Modelling the Ionic Capital

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Abstract. In the course of a study into the origins of the Ionic order, a group of fragmentary early capitals of historic importance were measured by short-range laser-scanning, and then reconstructed in their original state by means of NURBS surface modelling. Drawings, renderings and scaled facsimiles were produced from both types of model, and proved invaluable in the formal analysis of the objects by architectural historians. It is suggested that these digital methods are more objective and accurate than traditional drawings and plaster reconstructions, and the resulting datasets more sustainable and of greater value to subsequent researchers.

Keywords. *Classical;Ionic;History;Pointcloud;Reconstruction;Modelling.*

Background

Traditionally the second of the three great orders of classical architecture, the Ionic has been perhaps less popular than the Corinthian, and received less study than the Doric, yet its origins seem to be as ancient, and quite possibly older than either. When its capital does receive attention, it is usually the geometry of its characteristic spiral volute that is considered, with its supposed relationships to Bernoulli's logarithmic spiral, the shell of the Nautilus, and the golden section. Intriguing as these may be, they are not the only points of interest, particularly when the capital is considered as a three-dimensional object, rather than simply in elevation. The shape of the bolster (fig 1), the profile of the echinus (or cushion) and the overall proportion and relationship of parts are remarkably sophisticated and, for the historian, intriguing because they have not always had the now familiar Ionian form.

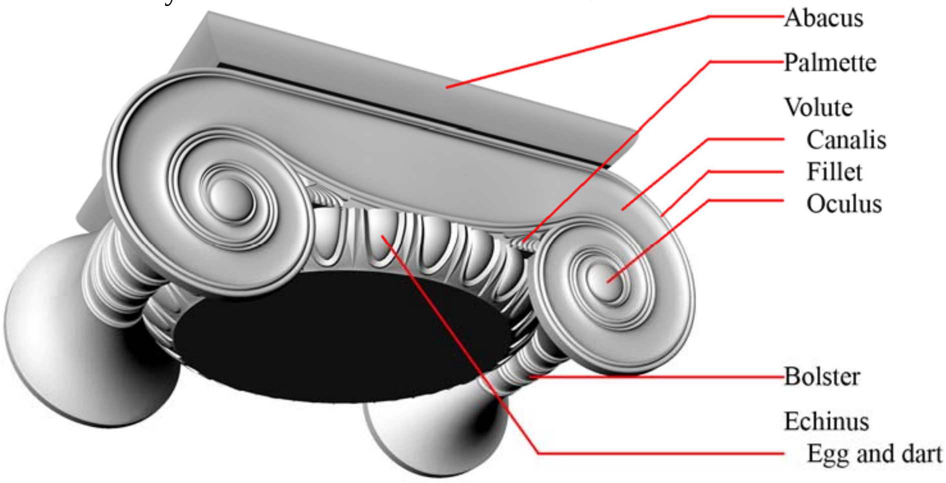

Figure 1
Anatomy of the Ionic capital. Mature Ionian form, Propylaea, Athenian Acropolis.

Prior to the 5th century BC, the Ionian capital (named from a coastal region around modern Izmir in Western Turkey) was in competition with a more primitive Cycladic form, associated particularly with the Greek islands of Naxos, Paros and Delos (Barletta 2001). Compared to the Ionian, this has a fatter echinus, more cylindrical bolsters, and an overall elongated plan (fig 2). The Ionian variant has an overall square plan, pushing the bolsters closer together, which themselves become heavily flared and absorb part of the echinus. The canonical Ionian volute has two and a half turns and a central oculus; the Cycladic typically one and a half turns, and no oculus. The Ionian echinus has a flat-topped quarter-round profile enriched with egg-and-dart moulding, whereas the Cycladic has a fatter drooping half-circle profile, and a petal-like enrichment.

