Morphogenesis and panelling, the use of generative tools beyond academia.

Case studies and limits of the method.

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The increasing complexity in architectural design brought a parallel evolution of tools for shape generation and management. Digital tools which better fulfil this need are the generative design software.The aim of this work is finding and testing real life uses of generative design software beyond academic edges. The specific target is transform a complex surface into a similar surface mostly made of flat panels.As a testing ground it has been chosen the support in construction of complex shapes made with ordinary and well known tools. The combination of software used is Rhinoceros, with its plugin Grasshopper, and a couple of opensource add-on, Lunchbox and Paneling tool. The cases are listed from the simplest to the most complex, and the first four are solved with the automated procedure, the fifth, manually. Based on the cases studied it is possible to confirm that the method is applicable to the majority of the complex surfaces.

Keywords: *Generative, Panelling, Discretization*

INTRODUCTION

The increasing complexity in architectural design brought a parallel evolution of tools for shape generation and management. Digital tools which better fulfil this need are the generative design software. Defining clearly this term is quite tough, because it is a new area in computer science, which lacks of cornerstone literature, that unifies terms and methods shared by the whole scientific community. A brief framing is needed to understand the core of this issue. The starting step in framing digital tools is the distinction between tools that document the design process and tools that eventually generate shape. The first family of tools is composed of all software able to document and optimize the design process. In this family it is included Building information Model. The second family, which is of main interest for the aim of this work, is composed by all the tools that create shapes which is not wholly foreseeable from the beginning of the process. Among these equipments which populates architectural design, it seemed important to understand the difference between the tools only used for generating shapes, for the sake of complexity itself, and the tools which give a factual support in the form-generating process. At this time the use of generative design tool meant as a shape generator, not only as a design documentation is limited to some top-notch architectural firms and academia.

OBJECTIVE

The aim of this work is finding and testing real life uses of generative design software able to manage shape complexity without using front end tools. The specific target is transform a complex surface into a similar surface mostly made of flat panels. As a testing ground it has been chosen the support in construction of complex shapes made with ordinary and well known tools. The combination of software used is Rhinoceros, with its plugin Grasshopper, and a couple of open source add-on, Lunchbox and Paneling tool. The choice of leaving outside direct scripting solutions is due to the adherence to the vast majority of professional design activities, where it is not common. A recent market analysis, reported that in Italy the use is limited below 10% for the BIM solution, and an astonishing 61% has absolutely no knowledge of it. The Generative Design solutions are even less common than BIM. Among the few who are capable of, for the purpose of this work it has been considered a common task, the need to discretize complex surfaces into simple planar panels. For the purposes of this paper, the name of this procedure will be meant as panelling. The need for this operation is generated by the fact that a built facade, made up of curved panels is a much harder task, than constructing the same shape with planar elements, in term of costs and construction issues. This process of discretization is aimed toward the optimization of panels in terms of differentiation, curvature and cost. The procedure aims at grouping panels into similar elements by reducing the curvature as much as possible, up to the result of having most of the flat panels. It is fundamental to control these processes to reduce the problem connected with surfaces complexity, without creating new issues. It is evident that the dimension of the panels has a strict relation with the cost, as the edges increases in size, so the cost is reduced, but this can be brought up to a certain point where the thought shape starts to be distorted.

METHODS

The case studies, which were the proving ground for these topics are five well-known buildings, which were designed in a time span from 2004 to 2008. At the time of their design, the generative tools were software with a steep learning curve, because they were made by explicit scripting only, which knowledge was much more limited than today in architecture field, and available only to highly specialised firms. Today the issues related to these buildings may be solved with ordinary tools, even without explicit coding.

The method applied starts from the understanding of the architectural shape, made by the analysis of the geometrical features. The process of form finding is useful to gain a complete control over the possible issues that the surface may encounter. All the geometrical analysis is held using Nurbs geometry, because of the easiness in edit the primitives. Once the shape has been completely defined it has been necessary to transform Nurbs into Meshes because these are the standard entity to feed the numeric control machines, which manipulates the numeric control machines, which created the final shape. This operation is completed through the use of the add-on software abovementioned, which accomplished in most of the case the transformation required. Starting from complex non standard surfaces, the output is a series of flat panels, which gave the perception of curvature once it has been assembled all together.

The different complexities of the surfaces in case studios has been accurately chosen to produce different results and feedbacks which showed the limits of this method. For four cases over five this process had developed acceptable solutions, but the last and more complex case, has created issues that had to be solved manually.

CASE STUDIES

The case studies have been graphically rendered and analyzed through a thesis the Faculty of Architecture in Politecnico di Milano, whose the author was the supervisor and the student is Elisa Beretta.

