequently offer alternatives in visualising objects. Through an interactive representation of an artefact one or several of the afore-mentioned parameters (i.e., changing the position of an object, the viewpoint, and light angle) can be manipulated or better simulated on the computer screen. From such an interactive approach, a 3D model that had been generated by capturing the object with either laser, structured light or by the multi-light approach, is usually displayed on a 2D screen, which by its nature always has limitations: It does not matter, from which angle the user observes the rendered 3D model. The human brain would not be able to extrapolate its actual shape, unless the software simulates how the reference points appear while rotating the model and altering the lighting conditions around it. This interactive approach allows the human brain to comprehend its actual shape. Virtual reality (also augmented reality) may at least in future offer new avenues to study 3D models.

In contrast to 3D models, the multi-light approach (also known as Reflectance Transformation Imaging) conventionally using 2D+ viewer software, allows the user to manipulate the light angle cast onto an object. An imaging technique, which aims at capturing and visualising all 3D characteristics of an object, the raw data should permit the control over one of the afore-mentioned parameters. Any other (conventional) visualisation technique leads to a static 2D representation, as does any snapshot of a 2D+ or 3D model. Conventional 2D representations such as these will only register and visualise features that are perceived from one given vantage point and in a particular light condition.

At the same time, an image can be more than just a visualisation of an artefact. Drawings can accentuate or even exaggerate certain features on the artefact. 2D and 3D renderings can be appended by all kinds of annotations. And certain imaging methods go far beyond the pure visualisation of surface features. This can vary from system that can look beyond the surface such as infra-red, X-ray or CT-scans, but one can also think of the ability to suggest restorations for damaged areas on a drawing or photograph.

In Assyriology images are crucial, in particular of artefacts that are not easily accessible for the researcher. Images also are the most appropriate manner to present the source data of a study. It is therefore crucial to examine the type of visualisation chosen by the researcher in order to represent an artefact. Does it provide all the necessary data in order to allow for a critical approach to a study or does this representation withhold any necessary information and whose importance for further research questions the researcher did not anticipated. This view is comparable, for instance, to different graphs that are considered to be varying representations of the same raw data. Nowadays, 3D models are often conceived as being an all-inclusive means to register an ancient artefact. But does the rendering include a texture map, which provides detailed information on the surface condition, such as colour. If the separately prepared scans of each side have been merged together, was this achieved precisely?

C. What is a good image?

It is therefore time to ask ourselves the crucial question: What constitutes a good image? What do we need to expect of such an image, or better, what does a good image have to fulfil for the end-user? If there is no immediate access to a cuneiform object, the importance of its representation grows with the variety of the data it provides. Therefore, one can conclude that a sufficient representation of a cuneiform artefact aims at opening up the data and does not limit it in order to highlight specific characteristics. Conventional photography usually has its limits when it comes to curved sealed surfaces, because the angle of light cast onto the object's surface is crucial. This situation is even more taxing when dealing with both inscribed and at the same time sealed cuneiform artefacts such as envelopes or administrative and legal texts. In general, the producer of an image or subsequently image dataset can only foresee a certain amount of research questions that might result from the capture process. The data should be freed, as much as possible, from restricting a researcher in asking more questions than are plausible at the beginning.

Such a model supports the research question and provides all the information about the respective object including non-visual data. Thanks to new technological advances, the quality of an image can nowadays be substantially increased and thus the spectrum of registered information supersedes early attempts. Nevertheless, new technologies undergo intensive testing stages and their development reduces constraints that used to be an issue. But one has to stress the importance of data that accompanies the visual representation of a cuneiform artefact. Non-visual data contains a whole range of information, whose inclusion increasingly opens up an object for further research. Such non-visual data contains not only metric information and technical meta data, which is directly related to the capture process and therefore provides information on the specific situation an object was registered in, but furthermore object-related data, such as bibliographical information, transliteration and translation, as well as many more. In a digital age a good image cannot exist without this kind of additional data or the goal for research-driven capturing is missed.

