The formal unity of the Greek Temple: The realization of the 9/A capital replica of Apollo Epicurius’ Temple at Bassai

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In recent years there has been a growing interest in preserving both urban heritage and the European landscape. The need to repair damage to historical monuments of the European tradition while maintaining the particular qualities of local areas is becoming increasingly evident.

In many cases the urgency of reconstruction has often resulted in the creation of built fabrics and architectural details, characterized by a low design and construction quality.

The possibilities offered today by informatics’ technologies (i.e. cad/cam processes), open new horizons within the theoretical debate on restoration and conservation, in terms of both partial and total reconstructions, architectural text integrations (substitution of damaged elements), or integral reproduction of original ruined architectures.

However this specific approach to restoration of monuments of the European tradition poses several delicate questions of both theoretical and practical nature, that have to be solved in the light of a generalized use of these methods as alternatives to existing ones for replica production.

The production of replicas in conformity with originals requires as essential preliminary condition the reconstruction of entire original design (i.e. original shapes and material choice), and therefore the conceptual and stylistic re-appropriation of the traditional construction processes.

In European countries stone represents a material so common in nature that in the past centuries the different civilizations largely employed this material in architecture.

The generalized use of load-bearing masonry systems with an organic character in traditional construction, contributed to the definition of the specificity and cohesion of this cultural area: stone architecture of the past have a strong identity, that results in a unified experience in which the synthesis of construction and design produces the architectural impression.

The Greek Temple could be easily considered as a paradigm in this sense: here stone, used as unique material for the definition of the aesthetic character, expresses directly the structural and decorative geometrical texture, and also defines the formal unity.

Figure 1
View of the temple from Noth-West side before the restoration works (Eforia Z’s Archives, Olympia)
of the architectural system as a whole. Moreover it is characterized by an exact design and perfection in execution, aspects that make it exemplar.

For this reason the damaged original 9/A Doric capital of Apollo Epicurus' Temple at Bassae, has been chosen for the elaboration of cad/cam processing software, and associated 3D virtual simulations for its realization with a CNC machining center.

The development of stereotomy techniques using modern advanced technologies will support the cultural heritage of each European region, and will open new perspectives for the design of architectural elements, providing competitive solutions in terms of quality, speediness of realization in comparison with manual fabrication. They will also help the traditional role of arts and crafts, but also that of stereotomy, to evolve.

THE REPLICA OF THE 9/A CAPITAL OF APOLLO EPICURUS' TEMPLE AT BASSAE

The work presented here resulted from an ongoing research project on the experimentation of cad/cam procedures to the realization of architectural elements in freestone, to be laid dry.

This research project, is focused not only to the ex novo designing, but also to monuments’ restoration.

The research's applicable object is a very restricted one (with no underlying hypotheses for the integral reconstruction of monuments, although this is not excluded theoretically). Moreover its objective is not that of taking a stance in any ideological dispute over whether it is correct to integrate, by remaking them, stone elements that are missing or damaged within the context of restoration; but only to demonstrate that it is possible to produce them satisfactorily using modern computerized technologies.

This is a possibility whose premises consist on the one hand of a knowledge of the original project, not merely of the individual element to be remade but obviously of the entire building; and on the other, of the capacity for attaining perfect workmanship. Obviously such workmanship cannot be that of a craftsman, whose skill, however great but always dependent on traditional tools and techniques, would never be able to reproduce the material conditions in which the original piece was created.

When these two preliminary conditions, deemed indispensable for any procedure of remaking architectural elements in freestone, are satisfied, such elements can be called true «replicas».

Among the possible applications, it was decided to operate taking as model the Doric capital, for its capacity to clearly demonstrate the thesis, since the apparent simplicity of its form tolerates no imperfection in design or execution.

The concrete case under study, coming from the scientific collaboration between the Dipartimento ICAR at the Politecnico di Bari and Eforia Z of Olympia on the one hand, and on the other CMS of Zogno (Bergamo), worldwide leader in the design and construction of numeric control machines, concerns the remaking of capital 9A from the temple of Apollo Epicurus at Bassae.

