# PHOTOGRAMMETRY FOR THE EPIGRAPHIC SURVEY IN THE GREAT HYPOSTYLE HALL OF KARNAK TEMPLE : A NEW APPROACH


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**ABSTRACT :**


The purpose of this paper is to present a method to carry out a computerized epigraphic survey of inscriptions engraved on columns. In fact, the epigraphic survey of Egyptian temples is essential to understand and to reconstitute these ancient monuments, and hieroglyphic engravings of columns are as important as the scenes that appear on walls. Columns often bear cartouche friezes and ritual episodes that give information on the date of the temple or on the nature of the activities that took place in its hypostyle hall. Furthermore, they sometimes describe techniques used by the architects to build the hall. It is therefore necessary to find a way to keep the texts engraved on the numerous temples' columns, as on the 134 columns of the Karnak Hypostyle Hall. Nowadays, epigraphic surveys are still for the most part done in a traditional handmade fashion, while computer-aided epigraphic surveying is only used for simple tasks, such as drawing the contour of hieroglyphic signs on scanned photographs. Different methods of survey are carried out, but practically only on plane surfaces. The GRCAO of the University of Montreal and the laboratory MAP-PAGE of the INSA Strasbourg have conducted research together. Using photogrammetry, they made it possible to survey and to register the hieroglyphics inscriptions engraved on conical or cylindrical surfaces. The present paper explains the adjustment and programming of general photogrammetric formulae for the three-dimensional reconstitution of a column and the two-dimensional surveying of its epigraphy, based on a series of snapshots of the column's surface.


**RÉSUMÉ :**


L'étude présentée dans cet article propose une méthode permettant de relever informatiquement des décors gravés sur des colonnes. En effet, le relevé épigraphique d'un temple est essentiel pour comprendre son fonctionnement et pour procéder à sa reconstitution, et les inscriptions hiéroglyphiques des colonnes sont tout aussi importantes que les scènes apparaissant sur les murs. Les colonnes présentent des frises de cartouches et de dessins de rituels, qui donnent des indications sur la date de construction du temple ou sur la nature des activités qui se tenaient dans la salle hypostyle. De plus, il arrive qu'elles décrivent les techniques de construction utilisées par les architectes pour bâtir la salle. Il est donc nécessaire de pouvoir conserver les textes gravés sur les nombreuses colonnes des temples, comme sur les 134 colonnes de la salle hypostyle du temple de Karnak. À l'heure actuelle, le relevé épigraphique des temples égyptiens est effectué essentiellement à main levée, et les techniques informatiques existantes sont utilisées seulement pour des travaux simples, comme le dessin du contour des signes hiéroglyphiques sur des photographies scannées. Différentes méthodes de relevé sont mises en œuvre, mais presque uniquement sur des surfaces planes. Les recherches menées conjointement par le GRCAO de l'Université de Montréal et le laboratoire MAP-PAGE de l'INSA de Strasbourg utilisent la photogrammétrie pour rendre possible le relevé et l'enregistrement d'inscriptions hiéroglyphiques gravées sur des surfaces coniques ou cylindriques. Cet article explique l'adaptation et la programmation de formules générales de calcul photogrammétrique pour la reconstitution tridimensionnelle d'une colonne et le relevé bidimensionnel de son épigraphie, à partir de photographies de la surface de la colonne.


**KURZFASSUNG :**


Ziel dieses Artikels ist eine informatische Aufnahmemethode der in Säulen geschnitzten Inschriften zu präsentieren. Tatsächlich ist die epigraphische Aufnahme der ägyptischen Tempel wesentlich, um ihre Funktion zu verstehen und um sie wiederherzustellen, und die hieroglyphischen Inschriften der Säulen sind genauso wichtig wie die auf den Wänden dargestellten Szenen. Die Säulen zeigen Kartuschenfriesen und Zeichnungen von Ritualen, die über das Baujahr des Tempels oder über die Betätigungen, die sich in dem Säulensaal abspielten, Informationen geben. Außerdem, stellen sie manchmal die Bauverfahren der Architekten dar. Es ist also notwendig die, in den zahlreichen Tempelsäulen geschnitzten Texte, erhalten zu können, wie die Texte der 134 Säulen des Karnak Große Säulensaals. Heutzutage wird die epigraphische Aufnahme der ägyptischen Tempel in der Hauptsache durch manuelle Techniken vollführt, und Computerverfahren werden nur für einfache Arbeiten benutzt, wie die Zeichnung der Umrisse der hieroglyphischen Inschriften auf digitale Fotographie. Verschiedene Aufnahmemethoden werden verwendet, aber fast nur auf planen Oberflächen. Die, von dem GRCAO der Universität Montreal und dem Labor MAP-PAGE des INSA Strasbourg gemeinschaftlich geführten Forschungen, benutzen die Photogrammetrie, um die Aufnahme und die Registrierung hieroglyphischer Inschriften von konischen oder zylindrischen Oberflächen, zu ermöglichen. Dieser Artikel erklärt die Anpassung und die Programmierung von generell photogrammetrischen Rechensformeln für eine dreidimensionale Wiederherstellung einer Säule und eine bidimensionale Aufnahme ihre Epigraphie, von der Fotographie der Säulenoberfläche aus.

