Geometric Evolution and Optimisation of “The Oval”

Abir Acharjee
Atkins Ltd, Architecture, London & International, Design & Engineering, UK
Bartlett School of Graduate Studies, University College London, London, UK
e-mail: abir.acharjee@gmail.com

Abstract

Computational freedom and emergent design tools are leading to geometrically challenging forms in the field of architecture. Designers are able to work with more complex geometries and design variations. The challenges lies in defining these geometries into buildable components with constraints in construction techniques, materials and cost. Designing with construction logic helps to avoid geometric post-rationalization.

Geometric abstractions of mathematical descriptions form an inherent part of computational design. These applications and tools in architecture attempt to solve a combinatorial problem like modular facades or generate pattern for surfaces.

This paper takes the project “The Oval” in Limassol, Cyprus, as a case study to explain the integrated design process of form finding to development of the design geometry, leading to a modular cost effective solution. It focuses on the use of computational approaches towards the design enabling the alignment of the design geometry with the design intent at every stage and embed constructional rationales. It further researches on developing an optimized paneling solution for this class of geometry.

Keywords: Computational Design, Parametric modeling, Rationalization, Paneling.

1.0 Introduction

Concept design explores visions from sketching to massing and then to defined geometry, which eventually defines the building components. This sometimes results in a process of post-rationalization. A well-informed design solution takes into consideration the construction logic and modularity at an early design stage. In this approach the building geometry is developed with an awareness of the details.

Computational approaches help to generate, visualize and evaluate spatial properties of the built environment. The notion of controlling geometric systems through parametric design has become a route for complex designs. Parametric modeling transforms the design process into an experimental series of actions that allows the discovery and analysis of unfamiliar opportunities. The model generates several variations for taking design decision and helps the transition from computational geometry to the materialization of the design.

2.0 Approach

The emerging digital tools are enabling designers to deal with more in-depth analytical design thinking and approach. They have a strong influence in designing forms and resolving complexities derived from concepts, site constraints, construction limitations and cost. It helps in the iterative evaluation process for the design options. The geometric descriptions allow for higher control of the design and achieve the required aesthetic expression. It helps in negotiating design options with competing disciplines. The combination of intuitive visual programming with the robustness of parametric design, offers unprecedented fluidity throughout the development of a project.

a b c

Figure 1. Concept development

The original concept was based on a pebble form (Figure 1a,b,c). Initial studies involved the formation of a generative model (Figure 2b) and analyzing this form with respect to the spatial and planning data. The concepts have been created in conjunction with the architectural team. Solutions have been devised that meet the architectural and structural requirements. This paper contains discussions of the form finding, geometric approach, design development and further research on paneling solutions.

3.0 Concept Development

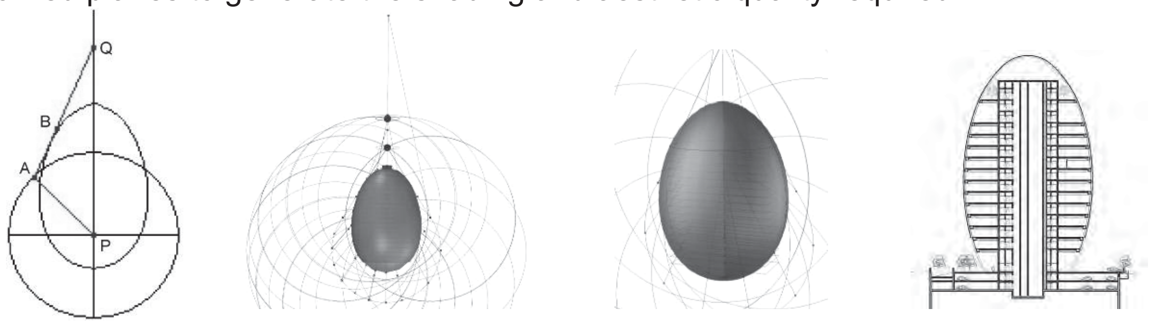
Atkins was commissioned the Concept and Schematic design of this 80 meter tall office tower. I assisted the Design Director at all stages from form-finding to final deliverables for his vision of this oval form. Initially in the concept design I was responsible for the geometry, envelope and facades. Later was responsible for the full project deliverables at the schematic design stage.

The concept of pebble form was approached by developing an egg curve using the mechanical egg curve algorithm (Figure 2a). The site and project constraints defined the final volume.