Let us come back to a type of cuneiform artefacts which used to pose problems. Conventional photography usually had difficulties sufficiently capture sealed documents, mainly because of the rather faint impressions that are left on the wet clay from a cylinder or stamp seal, but also by the very fact that the imprint of a seal usually leaves a negative impression on the clay surface whereas the cuneiform stylus does exactly the opposite. This creates two rather different appearances and the producer of a modern representation needs to adjust the light accordingly in order to highlight either one of the features. A low light angle, and therefore raking light, visualises a faint seal impression better, but produces deep shadows in the imprints of the writing stylus, which subsequently reduces the readability of a cuneiform document, and it leaves the opposite side of a tablet with a curved surface in darkness. A good image allows its viewer to visualise all those specific features in one and the same visualization. This is possible in dynamic images such as 3D and 2D+ representations. Although some attempts to represent both features can be observed in hand drawings of sealed documents as well, seal imprints are still frequently torn apart from the inscribed artefacts they belong to.

A 3D model fulfils certain criteria, which are lost in conventional 2D representations. Consequently, many imaging projects have labelled 3D modelling as the most favourable method (Lewis et al. 2015: 157). Such models visualise the physicality of a three-dimensional object and therefore allow certain research angles, which are not easy to achieve by conventional methods. The chosen capture technology should not put the image producer in the position of deciding what the end user of the image will look for in the image when it is being visualised in a publication, database or online. Conventional photography and also hand copies usually restrict certain features and therefore its producer, i.e., photographer or epigraphist, highlights specific aspects in order to attract the final recipient's attention to such a feature.

In those cases where the acquisition technique has gathered a lot of different types of data, we need to ask what we can do for that data in order to make sure that the created datasets become useful. The image producer is freed from most of the decision-making process, since the capture already sought to include as much meta-data and non-visual data as possible. All this information allows for any and new approaches as well as research angles. Thus, well captured images include various types of data. It is up to the researcher to approach them wisely and to present them in support of their study. Researchers or research projects need to modulate this vast and sometimes technically complex data to create a research environment suitable for the human eye.

In conclusion, a good image includes all the data of a given object covering all its aspects and characteristics. But, a couple of issues still needs to be addressed in order to achieve this. One main concern is image resolution and quality. In the past, certain minimal and maximal requirements for the capture of cuneiform signs have been brought forward. For photographs or scans one finds recommendations for resolutions of 300, 500, 600, or 1000 dpi. 3D renderings should scan up to about 50 µm (micrometer) or 25 microns (Anderson and Levoy 2002: 84; Kumar et al. 2003: 228). Given such variability a standardised approach appears to be favourable. However, strategies such as these must also be deliberated due to increased data management and storage issues. Is it really necessary to produce a 1000 dpi photograph or scan for a quite standard text artefact, such as an Old Babylonian school tablet? On the contrary, is an accuracy of 50 µm sufficient for a messenger text? This assessment even changes when we zoom in to the level of what types of information an imaging technique stores per pixel. Hence, multi-light reflectance methods conceal per pixel more than just a colour value, but as well its reflective characteristics in changing lighting conditions or even their physical spatial orientation; these all increase the abilities for the user to understand the features of interest on the surface of an artefact. Many parameters can be adjusted while working with datasets, that can be approached on an interactive level.

D. So what makes a good image dataset?

We have seen that a *good* image constitutes more than the visual representation itself. But already the visualisation itself depends on various aspects such as image quality, lighting, and of course focus as well as depth of field, ISO and so forth. We have seen that lighting for conventional photography often requires a decision to be made. This is the case, in particular with artefacts that have both sealed and inscribed surfaces. A good image dataset contains all visual and non-visual data and subsequently makes all collected data accessible in a format, which can be read and used for further research questions that might arise.