## 1. INTRODUCTION

This paper sets out a new method using photogrammetry in order to survey a scene engraved on a non-plane surface.
This study comes within the context of research conducted jointly by the GRCAO (Computer Aided Design Research Group) of the University of Montreal and by the laboratory MAP-PAGE (Photogrammetry and Geomatics Group) of the INSA Strasbourg. It has been carried out within a larger project called « Computer modelling as a means of reflection in archaeology : a new approach to epigraphic and architectural survey applied to the Karnak Temple». The GRCAO is in charge of this project through the Karnak Hypostyle Hall Project (KHHP) of the University of Memphis, and the collaboration contract signed by the two institutions put all data and material linked to the project at the GRCAO's disposal. One of the project's issues is to survey all the inscriptions engraved not only on the walls, but also on the 134 gigantic columns of the Hall. As an aim is notably to publish the hieroglyphic texts, the method to be developed should have a two-dimensional result.

Therefore, this study proposes a means to survey hieroglyphic engravings of columns in a two dimensional environment. Computer tools have been developed that allow the epigraphists to draw scenes and record the drawings with their meaning for future exploitations. Interestingly, it is based only on a series of snapshots of the column's surface. Thanks to the partnership above-mentioned, these tools have been eventually tested on a column of the Karnak Hypostyle Hall.

The survey method can be broken down into two main phases : the three-dimensional reconstitution of a column, and then the development of its surface for the two-dimensional surveying of the epigraphy.
The first part of this paper deals with the construction of a vectorial 3D model of a column. Three aspects have to be considered : the data acquisition strategy, the data available beginning the study, and the layout of a theoretical cone that represents the column.
The second part concerns particularly the epigraphic surveying of the column. There are also three steps : the development of the previously obtained cone, the orthorectification of the column's original photographs and finally the montage of these orthophotographs in order to draw the hieroglyphic signs in.

## 2. THREE DIMENSIONAL RECONSTITUTION OF A COLUMN

Through photogrammetric formulae, a vectorial three-dimensional modelling of a column has been calculated from photographs that cover the entire surface of the column, and from control points scattered proportionally on its surface**.**

### 2.1 Data acquisition strategy

The problem of the survey in the Karnak Hypostyle Hall stems from the fact that there are 134 columns erected in an area of only 102 x 52 square metres. A consequence is an obvious lack of space, since the diameter of the columns measures 2.8 m, while the space between them varies between 2.6 and 3 m. Moreover, the height of the columns is also a problem to reckon with, since 12 of them measure 21.20 m (in the centre of the hall) and the other 122 measure 13.17 m. (Figure 1)

Figure 1. Columns of the Karnak Great Hypostyle Hall

These constraints must be taken into account when choosing a strategy to take snapshots of a column *in situ*. Eight photographs of the column could be taken (for one level), in order to insure a good coverage of its surface and a sufficient overlapping of the photographs. The positioning of the different photographic stations within the Hypostyle Hall could be as shown below. (Figure 2)

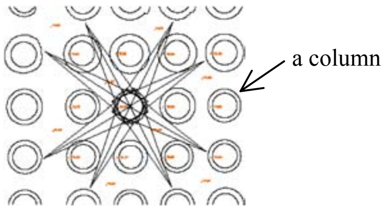


Figure 2. Position of the photographic stations

Considering that the greatest distance in space of the camera from a column is about 7 m, and that each of these structures is very high, several snapshots are necessary to cover its entire vertical surface. In order to cover a surface ranging from 0 to 6 m, a picture must be taken 3 m away from the column, while 9 m are necessary to cover between 6 and 12 m. Thus, 16 photographic stations are at least needed to cover the whole surface of the smallest columns and 24 for the biggest ones.
Such a number of photographs may appear constraining, but one must be aware that the epigraphist takes them with only one camera using the same lens. Moreover, the photographic coverage is practically the only work to be done *in situ*, because the coordinates of the control points can be calculated later through Bundle Adjustment. No important topographic survey is thus necessary, since the created independent model will be scaled down to proportion by measuring a length on the column, or will be replaced in the 3D space while surveying just three points in the field.