3.1 Mechanical Egg Curve

Point A (Figure 2a) moves in a circular path around point P and Q is another variable point in a line passing through P. Point B is a variable point collinear and in-between A and Q. The position of the point B describes an egg shaped curve as the point A rotates 360 degree.

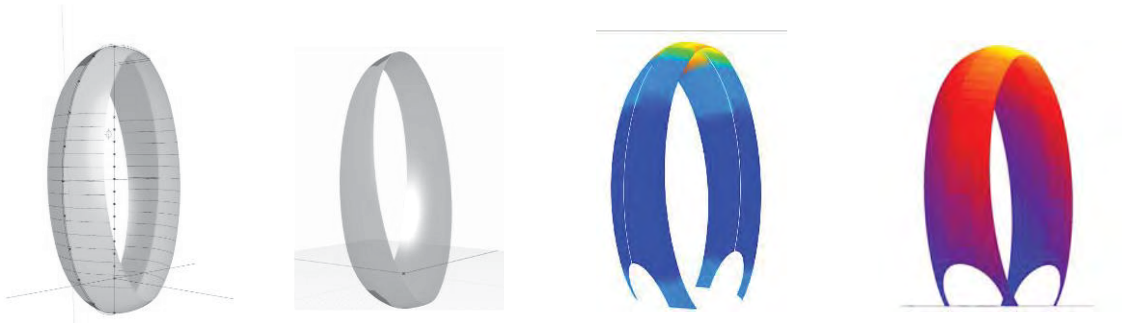
Initial studies involved generating a range of volumes with this logic transformed along translated and rotated planes (Figure 2b,c). Once a simplified volume meeting area requirements is achieved (Figure 2d), it was sliced in the middle (Figure 3a) to have a sharp change in curvature, producing a differentiating line of shading between the two halves of the shell. It was then sliced from both sides (Figure 3b) with inclined planes to generate the shading and aesthetic quality required.



a b c d

Figure 2. Mechanical Egg curve algorithm(a) and form finding (b-d)

This initial form was a double curved surface with more curvature towards the top of the envelope (Figure 3c) due to the inherent nature of the egg form.



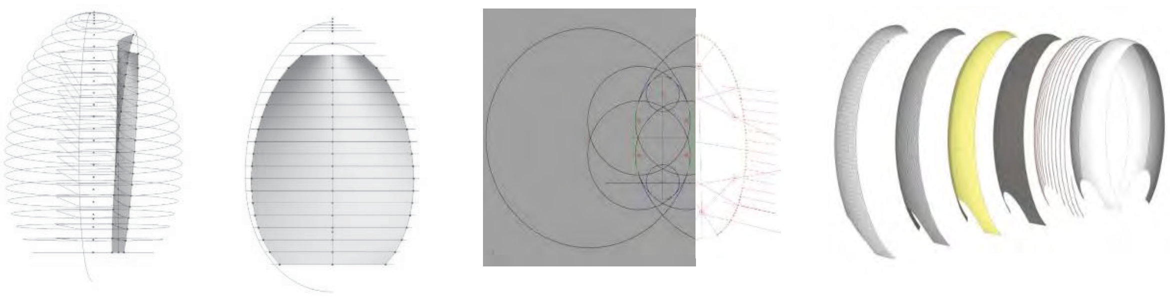
a b c d

Figure 3. Development and Analysis of the shell

The changes in curvature needed to be nominal towards the side for accommodating the areas and viewing angles from the floors. The variables in the parametric model helped to satisfy the area requirements, aesthetics and integrate structural solutions. Several iterations of the slice angle with solar analysis (Figure 3d) of the shell along with aesthetic judgements, produced the final form.

3.2 Geometric approach

The process of iterations of the geometry was informed by rationales and geometric implications at all stages (Figure 4a,b). To create a standardized approach to this non-standard surface, the surface was initially created as a combination of several parametrically controlled torus patches. The egg cross section of the form was realised using eight circles with tangential continuity, at the points of required structural joints (Figure 4c). Circle centres were derived after simple iterative loop of a function to minimize the distance from the original curve respecting the specific tangent points and satisfying the floor areas within a range.