In agreement with the Commission for restoration of the temple, headed by the archaeologist Joannis Tzedakis, it was decided to proceed experimentally to the realization of capital 9A, integral in conformation, by electronic means; and contemporarily to the manual realization of capital B3, to be replaced. The purpose was that of launching a vast process of comparing the results, the times required for realization and the production costs.
The experimental nature of the operation allowed us to:

— select as material Carrara marble, suitable for its degree of hardness to the technical characteristics of the set of tools (milling cutter and tips) available at the time of realization;
— produce a half capital, in consideration of its weight (approx. 1500 kg for a mean size of approx. 100x 60x120).

The time required for study (defining the laws of composition and examination) and designing the three-dimensional model was approximately 30 days (April 2000); the time required for realization, about 5 days (September 2000).

**Characteristics of the Apollo Epicurus’ Temple at Bassae**

The Apollo Epicurus’ Temple at Bassae presents elements of both innovation and tradition, audacity and control, research and calculation, contrasting factors which concur to define the overall quality and the high artistic expression of the building.

Tradition attributes its design to Ictinus (for a non-specialist approach to the problem, see the popular book by Rhys Carpenter, 1976).

The temple constituted a prototype that spread in the following century beyond the geographical limits of the Peloponneseus, extending up to the boundaries of the Greek world.

As concerns the exceptional nature of this temple W. B. Dinsmoor writes: «I believe we can say that within the perimeter of the peristyle may be found more fascinating problems than in any other building in the world of ancient Greece».

The temple is peripteral-hexastyle (6 x 15 columns) distinguished by the contemporary presence of the Doric order on the outside, in the peristyle, the pronaos and the opisthodom; and Ionic and Corinthian orders on the inside. Ionic are the columns standing against the spurs, which articulate the interior space of the cell and the frieze at the top, while the column placed on the axis of the cell is instead Corinthian.

The proportions of the layout, very elongated (width/length ratio: 2:47) confer on it an archaic features, in contrast to the «short» layout of the 4th century temples. This elongation is due also to the existence of an «adyton» between the opisthodom and the cell proper, presumed to be the original place of cult which, thanks to the presence of the eastern door of the cell, would have allowed the statue of the god to be placed facing the rising sun, as in a temple oriented in canonical manner.

As regards the Doric order, the columns in the peristyle, made of local calcareous rock, have twenty flutes separated by a very fine relief on the outside (2 millimeters) and a wider relief in the pronaos and in the opisthodom (about 4 millimeters). W. B. Dinsmoor has observed that the columns were wider on the facade and that the intercolumnation on the facade is wider than on the sides.

As in archaic times, the top of the shaft is adorned by three horizontal flutings, called dactylis. As
regards the Doric capitals, at least four different categories are reported in the sources: those of the northern facade, those of the other three sides of the peristyle, those of the pronaos, and those of the opisthodome. The first two categories differ from each other in size; the capitals on the northern facade are wider and taller than those on the rest of the peristyle. The profiles of the capitals on the opisthodome do not differ greatly from those of the capitals on the facade. The only obvious difference lies in the manner in which the flutes end below the echinus, that is with a slight curve, not with an almost horizontal elliptical calotte as in the capitals on the northern facade.

Accordingly, should examination of the Doric capitals confirm W. B. Dinsmoor’s thesis concerning the two stages of construction of the temple, the dates would have to be changed: the first stage to around 450-430; the second stage to the first decade of the 4th century. These dates, in fact, are consistent with the information deduced from the profiles.

**STUDIES AND SURVEYS OF THE TEMPLE AT BASSAE**

The temple has been the subject of studies the results of which are contrasting. A comparative analysis of these results reveals differences in both objectives and investigational methods (surveys and classification).

Joachim Bocher, the French architect attributed with discovering the temple in 1765, made the first study drawings of the monument. These drawings, which remained unknown for over two centuries and were published only in 1968, were done in pen and ink. Those which have survived show the plan and elevation of the monument viewed from the side ideally restored and the facade, also graphically integrated.

A more thorough study was conducted in 1811 and 1812 by a group of fourteen amateur archaeologists, all scholars and artists of different nationalities (French, English, German, Baltic). They belonged to an association which they called «The Xeinoi», whose members included Carl Haller von Hallerstein, director of excavations, Otto Magnus von Stakerberg, draftsman, Charles Robert Cockerell, who did not participate in the subsequent diggings, and John Foster.

