Controlled parametrical design over double curved surfaces

Dipl.-Ing. Milos Dimcic ; Dipl.-Ing. Florian Scheible
KHing, Stuttgart, Germany

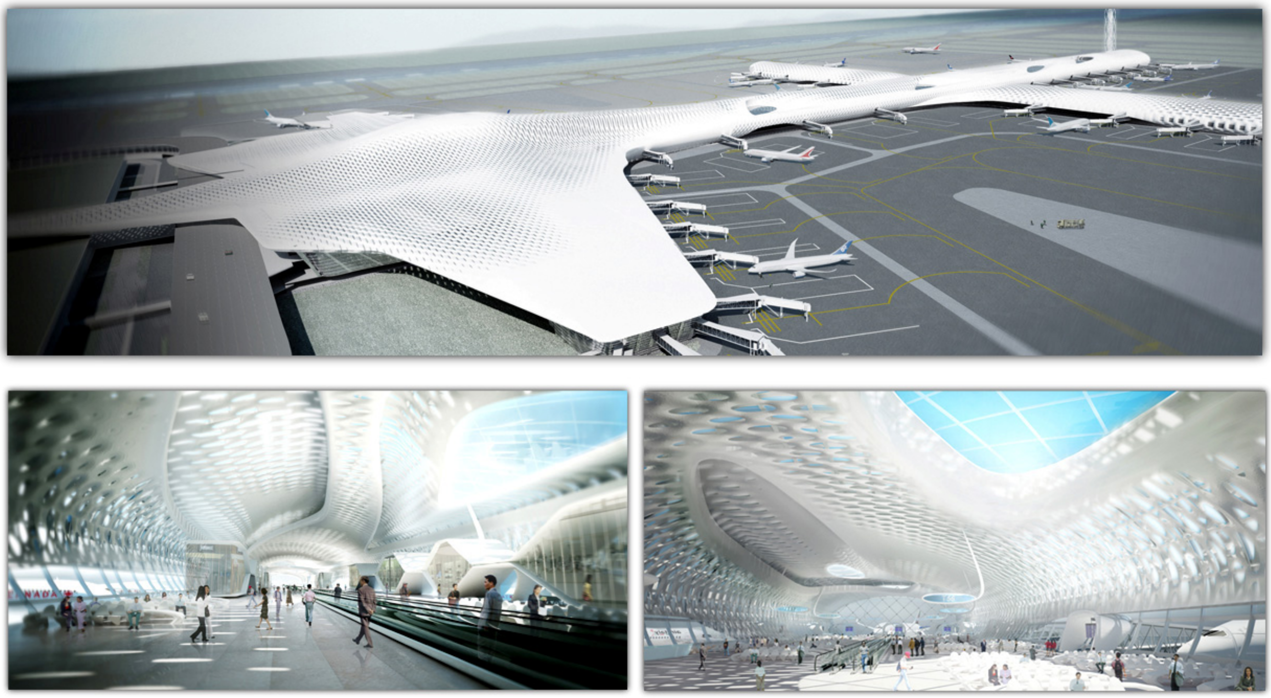

Figure 1: Terminal 3 of the Bao'an International Airport, Shenzhen, China (Fuksas studio renderings)

Project that will be described is the new terminal of the Bao'an International Airport in Shenzhen, China (Figure 1). In 2008 Masimilliano Fuksas Architects together with Knippers Helbig Advanced Engineering won the competition presenting bold free-form structure with 300.000sqm double-layered façade and roof construction with spans up to 80m. Knippers Helbig Office was in charge of the parametric façade development and structural design of the double curved roof construction. This paper will however describe only the façade development process for free forms leaving the construction generation aside. The completion of the airport is set for year 2011.
We are witnesses to the fact that the architects incline more and more every day to free forms in their design. From the various software on the market Rhinoceros pops out very often as the tool used for it, hence the NURBS mathematics defines the surfaces that we are supposed to turn into real life structures.
For this project architect's inspiration was visualized as a double layered skin where the honeycomb shaped pattern could be recognized. The basic façade element (4.5m x 3m) was also defined by architect with a number of its variations. This element was to be populated over the inner and outer surface making a closed structure together with steel construction between them. The structure was to enable light to come through from the outside as well as view to go through the structure from the inside.
The important fact was that the architect designed the form without detailed elaboration of the structural system and we knew that many changes in form and basic element would be made along the way. Physical analysis of light distribution changed constantly our element disposition. Static analysis changed our form and our surfaces. Drainage problems made us change elements or develop new kinds.
That is why we developed a method to easily change element, pattern or surface and still quickly generate the façade. Also we hade to bare in mind that input layouts have to have a simplified version so that the design office can suggest their own ideas and changes that we would transform later to our scripts.
Finally we used the architect's inspiration to design a system of control and to develop further the idea of evolving structure, something that becomes the signature of the 21st century architecture.

