COMPUTER VISION IN THE TEMPLES OF KARNAK : PAST, PRESENT & FUTURE

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ABSTRACT:

CFEETK, the French-Egyptian Center for the Study of the Temples of Karnak, is celebrating this year the 50th anniversary of its foundation. As a multicultural and transdisciplinary research center, it has always been a playground for testing emerging technologies applied to various fields. The raise of automatic computer vision algorithms is an interesting topic, as it allows non-experts to provide high value results. This article presents the evolution in measurement experiments in the past 50 years, and it describes how cameras are used today. Ultimately, it aims to set the trends of the upcoming projects and it discusses how image processing could contribute further to the study and the conservation of the cultural heritage.

1. INTRODUCTION

Mainly dedicated to the god Amun-Ra, Karnak had stubbornly remained the heart of the religious and political power for more than two millennia. It is among the best preserved sites of Egypt. Since the end of the 19th century, French Egyptologists have been studying the group of monuments within the main precinct, which expands over an area of 2.6 km^2. These include the temple dedicated to Amun-Ra and several other structures attached to the cultic center. The site was built by the greatest kings of Egypt, among which are Senusret I, Thutmose III and Ramesses II, and it presents a rich collection of monuments whose diversity is a unique witness of the religious, political and technical changes. Karnak continues to be an object of research that is periodically enriched by archaeological discoveries. The latter are partially made possible thanks to technologies in constant evolution.
As of today, more and more bridges are built between the so-called “hard and soft sciences”. This article aims to present how collaborations between the Egyptologists and photogrammetry specialists help the ongoing work of excavation and restoration, and to contribute to a better understanding of the hieroglyphic inscriptions studied in the *Projet Karnak* [1].

2. PAST

2.1 Early experiments

The 3D modelling of the environment has been a wide subject of interest in the 20th century. The evolution of measurement techniques has been an opportunity to create copies of our cultural heritage, which is still today a challenge for the preservation of endangered sites.
In 1967, a few years after its participation in the conservation of the antique Nubia heritage, including the famous Abu Simbel temple, IGN - the French mapping agency – produced the first thorough map of the Karnak temples at a 1:500 scale from an aerial stereophotogrammetric acquisition.
It is interesting to note that the process of acquisition and the restitution involved teachers as well as students (Yoyotte, 1966). Still used today as the base of the topographic canvas and refined years after years (Azim et al., 1998), this map proves how pedagogical programs can have an impact half a century later.
Starting in the mid 1980’s,(Vergnieux & Gondran, 1997; Vergnieux, 1999) led a study using modern computer aided design technologies focusing on 12 000 blocks from the reign of Akhenaten, who is known as the heretical pharaoh.

2.2 Twenty-first century

The technological revolution induced by the introduction of computers has impacted photogrammetric processes with the emergence of digital photogrammetry. In the early 21st century, the computer vision approaches brought a lot of automation in the processes, renewing the interest for 3D reconstructions from images.
At the beginning of 2000’s, digital photogrammetry has started to be employed, in combination with terrestrial laser scans in two digitization projects. This period constituted an intermediate technological phase before its current independent use, low-cost and overall easier method. The first one aimed at studying the 134 columns standing 13 to 20 meters high in the great Hypostyle Hall (Chandelier et al., 2009). A French-Canadian mission produced 3D models of the columns and derived unrolled orthophotographs. Another campaign is still undergoing and interdependent with the American-Canadian epigraphic mission conducted by J. Revez and P. Brand (Meyer, 2004; Meyer et al., 2005; Brand et al., 2013).
The second important project of this decade took place in the temple dedicated to the goddess Opet and the god Osiris. Led by E. Laroze, it aimed at producing a 3D model of the temple thanks to the use of both LiDAR and digital photogrammetry (Chazaly & Laroze, 2005). Among other uses, it was valuable to produce orthophotographs and cross sections scaled at 1:50.
Between 2011 and 2014, the Center, always open to innovative technical approaches, hosted several survey by the University

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of Oxford, which involved the use of Reflectance Transformation Imaging (RTI). (Frood & Howley, 2014) used this technique for the study of ancient graffiti located in various areas of the temple. This computational photographic method is particularly apt to get clear images of shallow engravings and so to gain a better understanding of these non-royal inscriptions.

3. PRESENT

3.1 Applications

After 50 years of progressive evolution and field testing, digital photogrammetry is now a relatively mature technology. It has impacted – at various degrees – each profession gathered in the Center, from that of the land surveyor, to that of the stone mason, including the photographers, the archaeologists or the Egyptologists.

3.1.1 On the archaeological excavations: Since 2008, excavations are being carried on in the precinct of Ptah, in the northern area of Karnak. The main goal of the work is to set the evolution of the enclosure walls, the better preserved period being the Ptolemaic one. To gather topographic informations of this brick-built Ptolemaic surrounding wall, the first archaeologists to work in the area were using a total station in order to create a minimalist pointcloud (a few hundred points). Each of these dots were then printed on paper and connected. The paper being then scanned and used as the basis to draw the final map on Illustrator or AutoCAD. This method soon appeared to be very long and not very efficient to deal with the large mud bricks structure in the investigated area. Having a very limited working schedule on the excavation, a solution had to be found to improve the survey. Meanwhile, photogrammetry has developed enough to study such structures efficiently.

A few years later, it has become essential for archaeologists and to speed up the process of field documentation. In comparison with the traditional method to maps of the excavated area, the image based approach appears to be much more effective in terms of time requirements, accuracy and completeness of the survey (introducing the possibility to produce new types of documents later on). Concretely, within the framework of the excavation of the temple of Ptah, a survey that previously required a full day of work on the field can now be achieved within an hour.