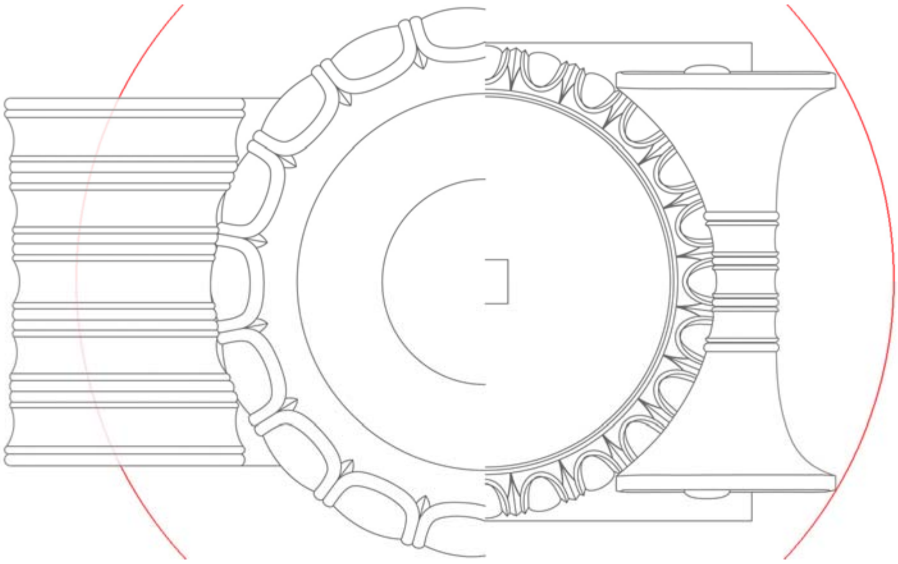

Figure 2
Reflected plan of a Cycladic capital (left) compared to the mature Ionian form (right)

Our work was part of a study into the origins of these forms, and the reasons for the eventual eclipse of the Cycladic variant by its more compact rival.

The traditional method of study of architectural fragments has been by scaled measured drawings, made with great care using ruler and pencil, calipers and profile gauge. Usually plan, front and side elevation are produced with some profiles, but multiple sections only rarely. Not surprisingly, given the complex three-dimensional nature of the objects, such drawings do not provide a full description. Most of the extant capitals are fragmentary, and after several thousand years' exposure, severely eroded. This means that they need to be reconstructed, a process that is particularly difficult and error-prone if conducted simply with the drawings. In museums, the more important objects may be given a three-dimensional reconstruction in plaster, but this is a cumbersome and inflexible technique, and hinders inspection of the fragments themselves. Studying the original objects themselves might be better in theory, but they are scattered across museums in Greece and Europe, and are usually too large and immovable to be analysed with any ease.

Our intention was to find an alternate method of recording these ancient stones, using laser scanning for the current state and computer modelling for restoration of the original, and then develop techniques for reproducing them in various drawn formats, and most importantly as conveniently scaled replicas using rapid prototyping (Herdt 2008).

Methodology

A series of 12 capitals were identified, located in mainland museums and several of the Cyclades (Table 1). Prior to organizing a field-trip to Greece, we carried out a trial at the British Museum in London. Originally we intended to scan a capital removed from the Erechtheion in Athens (by the notorious Lord Elgin), which is now in better condition than those remaining on the Acropolis. However, as it is preserved complete with its column, the scanner would have to be mounted on a scaffolding tower, which would in turn necessitate protecting nearby objects. It proved simpler to measure instead a detached capital from the Temple of Athena Nike. A contractor was employed to do the scanning, using a Minolta VI-910 close-range scanner, and to carry out the initial processing, returning a triangulated surface mesh at various resolutions. The purpose of the trial was to get a better understanding of the logistics and time needed to make the measurements, and the standards to be employed in terms of point spacing and resulting mesh size.

1	Naxian Sphinx	Delphi Museum
2	Votive column of Alexitides	Naxos Museum
3	Temple of Dionysios, Yria	Naxos Museum
4	Votive capital	Paros Museum
5	Votive column of Archilochos	Paros Museum
6	Votive with sphinx	Delos Museum
7	Corner from Propylon, Naxian Oikos	Delos Museum
8	Votive from Oropos	National Museum, Athens
9	Temple of Athena Nike, Athens	British Museum, London
10	Temple of Dionysios, Myus	Pergamon Museum, Berlin
11	Erechtheion, Athens	British Museum, London
12	Propylaea, Athens	in situ

Table 1
Capitals included in the survey, with current locations

The field-work, carried out in September 2006, proceeded most smoothly in the major museums in Athens and Delphi, where we could obtain access when the gallery was closed to the public, the lighting was well below the recommended 500 lux, and there was plenty of space. The process was much more difficult in open-air collections in the islands, where we had to improvise sun-shades and scaffolds, and could not always get access to all sides of the capital. The larger capitals (2m across) required up to 40 scans to cover the entire surface at a range of 1-2m. The point spacing was between 0.5 and 1.0 millimetre, yielding a total of up to 10 million points. The scanner has a low resolution camera built-in, which recorded the approximate colour and texture of the surface as additional rgb coordinates attached to each point.