### 2.2 Data available at the beginning of the study

The only data required to create a 3D model of one part of the column are the eight photographs covering its entire surface and some control information to be located on these photographs. A minimum of six homologous points between two consecutive overlapping photographs are required, and three more common points between three overlapping photographs. This has been done using a graphical software, in this case AutoCAD© because it is widely in use in archaeology. The photographs with the points can be seen below. Polylines that connect the different homologous points between the shots have also been drawn for a better visualization. (Figure 3)

Figure 3. Photos with homologous points and polylines

From now on, the homologous points have photo-coordinates, named (x', y'). Their object-coordinates (X, Y, Z) can be determined through Bundle Adjustment.
The unknowns of this photogrammetric method are the external orientation elements (Xo, Yo, Zo, $\alpha$, $\nu$, $\kappa$) of each shot and the object-coordinates of the control points. The camera parameters (x'o, y'o, c) must be known or estimated.
For each point of each shot, the linearized observation equations of a Least Square estimation can be written. Each point gives two equations coming from the equations of the central projection (calculation of the point's photo-coordinates from approximated values of the unknowns).

In a matrix form, this can be written as below (Kraus, 1997) :

$$v = B * X - L \qquad (1)$$

where
- v is a matrix containing the residual vector of the photo-coordinates
- B is a matrix containing the partial derivatives (regarding the unknowns) of the calculated photo-coordinates (these derivatives of the collinear equations are calculated from approximated values of the unknowns)
- X is a matrix containing the unknowns to calculate
- L is a matrix containing the subtraction of the measured photo-coordinates from the calculated

The Least Square estimation permits to write that in the following form (named normal equation) :

$$B^T * B * X = B^T * L \qquad (2)$$

For what follows, we adopt the notation :

$$N = B^T * B \qquad n = B^T * L \qquad (3)$$

In order to be able to resolve the normal equation for several shots, the previous matrix must be written as below :

$$N = \begin{vmatrix} N11 & N12 \\ N12^T & N22 \end{vmatrix} \qquad X = \begin{vmatrix} X1 \\ X2 \end{vmatrix} \qquad n = \begin{vmatrix} n1 \\ n2 \end{vmatrix} \qquad (4)$$

The unknowns are then calculated by Least Square estimation :

$$X1 = ( N11 - N12 * N22^{-1} * N12^T )^{-1} * ( n1 - N12 * N22^{-1} * n2 )$$
$$X2 = N22^{-1} * ( n2 - N12^T * X1 ) \qquad (5)$$

where
- X1 contains the external orientation elements (Xo, Yo, Zo, $\alpha$, $\nu$, $\kappa$) of each shot
- X2 contains the object-coordinates of all object points

Thanks to the 3D coordinates of the object points, we are now able to draw a vectorial model of the column. This model will represent the theoretical column's surface, calculated from the 3D control points.

### 2.3 Layout of a theoretical cone from the control points

It seems that the theoretical surface of Egyptian columns is a cone with a very acute angle at the summit. To obtain a vectorial view of the column, a 3D polyline has been drawn, based on points describing this cone geometrically.

Parameters of the cone have been calculated by a mathematical algorithm, which carries out the surface matching of a cone. (Shakarji, 1998)

These parameters are :
- the director numbers of the axis
- one axis point
- the summit angle
- the distance between the axis point and a generatrix of the cone

A solution is found through an iterative modification of the cone's parameters. The calculation ends when the average distance between the cone's points and the calculated surface stops decreasing.

The 3D polyline describing the cone is constructed and recorded by seven points :
- the summit [1]
- the point of intersection between the axis and the perpendicular plan determined from the higher control point (represented by the high circle [HC]) [2]
- the point of intersection between the axis and the perpendicular plan determined from the lower control point (represented by the low circle [LC]) [3]
- the point of intersection between the "(OX) axis" and the circle [LC] [4]
- the point of intersection between the "(OX) axis" and the circle [HC] [5]
- the point of intersection between the "(OY) axis" and the circle [HC] [6]
- the point of intersection between the "(OY) axis" and the circle [LC] [7]

It is worth noting that to determine the best cone approaching the points can lead to a cone, whose axis is not necessarily vertical. Indeed, the column might have suffered a slight subsidence or inclination in time.