The photogrammetric acquisition follows the recommendations of (Chandelier, 2011). A few Ground Control Points (GCP) are surveyed on the edges of the area of interest (with a relative accuracy of a few millimeters). A 4 meters pole and a remote control are used to get the most favourable viewpoints, and the shots are treated with Agisoft Photoscan. The ortho-images computed are likely the most important products for this specific mission, as they can be imported in a CAD software to draw the excavation map. Multiscale works can also be realised easily through this technique, as for example drawings of individual bricks that can be inserted directly in the georeferenced CAD file. By following this process several types of documents can be produced: 3D models (possibility to create videos), ortho-images, excavation maps, etc.

The production of the archaeological documents has benefited from that technology, and so has their exploitation. The realization of a 3D model in a sector constitutes a digital copy of an incomparable precision/resolution, while remaining a very simple tool that can be used by non-experts of 3D modeling. For every point in a 3D model, one can measure its height from the ground, or compute its distance from another point. This exploitation of the 3D imaging also allows to save time during the field work, as some of the measurements can be postponed to the post-excavation work. This type of document was difficult to produce until some years ago. Today, the export of these 3D models is made under PLY format, and they can be consulted with free and open-source software (CloudCompare, 2017).

When in 2015, a “favissa” was discovered next to the temple of Ptah (Charloux et al., forthcoming; Charloux & Thiers, 2017), digital photogrammetry was already employed as a common tool by CFEETK’s land surveyor. The experience accumulated in the previous years opened new possibilities; thanks to the expertise of K. Guadagnini, it was first time an animated video could be reconstructed from several photogrammetric acquisitions. Apart from its scientific value, the video proved an innovative and powerful tool to share the step-by-step discovery to the public.

Another application of the 3D model is the realization of stratigraphical cross sections, from the accumulation of several copies of ortho-images. In any location of the site, it is possible to define an axis of a few centimeters wide and obtain the various stages of the excavation for such axis. If this one followed the stratigraphy and if every stratum was ortho-rectified, a cross section can be derived from the various layers. The results of this technique are convincing as they deliver the same level of accuracy that can be obtained throughout the excavation on the field, which requires the installation of a permanent axis chosen in advance. This exploitation of the 3D imaging avoids the time-consuming realization of cross section along the excavation as well as it offers a large freedom concerning the choice of its location.

3.1.2 On the epigraphic studies: One of the main goals of the CFEETK is the study of epigraphic inscriptions. Traditional epigraphic survey is work that require patience, precision and flexibility. It sometimes requires to set up scaffolds, work in urgency, on extremely fragile surfaces, etc.

Photography has always worked alongside of this scientific activity, but the quality of digital images remained unsatisfactory for many years, especially concerning applications of photogrammetry (Rosenberg, 1955, Gruen, 1996).

Figure 1: On the left, general view of the inscriptions to study (inside the blue frame). On the right, result of the image stitching after orthorectification

With the recent full frame cameras and their very large sensor size and resolution (Nikon D810 with 36.15 megapixels as an example), the equipment is faster and more efficient to provide good quality images to the scientists. Furthermore, the production of orthophotographs became a new way of image making, as many close-range pictures can be compiled into a single one, in which the optical distortions and the perspective defaults can be estimated and corrected.

Traditional tracing techniques, that imply transparent plastic sheets fixed directly onto the stone surface, have been used for decades to produce facsimile. The technique has proven effective to copy hieroglyphic inscriptions, but it raises a few problems. The most striking drawback of this technique is that it requires to stay on the field during the whole study. A first drawing is usually made on the plastic sheet, which is then photographed and digitized in a vector software. The drawing is then printed on paper, and verified on the field against the original. An image-based approach in which an orthophotograph is the base for the vector drawing presents responses to these issues.

Some of the most immediate advantages are the possibility to produce images of very large structures, walls and blocks, with no distortion and with a result nearly as good as a traditional epigraphic drawing. In addition, when the set-back distance is so short that the photographer cannot shoot a whole scene within a single frame, he can apply a photogrammetric acquisition protocol and produce a photomontage with higher quality and better precision than the photomerge tool on photoshop software.

As an example, it is possible to make a photograph of an 4,5 meters high mast-grooves with only a 2 meters gap to take the photos (Figure 1).

The process that the CFEETK employs to create orthophotographs is the same than in archaeology but it doesn't require GCP, as the visual results are satisfying as they are for the epigraphic study. To solve the orthograph's orientation unknowns without GCP, a couple of points can be indicated on the horizontal or vertical lines that are often present on the Egyptian scenes.

This kind of process requires a high computing power so they can respect the studies deadlines. The VIIIth pylon has been the first massive monument in Karnak subject to a photogrammetric acquisition for its epigraphic study. 3500 pictures have been shot to cover one face of the structure (which would then require 14000 images for the whole monument). As a result of recent material investments, the chunk could calculated within a day (produced by K. Guadagnini & P. Soubias), while it took almost 3 days with older material. Moreover, the final ortho-image can be very heavy as a very fine resolution is mandatory for the hieroglyphic study: about 18GB in that case. Such high resolution documents can be hard to open on a standard working station, to work with or to upload.

CFEETK's photographic department has been using photogrammetry as a tool to overcome difficulties on the field and nowaydays the photographers's work in the center is made of 20% of field work (single shot images, mainly for objects) and 80 % of office work (image treatment with Adobe Photoshop and Agisoft Photoscan, e.g. walls and monuments). At the end of the process, these images are used as high definition reference image in the *Projet Karnak* which aims at labelling the temples as a whole. The computing power is surely the biggest challenge that one will have to overcome.