1. CREATING THE SYSTEM

1.1 Setting up the background for parametric design (ray-system)

First thing we needed for a parametric model is a point cloud on the surface. Since one of the conditions was to enable people to see through the structure we designed a system of rays. These rays started at different points on the eye-level line of

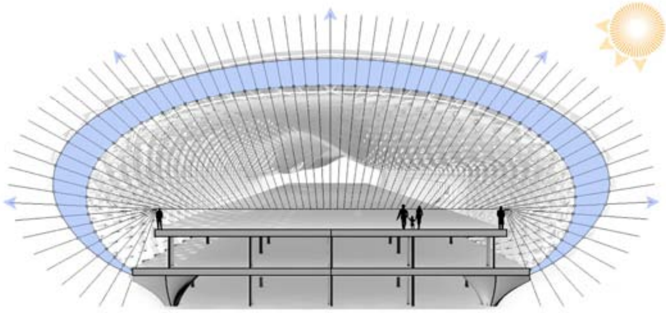

Figure 2: The ray-system (KHing)

the +8.8m slab resulting in different perspectives and a possible view to the outside from any standpoint. The rays then intersect four surfaces (inner and outer; structure and façade) providing us with the points we need for further generation, as shown on Figure 2.

1.2 The Basic Element

Figure 3 shows the definition of basic element and how it is transformed by changing the size of glass and the angle of plates, forming, with the combination of these two factors, around 20 different elements (only few of them shown in the picture), each with its unique number that defines it. The idea was to use different elements for different parts of the surface to control sunlight and to add another level of design and irregularity to façade. The important fact is that for the actual generation and scripting, in order to simplify the process and to have more control over population, the half of the element (4.5m x 1.5m (marked red)) is used as a basic unit.

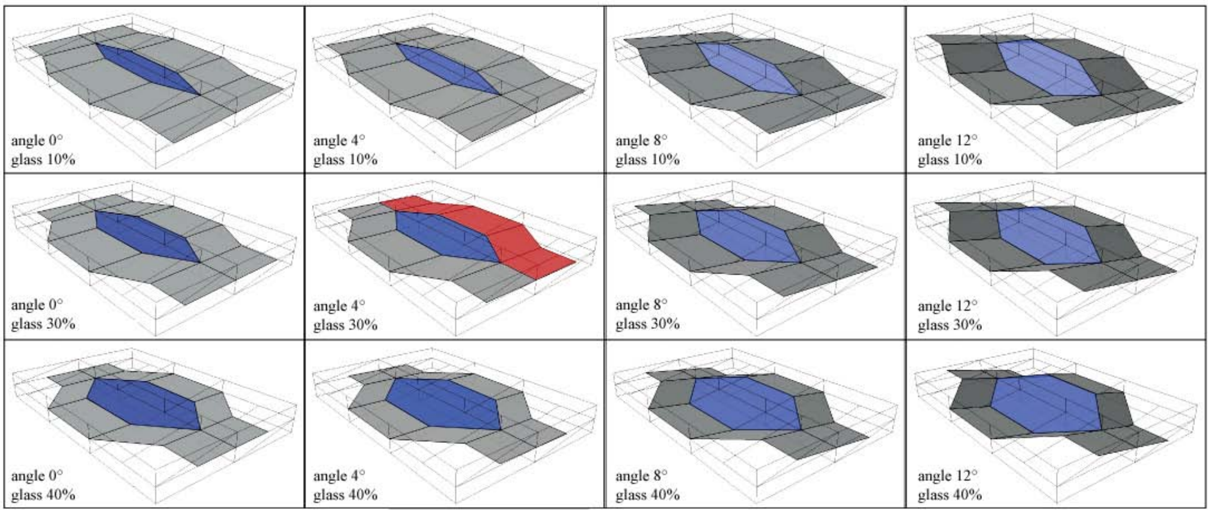

Figure 3: Panel morphing (KHing)

1.3 Excel Control

As mentioned, analysis of light distribution and frequent design changes led us to develop system for easy and fast definition of element distribution. We “unrolled” the surface into a 2D table, transformable to an Excel spreadsheet, so that architects could easily “paint” over it, marking where they want what type of element. These colours are then transformed into element unique numbers and used as input information for a script that generates the façade. So the surface is unrolled, divided and each cell represents an element with the number in it defining the type of the element.

