# The Oval - a complex geometry BIM case study

*Odysseas Georgiou*[1]
[1]*SEAMLEXITY LLC, Univercity of Nicosia*
[1] *odysseas@seamlexity.com*

*This paper documents the steps followed to design and construct an oval shaped, high rise structure in Limassol Cyprus. The author presents the developed computational framework which was purposely built to support multiple levels and disciplines of design, construction and digital fabrication leading to a successful delivery of a complex geometry project within time and budget. A fully informed model involving multi-disciplinary data ranging from its conception to its completion establishes a sustainable paradigm for the construction industry, mainly because of its single source of control as opposed to other precedents involving multiple models and information.*

**Keywords:** *Parametric Model, Setting out management, digital fabrication, BIM*

## INTRODUCTION

This paper attempts to illustrate the use of advanced computational tools through their application on large scale built project. The authors undertook a holistic approach on the design development and fabrication through a centrally built and controlled information model with parametric capabilities. The case study presented in this Paper, the Oval, was designed by Atkins Global and WKK Architects and planned to be built on the coastal area of Limassol, in Cyprus. The Oval was proposed to stand facing the southern coast of Limassol at a height of approximately 100m consisting of 16 stories of commercial space bound by a of a doubly curved aluminium shell. The Oval posted an early challenge both for the design team and the contracting team as it was the first large scale building of non-rational geometry to be built on the island. Furthermore, it's completion on time and within budget was of great importance as this was amongst the first ones to be constructed following the Cyprus economic recession. The Oval would be presented as the clients' flagship project marking the construction markets' recovery.

The authors were committed as geometry consultants to initially assist on the design development and the coordination of the complex shaped structure in relation to the architectural skin. As the project developed however, the authors engaged on managing a parametric Bulding Information Model that informed most parties involved in its construction. The computational design workflow therefore, as opposed to standard practice, was not predetermined but was constantly fed with additional capabilities as the project progressed. This proved to be the largest challenge for the authors, assembling a framework that was able to expand and incorporate information and capabilities (Aish et al, 2005). The basic geometric principles of the building were incorporated into the model in order to initially describe the shape and the structure to aid the design development at consultants level. Then the model was upgraded to manage the setting out and extract data for the sub-contractors and monitor the construction tolerances.

Figure 1
Completed project

At its final level of development, the model provided the basis for the panelisation and the panels fabrication and the coordination of the whole cladding build-up system.

## METHODOLOGY

### *GEOMETRIC PRINCIPLES*

The shell is described by two elliptic surfaces which intersect at the X-axis of symmetry. These surfaces are produced by sweeping two circular sections with an elliptical rail. The circular sections are sliced with two slanted (XZ planes with rotation along X axis) planes at north and south elevations, in a disproportionate manner in relation to the axis of symmetry, producing an open shell towards the North and the South. Even though the surfaces are produced with circular sections producing a rational surface of revolution, the structure is handled with sections parallel to the XY Plane, causing geometric non-linearities which weren't easily identified at first (Figure 3). Each horizontal floor plate is tangent to the shell thus creating varying concrete structure geometry with interconnected curved in space columns.

The shell cantilevers from the primary structure both at north and South sides depending on the offset of the vertical planes from the origin. The primary structure was proposed to be constructed using cast in situ reinforced concrete combining single curvature elements with faceted members. The secondary structure, comprising the skin would be composed out of curved tubular steelwork anchored on the concrete from the ground to the 15 floor. The dome area

Figure 2
Geometry evolution

was constructed using variable curvature steel arches braced together with linear members. The latter area was geometrically optimised to form flat quadrilaterals in order to be easily clad with rigid structural decking.

## THE PARAMETRIC INFORMATION MODEL

The authors developed the custom build framework in Grasshopper 3D [1], a plugin within Rhino 3D[2], a commercial CAD software, in order to initially control the doubly curved geometry and produce 2D information for the consultants. The aforementioned geometric principles were incorporated into the parametric model, along with the geometrically varying elements of the Project. Parametric rules were set for the curved columns of the building, the doubly curved slabs, the steel structure (supporting the skin) and the front and back facades. The model was able to automatically produce layer structured 2d sections and export in CAD formats for all the variations of the project along the design development (Figure 4). The model was also used as an interactive clash detection tool for all the interfering elements bound within the skin of the building.

