COMPUTER MODELING AS A MEANS OF REFLEXION IN ARCHAEOLOGY.

A new epigraphic and architectural approach applied to a monument registered on the World Heritage list.

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Abstract: Purpose of this paper is to present the first promising results of an ongoing research program that is part of a larger multi-year project carried out by the Computer Aided Design Research Group (GRCAO) of the Université de Montréal, in order to define new methods of archaeological restitution using computer-aided means. This novel approach involves a redefinition of surveying techniques, data processing and knowledge-based thinking in disciplines such as epigraphy and architecture. As its chosen field of investigation, the GRCAO is using the Egyptian temple of Karnak, a monument on the UNESCO World Heritage list that is of considerable historical importance. This impressive archaeological site serves as an excellent case study and testing ground for the project, since it underwent tremendous and complex architectural transformations in the course of its two thousand year-long history.

1. Introduction

Second only in size on the planet to the temple of Angkor, the Egyptian temple of Karnak is by far the most impressive divine complex ever built by the pharaohs. Erected around 2000 B.C. as a place of worship in honor of the most important deity of the time, Amun-Ra, the temple of Karnak was to be subsequently used for the next couple of millennia. The historical significance of this unique set of monuments goes a long way in justifying its inclusion on the UNESCO World Heritage list.

Surprising enough for a monumental complex of this importance is the fact that only a very small portion of the temple of Karnak has been surveyed thoroughly up to now. This is the more surprising as erosion, pollution and vandalism inexorably degrade the monuments. This inability to face hard reality is probably less due to the absence of political will (after all, the heavy reliance of Egypt on tourism is in itself an incentive big enough to justify the time and money spent on surveying and restoring the monuments) than lack of technological know-how that would enable the job to be done in a quicker and more efficient fashion.

Two main reasons explain why the Computer Aided Design Research Group (GRCAO) of the Université de Montréal was chosen by the permanent French CNRS mission-UPR 1002 in Egypt to use the temple of Karnak as the basis of its case study and to develop new ways of carrying out epigraphic and architectural surveys by means of computer modeling.

1) The temple of Karnak underwent major architectural transformations during the course of its long history, to the point that whole sections of the complex were gradually dismantled to leave room for newer constructions. What the average tourist is able to see of the temple today is only what is left standing of its latter phase of construction. Ten of thousands of blocks of earlier structures were either reused in subsequent structures or were scattered about the temple (*Figure 1*). The integration of the widespread cultural practice of block re-use represents a great challenge in tracing the architectural history of a monument by means of computer modeling.

Figure 1. View over the temple of Karnak with scattered blocks in foreground.

2) A great number of scenes and texts cover the walls of the temple. These reliefs, carved by various teams of engravers at differents periods in history, show a great variety in style, depth and size; paleography is regularly used to date architectural structures and *out-of-situ* blocks. Since the decoration may have also been recarved on the surface of a wall at several occasions and that traces of successive versions of wall reliefs may overlap in the form of palimpsests, the GRCAO wishes to develop, wherever possible, a computer-generated method that can restitute volumetrically the different stages that mark the composition of a wall relief and/or scene.

In order to reach these objectives and more, the GRCAO is actively collaborating with archaeologists working in the field. The French CNRS mission has lent the GRCAO all the documents required for the completion of its tasks, meaningly pictures, topographic surveys, architectural plans, epigraphic notes and drawings, as well as all other pertinent written records; in return, the GRCAO will lend the French team all the softwares and computer programs required for the completion of its tasks, in terms of computer-generated images and animations.

The present paper will be divided into two major sections. In the first part, we will have a critical look at the way epigraphic and architectural surveys, with or without the help of computer modeling, are currently carried out in the field. We will then turn to the approach adopted by the GRCAO in order to improve on those methods.

2. Current Means to Carry Out Epigraphic Surveys

2.1. THE ANALOGICAL METHOD

This method, favored by most archaeologists today, goes back to the 19th and early 20th centuries (Traunecker, 1987). There are two main approaches.

