

# Parametric Morphogenesis

## *An Historical Framing in London's Architecture beyond the Verge of the 20th Century*

*Domenico D'Uva<sup>1</sup>*

*<sup>1</sup>Politecnico di Milano - Dipartimento di Architettura e Studi Urbani, Milan*

*<sup>1</sup>[http://http://www.dastu.polimi.it/](http://www.dastu.polimi.it/)*

*<sup>1</sup>[doduva@gmail.com](mailto:doduva@gmail.com)*

*The approach of contemporary architecture with urban environment has always been in perpetual evolution. The path between concept and real building has been driven since ancient times by traditional drawing tools which discretized the architect ideas into shapes. The cases studied for morphogenesis evolution, featured in the top-notch architectural firms, have been framed into two different strategies. In the first family the shape is created by the modifications of several distinct geometrical elements, which create formal complexity. In the second family of buildings the complexity is the result of very few geometrical elements, whose morphogenetic process generates complex forms. As the geometrical elements decrease in number, the draft shape must undergo a deeper process of modification to solve the functional, sustainability and structural issues.*

**Keywords:** *Morphogenesis, Parametric design, London*

The approach of contemporary architecture with urban environment has always been in perpetual evolution. The path between concept and real building has been driven since ancient times by traditional drawing tools which discretized the architect ideas into shapes. The late eighties computer aided design machines speeded up the drafting and modifying process, leaving unchanged the rest of design techniques. The next evolution, target of this work, can be traced back to the verge of XX century, and it is still going on. A paramount achievement is the introduction of parametric tools, which are deeply changing the whole design process. Because all these modifications are still in progress, it is difficult to frame

samples into manageable categories, in an historical sense. Although for the purpose of this research it was not possible to analyze the morphogenesis (meant as the process that make shape out of an idea) of a large sample of buildings, a selection of these has been picked, where these kind of processes has been sedimented and completed in full. In these samples, the shape characterization was analyzed as perceived result of a synergy between environmental, structural and functional issues, not as a complexity showing off in itself.

Today architectural morphogenesis started relying more on digital tools as design instruments, more than traditional drawing companions (Del Mese,

2006). The three main purposes for using parametric tools in morphogenesis were the optimization process of a pre-chosen shape (D'Uva 2013), the generation of a completely new shape (also known as generative design), or a blend of these.

The optimization process made possible to build complex shapes, balancing the constructive feasibility with the perceptive issue of an idealized form. Generative design is, instead, intended as the act of full shape creation starting from a series of given rules. In this case shape generation is driven by geometric rules specifically designed. For the purpose of this research, the optimization processes haven't been explored, choosing to focus on relations between shape design and physical building.

The choice of constructions located in London is motivated because of the widespread cultural approach to architecture, in relation with urban landscape and sustainable issues, which were always held in strong consideration along the design processes. London downtown, being in continuous evolution for cultural, financial and economic reasons is a perfect environment to analyze the sedimentation of architectural construction. Among all of the buildings analyzed, two case studies were chosen and analysed in this paper. One is the Gherkin skyscraper, by Norman Foster, the second is the Ito's 2002 Serpentine pavilion.

These examples are at the opposite sides of modification in urban environment, because Foster's skyscraper has a permanent impact on City's skyline, having been naturally elected as landmark, while Ito's pavilion had a very limited impact because it lasted some months only.

The two case studies, featured in the top-notch architectural firms, used two different strategies. In Gherkin's building the shape is created by the modifications of a large set of distinct geometrical elements, which create formal complexity. In Ito's pavilion the complexity is the result of very few geometrical elements, whose morphogenetic process generates complex forms.

The comparison between draft buildings gener-

ated by these two processes had similarities and differences. Both will need optimization strategies to regularize façade, both achieved a certain degree of complexity. The difference relies on the operations whose buildings are subjected to, being design with different strategies. As the geometrical elements (that control shape) decrease in numbers, the draft shape must undergo a deeper process of modification to solve the functional, sustainability and structural issues. The framing of buildings into two strategies in terms of morphogenesis processes, more than a classifying spirit, is useful to point out how the generative procedures, which seem today the solution of every possible problem, can create different kind of constraints limiting the apparently unlimited flexibility of form.