a b c d

Figure 4. Analysis of surface, rationalisation, structural layering

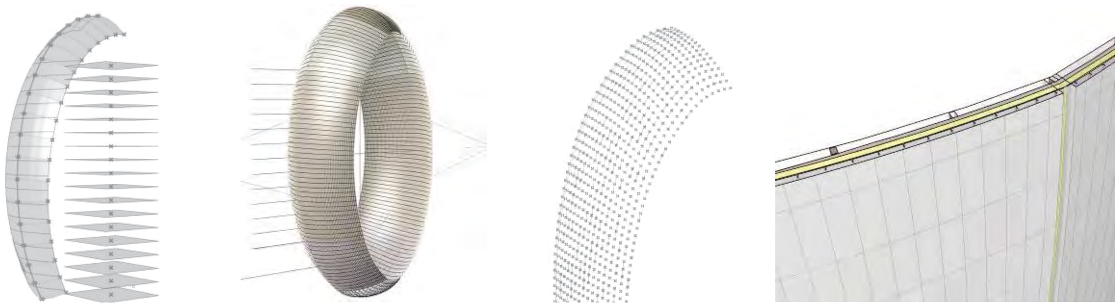
The top of the tower host a sky restaurant, so the curvature of this part was further reduced to accommodate the volumetric requirements and provide openness to the space. The oval cross section in the other direction was formed with three circles with tangential continuity. Since the shell geometry influenced the structural layers within the shell, the geometric relationship between structure and exterior facade were explored (Figure 4d). Two layers of panels, outer and inner layer, needed to be evaluated which required a paneling solution.

3.3 Panelisation Strategies

The paneling solution is generally achieved by using a tessellation algorithm to break the geometry into required subdivisions. The general approach is a top down methodology in which the surface is explored with regard to its global topology. For minimizing the overall cost planar quadrangular panels were preferred over planar triangular and bent panels. In contemporary construction, flat panels in general, have several advantages over warped panels, including productive time, manufacturing cost, durability and maintenance.

The full unsliced surface geometry was taken for the paneling. The edge line panels follows the slice line of the form and needed to be sized accordingly. Several paneling solutions were developed, some of these were based on the globally curved facade-locally planar panels, some were globally curved facade-locally stepped and others were based on the globally curved facade-locally planar with adjustable divergences, where divergence refers to the gaps between panels. The aim was to go with planar quadrilateral panels. Analysing constructional support system for the panels and aesthetic requirements, the panel size required was around 1350 (length) and 450 (width).

A torus patch can be subdivided into rows of flat quadrilateral panels. In the initial formulation, eight parametrically controlled torus patches combined to form the outer panelled surface geometry. However, within each strip there were variations in the panels as per the inherent nature of torus form.



a b c d

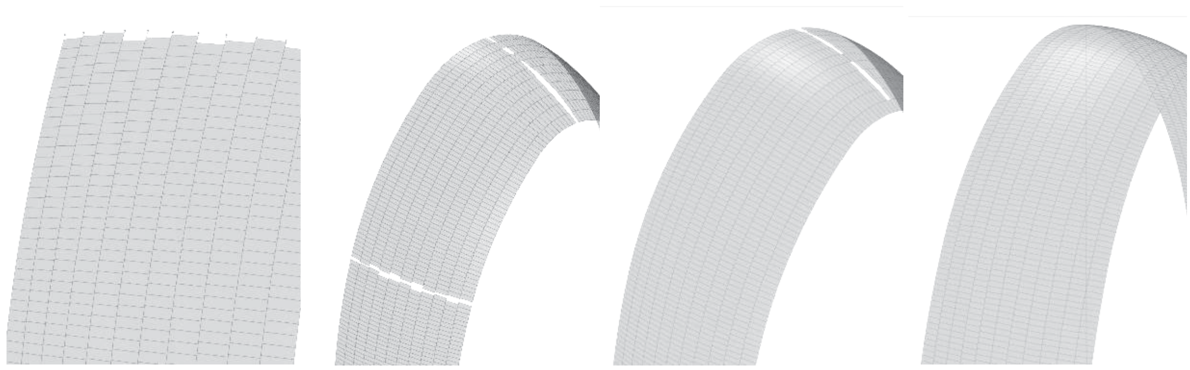
Figure 5. Variations in slice angles

3.4 Panel Optimization

In the previous solution, each torus panel strip had a number of variations as the panels start from centre of the tower and proceed towards the edge. The main aim of the optimization was to minimize the number of panel variations in the surface. The algorithm developed was broken down into a couple of simplified routines dealing with specific issues. The central cross section curve, which we derived earlier from eight arcs is taken as an input. Since the form had one symmetry axis, we had to deal with only five curvatures, which are treated one at a time. For each of the curvatures, the respective curve is taken and an iterative loop is used to generate the geodesics for that curvature.