2.1.1.The Chicago House Method.

The so-called Chicago House method, named after the residence built by the University of Chicago to accomodate the Egyptologists working in and around Luxor, has hardly changed since it was first introduced in the 1920s. Series of pictures of an inscribed wall are first taken at right angle in order to eliminate distortions. The pictures are then developed and enlarged to fit a 20' x 24' frame. A professional artist goes to the site and draws the contour lines directly on the picture (other teams sometimes draw on tracing paper rather than directly on the photograph; *Figure 2*), before checking and double-checking his/her work with the inscription carved on the wall.

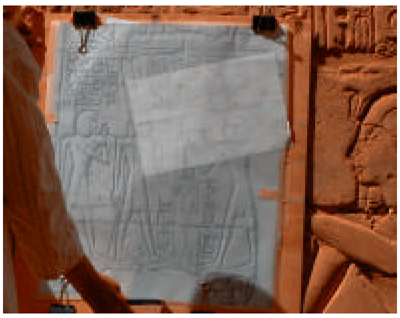

Figure 2. The analogical method of epigraphic surveying

The picture is then immersed in an iodine bath that makes the photographic image disappear, leaving behind only the pencil drawing. An epigrapher compares the drawing of the artist with the original and adds in modifications. In the end, the artist and epigrapher, and then the field director all agree on the final version of the drawing before it is inked for good (Bell, 1987).

2.1.2. The CFEETK Method.

The Centre Franco-Egyptien d'Etude des Temples de Karnak has also developed its own method of epigraphic surveying. Epigraphers use large transparent plastic sheets which they apply against the surface of the wall to be drawn. They use a felt pen to draw the contour lines of the scene. Back at the office, they re-draw and correct the lines to make it fit better to reality. They then draw the whole scene over again on tracing paper, using a Rotring rapidograph. The drawing is then photographed and reduced to one tenth of its original size. Drawings and pictures are then assembled for publicaton.

Other methods, quite common among epigraphers, involve laying some tracing paper against the flat surface of a wall and then rubbing it with charcoal to bring out the sunken reliefs which are left in blank, as well as the use of estampage.

All these techniques are in fact mere variants of the general method described above and the pros and cons to this type of epigraphic surveying are quite manifest:

1) The main advantage in the traditional and analogical method of epigraphic surveying lies in the direct *in-situ* observation of the wall reliefs, which are copied on the spot. Details, such as traces of hacking or erosion, palimpsest inscriptions, blobs of plaster, interruption of the contour lines of a sign or figure, items otherwise difficult if not impossible to pick out on a photograph alone, can come to the fore and be consequently included in the drawing

2) On the other hand, this process is time-consuming, since it requires drawings to be copied several times over again; it is also tedious in cases where the use of a scaffold or a crane becomes mandatory, for example, when it is necessary to copy texts located in areas difficult to reach, such as the top section of obelisks. As for the use of transparent plastic sheets, it is rather not very well adapted for inscriptions engraved in raised (as opposed to sunken) relief, the protruding signs preventing the epigrapher from applying his material against the flat surface of the wall.

3) Even more troublesome are the conceptual drawbacks to this analogical approach. On the first hand, the reproduction of scenes and figures on paper is ill-suited to any in-depth computerized analysis of the recorded data. The drawings serve only to illustrate the end result of a process rather

than the process itself. In other words, this type of work does not aid the researcher in either gaining additional insight into the method used by the Egyptians to carve their reliefs, or in shedding more light on the internal logic behind the decorative program of monuments.

4) Finally, the transposition of a 3-D decoration into a 2-D format poses serious limits to an accurate reproduction of reality, especially if one hopes to capture the depth of the engraved signs and figures.