The workflow following on from scanning goes through many stages (fig 3). The first is to register the individual scans to a common coordinate system, and merge them into a single pointcloud. Then the points are joined up to their nearest neighbours to form a triangulated mesh. From this, the surface normal at each point can be estimated, and added to the pointcloud, which greatly improves the rendering quality, as it enables lighting to be calculated properly. The triangulated mesh could have 20 million triangles, which is too many to handle conveniently on a 32-bit computer, so the next stage is to decimate the mesh by reducing the number of triangles, especially in the flatter regions. In general we aimed for a decimated mesh of 1.25m points and 2.5m triangles. Any holes in the decimated mesh (due to occlusion and inaccessible surfaces), were filled-in but coloured black, so as to be distinguishable from measured surfaces, while yielding the watertight mesh required for rapid-prototyping.

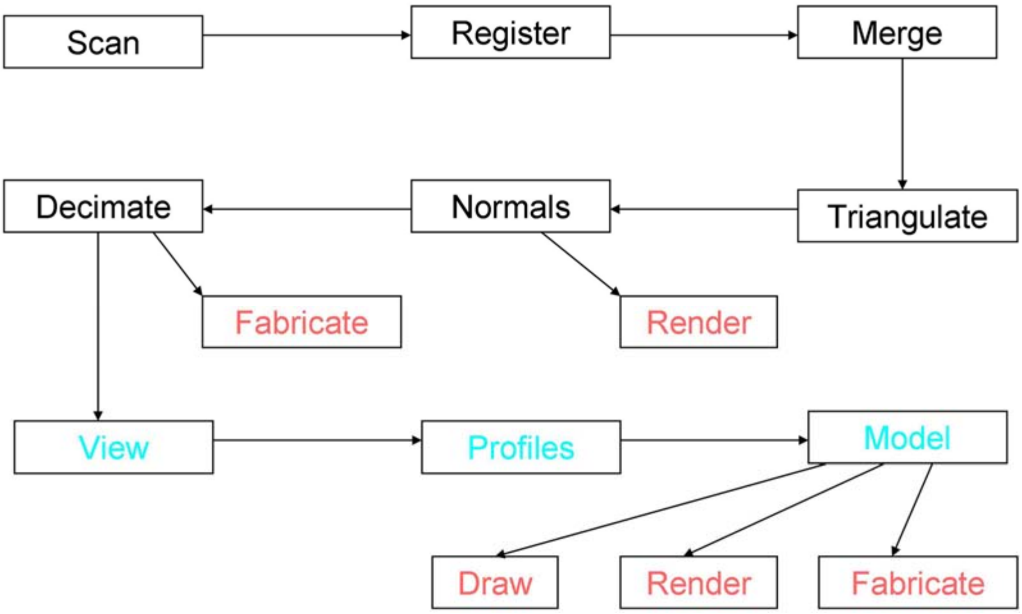

Figure 3
Overall workflow

After a successful first trial based on published drawings (Palladio 1738), the reconstruction modelling was committed to Rhino (McNeel 2008). The basic modelling technique is to analyze the capital into discrete smooth surfaces separated by sharp arrises or grooves. For example, in figure 1, the whole of the canalis in the two volutes and across the front is such a surface. The arrises are extracted as space curves, a process which is eased by the fact that most lie in axial planes. The network of arrises is supplemented by profile curves which sample the bulge of the surface, taken in planes perpendicular to the arrises (fig 4). Then the surface is constructed using a 2-rail sweep. Adjacent surfaces are similarly constructed, and joined together along their common edges. Eventually the major components (abacus, volutes, balusters and echinus) are constructed as watertight boundary surfaces, and combined using Boolean operators.