The curve of any one curvature is taken and a conical surface is defined with its base on this curve and apex lying on the vector passing through the curve centre, normal to its base plane. A variable plane parallel to this base plane is defined to intersect this conical surface. An optimization loop of a minimizing function is set up to get the intersection curve on the conical surface which is at a specified distance of panel length and it closely matches the curvature in the other direction. This curvature match is done by taking a cross section curve following that curvature in other direction and dividing them into points. Then the distance of the intersection curve on the conical surface from the corresponding point is obtained. Minimizing this distance to zero, gives the closest match. Since both the curve planes are parallel, so we get a conical strip with width equal to the panel length and which closely follows the curvatures on both directions. Taking this new curve, the above steps are repeated to generate its corresponding next curve. This is repeated till the full curvature in the other direction is covered. Repeating this for all the five curvatures the required geodesics are generated.

Next step was the formation of the panels. Taking a pair of consecutives curves, equal walking steps were taken on the first curve to place points. For each of these points a corresponding nearest point was searched in the other curve. The four points generated by walking two step forms a panel.



a b c d

Figure 6. Variations in slice angles

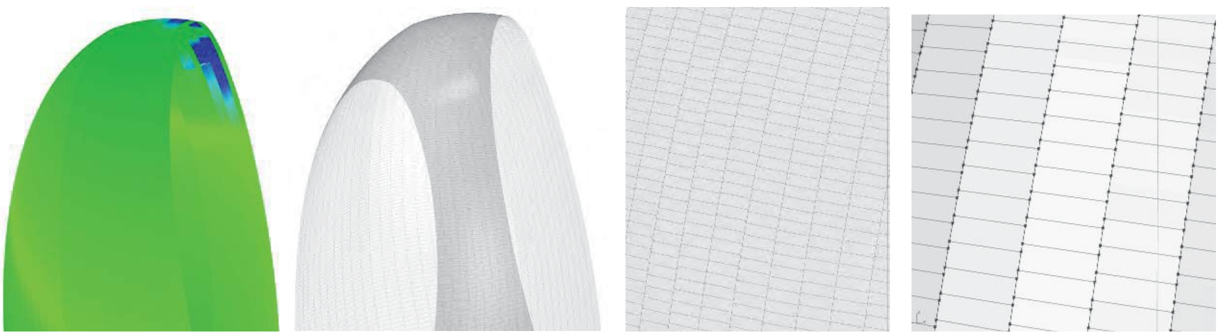
This process continues for the remaining length of this curve pair. Next this second curve and its neighbouring counterpart curve are taken and again for these two curves the previous approach is taken to form the panels. This continues for all the curves in this curvature. Then the curve in the next curvature is taken and the above routine continues. This repeats for all the different curvatures.

For each curvature, while taking a pair of curves, several walking approaches along the curves was experimented with mainly two line of approach. In the first approach (*Figure 6b)*, curves in different curvature are taken one at a time with the walking process stopping at the end of each curvature . In the second approach (*Figure 6d)* all curves in one cross section loop are treated as a single composite curve for walking without stopping at the curvature change points. Other experiments included taking three curves in one quadrant as a composite curve (*Figure 6c)* and looking into ways of making simple proximity decisions at the top end points.

3.5 Paneling analysis

A control over the panel variation was achieved and analysis of the panel types indicated a significant reduction in the number of panel variations. Geometric results were evaluated against construction conditions. The panels formed with such technique are all planar within a tolerance of 5mm as there tend to be slight negative curvature at the top where the curvature is minimum (*Figure 7a)*. The panels are staggered from each other accommodating the panel sizes (*Figure 7b,c,d)*.

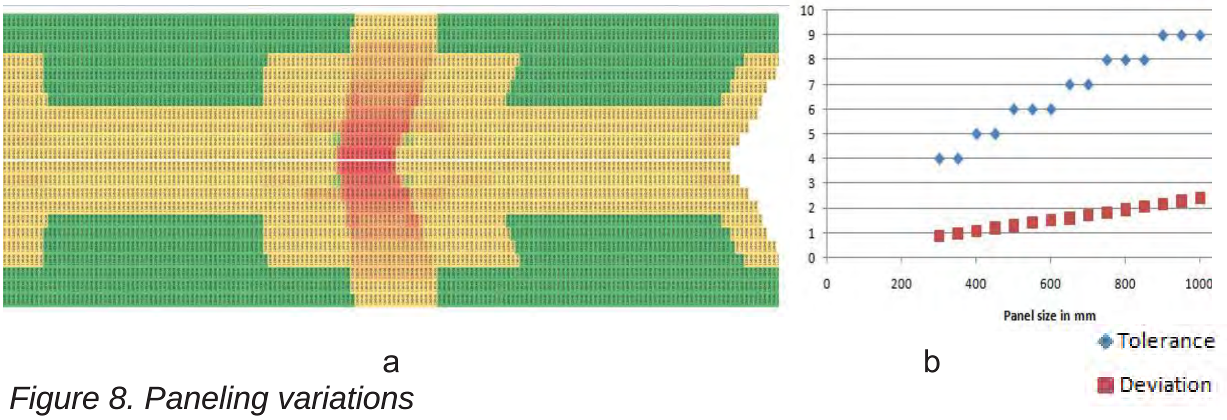
In the first approach when dealing with individual curvatures, similarity in panels are achieved with few irregularities at the curvature transition areas. In any one curvature, as we go from a large to small radius of panel strip, the panels tends to get smaller, however when working with very large curvatures, like this form, taking small steps allowed to distribute the differences to get uniform panel sizes and the number of panel types are minimum. In this first approach, all panels are planar within a tolerance of 3mm.