2.2. THE NUMERICAL METHOD

A numerical approach to epigraphic surveying has gradually gained favor among an enlightened and increasing larger circle of researchers who have attempted to integrate new technology into their working methods, but whatever the software used, the approach is to a large extent the same: numerical pictures of the wall to be drawn are scanned and the tracing is done directly on-screen with the help of Bezier curvelines. Laser prints are made of the drawings that are then collated on the site, in order to compare with the original scene.

2.2.1. Method A

In a seminal article written some years ago, the American egyptologist P. der Manuelian (1998) convincingly showed that speed was definitely an important benefit derived from this method, since corrections were being made directly on computer. He also pointed out that work could for the most part be done at the office, the amount of time spent on the field being essentially reduced to checking out details that were otherwise difficult to detect on-screen, saving along the way as much time as money. Furthermore, this system lent itself well to tracing glyphs and figures with the help of older prints dating from a time when the wall reliefs were in a better state of preservation. Finally, P. der Manuelian devised a clever numerical way of reproducing the shadow lines of a drawing, an optical trick, the aim of which is to help the person who looks at the illustration to determine whether the original scene was carved out in sunken or raised relief.

On the minus side, this method is simply a modern transposition of the drawing board rather than a truly innovative computerized tool; the model generated is strictly graphic, and what is more, it is again in 2-D. As with the analogical method, this approach does not lead to any thorough and significant reflexion on epigraphy as a discipline, an exercise that could eventually redefine its current methods.

2.2.2. Method B

As part of a program which aimed at making photographic montages of thousand of re-used blocks extracted from the inner structure of a pylon that stood in the temple of Karnak, the egyptologist Robert Vergnieux (1999) created a database which made it possible not only to reconstruct parts of buildings on paper, but also to make epigraphic surveys of the reconstituted structures. The way he proceeded was as follows: after having numerized the pictures of each individual block, he made sure that the perspective, the lighting and the scale of each photographed block was the same. He then used keywords based on iconographic units to call up blocks from his database and managed to put some pieces back together on-screen. Using infography, he was able to complete parts of the wall segments that had been missing, restoring and painting the blocks in the process, as if they were new (Brocard, 1999). Purpose of this task was to give the impression that the reconstitution was as faithful as possible to the original (*Figure 3, Vergnieux and Gondran, 1997*)

Figure 3. Photomontage and restitution of a scene by R. Vergnieux's team.

Although this approach proves to be extremely valuable when it comes to making a restitution of the scenes and the colours of the wall reliefs of an ancient monument, neither the phonetic value of the hieroglyphic signs, nor their geometric shape are recorded, a fact that prevents the scientist from gaining deeper comprehension of the use of the texts and scenes which adorned the walls.

2.2.3. Method C

The ICAUL (Interdisciplinary Center of Archaeometry of the University of Liège), with Hololab and SURFACES (Service universitaire de recherches fondamentales et appliquées en cartographie et études spatiales) are developing a complete portable setup, based on optoelelectronics, which is dedicated to giving a precise 3D reproduction of any archaeological documents, including temple walls and their decoration (Laboury & al., 2002).

This novel approach enables a very accurate graphic 3D rendering of the reliefs, but is less useful when it comes to analyzing the way the ancient Egyptian architects and artists built and decorated their monuments, since the 3-D result can't be used efficiently for further intelligent computer treatment.

3. Current Means To Carry Out Architectural Surveys

3.1. COMPUTER TOOLS USED FOR CARRYING OUT 2-D ARCHITECTURAL SURVEYS

Carrying out an architectural survey of the stone masonry involves making a drawing of each block by means of measuring by theodolite at least three points per stone. Some irregular shaped fragments may require up to 20 points to be measured. This type of survey gives rise to numerical documents in the form of dots which are processed by a topographical software that builds an orthogonal projection of points, later to be printed.

The drawbacks of this method are more or less the same as with the epigraphic survey, neither the plan, nor the elevation of the walls (not to mention their inclination) are rendered in 3-D fashion. Once again, the computer is essentially perceived as a technical or graphic instrument. It does not assist the architect either in his formulation of hypotheses of reconstitution, or in the explanation of events that took place during the course of the architectural history of the monument.