However, open access comes with various constraints, which are not always foreseeable. A major concern is technical issues. Whereas conventional photos and representations of artefacts are quite easy to visualise, the more sophisticated the technology is, which is being used to capture an object, the more problems arise in order to visualise the data efficiently for the end-user. That is unfortunate, as it is precisely these extended dynamically approachable datasets which allow a whole new set of studies. Interactive models such as 3D and 2D+ representations are often too heavy to be consulted online and web-based viewers frequently come with technological limitations (plugins, software extensions, up-to-date java and flash player, …) compared to desktop applications. A good image dataset should therefore be able to cope with what the possibilities are to publish the outcome; to digitally safeguard it in the long term; and to take into account the technical abilities of the available systems of the end-user. 3D models can be formidable datasets for cuneiform studies; but visualising and dynamically consulting them in original quality on standard computers used by researchers in the field of Assyriology remains problematic (Kantel et al. 2010). Perhaps the ability provided by Adobe Acrobat to incorporate 3D models in PDF's, consultable on any computer and even smart devices, can guarantee the best dissemination and digital preservation conditions for this type of datasets. However, most online and PDF visualizations are decimated datasets with a poorer quality, with a lower variety of properties and fewer meta-data.

While these technical issues are being resolved, there are further problems that make open access an ever-challenging task. Many owners of cuneiform collections want to make their holdings available online as long as they have been published in print. Print publications take time in both preparation as well as their lay outing and printing. Therefore, the availability of cuneiform sources may undergo huge time-lapses. On a marginal note (see also above), print publications frequently pay preference to better preserved cuneiform artefacts and leave crumbling and less attractive objects in store for later publication. This inevitably brings us to issues concerning the copyright of images and questions of owners' rights and the fair use of data as well as the intellectual property in the case of transliterations and text editions. Whereas the copyright of a photographic representation, be it either one done using a conventional imaging method or a more sophisticated technology, lies with the person producing that image, unless he has agreed to transfer it to the owner of the object, other representations such as a hand-copy or the edition can be considered the intellectual property of the respective producer and/or its publisher.

The practical issues outweigh some of the challenges addressed so far. One among these is the availability of server space in order to store the collected data, and in particular means to maintain the implemented data structures. Data-collecting projects might die because of the end of funding periods, but the data they collect must never die and needs to be stored in a sustainable way, in order that it can be used in the future as well. Except for the cost of server space, whose support needs to be occasionally prolonged, the costs for the maintenance of data need not be relevant in case the data has already been stored within a meaningful framework. Sustainability is achieved through open data formats, via stable pathways and repositories, which allow for unlimited access to collected data also in the future. It must be a joined effort by host institutions of data-collecting projects, the collection holders and third parties with data management systems to digitally safeguard the collected data; to further develop its potential and to keep it presented to the public. Datasets can be complex and might include various layers of information, but their accessibility need to be guaranteed by upgrading systems. Nowadays, online databases provide a distilled quantity of data, which excludes the whole spectrum of information provided by the image dataset. However, strategies need to be explored and developed, which allow access to the complete dataset in their original quality and extent.

E. What do we want with our image dataset?

A good image dataset fulfils various tasks and purposes depending on the respective recipient's needs. However, it needs to be highlighted here again that such an image dataset allows for further research queries, which have not necessarily been intended in its creation. The various purposes of such an image dataset rest on three columns, whose respective areas appear not to have clear boundaries.

One of the main purposes of an image dataset is curatorial in nature. Owners and curators of cuneiform collections require an up-to-date database in order to manage the collection and make it accessible to scholars and other stakeholders. Today, quite a few museum collections use database systems, which are rather interdisciplinary in nature encompassing information not only on ancient Near Eastern artefacts, but also, and on the same level, data concerning Greek vases, Renaissance paintings, and so forth. Such database systems are often not suitable for the rather specialised field of cuneiform artefacts and the data presented in them usually only fulfils the purpose to take inventory of the holdings of a collection. Frequently datasets such as these contain visual representations of a given object, but such a representation solely fulfils the purpose to visualise the object in a rather purpose-driven way. The image usually is not destined to feature in further research. An