The following drawing represents the calculated points and the 3D polyline describing the best cone based on these points. (Figure 4)

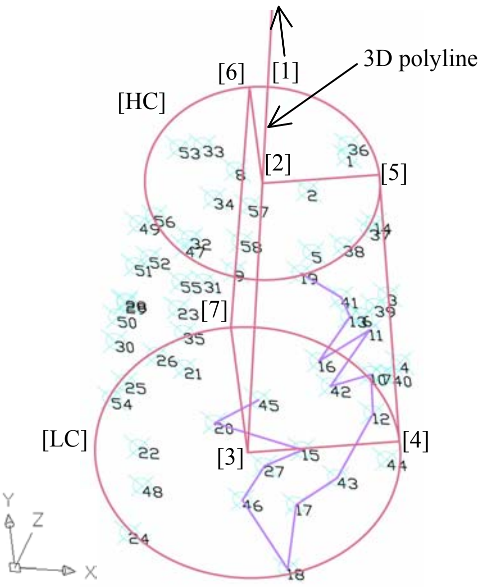


Figure 4. Theoretical cone drawn from the calculated 3D points

For better 3D visualization, there also appears on this layout one of the polylines joining the homologous points between two shots.

Thanks to this vectorial representation of the column, we are now able to develop the obtained 3D polyline on a plane, so as to survey the hieroglyphic signs on a two-dimensional surface.

## 3. EPIGRAPHIC SURVEY OF THE COLUMN

In order to make a survey as accurate as possible, the column's inscriptions will be drawn by means of Bezier curves on the developed surface of the shaft, in which the orthorectified photographs will be inserted. This two-dimensional drawing leads to a direct publication of the hieroglyphic texts.

### 3.1 Development of the cone

As mentioned above, the best cone approximating the points can be at an angle. So, the first step of the development is to make the previously obtained cone vertical, for the simplicity and the accuracy of the development's calculation.

A change of reference has been carried out so as to move the summit of the original cone to the zero point and to put the axis in a perfect vertical position. The transition from one coordinates' system to the other is possible through three non-coplanar homologous points in each system. These three points are chosen at random among the seven points of the previous 3D polyline. Knowing that the summit must be translated to the point (0, 0, 0), the coordinates of the two other needed points are easy to deduct.
A matrix has been calculated to enable the transfer of all the cone's points from one system to the other. These object points are replaced exactly « on » the theoretical surface of the new vertical cone by means of an orthogonal projection.

The vertical cone can thus be developed, that is to say the points of the 3D polyline will be put on a same plane.

The cone can also be described developing its surface, which consists in five coplanar points :

- the summit [1]
- the cone's generatrix going through the intersection between (OX) and the circle [LC] (see above) [1-2]
- the arc describing the development of the circle's circumference, intersection between [LC] and the cone's surface [2-3]
- the generatrix representing the end of the unwinding [3-4]
- the arc describing the development of the circle's circumference, intersection between [HC] and the cone's surface [4-5]

(Figure 5)

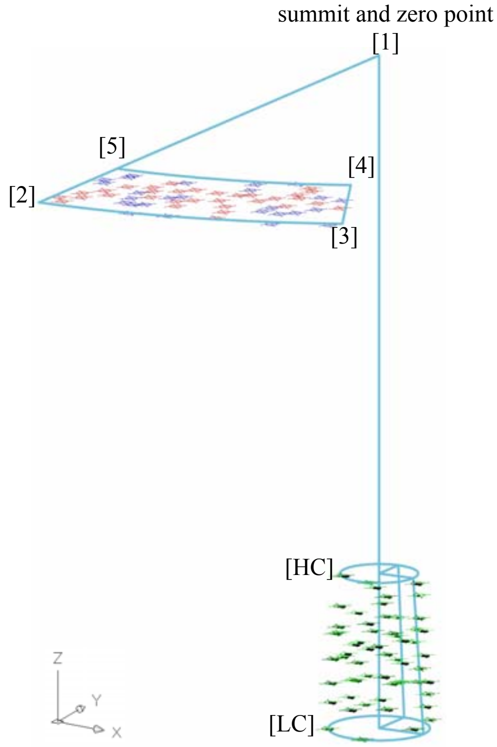


Figure 5. Link between the 3D model and the development of the cone

The points previously projected on the theoretical surface of the vertical cone have been located on the development by multiplying their (X, Y) coordinates by a rotation matrix. Their Z coordinate is the distance between the real and the projected points.