3.2. COMPUTER TOOLS USED FOR CARRYING OUT 3-D ARCHITECTURAL SURVEYS

Egyptologists have increasingly made use of computer modeling in order to give 3-D rendering of Egyptian temples, and the temple of Karnak, the biggest and most important of its kind, is no exception to the rule. During the late 1980s, the Fondation Electricité de France used a software called PDMS to show the general public this temple at different phases of its history (Albouy & al., 1989; Golvin, 1994).

This system was very practical towards visualizing how the temple looked under the reign of a given king. One could for example see the temple under the rule of Thoutmosis II, a king who lived in the middle of the 16th century B.C., where the new constructions added by this pharaoh were marked in red and wireframing was used to distinguish between the architectonic features; the walls were however left in blank, while stone masonry in another popular model of the same temple was simply rendered by texture mapping. These two cases illustrate how little attention has been paid up to now in the computer world in accurately reproducing the actual stone masonry.

4. The New Theoretical Approach and Dynamics of the GRCAO

The project deals with the definition and development of new computer modeling methods based on a better integration and greater flexibility of treatment of knowledge involved with the reconstitution of ancient architectural structures. An important aim of the project is thus to find new ways of understanding, organizing and integrating knowledge of various sorts, in order to reconstitute architectural and archaeological heritage, from Antiquity to today. Four objectives are to be met in this regard:

1) to define and experiment original methods of modelisation which make best use of the latest computer high-tech, in order to reconstitute these ancient structures.

2) Based on a systemic approach, to carry out research that emphasizes process rather than end result. In this respect, a great deal of attention is paid at comprehending the way monuments were built (by studying the professional know-how displayed by the ancient architects and artists) and the cultural significance of ancient architectural complexes (by apprehending the monument as the social product of any given civilization).

3) to integrate some of the theoretical and practical knowledge of disciplines such as epigraphy, architecture, archaeology, history, geometry and computer science for the representation and reconstitution of physical objects of the environment.

4) to validate or refute various hypotheses of reconstitution by testing these theories on a 3-D model.

In other words, an important purpose of the project is to produce a 'meta-model' which integrates time, and which is susceptible to generate tridimensional models produced by a set of logical interrogations, for example, on the organisation of a building and its components at various periods in history, or on the nature of the modifications brought about at a specific date. (Tidafi, 1996; De Paoli and Bogdan, 1999).

5. Approach adopted by the GRCAO to carry out Architectural and Epigraphic Surveys.

5.1. RECORDING OF THE GEOMETRICAL SHAPE OF THE HIEROGLYPHIC SIGNS.

In the first place, the computer platform developed by the GRCAO aims at recording the geometrical shape of the hieroglyphic as they are drawn. As of now, one can trace the contours of a sign by calling up the prototype from the data base, and then adapting it to each of its occurrences (*Figure 4*).

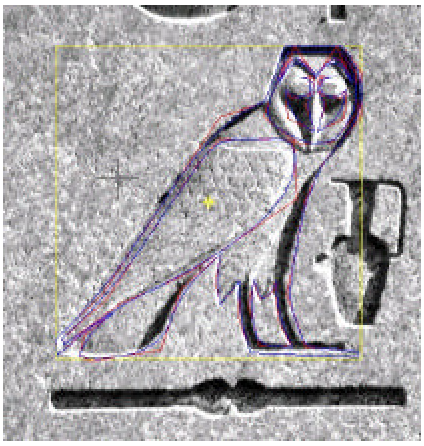

Figure 4. Prototype of a digital hieroglyphic sign
to be adapted to a specific occurrence.

By doing so, it is possible to make paleographical comparative studies of a sign, diachronically as well as synchronically, and thus to analyse how the shape of a sign evolved in space and time. Setting up such a database is of paramount importance to the historian, since the stylistic variants of one and the same sign can serve as a very useful dating criterion in cases where decorated strewn blocks are to be reinstated in their original architectural setting (*Figure 5*).