The notes and drawings in Haller von Hallerstein’s notebooks, executed during a campaign of excavations, represent one of the most reliable sources of information, as valuable as that of the temple itself, and are extraordinarily important for all those architectural elements which were later dispersed.

In his drawings Haller von Hallerstein made a scientific survey of all of the architectural elements, going so far as to define their regulatory geometries. For example, his drawings of the Corinthian capital (later destroyed) show the succession of the investigative stages, from an overall representation of the find up to an in-depth study of the generator plots.

Among the most recent studies of proven scientific worth, conducted starting with direct examination of

![Figure 4](image-url)

Karl Haller von Hallerstein, drawings from study notebook of Apollo Epicurius’ Temple (from G. Roux, Karl Haller von Hallerstein, 1976)
the temple, are those of Lucy T. Shoe (1936) and of Friederick Cooper (1996). Their drawings reveal the different objectives pursued.

Starting from the 1920s the Greek Ministry of Culture has promoted a campaign of surveys, which today constitutes the most reliable scientific basis yet published (edited by D. Svolopoulos, 1995).

In the academic year 2000/2001 the Faculty of Architecture of the Bari Polytechnic Institute held a workshop dedicated to study of the temple (coordinator: prof. Claudio D’Amato; students: Mariangela Alicino, Francesca Aulicino, Cosima Carone, Francesca Cavone, Valeria Chieti, Giuseppe Dell’Aquila, Simona Dentico, Loredana Donatelli, Alessandra Paresce with the assistance of the graduate students Giuseppe Fallacara and Annalisa Di Roma). In agreement with Eforia Z of Olympus and in collaboration with the architect Sofoklis Alevridis of the Temple Commission, a campaign of surveys was carried out on April 9–12, 2001.


The «electronic» modelling of the capital and the eighth drum of column 9A was conducted by processing the data derived from traditional survey (investigation, examination?) (manual) on a scale of 1:1.

Capital 9A consists of a square-based parallelepiped abacus, an echinus whose contour is defined by a polycentric or spline curve, by a collarino and by the end of the fluting which is joined to the collarino through a complex surface.

The eighth drum 9A consists of a truncated cone with fluting and engraved end (hypotachelion).

The identification of the different parts of the capital was done through computerized polygonal CAD modelling by «surfaces» and not by the parametrizing of «primitives» or «extrusion» of polygons, for the purpose of facilitating manipulation of the 3D object.

The abacus, a square-based parallelepiped volume, was obtained by the mutual and orthogonal composition of flat surfaces («2d faces»).

The echinus and the collarino, a single volume of rotation, are the result of a surface of revolution.
obtained by rotating the profile of these elements for 360° around an axis of radial symmetry.

The collarino, serving as union between the end of the fluting and the echinus, mathematically defined as a quadric surface, was obtained through a «polar series» of a bilinear curved surface consisting of 20 elements through an angle of 360°. This surface was modelled in two successive stages: the first by interpolating a «Coon surface» for four spatial curves: the first of these is the portion of convex circumference termination of the annuli, contained in the horizontal plane included in an angle of 9° (half of 360°/20); the second is the profile of the fluting, contained in the vertical plane passing through the axis of radial symmetry; the third is the section measured at the centreline of the fluting, contained in the vertical plane passing through the axis of radial symmetry; the fourth is the portion of concave circumference at the base of the fluting contained in the horizontal plane. The surface determined in this way represents half of the global surface, which is completed, in the second stage, by «mirroring» the surface found according to the axis passing through the centre point of the fluting, perpendicular to the axis of radial symmetry.

The drum consists of a surface passing through three sections contained in horizontal and parallel planes, measured at different heights. The hypotrachelion has been obtained by generating a surface having as generatrix the raised profile (saw-tooth section) contained in the vertical plane passing through the axis of radial symmetry, and as directrix the section of the drum, contained in the horizontal plane, at that height with the fluting.

Today’s processes of three-dimensional computerized modelling provide, to various degrees, a complete description of any real object, by reappropriating in virtual manner all of the mathematical-geometric laws which subend the physical description of the object.

Through management/unitary appropriation of the geometric apparatus of the object under analysis, it is possible to investigate a multitude of phenomena at the basis of its conformation.

The forms possessed «in positive» restitute the importance of structural processes which can be hypothesized as «negative» (as in the case of the profile of the hypotrachelion and the generator tool).