3.1.3 On the objects and statuary study: The excavations led in various parts of Karnak Temples have dug up hundreds of objects in the last years (statuettes, ceramic, millstones,…). Their study is sometimes complex as their fragility can necessitate to limit their access. Traditionally recorded in the archive through photographies, the lack of reliable 3D informations can be restrictive, for example when the elements are considered in a reconstruction hypothesis.

In addition to the traditional photographic archive, a photogrammetric acquisition is realised on the best pieces. As a 360° acquisition is generally possible, the use of GCP is not necessary as such acquisition geometry does not lead -in the authors experiences- to problematic drift errors. A calibration card is used to resolve the unknown scale factor, which has proven to be cost-effective as well as efficient for the usages considered. A short video presenting the object can then be produced, this is a powerful means to share discoveries that could otherwise remain hidden for years. Ortho-images can also be realized to have different views of the object.

As for the field documentation, the creation of a cross section on an object from its 3D model is an interesting application. The tools included in Agisoft Photoscan are helpful to segment an object and to export an ortho-image of the remaining half (Figure 2). This application facilitates the drawing of voluminous objects such as millstones, whose heavy weight are not a problem any more as it is not necessary to manipulate these. Meanwhile, the archaeologist is released from a tedious activity, he only intervenes in the realization of the vectorization in the post-excavation.

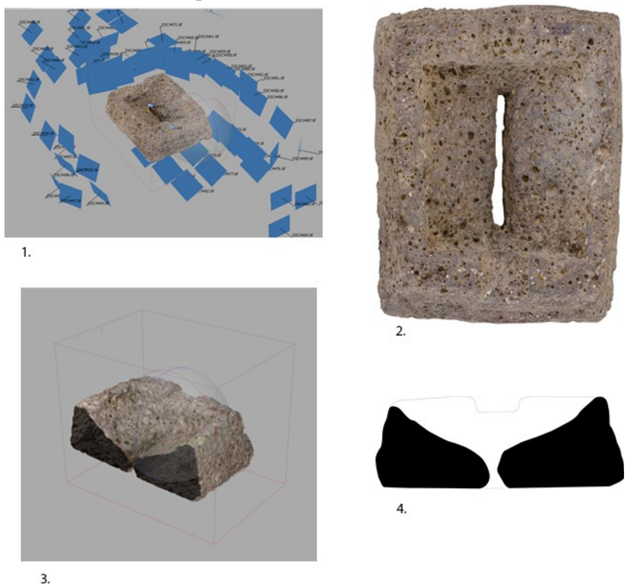

Figure 2: Study of a millstone: 1- Textured 3D model; 2- Ortho-image (top view); 3- 3D model segmented; 4- Cross section drawn from the segmented 3D model

3.1.4 In the anastylosis works: For more than a century, dozens of monuments have been rebuilt in Karnak Temple by studying thousands of stones, coming from fallen structures or excavations, participating thus in the conservation and the enhancement of this unique site.

A new reconstruction project has recently started: the reassembly of 250 blocks onto the Cachette Courtyard walls, built by Thutmose III and especially decorated by Ramesses II and Tutankhamun. Partially rebuilt following the study of (F. Le Saout, 1982), this anastylosis is based on a research done by (G. Dembitz, to be published) who produced, from epigraphic survey and old photographs, some views of the reassembled stones. These studies were done to document the meaning of the decorated scenes and the hieroglyphic texts. Even if these documents are scaled, they aren't accurate enough to take measurements on and be used on the field in the reconstruction process, as they only indicate the relative positions of the decorated faces.