image dataset fulfilling all the requirements of a good image outlined above fulfils important needs for curators and museum staff alike. Collections frequently receive requests from researchers to provide images of objects. The collation of a single or a few texts often does not justify a long travel, and a good image dataset can provide the necessary data in order to avoid additional costs for the end-user. But an image dataset fulfils many other curatorial tasks. It visualizes the content of collections for its owners. This is, in particular, the case with larger collections, whose holdings are not apparent through a quick survey. This is an important task, since many collections lend their holdings to exhibitions either within the same premises or elsewhere. An image dataset helps with the assessment of the insurance value and therefore facilitates the related administrative work. However, most relevant is the fact that an image dataset provides the current condition and state of preservation of an artefact. Here, besides state-of-the-art visualisation as 2D+ or 3D imaging, the dataset should include previous representations such as, for instance, excavation photos, photographs before and after eventual conservation treatments, hand-copies, notes, etc. The present conservation status of a cuneiform artefact depends on the treatment it received in the past, which sometimes needs to be partly reversed. This kind of digital preservation represents a snapshot of the object at the point in time when the last capture has been taken. Furthermore, intranet collection databases can conceal details on the acquisition history of the artefact; estimations on the value for assurance purposes or incomplete entry field. Collection holder will ask themselves whether all this data need to be available online? Although some of this information should be for internal consumption only, it is important to make as much as possible of the visual information available online in order to open up the data and allow for any research questions that might arise. The inclusion of non-visual data helps to achieve to establish a proper information management.
Curators also usually provide a public function. They want to open up their collection online or within a museum context. For that purpose images play an important role. Together with researchers, it is therefore quite often curators who take the lead in introducing new visualization techniques which give them the ability to interactively present their collections. It is an added value if datasets, based on one and the same imaging effort, can serve academics as well as those interested in heritage.

The main incentive for a complete registration of a cuneiform artefact and the creation of a complete image dataset is research-driven. Hence, an image dataset is either part of an institution or of a personal research database, both of which can be used online and/or offline. Such a research database can use the complete image dataset or highlight specific features, which are guided by the specific research question asked. A rather narrow array of query might be limited to stamp seal impressions on the edge of Hellenistic legal documents. However, it is important to emphasise that the producer of an image must not have this narrow research question in mind when producing image of them. The afore-mentioned query is merely a later step, in which certain features of the cuneiform artefact are highlighted or extrapolated from the image dataset.
Many image datasets are being produced and used to illustrate research in cuneiform studies. A win-win situation is found if extra projects and research avenues can be grafted on these same datasets. Objective images in support to a text edition can be used for palaeographic studies (Cuneiform Digital Palaeography – CDP – Project; Ossendrijver 2015). When imaging techniques which include three-dimensional metric data are available even more particularities can be studied or explored in detail, such as handwriting (Fisseler et al. 2013; Cammarosano et al. 2014), automated sign extraction (Mara and Krömer 2013; Richardson and Smilansky 2014; Bogacz et al. 2015), tablet reconstruction (Fisseller 2014; Collins et al. 2014) and fingerprints (Mara et al. 2010: 136).

Last but not least, an image dataset of course fulfils needs for publishers. Traditional media publications require high-quality photographs, which may be done professionally by conventional photography in a studio. Good print publications rely on the reproduction of these high-quality raster images. The more an image dataset allows for adjustments in the visualisation of an artefact the easier that specific data can be used for publication. Thus, although for research-driven or curatorial purposes interactive images might be desirable; they might be very problematic or without added value when they are used for printed publications. To overcome this, algorithms have been suggested to unwrap 3D models (Anderson and Levoy 2002; Pitzalisy et al. 2008) or multi-light reflectance datasets come with visualisation filters which can graphically enhance in 2D what is discussed (Willems et al. 2006; Earl et al. 2011). Unfortunately, interactive visualisations are mostly disseminated in printed media with the help of a series of screenshots. On the other hand, more and more publishers try to reduce the costs for printing and allow for cross media publications, which contain links to a database or have their own online repository for a variety of datasets. For such an approach it is, however, essential that the data is stored together with stable pathways unaltered for the foreseeable future.