The parametric model was developed incrementally to incorporate information needed by consultants and sub-contractors in-volved with the project. The steelwork comprising the structural skin was incorporated into the model in order to fully understand the complexities arising and provide better insights on its cost.

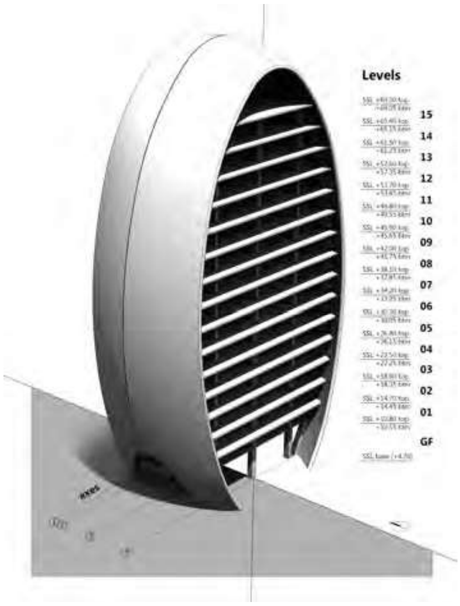


Figure 3
Shell including the horizontal elements

Figure 4
Proposed Dome structure with flat panels

Figure 5
2D information generation from 3D model

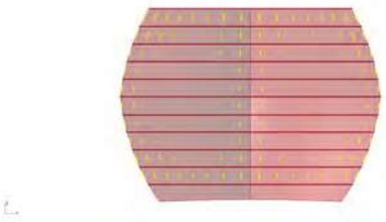


Figure 6
Clash detection at the Shell dome

## INTEROPERABILITY MODELS

The initially proposed structural envelope of the Building was abandoned due its geometric complexity and therefore there was a need for a fast development of a new proposal for the structural skin. The central model was therefore modified to include analytical information in combination with the structural geometry information. This provided the basis for an interoperability model which directly connected the geometry with the structural analysis software, ETABS[4] in order for the Structural Engineer to precisely model the structural information, provide feedback and revise the geometry model (Georgiou et al, 2011) (Kolatsou et al, 2017). Due to the complexity of the structural geometry, each design iteration would demand a great amount of time when modelled traditionally. Additionally, in each structural iteration, the geometric information was passed to the Steel Fabricator [3] through tabular data in order for the fabrication model to progress.

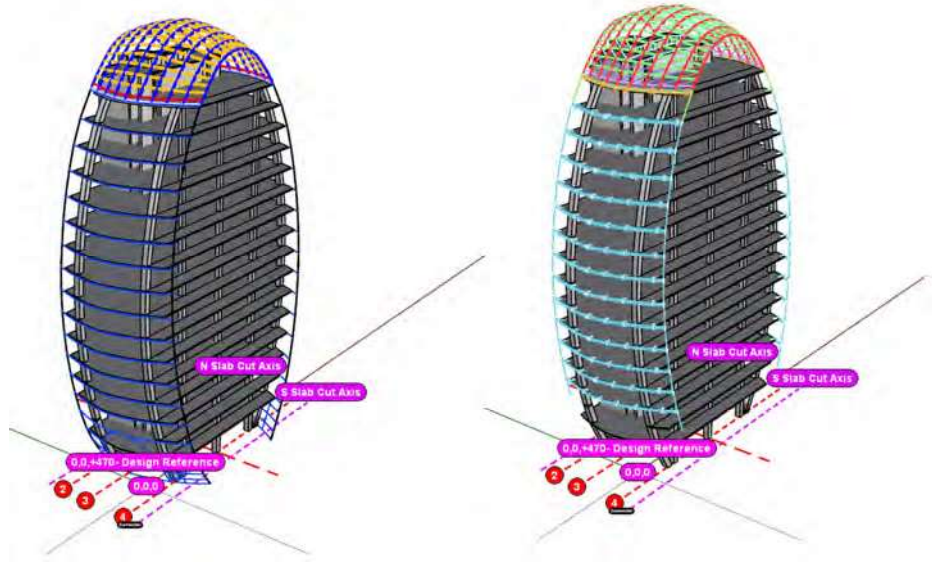
The above information could be reinstated at a later stage with the precise setting out information received from site. Structural information was also passed to the Wind Tunnel subcontractor in order to conduct the wind simulation. Incorporating the load information into the central model saved valuable time to the engineers in passing the loading zones into their Structural Analysis software.