The case studies are:

1. New Trade Fair by Massimiliano Fuksas
2. The Sage Gateshead by Norman Foster
3. Swiss Re tower by Norman Foster
4. Peek and Cloppenburg department store by Renzo Piano
5. Kunsthaus by Peter Cook.

The Rho Fair by Massimiliano Fuksas is a large complex mainly used for Exhibition purposes; the analysis has been focused on the roofing structure toward the eastern entrance. The morphogenetic process starts with the geometrical decomposition of the top and of the bottom boundary curves that edge the roofing. These curves are made by the smoothing of two circular shapes by arc of circumference which results into a couple of ovoid shapes. These two curves, rotated around a centric axial, are linked by profile curves, which creates a vortex. Once all the curves that create the edge have been pointed out, the surface has been laid out by a sweeping operation. The next step has been the panelization in flat triangles, which has been made through Lunchbox. This process wasn't applied in a uniform way, but the surface has been grouped in areas by similar curvatures. The planar areas was subdivided through the projection of specific lines. The single-curvature and double-curvature areas have been subdivided into diamonds (and then triangles) with the use of Lunchbox. The automatic procedure was impossible to be applied in the junction areas between the curved and the planar areas, therefore the panelization has been made manually.

The Sage Gateshead by Norman Foster, as shown in figure 1, is a musical center which faces the river Tyne and it is made by a large roofing structure which covers three auditoriums. The case analysis has been made on this structural element. The morphogenesis analyses the key transverse section and the main longitudinal section which both are paramount to define the shape. The first section is composed by the junction of a golden ratio arc with a circular arc. The second section is all composed of portions of circular arcs of different radii. Once the surface is created with the given edge curves, there are holes to be applied along the bottom edges, created by the projection of rotated parabolas and a free-form curve. The panelization process aim at the subdivision of the main roofing structures into quadrangular panels. The tool used in this case is Paneling Tools, which gives a certain flexibility in the giving panel a given direction. In fact the paneling is driven by two main perpendicular directions.

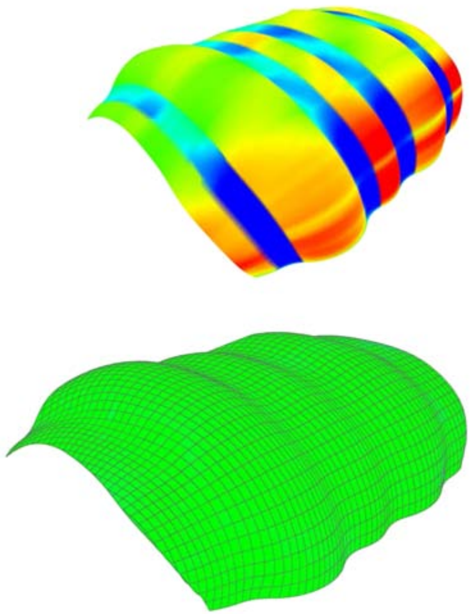


Figure 1
The Sage Gateshead. Analisys of Gaussian curvature

The first direction is created by a stream of parallel lines with a given distance among them. The second direction is created by a polar array of lines with a given angle of 5 degree among them. The intersection between these two streams of lines gives quadrangular shapes which subdivide the whole surface in flat quadrangular panels.

The Re Swiss tower, see figure 2, is a high-rise building located in London, designed by Norman Foster, which is a higher step in the complexity scale parameterized by other case studies analyzed. The morphogenesis starts from the generation of the profile curve, made by different circular arches linked each other by a geometric relation between their centers. The resulting profile is revolved around the axis of the building, to generate the draft surface. This facade is splitted each floor by the array of levels by which the building is composed. Each floor is then holed by equilateral triangles, which creates the landmark bands which characterize the façade. The paneling is solved through Lunchbox, subdividing the surface into rhomboid panels with an automatic process.