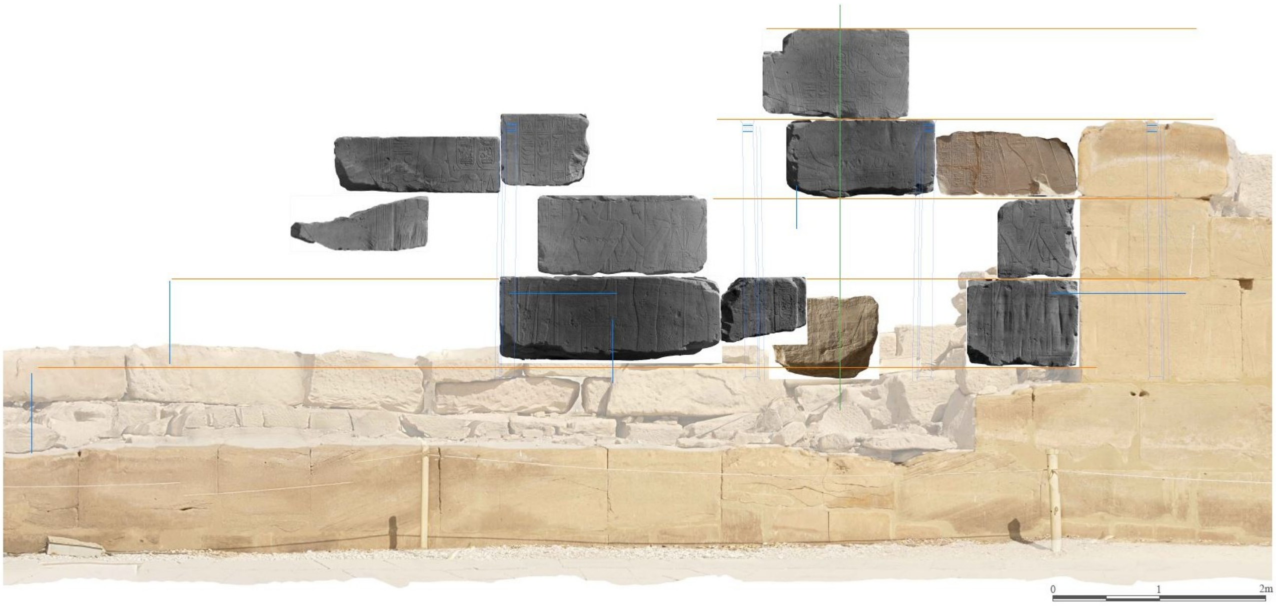

Figure 3: Tutankhamun scenes on east side of the Cachette Courtyard East Wall. Old photographs and ortho-images of all the blocks to be rebuilt have been scaled and accurately preassembled on CAD software (ongoing reconstruction hypothesis).

One of the main difficulties of anastylosis, especially when the monument is incomplete, is the first laid courses cannot be readjusted during the laying of the next ones, and these not only have to connect with the part already assembled but also, in the end, with those of the existing building. Note that each stone weights about 2.5 tons.

The reassembly of all the blocks to their original position on the structures still in place requires a millimetric accuracy. Each one needs to be carefully surveyed with these specifications to know the dimensions and the precise architectural characteristics as to the course heights, block lengths, and distance between the decorative elements and joints.

As explained above, traditional survey techniques are long and tedious (in this case, it would require scaffolding, plumb level, drawing board, etc.), while an image-based approach is an opportunity to accelerate this process.

Therefore, orthophotographs on both sides of each wall have been made with a resolution adapted to the direct needs of the reconstruction work: sufficient enough to record all necessary information, allowing the reading of hieroglyphs, the measurement of decor elements and joint positions, without being overly cumbersome.

Unlike the epigraphic use-case, the visual information derived from the image reconstruction are not as important as their geometric quality. On a 60m long and 8m high wall, about a hundred images were taken from 3m (Nikon D90). To guarantee this geometric quality, 6 to 10 GCP are set on the wall, associated with close-up pictures indicating their positions (defined on easily identifiable elements such as the end of a line of decoration, the tip of a particular crack, etc.). A 3D model is created, allowing to compute orthophotographs on the vertical side. Inserted into a CAD software, the next step is to integrate all the blocks into the complete orthophotograph of the wall. Two solutions are possible:

- Using historical images if the quality is good enough, although this may not be the best solution.
- Making orthophotographs of each block (limited to 5/6 shots)

In both cases, the distance between two details on each decorated face are measured, and thus all blocks can easily be imported and scaled in the CAD file. (Figure 3)

Therefore, it is no longer necessary to make measurements either on the wall or on the blocks as the measurements are all

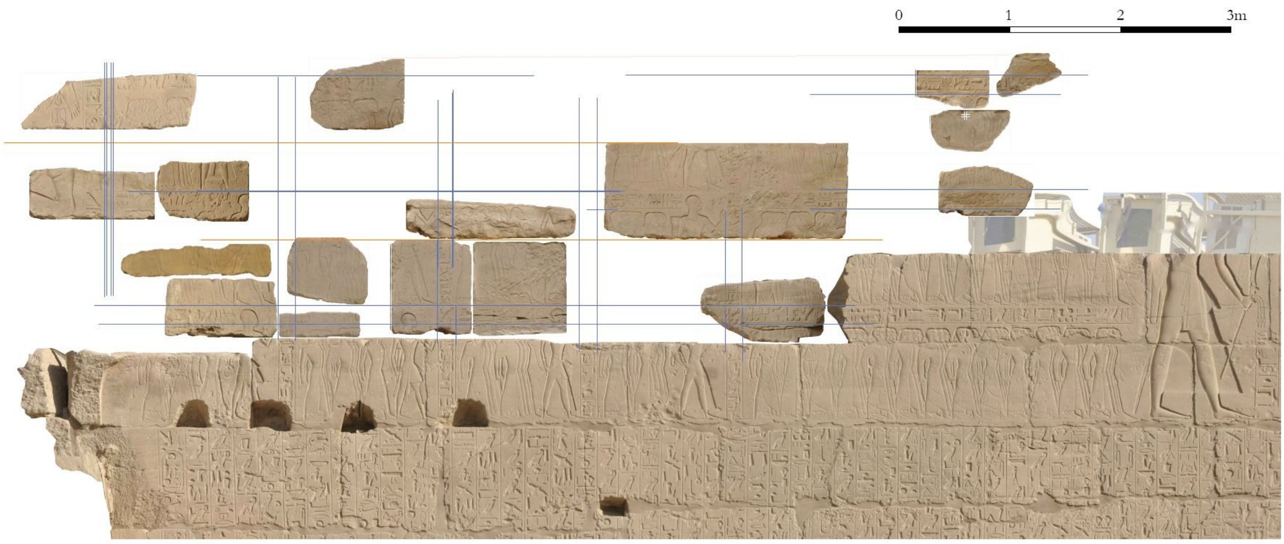

Figure 4: Assembly test scaled on the 12m high wall top part with orthophotographs of recently discovered blocks (Cachette Courtyard North Wall, ongoing reconstruction hypothesis).

easily accessible in the ortho-image CAD file: widths of the different scenes, height of the text lines, distance between a line and a joint, etc. all within millimetric accuracy.

With this kind of information, the reconstruction work can easily be done "virtually" and then on the field. For the North Wall top part (Figure 4), which is 12m high and difficult to survey, the position of 16 recently discovered blocks has been confirmed by using this photogrammetric process without even moving them, which is rather practical because some stones weigh more than 4 tons.