F. Excursus: Table of comparison: Imaging techniques and their criteria of importance

	Hand-Copy	Standardisation	Digital Vectorization	Conventional Photography	HDR photography	Flatbed scan	Multi-light	3D model
objectivity	★	(★)	★★	★★★	★★★	★★★	★★★	★★★
speed	★	★★	★	★★★	★★★	★★★	★★	★ (★★)
experience	★	★	★	★★	★★	★★★	★★★	★★
accuracy	★	(★)	★★	★★★	★★★	★★★	★★★	★★
new research questions	★	★	★★	★ (★★)	★ (★★)	★ (★★)	★★★	★★★
sealing	★ (★★)	---	★ (★★)	★/★★ (★★★)	★★ (★★★)	★	★★★	★★★
visual clarity	★★★	★★★	★★★	★★	★★ (★)	★★	★★★	★★★
storage	★★★	★★★	★★★	★★	★★	★★	★★ (★)	★
durability	★★★	★★★	★★★	★★★	★★★	★★★	★	★★
accessibility technology	★★★	★★★	★	★★★	★★	★★	★ (★★)	★ (★★)
accessibility results	★★	★★	★★	★★	★★	★★	★	★ (★)
equipment cost	★★★	★	★★★	★★★ (★)	★★★ (★)	★★★	★ (★★)	★ (★★)
real cost	★	★★	★★	★★★	★★	★★★	★★	★ (★★)

★★★: very good/easy, ★★:moderate/acceptable, ★: problematic/bad

Extensive legend to the table of comparison

In advance – The exercise in the table above aims to be an estimation of what the different imaging techniques in cuneiform studies are about. But obviously, such exercise is a simplification of a much more complex reality. There is no such thing as *the* prototype hand-copy and for both multi-light as 3D modelling, there are several different techniques with their own mutual advantages and disadvantages.[§] One 3D model might be made faster than the other; but the faster one might be, it probably consequently has to make sacrifices in accuracy. The table therefore tries to provide an average rating; or if extremes can be obtained within one and the same technique; two rating were given, the second in between parentheses. The color codes visualize the rating where the most weight was given to.

Objectivity: *is the final result an objective★★★ or a subjective★ representation of the original.*
Quite obviously it is the imaging technique which require a lot of human interference which scores the lowest. Digital vectorization is valued higher compared to a hand-copy as the standard vectors are adopted to the actual characteristics and shapes of the signs with help of a photo editor.

Speed: *the final result is obtained fast★★★ or it takes a lot of time★.*
Strictly spoken, any of the imaging technique discussed in the table can be executed fast. The scores are therefore based on well accomplished results. The simple setup required for flatbed scanning and (HDR) photography make these methods by far the fastest. Multi-light gets two stars as the setup is a bit more complex and the processing of the images is for most available systems a fairly automated process.

Experience: *the threshold and training to acquire good results is low★★★ or high★.*
Flatbed scans and multi-light require no technical or substantive experience in relation to the material to visualize. Once these systems are setup; any researcher can make good images. Photography, and to a lesser extend HDR, require more experience as the most preferable lighting conditions have to be established by the executor each time again in relation to a new artefact. 3D modelling remains a technical challenging method, which in almost all cases still needs substantial post-processing by experienced staff to acquire good results.

Accuracy: *compared to the original is what the result shows an accurate (1:1)★★★ representation or are mistakes inherent★ to the method.*
Hand copies, and even more representations with standardized signs, can never be really exact. They only accentuate or visualize what the copier detected and decided to draw. Digital vectorizations receive a higher mark as it is inherent to the method the tracing of the signs in done on top of a photograph. All technique with a pure photographic outcome can be regarded as accurate. For 3D modelling, in which separate scans or photographs are merged into one textured and/or untextured model, this initial accuracy is affected, and on most occasions reduced in the final model.