## METHOD

The path between conceptual shape and real-life building is splitted in several steps, whose control has been always difficult. The spread of the digital parametric tools gave to a wider number of designers the possibility to achieve complexity. This complexity, though, is very easy to be reached, but very complex to be managed. The complexity of form definition tends to put distance between idea and feasibility of architecture. In fact the unparalleled possibilities of form generation hit against the possibilities of construction, which are much more constrained. That is why, it is important to drive the morphogenesis with geometrical precise definitions (Rolando 2008) before the concept has become concrete. Starting from these base concepts this work analyses the relations between the initial geometric constraint, the complexity and the feasibility of buildings. The shape complexity can be reached with two distinct methods. The first is the form generation starting from a full-bodied set of geometrical parameters, second is the generation of complexity starting from a small set of elements.

As previously stated both methods bring to complexity, but the real life construction has different results. With the first method the feasibility is possi-

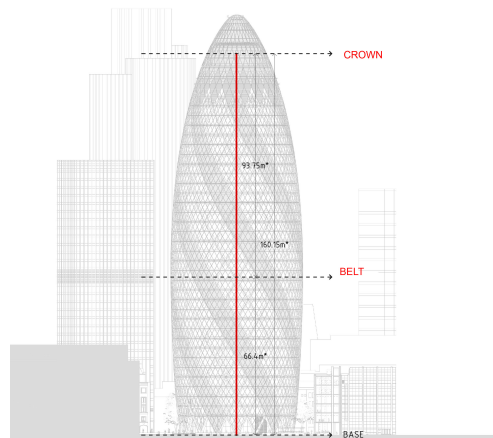
ble within few modifications, while the second one needs a more difficult path.

## MORPHOGENESIS OF THE GHERKIN SKYSCRAPER

This skyscraper is located in the heart of London, having an impact so huge on the City, to become an important landmark in the urban environment. The proposed analysis is the morphogenesis of the main section of the building, which is to be revolved to generate the final skin. The main geometry of this building is the circle, which is both the base for the section, both for the set of arcs that creates the profile.

The first geometric input is the origin of the coordinate system, which is not the base of the building, but a specific point called the belt, (figure 1) located 66,4 meters from ground, measured on the revolving axis. At this very position the max width of the building is fixed, 27,20 meters which is the radius of the circle, whose center lies on the revolving axis.

Figure 1  
Morphogenesis of  
30 St Mary Axe.



The second geometric input is measured on the revolving axis at a specific point called the crown, which is 160.15 meters from the ground. The half-width of the building, as above explained, is 11.76 meters at this point.

Once all these input have been satisfied, the profile curve is composed of 7 arcs, which position and radii are calculated with the algorithm, following a construction scheme, as displayed in figure 2.

For each arc, the two radii and the conjunction line form a triangle if considered together. So the problem of looking for seven arcs become the problem of finding the geometry of seven triangles.

The seven triangles, because of the geometrical equivalence of radii are isosceles, so all triangles linked to the first by angle similitude. A further connection is geometrically defined by the continuity of two arcs, because of their equal tangent in the point of contact between them. Furthermore there is another geometrical relation between two nearby triangles. One is similar to the next, thus creating a series of geometrical correspondences. Furthermore if I take any of the two triangles in the set, the larger has multiple edges if compared with edges of the smaller one and the angles of nearby triangle are equal.

Based on these data, a general rule can be laid out:  $180^\circ = x + 2 \cdot x + 2 \cdot (x + b)$  where  $x$  is the angle ( $\delta$  in figure 2) between the major side of the base triangle, and the base of the next isosceles triangles. The  $b$  parameter is, instead the angle between the major side of the base triangle and the Belt width. With this calculus, the internal angles of the generic triangle may be determined.

Once the angles have been determined, starting from the minor side of triangle it is possible to trace the two equal major sides.

It is possible to determine the shape of five among seven triangles/arcs with the aforementioned method, because it is valid in the area of the building between the Crown and the Belt. For the upper and the lower triangles some of the properties are still valid. The similarities among the triangles continues to be verified, as it is the geometrical continuity between nearby shapes. Once all the arcs have been determined, cut and joined it is possible to determine the final profile curve to be revolved.