Computer vision applications are also possible in other reconstruction projects: on the Thutmose III bark shrine anastylosis (achieved in September 2016), a huge broken monolithic ceiling slab had to be moved and reinstalled on the chapel's top. After 3D modeling each of the fragments, Cloud Compare was used to know accurately (to cubic centimeter) their volumes, which would have been hard with traditional approaches as the objects shape were not rectilinear. Knowing the density of the calcite, the slab mass was estimated at 76.2 tons. Having to lift it manually onto the 4.5m high chapel (with hydraulic jacks and temporary walls), it was very useful to first know its mass precisely. In addition, by daily shots, a time lapse video has been realized of the complete lifting operation to highlight the anastylosis and his its presentation to the public (https://youtu.be/8D2Fl8A3rIY).

Figure 5: General view of a block difficult to access

3.2 Recent experiments

The multidisciplinary team has now been experimenting 3D reconstruction from images for years. Then a new look can be given on problems that were though unsolvable – or really hard to overcome. Three recent and original applications are being explored.

3.2.1 On the use of small cameras: It is very common to find re-employed epigraphic blocks in the foundations of an edifice. The sanctuary of Ermant-Hermonthis, on the west side of Luxor, is a good example of this practice. Many blocks from the 18^{th} Dynasty have been used to build the foundations of the temple from the Ptolemaic and Roman period.

Although the epigraphed faces are usually hidden, a block from the reign of Hatshepsut (middle of 15^{th} century BC) is accessible through a small gap (Figure 5). Unfortunately, it is too narrow to get a complete photography cover of the hidden inscriptions, and even more for the epigraphist to produce a facsimile from a plastic sheet.

This re-employed block studied by S. Biston-Moulin (to be published) is a subject of interest, as only few traces remain from the queen's reign. About 15 cm at the most narrow spots, the gap is still wide enough to slide a camera and take images. Too small for a DSLR, a Coolpix compact camera was used.

A mirror was reflecting the light from the sun towards the engraved face, providing a diffuse lighting on the whole surface. The camera was then moved horizontally and vertically from a few centimeters for each poses, literally scanning the block within half an hour. In total, 397 images were taken on the 60 by 70 cm face.

Although it is very well known that zoom lenses with unstable mechanical parts do not offer the best geometric stability of the calibration (Remondino & Fraser, 2006), the automatic post production work was completed within a few hours, providing an overview of the entire block (Figure 6). The results achieved both in terms of time requirement and visual quality are satisfactory. Another way to get these results would have been to move the massive stone, which is for obvious reasons more complicated. Although, if the general view of the block is acceptable for the epigraphic study, its quality is way beyond the one produced in proper conditions, which is probably due to the lack of good lighting source and to the low-cost camera that was used (16MP CMOS sensor, with a mediocre optical Zoom-NIKKOR glass lens 28-140mm that made achromatic aberrations and the compressed jpg files as the only option on this camera).

It is still interesting to note that the first photographic acquisition resulted in an incomplete orthophotograph. The lack of a sufficient overlapping pictures produced a couple of holes, which have been completed through additional shots.

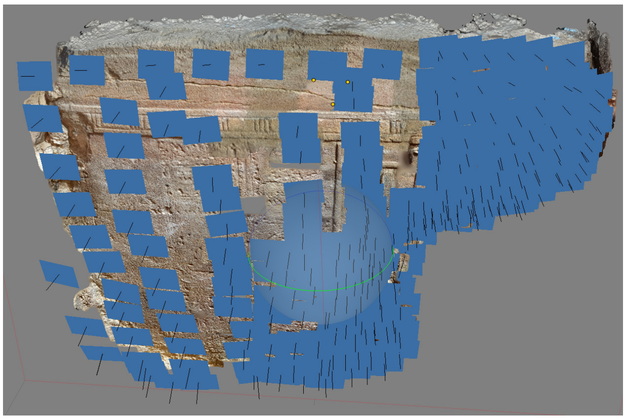

Figure 6: Screenshot of the textured model and camera poses. The lower right part has been completed through an additional acquisition

3.2.2 On the use of depth maps: To improve the full understanding of the Karnak Temple, the epigraphic study of the numerous engraved inscriptions is essential. The site is sprinkled with historical or religious inscription on various substrates : architectural elements, furniture, statues, etc. Their conservation state are sometimes really good, while others are highly deteriorated, in which case it is complicated to read or even distinguish the signs carved on the stones. It is especially true when their surface have eroded or when the inscriptions have been hammered. When working from pictures, the texture of the stone, the shootings conditions or even the location of the block can have a negative effect on the study. The method presented here has produced convincing results mainly on magmatic rocks, which are granular and heterogeneous such as the granitic stones from Aswan.

As presented by (Capriotti Vitozzi & Angelini, 2013), the recent evolutions in image reconstruction can be tweaked to provide additional information from photographs. The idea is to take advantage of the depth information through a photogrammetric process to get another view of the carvings made on an object. Generally deeper than the breaks, a proper acquisition and 3d reconstruction make these appear more clearly than with a trained eye on the field, as the stone texture -here invisible- does not mislead the reading. Three examples can illustrate the results achievable through the technique.