## STRUCTURAL ELEMENTS SETTING OUT

To ensure a better adaptation to the curved shape, exact setting out information was extracted for the concrete frame for each level of the building. The central parametric model was able to extract setting out data in excel and ASCII format which were used by the Surveying engineers to precisely mark the curvature of the concrete structure. The direct workflow between the parametric model and the Surveying teams Total Station equipment would mean that the setting out marks with the corresponding numbering could be returned back for tolerance checks after each element was cast (Figures 7 & 8).

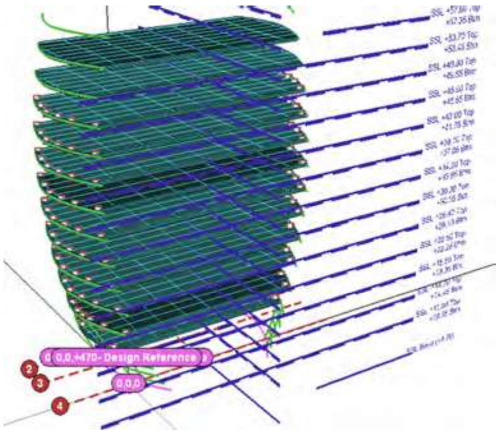
A setting out management process was adopted by the authors which was biderectionaly linked to the central parametric model. This meant that all the date to and from the model was fully coordinated and controlled. The required positions of the steel anchoring system were input from the structural engineer to the central model and were then exported as data for the Surveyor engineer to stake out. After the concrete casting this data, filtered through the model was sent to the fabrication subcontractor. Following fabrication and installation of the steelwork and as the full adaptation of the proposed Shell shape was crucial, a tolerance check took place which

Figure 7
Analytical model translation to CAM model in TEKLA



verified the theorectical geometry and proposed corrections were needed (Figure 9).

Figure 8
Monitoring stage



## PANELISATION AND CLADDING FABRICATION

The parametric framework had also aided the most demanding aspect of the project, the cladding. Data related to the doubly curved shell built up consisting of the secondary steelwork, the aluminium standing seam membrane and the quadrilateral panels had to be extracted from the central model. These elements were included and were constantly coordinated with their interfering elements like the concrete and steelwork primary structure.

The build-up elements were initiated from the shell surface used to generate the structural geometry and were offset accordingly to the desired depth. The standing seam aluminium sheets (Kalzip) were produced using information extracted from the central model. Due to the fact that these elements were doubly curved at their majority and needed to be produced overseas there was a demand great accuracy both during the fabrication and during the installation of their fixings on site. These meant that