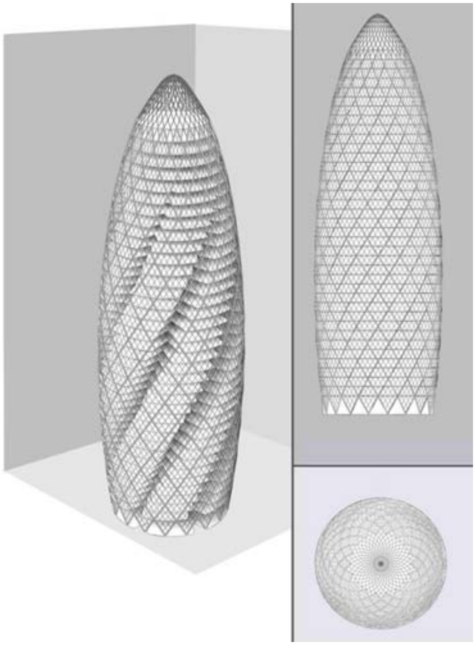


Figure 2
Swiss Re. Final Results

The fourth case study is the Peek & Cloppenburg department store in Koln, Germany, designed by Renzo Piano, see figure 3, whose roofing is made of vertical wooden bands, having an in shape of arc, raising to 28 meters. The morphogenesis is based on the searching of guide rails along which the profile curves generate the main surface. Once the railings have been found, the next step is the division of the binaries into 3 areas, where the resulting surfaces have homogeneous curvature. This step is paramount for the surface construction, because the location of the edge changes completely the final output in complexity and construction issues. The profile curves are portion of ellipses, which are splitted in sub-ellipses in the diverse areas and changed in dimension proportionally to the railings. When the ellipsis have been all defined the resulting surface is a loft through the diverse ellipsis, grouped in the different areas. The paneling operation in this case was direct; Lunchbox gave as output the complete control of the shape, generating quadrangular panels, in a single step and without additional functions, see figure 4.

The very last case, the Kunsthaus in Graz, see figure 5, required a completely different approach in comparison with the other analyzed buildings. It was impossible to define a unifying geometry for the whole surface, because it belongs to non standard building family. The morphogenesis based on the sole geometry was impossible, because reference researches have pointed out that the building to be generated by complex non-standard geometrical tools. Therefore, the first step was to represent a similar structure, an ellipsoid, and it was brought through the translation of surface control points toward a similar final shape to the real building. After this direct modification it was necessary to apply a smoothness algorithms, as the Catmull-Clark algorithm, to preserve the curvature. Then, both Lunchbox, both Paneling Tools plugin have been unsuccessfully used, to panelize the surface. So, the exit strategy to this problem has been the division of the surface into smaller areas. The separated areas were

Figure 3
Peek and Cloppenburg. Left. Surface morphogenesis. Railing in red. Profile sections in Black. Right. Loft creation

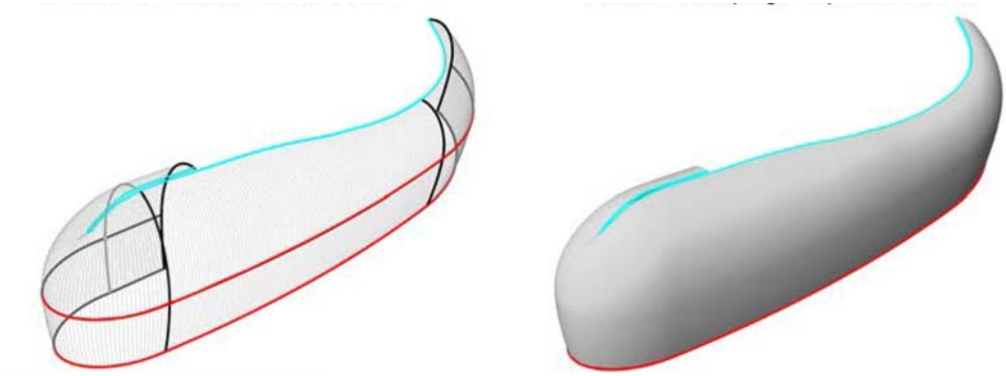
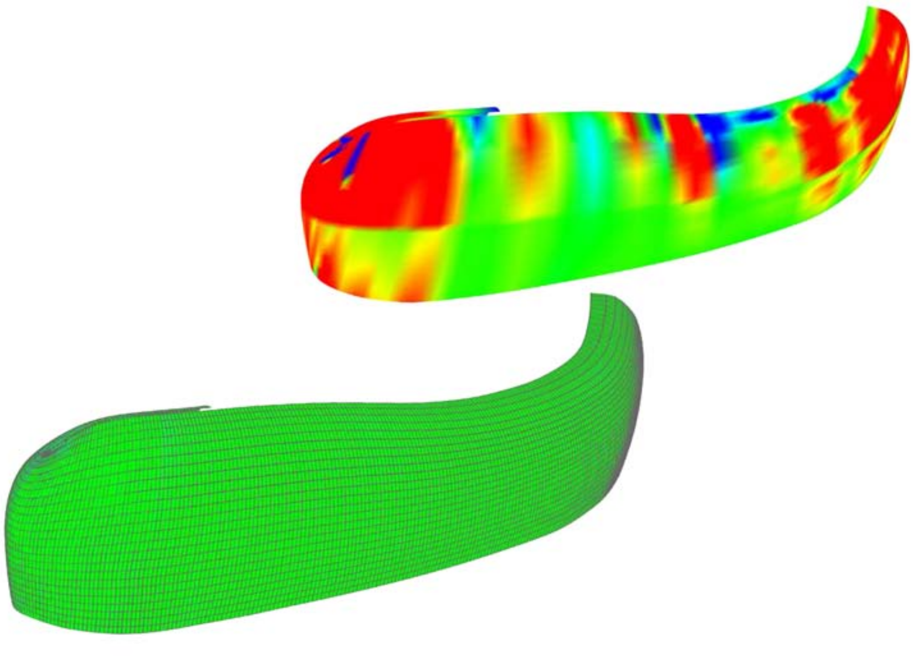