To be able to draw the hieroglyphic inscriptions, it is now necessary to orthorectify the original photographs of the column and to insert these pictures in the development.

### 3.2 Orthorectification of the photographs

To put the shots in the development, these must be transformed into orthophotographs. The epigraphy will thus be surveyed on this « front view » of the column.

The orthorectification process has two phases :

- the first consists in drawing, on the original shot, the edges of the column's shaft (generatrix), and in obtaining their equivalent on the development, so as to finally have the limits of the orthophotograph to be produced
- the second carries out the transfer of the grey values of the pixels from the original photograph to the development

A new picture will thus be created by assembling these pixels inside the previously drawn limits.

The limits of the eight orthophotographs have been obtained by means of a « re-wrapping » procedure that transfers points from the development to the original shots.
The steps are as such :

- on the development, creation of a point and the cone's generatrix going through this point
- positioning of this point and its generatrix on the vertical cone (change of reference based on the development's polylines and the cone's)
- transfer of the point and the two end's points of the generatrix from the 3D model to the photograph, by means of a Direct Linear Transformation (DLT)

The DLT is applied « from 3D to photo », that is to say the calculation of the photo-coordinates of the points from their object-coordinates on the vertical cone. The DLT is a non-iterative method consisting in the linearization of the equations of the central projection. It is based on 11 coefficients ─ named L1 to L11 ─ calculated (for each shot) from the control points that are known in both coordinates' systems (photo and object).

In a matrix form, the computation of the photo-coordinates (e, n) from the object-coordinates (X, Y, Z) can be written as following (Karara, 1989) :

$$\begin{bmatrix} X\ Y\ Z\ 1 \end{bmatrix} * \begin{bmatrix} L1 & L5 & 0 & L9 \\ L2 & L6 & 0 & L10 \\ L3 & L7 & 0 & L11 \\ L4 & L8 & 0 & 1 \end{bmatrix} = \begin{bmatrix} L1*X+L2*Y+L3*Z+L4 \\ L5*X+L6*Y+L7*Z+L8 \\ 0 \\ L9*Y+L10*Y+L11*Z+1 \end{bmatrix} \quad (6)$$

The two first lines are thus divided by the last one, in order to obtain the photo-coordinates (e, n) :

$$e = \frac{L1*X+L2*Y+L3*Z+L4}{L9*X+L10*Y+L11*Z+1}$$

$$n = \frac{L5*X+L6*Y+L7*Z+L8}{L9*X+L10*Y+L11*Z+1} \quad (7)$$

The « re-wrapping » procedure is programmed as to see "live", simultaneously with the cursor movements, the motion of the chosen point and of its generatrix, at the same time on the development, on the vertical 3D cone and on the photograph.

So, the limits of the orthophotograph to be produced have been drawn, by moving the cursor on the development surface while controlling the position on the original shot.
(Figure 6)

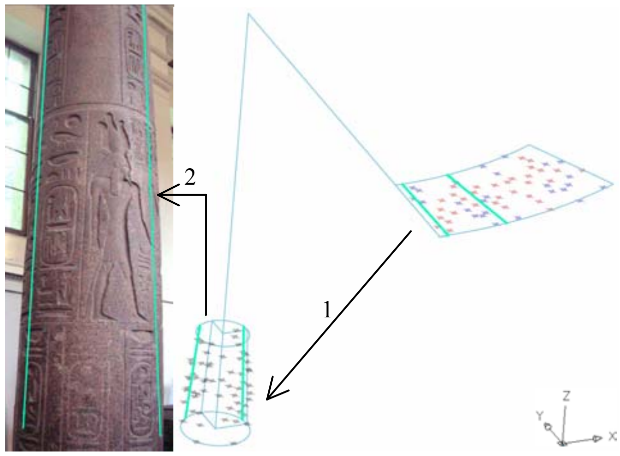


Figure 6. Layout of the limits of the orthophotographs to be produced in the development

The orthorectified photographs are generated in the same way, by applying the « re-wrapping » procedure to all the pixels' positions of the picture to be created in the previous limits.
The pixels corresponding to these positions have been taken from the original photos and their colour values have been transferred to the development. The orthophotograph is the result of the assembling of the pixels thus defined. (Figure 7)