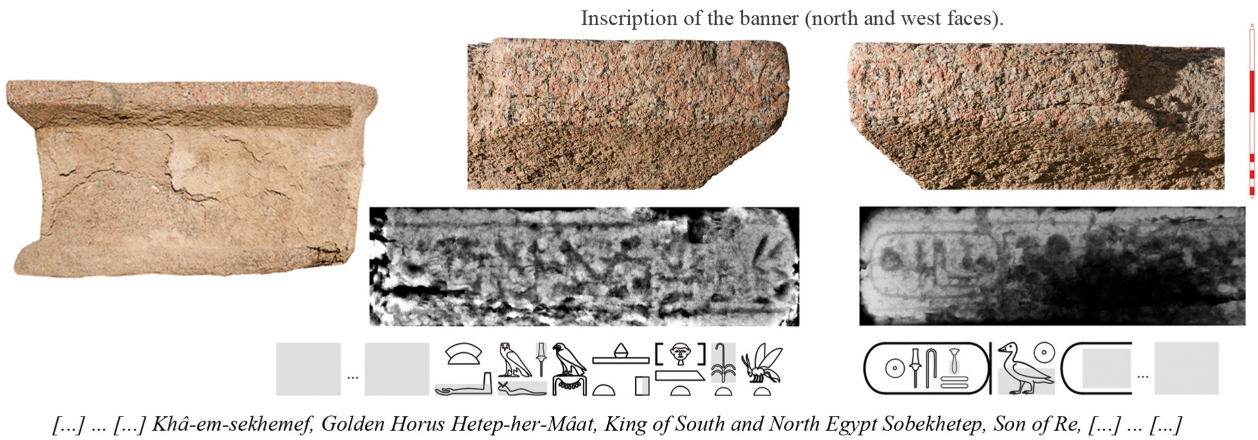

Figure 7: Depth maps application on temple furniture: the case of the support of Sekhemre-Seouadjtaouy (XIII[th] dynasty) in the "Middle Kingdom court".

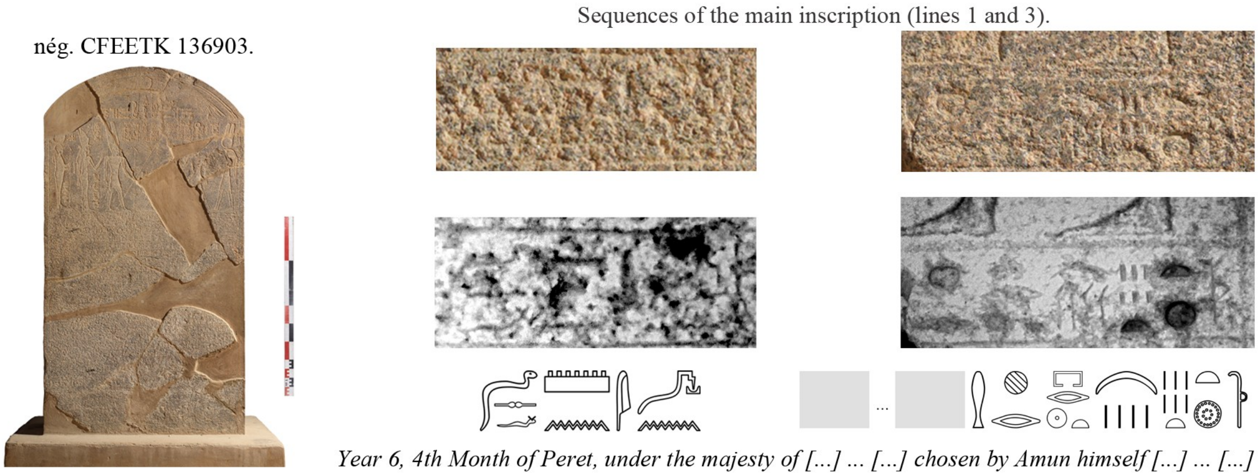

Figure 8: Depth maps application on hammered royal stele in granodiorite from the First Court.

The first application case is a granite piece of furniture from the 13[th] dynasty (first half of the 18[th] century BC), on which a dedication banner spreads around the four faces (Labarta, 2017). The banner is in a very bad conservation state, as the stone has been eroding year after year along subparallel faces. The carvings are not deep enough, or too much degraded on 2 faces, but inscriptions clearly pop out from the depth maps computed on the two other sides (Figure 7). The method proves to be effective as some of the signs had not been mentioned in the first (and unique) hieroglyphic transcription of the furniture in 1950's.

The second example relies on the study of a royal stele made of granodiorite. Its inscriptions have been voluntarily hammered (Figure 8), as it happened for various reasons along the history of Egypt. G. Legrain, a prominent Egyptologist that led Karnak reconstruction in the early 20[th] century, found the stele and wrote about it : "The name carved in the cartouches seem to be Nekhao (?). A historical twenty lines text was carved above the scene, but its deplorable state of conservation prevents from reading it. It seems to be dating from the year 6" (Legrain, 1929) [2]. Currently under study, the date of the year 6 has been confirmed on the first depth maps but it also appears that the proposed main dating must be analyzed again. It is hoped that the technique will help to confirm the king mentioned as well as the nature of the text that could be linked to a drawing of a sacred bull in the offering scene from the stele's upper part.

The third and final example illustrates how the technique can be used for architectural reconstruction purposes. During the study of the epigraphic inscriptions on the central bark shrine of Philip Arrhidaeus (323-317 BC) (Thiers & Tillier, forthcoming), two blocks have been identified as part of the monument's ceiling. The depth maps revealed some very thin and flattened inscriptions, as well as continuous drawings elements (Figure 9).