With the purpose of achieving a higher degree of precision and a wider range of non degeneration in

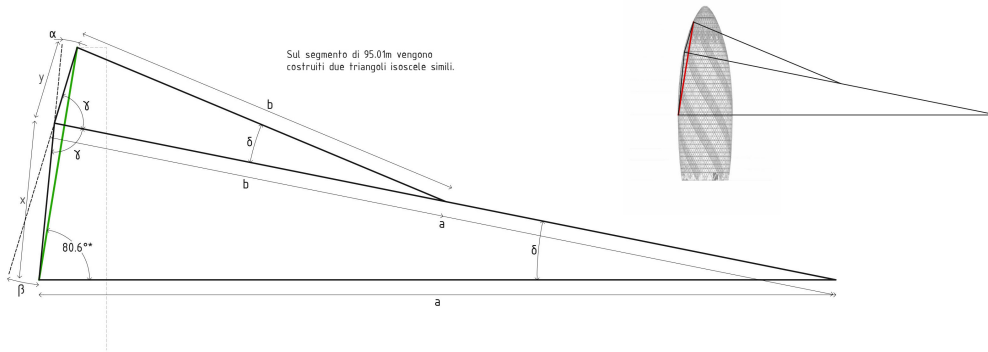
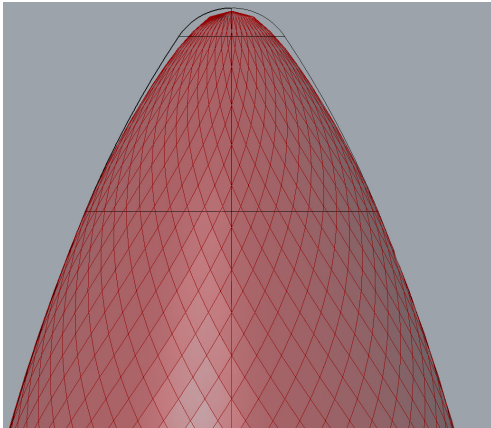


Figure 2  
30, St, Mary Axe,  
Similar triangles

the generative algorithm, it has been experimented the addition of correction factors to the aforementioned script (Figure 3).



The first correction has been applied to the proportional ratio between base triangles, which has been modified from 200%, to 210%.

The second correction is the application of a fixed distance between base triangle and the nearby of 10 meters, which means that the vertex of the nearby triangle is 10 meters far from the medium point of base triangle. This fixed distance is repeated in the following triangles, with the given proportions. Figure 2 and 3

The chosen parameters are the input data for a Grasshopper algorithm that generates the real building at the end of the process, if afore-mentioned values are assigned to the parameters. For the purpose of this paper all the further studies about the sustainability and environmental performance have been avoided, but they can be applicable on the algorithm provided with no effort.

### MORPHOGENESIS OF SERPENTINE PAVILION 2002

Serpentine pavilion is a temporary exhibition pavilion located in Hyde Park, London, which is built and removed within a short period of time. The building erected in 2002, designed by Toyo Ito and Cecil Balmond, is the second case study analyzed in this work.

The main geometrical shape is a square 16,4 meters wide, extruded by 4 meters. Inside this virtual envelope the whole building is contained. The only parameter that generates complexity is the ratio in which each side is divided. The real life building has a division ratio of  $\frac{1}{2}$  and  $\frac{1}{3}$  for adjoining edge of the square, so that each vertex has a distance from its following point determined by two expressions:  $\left(\frac{1}{X}\right) \cdot L$  or  $\left(\frac{1}{Y}\right) \cdot L$ , where x and y are the vertices and L is the length of the edge. In the real building case, X is equal to 2 and Y is equal to 3. This operation locates the points on each edge, after it is

Figure 3  
30 St. Mary Axe -  
Final Skin model  
with basic  
algorithm (external  
curve) and with  
additional  
correction  
algorithm (filled)

possible to trace the segments that connect each of this vertex. Then each segment is extended and each couple of extended lines undergoes a chamfer operation. So a new square, smaller than the original is formed. Then the edges of the new square are divided, extended and cut with the same method, figure 4. The operation is repeated recursively and it

can go on indefinitely. In the real life building it is repeated eight times.

Once the operation is completed in planimetry, each of the four building façade is rotated by 90 degrees by the edge of initial square and the division/extension/chamfer operation is extended also on this faces.