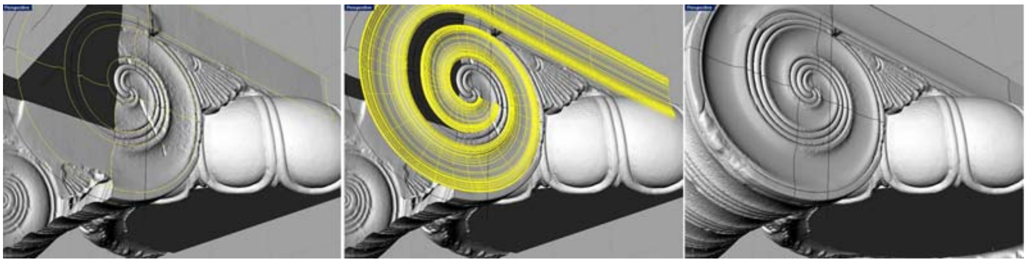

Figure 4
Modelling in Rhino with scanned mesh as background. Extracted arris and profile curves(left), rail-curve formation (centre), resulting smooth surface (right).

Having made meshes, either from the laser survey, or the Rhino models, the ultimate process was to make facsimiles by rapid-prototyping. Several different methods were tried, including Selective Laser Sintering, and Fused Deposition Modelling. The best results were obtained using a Z-Corp 3d printer, working at a scale of 1:10. The models resemble plaster casts, and with the colour version can approximate the texture of the original marble.

Standard rendering and line-drawing techniques were used, mainly to prepare material for publication. Beyond these, transparent rendering, to superimpose the reconstruction onto the scanned surface, was found to be particularly valuable for checking the accuracy of reconstruction, and for historical analysis (fig 5). The ICF streaming format from INUS Technology Inc, is used on our website to provide an very interactive display of the models (www.bath.ac.uk/ace/3d-models/).

Figure 5
Corner capital in the Delos Museum (left) and transparent reconstruction superimposed on the scanned model (right). Black areas are those not scanned because of the adjacent wall.

Discussion

The most acute difficulty we faced was in using the laser scan as a background for reconstruction modelling. We tried three different approaches. The first was to view thin sections of the pointcloud in Autocad, generate lines by tracing, and import these into Rhino. The second was to view the pointcloud directly by a specialized plugin in Rhino itself. The third was to import the decimated mesh into Rhino, and use that as background (this only became possible following a software upgrade during the project). Our conclusion was that when cross-sectional information is wanted, all these techniques are viable, but when elevational information is needed (for example when tracing the spirals of the volutes), the mesh was the best by a considerable margin. The reason is that the mesh can be viewed with lighting applied, which makes the position of surface features defined by small changes of orientation much more visible, and the meshed surface, unlike the pointcloud, does not break up when zoomed in.

Even so it remains difficult to precisely place an arris. The marble is heavily eroded, and original sharp edges are unlikely to exist. Even if they did, the scanning process never produces an echo on the actual edge. It would be theoretically sounder to reconstruct the arrises by estimating the adjacent surfaces, and finding their intersection curve.

A major constraint on the modelling was that we wished ultimately to produce .stl files for rapid prototyping, which meant that we had to use solid-modelling techniques to produce a watertight manifold surface. This is much more demanding, on both the software and the operator, than the “cheap and cheerful” interpenetrating-surfaces modelling usually used for architectural graphics. Rhino can, in principle, perform the necessary Boolean operations on nurbs-based polysurfaces, though we found them to be reliable only when the surfaces intersect at a sharp angle. This limitation caused many difficulties, for example it might not be possible to benefit from the symmetry of the capital to model a quarter, and then reflect and merge the result to obtain the whole, because the meeting surfaces when this is done are mostly tangential to each other, and the Boolean union fails.

A technical difficulty that arose quite often was that it was not always practical to model the whole of a smooth surface with a single construction. This is visible in fig 4, where the eye of the volute, and the mirror-image part of the canalis, have not been included. When eventually these parts are constructed, it is necessary to take great care to align the surface normals along the seams, otherwise shading glitches will be visible when the object is rendered.

Although capitals of the classical period from the Athenian Acropolis are admirably precise and symmetrical in their geometry, this does not apply to the earlier objects. Their reconstruction inevitably involves choices between different detailed interpretive possibilities, some quite difficult to call. For example, when should slight deviations from planarity or symmetry, or irregular spacings of egg-and-dart enrichment, be regularized?

In two cases (capitals 10 and 11) we were not able to scan the originals, but did have access to traditional scale drawings by leading scholars eg (Cordingley 1842), which we used as the basis for reconstruction. The process was instructive, in that it demonstrated that such drawings are most unlikely to be complete and self-consistent. The 3D shape of a flared baluster is simply not conveyed by traditional drawing formats, and the process of extracting edges and assembling them in 3D space will expose the slightest inconsistency between the various projections. In other cases we compared our scans with published drawings, often finding small errors and sometimes gross inconsistencies - such as the wrong number of eggs in the echinus moulding. A much better result was obtained for capital 12, from Mnesicles' Propylaea on the Athenian Acropolis (fig 1). Here we used the meticulous full-size drawings prepared by the restoration architect Dr Tasos Tanoulas for the stonemason who was cutting two new capitals for the building.