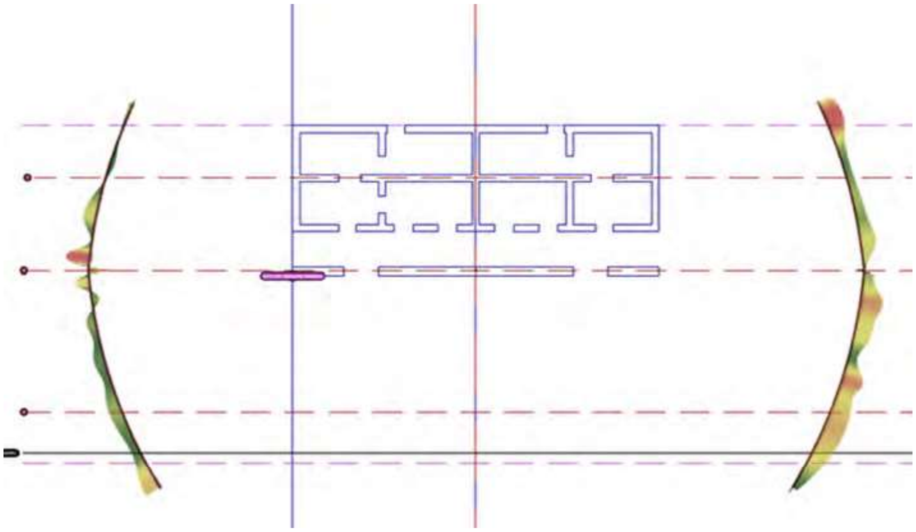


Figure 9
Curved Steelwork tolerance checks

big amounts of data needed to be passed to the Surveyors for the accurate placement of the supporting elements.

The shell panelisation scheme was proposed by the author as the most adequate for the adaptation to the geometry and the horizontal elements of the structure. The scheme suggested horizontal joints, aligned with the slabs of the building.

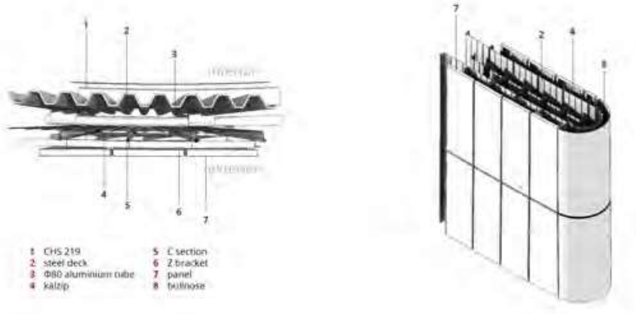
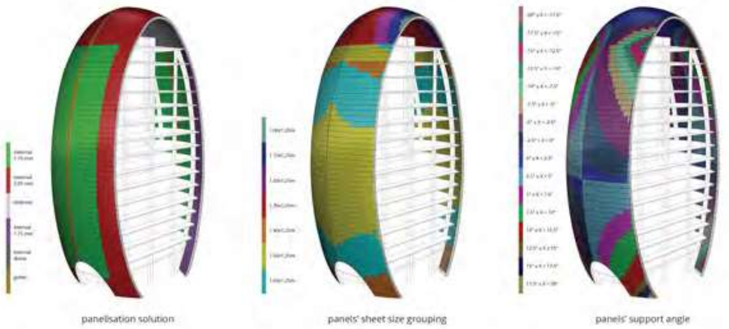


Figure 10
Cladding build-up

Figure 11
Installation of doubly curved aluminium membrane substrate.

Figure 12
Panelisation scheme panel grouping and fixing rotations



This scheme would greatly improve the intersections of the interior panels with the afformentioned elements and would ease the setting out process of the intermediate supporting elements. All the supporting elements and fixings would be parallel to the horizontal plane which meant that they could be linearly set out. The scheme however created a large domain of unequal panels