Figure 4  
Ito-Balmond -  
Serpentine Pavilion  
- Morphogenesis  
process. Lower  
images, in red  
modification from  
generative process.

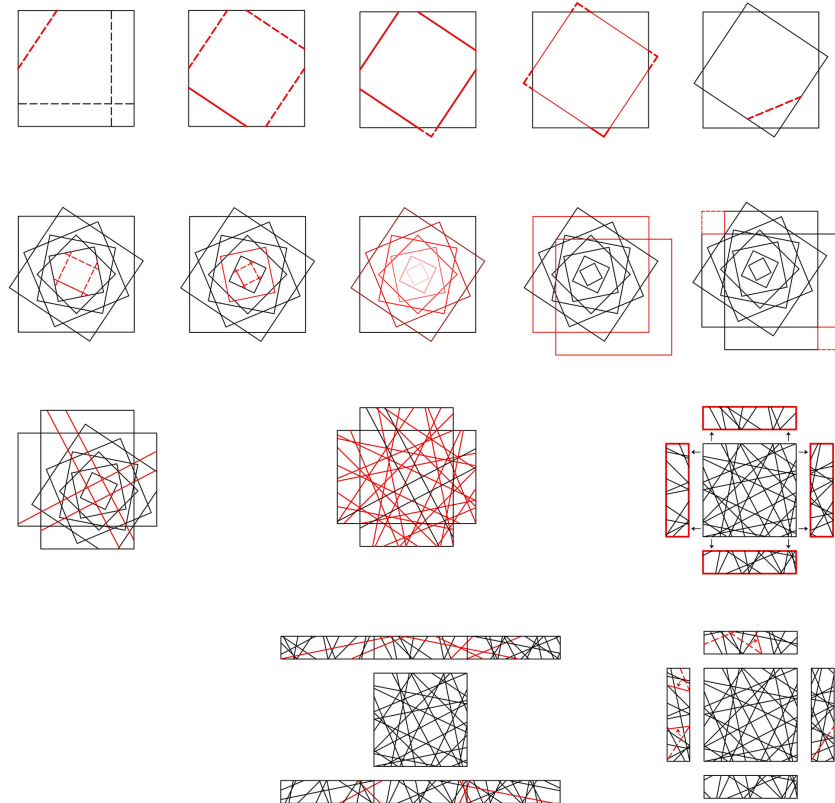
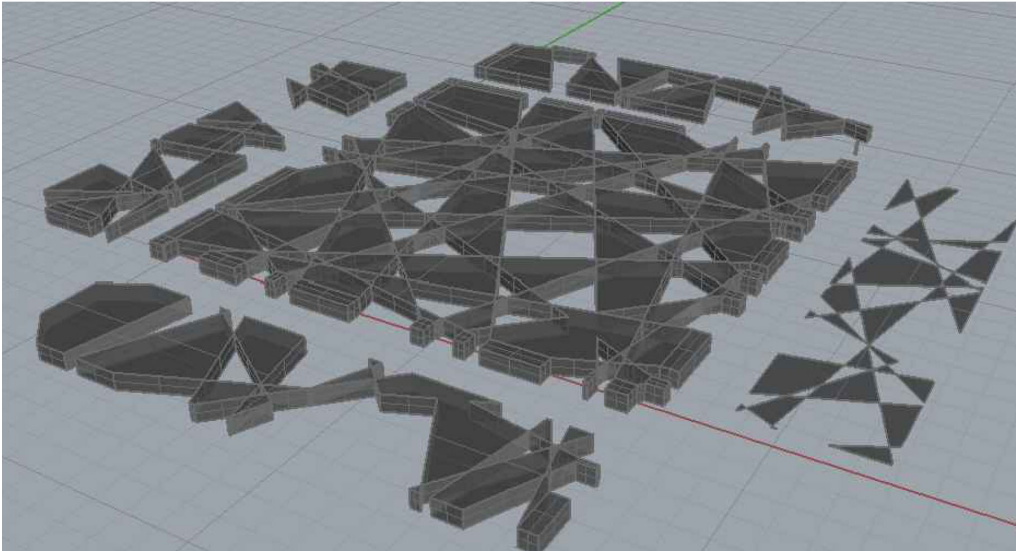
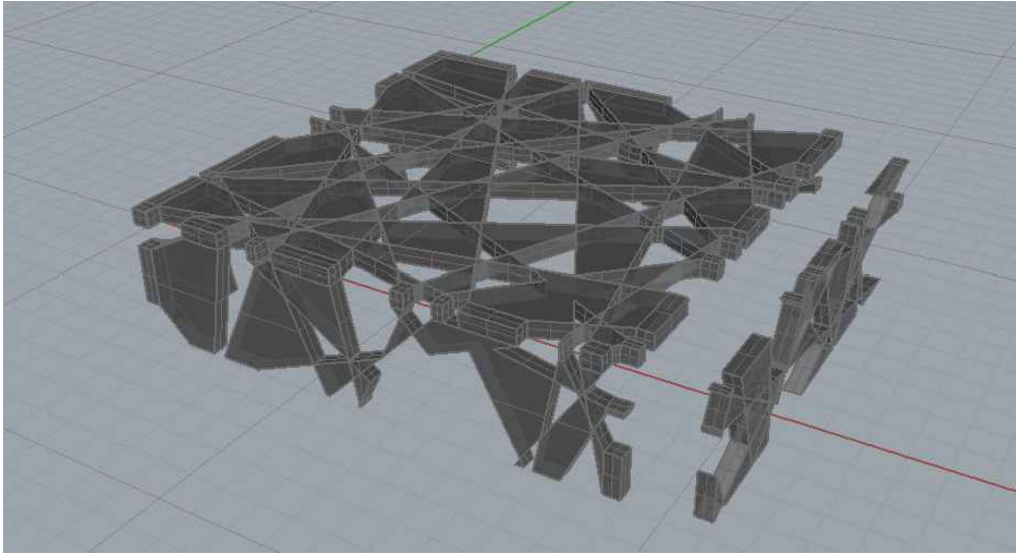