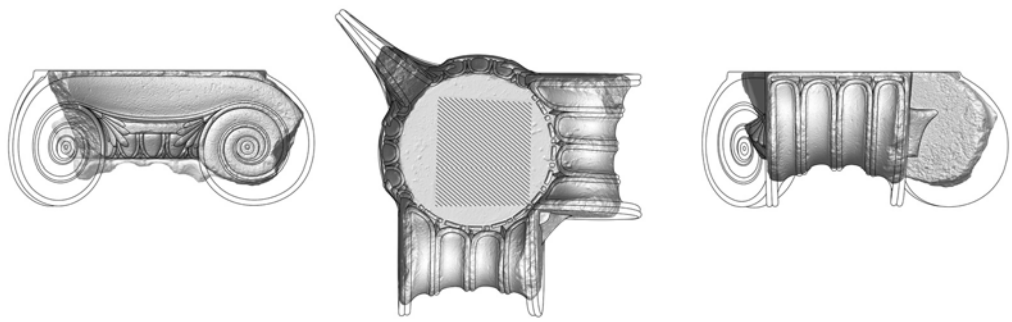

Figure 6. Reconstruction of the diagonal volute of the Delos corner capital. Line drawings superimposed on the scanned mesh. The volute tapers in plan and also vertically downwards.

The mature Ionic capital is a very sophisticated object – apart from its bearing surfaces nothing in it is flat or straight – and very demanding to model to the high standards that we set ourselves. Even more complicated is the form of capital eventually evolved for use at the corner of a peristyle, where volutes show on two adjacent faces, rather than two opposite ones. The solution (figs 5,6) is to use standard volutes and balusters meeting at right angles on the interior, but on the external corner a pair of volutes back-to-back, with no baluster, and twisted to a plane on the diagonal, so that they can be read on either elevation. In the case of the early example from Delos, the rather fragile corner volute is mostly missing, posing an exceptional challenge to the restorer. The most authoritative published reconstruction (Gruben 1997, p358), which appears to have been worked out from 2D drawings, shows the corner volute as having parallel faces. In our case, with the advantage of working with the full 3D data, we can see that the sweeping curves of the canalis on the two adjacent faces leads inevitably to a volute tapered in plan. As an additional sophistication, we can see by close examination that the surviving standard volutes are in planes slightly inclined downward from the vertical, and this additional inclination is most likely shared by those missing in the corner.

Conclusions

The laser scan pointclouds have proven to be an accurate, complete and durable record of the state of the stones, and, compared to the traditional measured drawings, objective in the sense that they are free of selection, interpretation and internal inconsistencies. The Rhino reconstructions are, of course, interpretive, but because they are worked out in full three-dimensions, are more plausible and self-consistent than those developed traditionally on a drawing board. Indeed we have by this means found several incongruities in published and generally accepted reconstructions. The facsimiles are ideal aids for discussion and thinking about the geometry of these intricate objects (fig 7).

Figure 7. Facsimiles made by 3D printing from laserscans(dark) and restored Rhino models (light). In the centre are various Cycladic forms; on the left is the canonical Ionian version from the Erechtheion.

In terms of architectural history, this work is lending support to two distinct hypotheses. One is that the Cycladic form was only suitable for prostyle temples (with columns in front): when architects became more ambitious and wanted to erect peripteral buildings (with columns all around) the squarer Ionian form worked better, because it could be adapted to the corner condition, as in our example from Delos (Wilson Jones, forthcoming); there is no satisfactory way of adapting the elongated Cycladic capital to this situation. The other hypothesis is that the Cycladic form may have originated not as part of a building, but as a free-standing column supporting votive sculpture, such as the famous Naxian Sphinx at Delphi.

In the future we hope to extend our study series back the Archaic period, by including Aeolic capitals with rising volutes (Betancourt 1977), of which some of the most intriguing examples are to be found in Cyprus and Turkey, eg at Bodrum and Izmir. It seems likely that these were inspired by Phoenician and possibly even Minoan precedents.

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