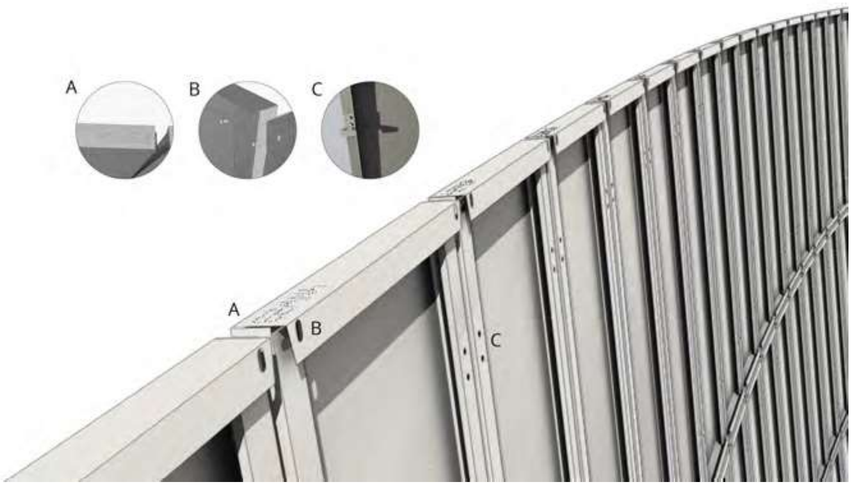


Figure 13
Panel trays in simplified breps

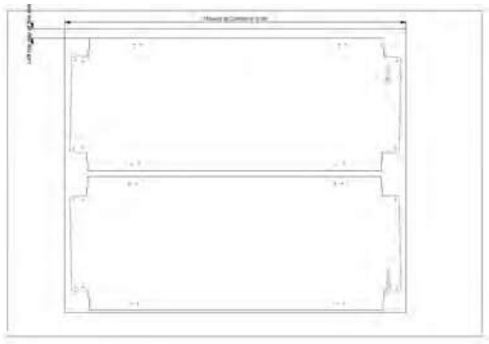


Figure 14
Unrolled cutting layout

The panels were designed to be constructed out of 1.75mm and 2mm aluminium sheet bent to form trays, The panels were adapted onto the original surface, initially as single surfaces in order to create a light-weight model responding to architectural and aesthetic decisions. This was later developed to incorporate the trays and be continuously informed by the fabricator regarding the parameters influencing primarily the CNC bends. It was decided for the panels to be fabricated locally in order to achieve speed in production and affordability. Due to the installation limitations and the tight vertical and horizontal gaps (20mm) the allowable tolerances were relatively small. Less than 5mm was allowed for vertical movement for alignment, which meant that the supporting structure needed to be precisely set-out. The setting out data for the supporting elements was returned for each installed floor and fed the model generating the hanging holes for all the different supporting heights. Precise fabrication data and cutting layouts was automatically exported directly to the CNC puncher. A custom algorithm translated the markings for approximately 10000 different panels in a dot format to be read by the Puncher CNC machine.

## CONCLUSIONS

The Oval was delivered in the summer of 2017 despite the numerous technical difficulties arising due to its geometric complexity, many of which were overridden using bespoke computational tools. The use of a central information model was used for managing both the design development and the construction of the project successfully, solving numerous issues arising during the projects progress. The high non-linearities opposed by the unequal discretisation of the shell meant that the construction site

Figure 15
Installed panels at the dome

had to deal with huge logistics administration, which proved to be a big challenge for the whole team. A big amount of data, other than machining data, was communicated to all involved parties using excel sheets, Ascii files and simplified sketches, removing the need for complicated construction documentation. This also released some valuable time from the contractors of the project directing them on specific items and tasks of the project.

The Oval case study proves the need for an application and control of a holistic BIM model able to inform the various consultants, contractors and fabricators that contribute to a project. This need is apparent in geometrically complex structures which feature non-rational shapes. A bespoke computational framework which is project-specific enables a lightweight solution for handling large scale and geometrically demanding projects, like the Oval, provided there exists a clear CAD project plan from the initial design stages. If not, even if BIM models are adaptive in changes, a much more effort is required from the model vendor in order to incorporate additional capabilities and a larger amount of errors is anticipated during the process.

## REFERENCES

Aish, R and Woodbury, R 2005 'Multi-Level Interaction in Parametric Design', *Bentley Systems Incorporated.*

Georgiou, Odysseas, Richens, P and Shepherd, P 2011 'Performance Based Design', *Proceedings of the Design Modeling Symposium Berlin 2011*, Berlin

Kolatsou, K, Aggelopoulos, J, Kalyvas, S, Georgiou, O, Lykomitros, V, Louka, A, Gkologiannis, C and

Gantes, C 2017 'SUPPORT STEEL STRUCTURE OF THE CLADDING AND THE DOME OF THE "OVAL TOWER" BUILDING AT LIMASSOL OF CYPRUS', *9th Hellenic National Conference of Steel Structures*

Shepherd, P and Hudson, R 2007 'Parametric Definition of the Lansdowne Road Stadium', *International Association of Shell and Spatial Structures*, Venice, Italy

[1] http://www.grasshopper3D.com/
[2] www.rhino3d.com
[3] https://www.tekla.com/
[4] https://www.csiamerica.com/products/etabs