New research questions: *is the potential for opening new avenues of research questions high★★★ or low★.*
Most imaging methods have as final product a static raster image; they were given the lowest rating. It is images for which the data sets incorporate additional information, if possible, which can be approached interactively, which surpass the pure visual character of

[§] For 3D modelling recently a similar assessment and comparison was made for photogrammetry, structured light (MechScan), laser scanning (NextEngine) and CT Skyscan, see Mathys, Brecko and Semal 2014.

an image. For digitally vectorised texts the vectors are stored virtually and can be used for on demand searches or trans-artefact comparison. In multi-light and 3D models the full knowledge of the surface allows all kind of researches for which the tri-dimensionality of the artefact is of importance. Well preformed photographed based imaging methods in addition give good potential for future studies as well, if these outcome gives a complete coverage of the surface in a sufficient definition.

Sealings: *do the results visualize seal impressions well*★★★ *or not*★
For some of the methods listed in the table this can vary according to on which feature the imager focused on. For hand copies, digital vectorization and flatbed scans experience shows the result should or can never be titled as excellent. Or the outcome is to subjective or the imaging technique can insufficiently deal with the physical characteristics of the sealing. Conventional and HDR photography can deliver images with excellent, moderate, but as well very badly visualised seal impressions. It is by far multi-light and 3D models which are able to image sealings best as they can equally register features which are impressed in the clay as those which protrude from the surface.

Visual clarity: does the image *visualize the features of interest distinctively and clear*★★★ *or not*★*.*
Photographic approaches here have the disadvantage. As all visual features are imaged into one static raster file, cuneiform signs, seal impressions or other features do not necessarily stand out. It is the more traditional methods which simplify the characteristics to black and white images and the approaches with data sets which can be approached interactively which receive the highest scores.

Storage: *does the outcome create serious challenges*★ *for the storage of the data or not*★★★*.*
The digitalisation or virtualisation of images causes for some approaches loads of bytes. The black and white images; even if they are scanned or saved at a high resolution give the least challenges. High definition compilations of photographs and flatbed scans are more demanding, but it is certainly the heavy 3D models which cause the most troubles. Multi-light datasets are generally not larger than HD photograph (so two stars); but the raw data does demand serious storage capability (so 1 star between parentheses).

Durability: *will the result stay consultable over time*★★★ *or are there specific issues*★*.*
Printed raster images or digitally stored commonly use computer files such as .jpeg or .tiff which should not cause future problems, and can as such be considered as durable solutions. The imaging methods with an interactive outcome have the disadvantage that their file formats are currently not yet always standardized. When 3D models are stored in one of the most widely used formats (.obj, .ply, …), their future prospects are most assured. Multi-light file formats, on the other hand, are (*anno* 2015) still a niche; handled only by a limited number of user groups, almost uniquely within heritage applications.

Accessibility of technology: *are the materials, equipment and possible software easily accessible*★★★ *or not*★*.*
Having access to a pencil, calliper, pen, millimetre paper, computer or digital camera is estimated as basic equipment for a researcher. For the modern version of standardization of cuneiform signs, easy conversion is possible thanks to Unicode. HDR photography, digital vectorization and flatbed scanning require more specific software and/or hardware support and equipment. For multi-light and 3D modeling both the needed hardware and software solutions are very specific, and in some cases, assess to them is limited. At the same time,

for both approaches more accessible methods are available: for ex. hightlight RTI or photogrammetry.

Accessibility of results: *is a result easy★★★ to consult or not★.*
It is essential that acquired data should be published or made accessible as soon as possible; otherwise they remain unconsultable for 99% of the interested researchers. The publication of images (whether in print or as digital file in an online database) depends on both the user of an image (identical with its photographer or not) and the owner of an object. Technical difficulties or publication strategies may influence the decisions for access to an image.
Therefore, none of the imaging techniques in the table were rated as excellent. Interactive datasets – as being more recent inventions – have an outcome which is written in more rare digital file formats which are, to a much higher degree, less integrated in standard imaging tools on computers and in browsers. For many of these results specially designed software packages and plugins are required. The good news is that these solutions are mostly provided for free and that viewing – but unfortunately mostly in reduced quality – of 3D models is rapidly becoming easier.