a b c d

Figure 7. Curvature analysis and Panelled surface

In the second approach for the paneling, we start walking from the lowest point in the ground level of one side and loop through the full composite curve. This approach provides no irregularities at the areas of curvature change and planarity of the panels was achieved within a tolerance of 5mm with the curvature change of the panels being minimum. A control over the panel similarity is achieved within a specified range (Figure 8a) with slightly more panel types than the previous approach. There are some irregularities at this bottom area on the other side where it joins back. Since the full geometry was taken for paneling, this part of the shell is below ground, so it creates no issue in this case. Further investigation is required as to how the paneling end edges wraps up with the starting edge line for other designs which are continuous.



a b

Figure 8. Paneling variations

Keeping the panel length constant, experimenting with the step distance (panel width) from 300 to 1000 mm (Figure 8b) shows that as the panel width increase there tend to be minor angular deviations of the panel and the overall planarity is achieved within a tolerance of 9mm.

Taking into account the overall structural as well as material behaviors, this approach can lead to trade off the number of panel types depending on the required aesthetic of the visible edge quality for the design.

4.0 Discussion

Architecture stands as a product of hybrid processes in which traditional and digital methods merge with computational freedom and emergent digital tools. In a digital environment, Architects are able to customize one's own tools and realize design intensions more rationally. Using these tools from the early design stage offers unprecedented fluidity throughout the development of a project.

Every design problem now demands custom approaches, tools and analysis. This paper demonstrates the cohesive use of computational approaches in the design process from concept development to the final design. It explains the gradual development and strategies to support the design intentions at all stages. It further researches on different strategies to the paneling solution for the envelope. These approaches support the design process across several disciplines and can be further investigated for specific needs in materialization of the design.

5.0 Acknowledgements

I am grateful to Atkins (Architecture, Design & Engineering) for the support in this research. I would like to sincerely thank the Design Director of this project for his guidance and support. I would also like to thank the design team members for the discussions during the project.

6.0 References

[1] Eigensatz, et al., 2010. Panelling Architectural Freeform Surfaces, *ACM SIGGRAPH.*

[2] *Liu, et al., 2006. Geometric modeling with conical meshes and developable surfaces, ACM Transactions on Graphics (TOG) - Proceedings of ACM SIGGRAPH.*

[3] *Pottmann, et al., 2010. Advances in architectural geometry, Vienna: Springer-Verlag.*

[4] Golovinskiy, A. Podolak, J. Funkhouser, T.,2009. Symmetry-Aware Mesh Processing, *IMA Conference on the Mathematics of Surfaces*.

[5] Fu, C. Lai, C. He, Y. Cohen-or, D., 2010. K – Set Tilable Surfaces, *SIGGRAPH, Technical Paper, ACM Transactions on Graphics*, Article No 44, Vol 29.

[6] Singh, M. Schaefer, S., 2010. Triangle surfaces with discrete Equivalence Classes, *Proceedings of ACM SIGGRAPH*, pp. 46-47.

[7] Kolarevic, B., 2005. *Architecture in the digital age: design and manufacturing*, New Edition. London: Taylor and Francis Ltd.

[8] Boer, S. Oosterhuis, K., 2002. Architectural Parametric Design and Mass Customization, *ONL Architecture*, *Rotterdam, Netherlands*.

7.0 Image credits

All project images are copyright of Atkins unless otherwise noted.

Figure 2a. Mechanical Egg Curve. [image] Wikipedia < http://www.mathematische-basteleien.de/eggcurves.htm >