Original cartouche of Ramses II
(13^{th} Century B.C.)

Restored cartouche of Ramses II
(3^{rd} Century B.C.)

Figure 5. The use of paleography as a dating criterion (note the s tylistic differences)

It is also a well-established fact that several teams of engravers could work simultaneously at either end of the surface of a wall. Each group was then led by a master engraver whose personal and distinctive style can sometimes be traced down by the historian, to the extent that creating a library of prototypes of hieroglyphic signs becomes a great tool to follow work in progress and see how the Ancients conceived and applied a decorative program initiated from above.

In the same line of reasoning, it is noteworthy that there was a definite disparity in terms of quality of craftsmanship between artisans who worked in major urban centers like Memphis and Thebes, on the one hand, and those employed in isolated sites located outside the Nile valley, such as in oases of the Libyan desert, on the other hand. The recording of signs along their geometrical properties lends itself well to the analysis of the degree of competence shown by the Egyptian apprentices.

Finally, on a more practical point of view, using prototypes proves to be a very fruiful strategy when it comes to reproducing repetitive and recurrent decorative motifs such as the toponymic list of captured foreign towns that often accompanied military scenes. Instead of drawing each occurrence individually, it is far better to simply adapt the prototype of that decorative pattern to each example that comes up.

5.2. RECORDING OF THE PHONETIC VALUE OF THE HIEROGLYPHS

Another essential feature of the project is the recording of the hieroglyphic signs according to their phonetic value. One does this by displaying a list of all hieroglyphs divided up by semantic categories (parts A to M comprise all living species, starting with divinities, human beings, animals and then plants, while lsts N to Z include all types of human products – buildings, crafts, etc.) (*Figure 6*). By clicking in the list on the sign that has just been drawn, its phonetic value is automatically recorded. One can then search for all the occurrences of a word that can be visualized in the three-dimensional model of the temple. This makes it possible to study in a more exhaustive fashion the vocabulary used in temples according to literary genres (commemorative texts, oracular decrees, dedicatory inscriptions, etc.) and to analyze the link between type and location of text inside the monument. This also helps to trace the evolution of a word in terms of its spelling.

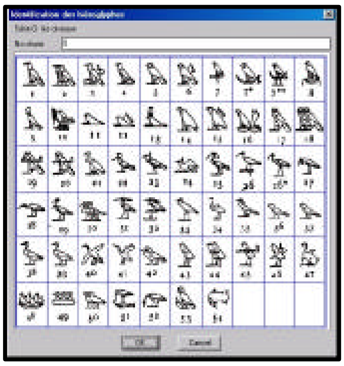

Figure 6. List of birds used in hieroglyphic signs.

5.3. RECORDING OF THE ICONOGRAPHIC THEMES OF THE DECORATIVE PROGRAM

The approach favored by the GRCAO makes it easier to replace the decor into its architectural context, and thus to study its iconography. One can thus examine the relative position of the scenes. Various other questions can be dealt with, such as the nature and the orientation of the scenes, the attitude and posture of the persons depicted, the type of rite they perform, the way they are dressed up and the royal or divine attributes that may be characteristic of them.

5.4. 3-D REPRODUCTION OF A RELIEF

By tracing figures by means of closed Bezier curvelines, the defined surfaces can be extruded in one direction or the other, depending on whether one wishes to recreate the effect of sunken or raised relief (*Figure 7*).