Equipment cost: *is the cost of the equipment low★★★ or high★.*
For several of the techniques the cost will vary if, or if not, high performing equipment is used; that explains the double rating of the approaches which use HD photography. Obviously multi-light and 3D modelling are the most costly, some of the equipment is even not available on the open market and has to be custom-built. But again, obtaining good results with techniques such as highlight RTI and photogrammetry are not necessarily expensive.

Real cost*: is the cost of needed equipment, time investment and data management low★★★ or high★.*
Both for researchers as well as for collection holders this estimation plays a crucial question in selecting a preferred imaging technique. Although the equipment to produce a hand-copy is inexpensive, the time needed to produce a drawing is vast. For 3D modelling the real cost is high, as the equipment, software packages and data management can be costly and as the acquisition time and (post-)processing is time-consuming. The methods with the lowest real cost are those which only require a simple setup, where recording is speedy, where minimal experience is needed, that have acceptable storage demand and with a low equipment cost. From this perspective, digital photographs and flatbed scans can be regarded as most recommended.

G. Conclusions

Following all that has been said above, one must conclude that there is currently no imaging technique that would cover all the criteria making up a good image or all-inclusive dataset. A crucial criterion lay in the research questions that are being asked or the objectives that are intended. A researcher, for instance, may only be interested in seal impressions, and not necessarily care for any other information provided by an artefact. Of course, the producer of an image dataset should *not* limit the data to such a narrow research angle.

In an ideal situation, with no financial constraints or time limitations, an object should be imaged using as many imaging techniques as possible in order to open up the data to any research question that might come up in the future. However, the practical situation looks rather different and the major constraints are limitations of time, the crucial storage of data and, of course, the access to original objects, which might be limited for various reasons. Be that as it may, image datasets that may comprise data derived from various imaging techniques, need to comply with certain standards and also allow communication between the techniques used. Therefore, open data formats are the primary necessity in order to guarantee that data is still accessible in the future. Similarly important is a backup or mirror of the collected data at various locations, in order to safeguard the data for future consultation. This is particularly important in light of artefacts that deteriorate over time.

The goal is to capture any inscribed or sealed document. This includes both easy as well as difficult objects, such as fragmentary texts with eroded surfaces or barely visible seal impressions. As was discussed above, the imaging method either needs to be adjusted for such objects or a method is added in order to achieve the best result. We are well aware that technology will keep advancing, but since the artefacts will not keep their current state of preservation, action is needed now. Their handling, the storage and time alone will cause them to deteriorate, no matter how well they are cared about. As was mentioned earlier, print publications used to favour better preserved or highlight documents over less appealing or less interesting artefacts. But imaging must not be restricted to just a selection of objects. Any fragment needs to be digitally registered and open access to it needs to be established. The more people can benefit from the data and use it for their research, the greater is the appeal for collections to add further data. And this appeal will grow in the near future. Due to the crises in the Middle East and the vast destructive forces sweeping through museum stores and sites. As has happened in the past decades, vast numbers of artefacts will soon overwhelm the international heritage stakeholders. It is their registration which will help to identify looted artefacts and repatriate them, but it will also guarantee that artefacts are digitally preserved. Therefore, it is a prerogative to provide simple user guidelines for imaging techniques, because any image of an artefact is better than no documentation at all. In the last couple of years, members of the CDLI have been training museum staff in producing images and administering the data. RTI workstations in various collections (e.g., Louvre, Yale, etc.) are being used to capture objects by trained staff and students. Both the Leuven Portable Light Dome and the RTI systems built by University of Southampton have provided many scholars with interactive images in support of their on-going research. RTI has, more than 3D, proven essential, in particular for scholars, who cannot easily travel to collections worldwide, be it out of financial or political reasons. While RTI and other modern imaging techniques have a wide field of applications, the field of cuneiform studies profit immensely from this data. The more such datasets are being made available to the broader public, the more the field can make use of it and will be able to make progress (e.g., hand writing analyses, seal use, etc.).

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