Figure 5  
Ito-Balmod,  
Serpentine Pavilion  
2002, London - Final  
result



This simple process brings to the results shown in figure 5. When the process is over, the final result is composed by a net of lines, which make the bearing structure of the pavilion. The space in between the grid will be filled with matte white panels, leaving voids where necessary.

In this case study, as in the previous one the chosen parameters are the input data for a Grasshopper algorithm that generates the real building at the end of the process, if afore-mentioned values are assigned to the parameters. As forecast, there will be some modifications from the concept to the final building. The concept grid hadn't any openings for doors or windows, so a part of the flat panels covering the holes have been removed.

## ANALYSIS

Once the morphogenesis of the two buildings have been laid out in detail, an analysis can be carried forward through geometry, because of the its inner clarity and coherence. The measure of analysis is linked with the reach for this work. This purpose will be achieved if the case studies would have reached a level of complexity comparable to real building, within the boundaries of precisely defined geometries. The outcome of the first case study is a curve, the second one is a net of lines; their generation, although obtained with similar computational methods, produces a different kind of complexity. Recalling what aforementioned, the Gherkin parameters are: origin point, width on the ground, height and width of Belt, height and width of Crown, plus the correction factors of triangles ratio and fixed distance. The parameters of pavilion are edges, height and split ratio. It is therefore clear that Foster's building falls in the category of complexity by large set of parameters and Ito's building belongs to small set. They both brings to a geometrical complexity, which results are compelling in their similarities and differences. Both Gherkin's large set of geometrical input data, and Ito's small set bring to a completely controllable shape. The production of the final shape is possible, because of control. The geometry within

the complete control allows flexibility to all the environment constraints and interference with building. Differences are the geometrical shape drivers as the skyscraper similarity of triangles and arc continuity; pavilion constraints are instead edges division and façade extension.

## RESULTS

The parametric approach to the morphogenesis creates a window of results, in which we choose only the real building, but it would be possible to choose infinite other variants of it. Furthermore in Gherkin morphogenesis the final result is absolutely coherent with the skin of the real building, while in Ito's pavilion some ruptures of the forecasted scheme were necessary to achieve the level of functionality required. The results of this work can be summed up explaining that, as more the design is rich of geometrical inputs from the beginning of the design process, as more the final building will need less manual deviation from the general parametric scheme. However, these results are valid for any complexity of the final result, and any set of parameters whatever the number of geometrical parameters.

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