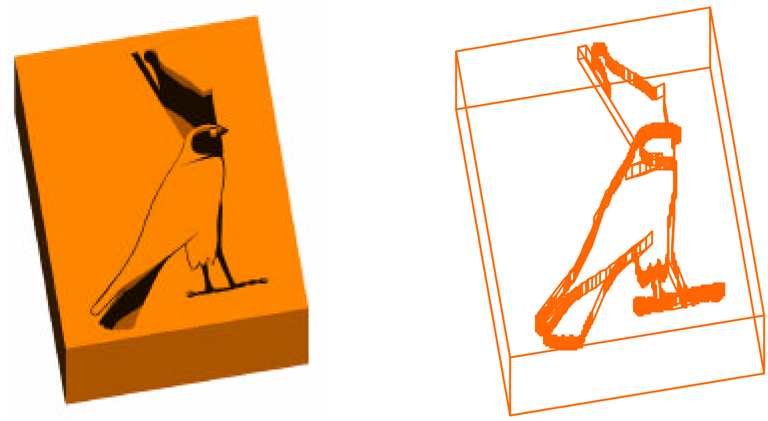

Figure 7 . 3-D rendering of an hieroglyphic sign.

This 3-D approach proves once again to be of great use, since it leads to the determination of more dating criteria. The depth and the size of the signs carved on a wall vary considerably from reign to reign to reign, so that a 3D rendering of the wall decoration gives a great deal of invaluable information otherwise impossible to obtain on a 2-D reproduction of a bas-relief. Furthermore, it lends itself outright to the volumetric restitution of the successive phases that mark the composition of a scene and/or text (*Figure 8, Fortier and Loeben, 1993*).

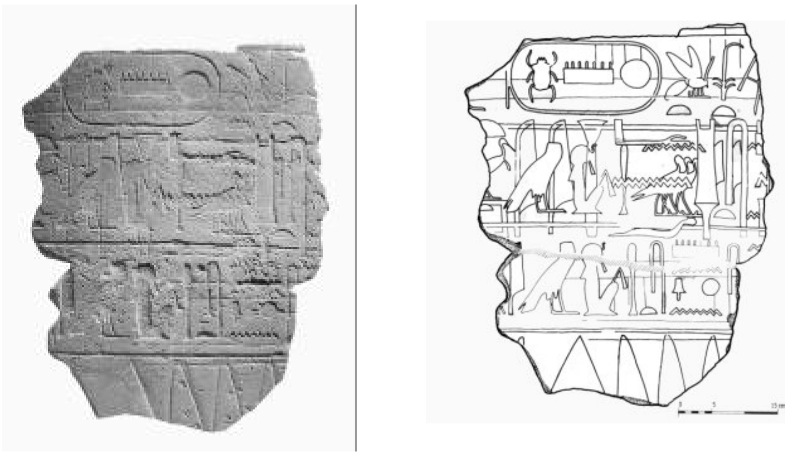

Figure 8. Palimpsest inscription.

5.5. ACCURATE REPRODUCTION OF THE STONE MASONRY

The GRCAO is in the midst of making a detailed and precise reproduction of part of the pharaonic stone masonry of the temple, with each block being traced up to scale. This facet of the project is particularly relevant to the methodology employed in surveying and will doubtless lead to tremendous breakthroughs in various domains. Developing such a computer-aided assistant helps to follow the reasoning applied by the ancient Egyptian architects in erecting their monuments. In the course of the history of Egyptian architecture, temple stone masonry has indeed evolved quite tremendously and additional knowledge can definitely be gained on the chronological evolution of the size and shape of blocks and on the type of joints and mortar used in the construction of the walls.

As many parts of the temple have been dismantled, with some of its blocks being reused in later constructions, it is essential to take this very widespread practice into account when dealing with the computerized reconstitution of monumental architecture. The very heterogeneous nature of walls, which are often made up of blocks dating from various periods, can thus be studied more in depth. Very commonplace Egyptian practices, not only of the insertion of reused blocks in newer structures (*Figure 9*), but also of reparation of damaged architectural features by the inclusion of restoration blocks into older architectural features (*Figure 10*), are aspects of Egyptian architecture that are especially worthwhile examining.

Figure 9. Reused blocks.