Figure 4
Gaussian curvature analysis. In green flat surfaces. Positive and negative curvature (Red and blu colours) means curvature different from zero



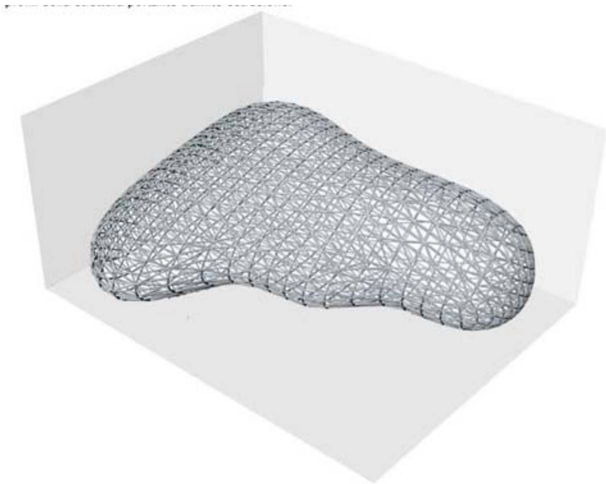


Figure 5
Kunsthaus Graz.
Structural output.

easily discretized into flat panels, then the junction areas have been panelized manually.

The procedure works for receiving as an input a complex surface, giving as output a series of flat panels, chosen by dimension, number and shape. If the results are not satisfactory, it is necessary to repeat the procedure, until the panels are correctly shaped. The balance point between curvature and shape of the panel would be achieved with some reiterations of the procedure, which is far from being optimized. A possible solution of this issue is the use of evolutionary solvers applied to the panels generation. One example of this tools is Galapagos. But this work hadn't taken this last step because it seemed unuseful to parameterize a subtle feeling, as the perception of the shape with tools which had not reached a satisfying level of stability and diffusion.

RESULTS AND LIMITS OF THE METHOD

The cases are listed from the simplest to the most complex, and the first four are solved with the automated procedure mentioned before. The sole Kunsthaus, see figure 6, was analyzed with the paneling software and the process didn't manage to reduce completely the surface into flat panels. Based on the cases studied it is possible to confirm that the method is applicable to the majority of the complex surfaces.

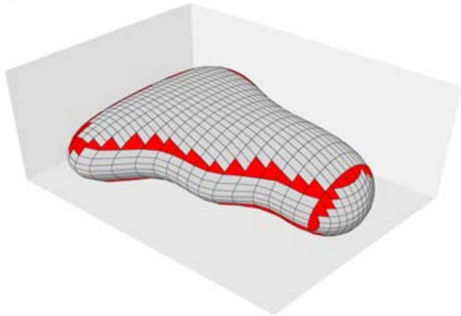


Figure 6
Kunsthaus Graz.
Limit of panelization method. Manual paneling area in red.

The results have been achieved through the use of two different software, Lunchbox and Paneling Tools. Both have been proved to be easy to use, but Lunchbox is more friendly, because it provides straightforward results. Paneling tools, despite the slightly more complex procedure, provides more flexibility in defining of panels with specific aspect and specific location in the facade. The advantages of this method are summed up in the easiness of the process, which is completely automated in most of the cases analyzed, giving the opportunity to all of the designers to cope with a once complex task. The limits of this procedure start from the obvious constraint given by the shape complexity, which is intrinsic with the dimension of panels and the necessity to understand wholly the geometric morphogenesis, otherwise the panelization process is not straightforward. The aforementioned limits can be managed with this method, whose output is a geometric surface component. More complex constraints should be considered, as material and construction technology, but it was chosen to frame this work to geometrical and perceptive aspect which are easily manageable within wide spreading tools. The economic constraints would force the choice of larger uniform panels clashing against the architectural need to have a perceived shape as near as possible to the architects' desiderata. The perception issue is paramount in most of the cases, if we consider large-funding buildings. If, instead we consider more sober buildings (with more limited funding) the possibility to cope easily with complexity is a leap forward in the free use of these architectural components once opened to top notch firms only.

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