3.2.3 On the use of historical images: The "Cour de la Cachette" holds its name from the discovery by G. Legrain of more than 800 statues and 17000 bronze statuettes between 1903 and 1907. The profusion of elements to unearth combined to the conditions of the excavation (up to 15 meters deep,

Figure 9: Depth maps application on architectural blocks: the case of ceiling fragments from the Central Bark Shrine in granite.

groundwater penetration,...) have been obstacles for a proper and complete documentation of the findings. No precise survey was made, leaving the archaeologists with a doubt about the limits in which the diggings happened.
The photographic archive is made of about 50 images of the scene, taken by G. Legrain as well as professional and amateur photographers. They have been lying in boxes for decades, serving as a graphical documentation along with sketches and historical texts.
(Egels & Laroze, 2015) present how modern algorithms can help to solve an old problem. Taken at different times with various cameras, the orientation of the images is the first issue to solve. The SIFT and ANN algorithms can detect and match a sufficient amount of tie-points, however the external orientations are tricky to determine using today's classical camera models. The focus differences as well as focal length changes have been neglected (experiments with individual calculations led to small differences), but a high decentering variable has to be applied to take into account the specific cameras which were adapted to the lack of tripod heads. A 3D model has been calculated using dense correlation algorithm. It is a helpful document to clarify the limits of the excavation, as well the position of some of the statues before they got unearthed.
Still under study, the lack of pictures is the main obstacle for a full documentation of the process. Some images can not be oriented properly as not enough tie-points could be found (even manually) to orientate the whole archive, or it is simply not possible to derive reliable 3D information due to the lack of overlap. It is hoped that more pictures will be found in the future to correct that problem.

4. FUTURE

Computer vision and photogrammetric processes are already adopted by many within the research team. It is wished to integrate these systematically in the process of the study of the collapsed structures, among which two projects started to study the epigraphy of the 7th pylon and the Taharqa edifice. Iconem's ambition is to preserve the knowledge of threatened heritage using digital advances. Aiming at producing real digital doubles of archaeological remains or expanses, Iconem will bring its expertise in these projects, offering the scientific community and the public an innovative means of exploring famous places of world heritage.
The rise of 3D modeling is not only due to the advances in image reconstruction. It benefited from both the laser scanning and the Unnamned Aerial Vehicle (UAV) techniques, which both improved substantially in the recent years. Laser scanner are getting quicker and cheaper year after year. Some of these tools are in the same price range as good cameras, and rather than a competitor, they can be used in combination with these, especially terrestrial laser scan and UAV photogrammetry (Eisenbeiss & Zhang, 2006).
The developments of UAVs is also popular thanks to the quick drop in the sensors price (IMU, GPS,…). More and more reliable, various sensors can be carried out, providing additional information. The famous (Scan Pyramids Mission, 2016), and its impact both as a scientific, a historic and a communication tool, is a clear argument for that cause, although they are still complicated to use due to the regulation. They could be a major asset to get the best viewpoints of remote objects, as the top of the obelisks that can reach up to 30 meters high. It is hoped to be able some day to cover the whole area with such a tool. Integrating a global 3D model in which the documents in the *Projet Karnak* would georeference each of the historical findings would be a major advance in the digital conservation of Karnak.
The amount of data accumulated will likely, at some points, become so massive that it will require too much workforce to be analysed, exactly as the 2 km² area is complicated to fully study on the field. The developments in the image recognition and classification fields could help to automatically extract semantic elements, as presented by (Franken & van Gemert, 2013, Nederhof, 2015). *Projet Karnak's* database, designed to index every inscriptions on the walls of the temple, is expected to continue its growth upward the current 8500 documents. Associating images, hieroglyphs, transliteration and translation, it constitutes a reliable learning base that could be helpful for neural machine approaches.
It might be risky to bet on the future, but one surely can be confident that the forthcoming material and technical improvements will be a great help to build a global and thorough preservation of our most magnificent cultural heritage. These advances are however hardly imaginable without collaborations with various research centers, as they have shown through time how impacting they have been.

5. CONLUSION

The article presented the historical evolution of the use of image processing, starting 50 years ago. After a few experiments, the technique proved to be effective but costly, reserved to a few experimented people and specialized equipment, out of the range of an archaeological mission. The recent automation advances, made possible thanks to the collaborations with the computer vision community, have drastically mitigated these drawbacks. As of today, the techniques described in the article have deeply impacted the nature of the field work. It benefits to the research center as a tool for the study of the temple, of the objects and furnitures, as a communication tool, and it stimulates the innovative spirit of the team which finds original applications while not being experts in that specific field. The future is by nature hard to predict but it is expected that the technological revolution we are living will continue to benefit to the study and conservation of the cultural heritage. Collaborations with interested research institutes, universities or companies have proven their value in the past, as they still impact the present work. They are still warmly welcome, especially to overcome the challenge of a digital copy of the entire temple including all the hieroglyphic inscriptions and details as thin as graffitis.

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REFERENCES

Azim, M., Bjarnason, Fr., Deleuze, P., 1998. *Karnak et sa topographie*, Vol. I, CRA, 19, Paris.

Biston-Moulin, S., Thiers, Chr., 2016. *Le temple de Ptah à Karnak I. Relevé épigraphique (Ptah, nos 1-191), II. Relevé photographique (J.-Fr. Gout), Travaux du Centre Franco-Égyptien d'Étude des Temples de Karnak, BiGen*, 49, Le Caire.

Brand, P.F., Laroze, E., Revez, J., 2013. Le projet américano-canadien de relevé des colonnes de la Grande Salle Hypostyle de Karnak : objectifs globaux et méthodologie, *JSSEA*, 38, pp. 17-34.

Capriotti Vittozzi, G., Angelini, A., 2013. Una ricerca tra antichi disastri ambientali tecnologie avanzate in R. Pirelli (éd.), *Ricerche Italiane e Scavi in Egitto,* 6, Cairo, pp. 81-96.