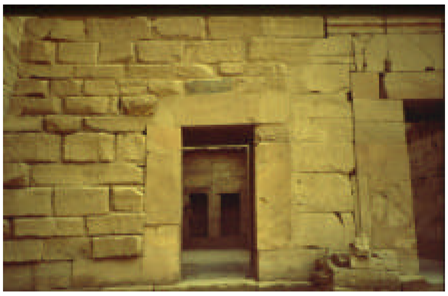

Figure 10. Restoration blocks.

Finally, individual recording of each block makes it far easier to restitute the missing or damaged parts of architectural features, since the archaeologist will know the size and type of stone used in the construction of the temple and have more information on its decorative program. Indeed, recording the geometrical ouline of hieroglyphic signs and figures (as seen in section 5.1 of this article), together with the shape of the architectural feature on which the texts and/or the scenes were carved, makes it possible to reinstate *out-of-situ* fragments in their original position, atop some still standing walls. For instance, if we were to look for the block that was originally set up on top of the upper left one shown in fig. , it would be possible to do so by searching in the database for a block on which the top section of the Horus falcon would have been engraved. This operation becomes the more feasible as the expected size and shape of the neck and head of the bird are recorded automatically by computer (*Figure 11*).

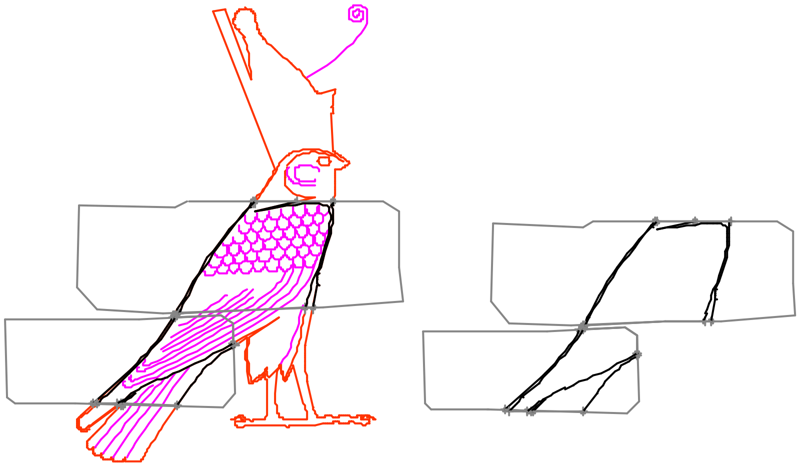

Figure 11. Computer model of blocks together with their decor.

5. Conclusion.

In a context where the scientific community still uses out-of-date working methods inherited from the past to carry out surveys, it is essential to make the best out of the technological breakthrough of recent years in terms of CAAD, so as to restitute ancient monuments in all their spacial and temporal complexity. Instead of the traditional approach that uses paper as the main support to reproduce historical architectural structures bidimensionally, the GRCAO uses computer programming as an aid other than a modern computerized version of the drawing board; it seeks to build a ‘metamodel’ that will serve as a prototype to better study and understand a great number of monuments.

Moreover, far from considering epigraphic and architectural surveys as two distinct activities with a method specific to each, as it is usually the case, the GRCAO wishes to establish a greater interdependance between those two complementary disciplines, in such a way as to integrate and harmonize all the components that make up a monumental historical complex.

By developing new methods of modelisation which should ease the process of architectural and epigraphic reconstitutions, it will be possible to put at researchers’ disposal an efficient platform that will not only help them to manipulate information in quicker and more logical fashion, but also allow them to verify various hypotheses of reconstitution. From models that often tend merely to introduce the general public to the end results of an archaeological project, our computer program will significantly help professionals in carrying out their research as it unfolds. New avenues will subsequently be opened up, which will utimately lead to major transformations in the world of archaeology, on the one hand, and architecture, on the other, since greater knowledge of ancient modes of construction can stimulate the modern architect in his creative process.

Acknowledgement.

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