The conformational unity of the computerized model supersedes processes of graphic representation.
by plane projections (which provide poor interpretations of reality), being at the same time both one and infinite (the planes tangent to the infinite points of a sphere at whose centre the object is placed being as many as can be imagined!) planes of graphic representation.

In other words, in possessing the computerized model we possess a reality which is the more real the more virtually it can be described.

Figure 9

STAGE OF CAM ENGINEERING AND NC POST-PROCESSING OF THE FILE

The CAD/CAM software used for realization of the Capital is MasterCAM. By importing the model into the dwg format it has been possible to read the three-dimensional geometric conformation of the capital and to proceed to all subsequent steps\(^1\), first among them the re-dimensioning and positioning of the surface area (to be machined) on the machine table.

The next step was selecting the milling cutters\(^2\) suitable to the various parameters required by the program: geometric nature of the «object», type of machining (rough-finishing, finishing with 3/5 feed drives), material utilized (Carrara marble), speed of feed and rotation of the milling cutter. The type of movement (zigzag, spiral, etc.) to be used for removing the material, within a «pocket» of volume of the object, was then selected.

Having effected all of the CAM parametrizing, we then prepared the NC postscript file, directly readable by the controller of the 5 drive feed CMS-MAXIMA utilized for machining.

Figure 10
CNC Machining Centre of CMS, with 5 axes. Spindle’s degrees of freedom in CMS Maxima machine.

MACHINING STAGES

It was deemed advisable to carry out preliminary rough-machining to eliminate the material of the blank that would have prevented the tool from approaching the surface of the piece.

The rough-machining stage called for the selection of the type of tool progress (zigzag, spiral, etc.) which the tool executed during machining, remaining orthogonal to the fixed table, and the choice of type of tool; in this case a cylindrical milling cutter was selected.

The next stage of work was finishing\(^3\). This process was carried out with 5 feed drives and with a spherical tool. During the finishing stage, the machining allowance (amount of rough material left above the actual surface) was removed, and machining of the details was carried out.
Figure 11
Politecnico di Bari-CMS (Zogno, BG): phases of the 9A capital reconstruction process with informatics' technologies (September 2000).

Figure 12
Politecnico di Bari-CMS (Zogno, BG): Detail of the 9A capital replica’s echinus and hypotrachelion.

Figure 13
Politecnico di Bari-CMS (Zogno, BG): General view of the 9A capital replica.

Figure 14
Politecnico di Bari-CMS (Zogno, BG): General view of the 9A capital replica.
NOTES

1. The research project was co-financed by MURST and the Bari Polytechnic Institute, and by CMS SpA Costruzione Macchine Speciali, Zogno (Bergamo)
   Scientific Directors
   — prof. Claudio D’Amato Guerrieri, Bari Polytechnic Institute
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   Survey
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   — Gian Paolo Margheriti, CMS
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   — Vartelio Migliorini, CMS
   Realization
   — Festi & C., Ghisalba (Bergamo), with 5 feed-drive NC machine Maxima from CMS.

2. The term «replica» in architecture differs substantially from that of pictorial or sculptural replica, which instead always implies execution by the hand of the same artist. In architecture the significance of replica is limited to compliance with the original project, also executed in its first realization by other hands; and the question of authenticity becomes irrelevant at the moment in which the individual element is acknowledged no independent value as work of art.


4. In the design stage, analysis must be made of the problem of congruency between the shape of the tool, the characteristics of the machining path and the final shape to be obtained, in order to perform good machining and to avoid the co-penetration of tools and material.

5. Tool repertoire.
   The characteristics of the machining tools vary in relation to three main parameters:
   — type of machining (preliminary rough-machining stage, finish stage);
   — geometrical characteristics of part to be realized;
   — physical characteristics of material to be machined;
   — speed of feed and rotation of the milling cutter.
   Types of tools:
   — milling cutter for shape (contouring and incision),
   — cylindrical milling cutter (machining on cutting edge),
   — spherical milling cutter (machining on side and end of cutting edge).

6. Finish. The type of run selected for the finish is called «scanning».
   In this case the tool proceeds by successive passes, parallel along the entire surface of the piece, with the depth of each progressive deepening calculated automatically.

REFERENCE LIST