Charloux, G., Thiers, Chr., 2017. The early temple of Ptah at Karnak. *Egyptian Archaeology*, (50), pp. 11-15.

Charloux, G., Thiers, Chr., Abd al-Aziz, M., Ali al-Abady, M ;, Bout, St., Bourse, C., Laroye, J., Guadagnini, K., Nasseh, A. The Afterlife of Egyptian Statues: New Evidence From a Cache of Cultic Objects in the Temple of Ptah at Karnak, *Antiquity* (forthcoming).

Chandelier, L., Chazaly, B., Egels, Y., Laroze, E., 2009. Numérisation 3D et déroulé photographique des 134 colonnes de la Grande Salle Hypostyle de Karnak, *Revue XYZ*, 120, pp. 33-39.

Chandelier, L., 2011. *La prise de vue photogrammétrique*. http://cours-fad-public.ensg.eu/mod/resource/view.php?id=495&redirect=1

Chazaly, B., Laroze, E., 2005. Le relevé par scannage 3D du temple d'Opet à Karnak, Egypte, *Revue XYZ,* 102, pp. 21-26.

CloudCompare (version 2.9) [GPL software], 2017. Retrieved from http://www.cloudcompare.org/

Egels, Y., Laroze E., 2016, November. From photographic archives to 3D data: experience of the "Cour de la Cachette" at Karnak, CIPA Newsletter 10, pp. 1-2 http://cipa.icomos.org/portfolio-item/newsletter_10/.

Eisenbeiss, H., Zhang, L., 2006. Comparison of DSMs generated from mini UAV imagery and terrestrial laser scanner in a cultural heritage application. I*nternational Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 36(5), pp. 90-96.

Franken, M., van Gemert, J. C., 2013. Automatic Egyptian hieroglyph recognition by retrieving images as texts. In Proceedings of the 21st ACM international conference on Multimedia, pp. 765-768.

Frood, E., Howley, K., 2014. Application of Reflectance Transformation Imaging (RTI) in the Study of Temple Graffiti. In Pischikiva, E., Budka, J., Griffin, K. (ed.), *Thebes in the First Millenium B.C.*, Cambridge, pp. 625-638.

Labarta, Ch., 2017. Un support au nom de Sobekhotep Sékhemrê-Séouadjtaouy – Karnak varia, *Karnak*, 16 (forthcoming).

Laroze, E., Chazaly, B., 2009. Relevés des colonnes de la grande salle hypostyle de Karnak, *CRAIBL*, 153(2), pp. 669-686.

Legrain, G., 1929. *Les temples de Karnak. Fragment du dernier ouvrage de Georges Legrain, Directeur des Travaux du Service des Antiquités de l'Égypte*, Bruxelles, p. 140.

Le Saout, F., 1982. Reconstitution des murs de la Cour de la Cachette. *Karnak,* 7, pp. 213-58.

Meyer, E., Grussenmeyer, P., Tidafi, T., Parisel, C. and Revez, J., 2004. Photogrammetry for the epigraphic survey in the great hypostyle hall of Karnak temple: a new approach. In *Proceedings of the XXth Congress of the ISPRS*, Istanbul, Turkey, pp. 12-23.

Meyer E., 2005. La photogrammétrie pour le relevé épigraphique des colonnes de la Salle Hypostyle du temple de Karnak, *Revue XYZ*, 102, pp. 29-34.

Nederhof, M. J., 2015. *ORC of handwritten transcriptions of Ancient Egyptian hieroglyphic text*. Altertumswissenschaften in a Digital Age: Egyptology, Papyrology and beyond, Leipzig.

Remondino, F., Fraser, C., 2006. Digital camera calibration methods: considerations and comparisons. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 36(5), pp. 266-272.

Rosenberg, P., 1955. Information theory and electronic photogrammetry. *Photogrammetric engineering*, 21(4), pp. 543-555.

Scan Pyramids Mission, 2016. Press release, Cairo, Egypt. http://www.hip.institute/press/HIP_INSTITUTE_CP9_EN.pdf. Last access : Apr. 1th 2017.

Thiers, Chr., Tillier, A., *Le reposoir de barque de Philippe Arrhidée. Relevé épigraphique*, Le Caire (forthcoming).

Vergnieux, R., Gondran, M., 1997. *Aménophis IV et les pierres du soleil. Akhénaton retrouvé*. Arthaud, Paris.

Vergnieux, R., 1999. *Recherches sur les monuments thébains d'Amenhotep IV à l'aide d'outils informatiques. Méthodes et résultats, CSEG,* 4, Genève.

Yoyotte, J., 1966. Religion de l'Égypte. *École Pratique des Hautes Études: Ve section - sciences religieuses,* 79 (75), pp. 267-282.

APPENDIX

[1] Based on a comprehensive inventory of documents and inscriptions from Karnak collated in the field, this project is available in http://sith.huma-num.fr/karnak

[2] Original french text from G. Legrain on the study of the royal stele : "Le nom gravé dans les cartouches paraît être celui de Nekhao (?). Un texte historique d'une vingtaine de lignes était gravé au-dessous du tableau, mais son état déplorable en empêche le déchiffrement. La date paraît être l'an VI."

[3] The Macedonian king Philip Arrhidaeus dedicates (repeatedly in the wall inscriptions) his construction to Thutmose III, king of the 18th dynasty and builder of the previous shrine which was erected in the same place and performed the same function (Biston-Moulin & Thiers, 2017). Furthermore, this assignment proposal is based on a typological study of starry decoration, also carried out using depth maps.