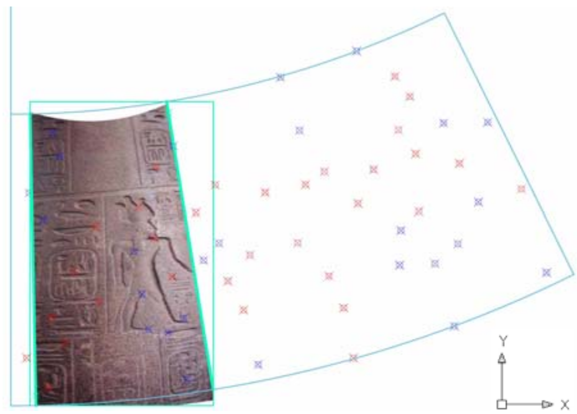


Figure 7. Front view of the development with one orthorectified photograph (the projected object points enable to verify the position of the orthophotograph in the development)

### 3.3 Montage of the orthophotographs and drawing of the epigraphy

After orthorectifying all the shots, a single photomontage is made, on which the hieroglyphic inscriptions are drawn.

The montage of the orthophotographs is not easy to realize, because the exact positions of the different pictures must be strictly respected, and their scales likewise. Moreover, there are differences in light exposure from one original shot to the other (see Figure 3), which requires image processing to obtain a homogeneous picture of the entire surface of the column's shaft. This problem can be avoided by taking the photographs in good light exposure conditions.

Despite all this, once the photomontage is done, we obtain a « photograph » of the developed surface of the column's shaft. This picture represents a plane surface, on which the hieroglyphs can be drawn. (Figure 8)


Figure 8. Montage of the orthorectified photographs with the layout of some hieroglyphic signs


Figure 9. Epigraphic survey on the developed surface of a column of the Karnak Hypostyle Hall

The epigraphy and iconography of the column have been drawn on the orthophotographs using Bezier curves. Procedures developed for an interactive construction of the curves allow to modify them at will, so as to adapt them to the signs in the best possible way. From the layout, the curves can be grouped and recorded as « standard signs » that will be inserted afterwards at a particular place and at a desired scale, thus making it unnecessary to draw a sign several times over. Each sign can also be recorded with its original position on the picture.
The goal is to make up a database with the standard signs that will later be used and questioned like any database. Henceforth, the epigraphic survey can be carried out more quickly with the developed method, not only on a wall but also on a column. The publication of the texts can still be made in paper form, but can now be in numerical form too. Moreover, the method developed by the GRCAO for the epigraphic survey enables the user to gather data about the meaning and the geometrical shape of each sign. This will in turn lead to statistical studies on the hieroglyphs' form, to automatic translations of the texts and to the search for missing elements, based on geometric as well as grammatical criteria.

The method introduced in this paper for the epigraphic survey of conical surfaces has first been carried out on a column of the British Museum (Red granite column with palm capital, 19th Dynasty, about 1250 BC, from Heracleopolis), because of its medium size and the good preservation of its inscriptions. It has later been applied on a column of the Great Hypostyle Hall of the Karnak Temple, for which we had had seven black and white shots. This column is much bigger (2.8 m in diameter, 13.17 m in height) than the museum's column, so the development seems to be rectangular. Some hieroglyphic signs have also been drawn on it. (Figure 9)

## 4. CONCLUSION

This paper has presented an epigraphic survey method for all the conical and cylindrical elements of the Egyptian temples. One aim of the study being the publication of the hieroglyphic texts and iconography, the result is in two-dimensional format. In consequence, we lost the three-dimensional aspect of the conical surfaces. But, knowing that the inscriptions engraved on the monuments have been deteriorating at great speed for a few years, it is primordial for the KHHP's researchers to have a simple and rapid method to survey and publish the texts of the Great Hypostyle Hall of the Karnak Temple. The study has therefore been conducted in this perspective. The computer tools developed are simple to use by the epigraphists on the field, with minimal computer equipment (that's why the tools have been made in the AutoCAD's programming language).

The ultimate aim of the research conducted by the GRCAO is to conceive a computer assistant to validate reconstruction hypotheses in archaeology that will integrate the newly developed tools described in this paper. It is an effective example of computer modelling use both in the fields of cultural heritage and of architectural reconstitution in archaeology.

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