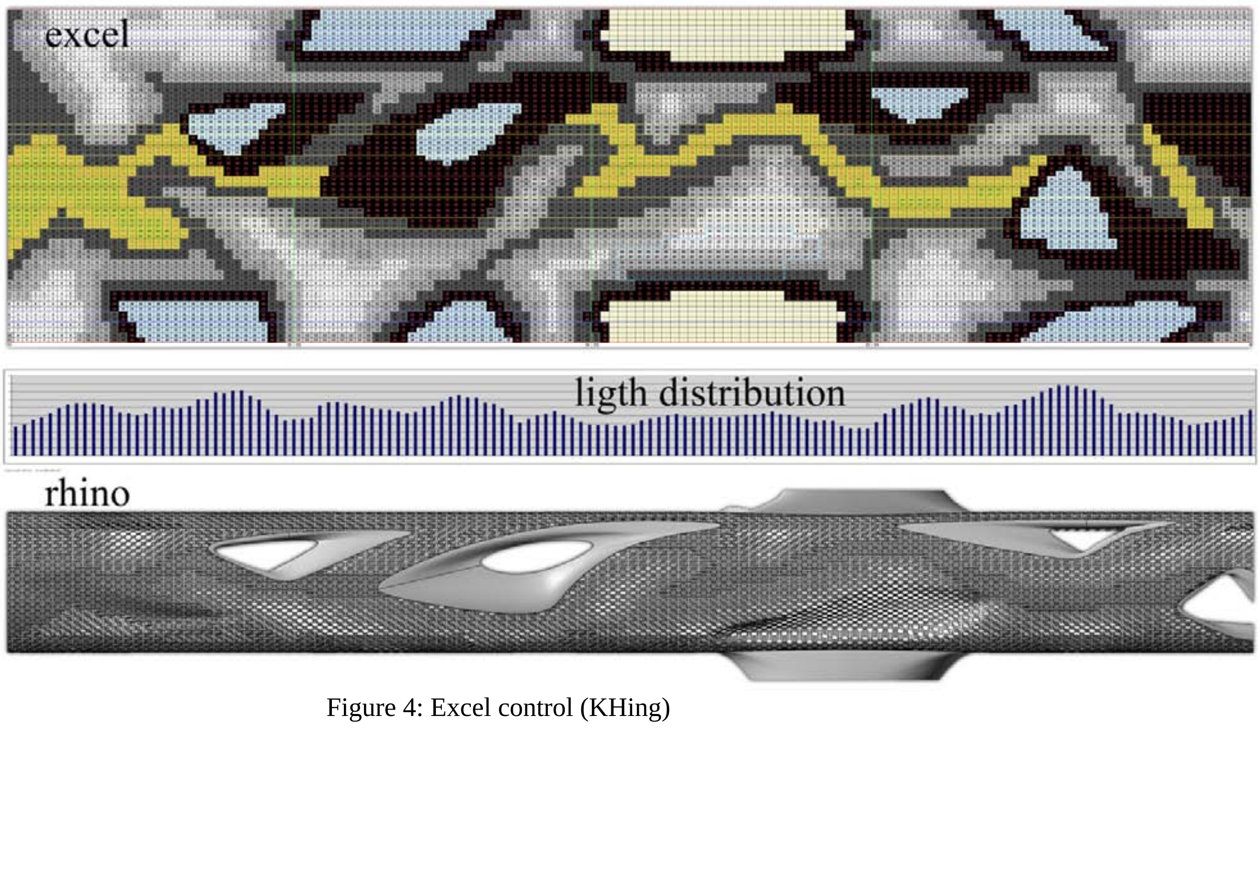

Figure 4: Excel control (KHing)

1.4 Element generation

The basic element is defined in a box. That means that we have 8 basic points that will help us "stretch" it to its position on a surface. Since we were so far restricted to the surface, we had 4 points on it defining the cell where the future element comes. The surface normal with a defined length is being pulled from each of those 4 points outwards and inwards creating two new points from each one. Hence, disregarding the original 4 points, we created an 8-point box.

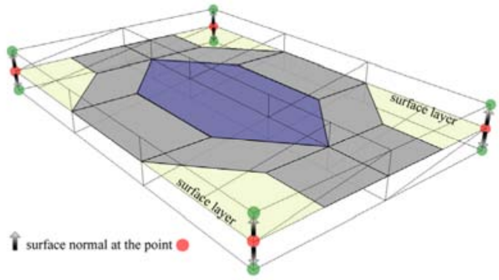

Figure 5: Base Element (KHing)

2. GEOMETRY CORRECTING ALGORITHMS

The initial transformation of elements and putting them to their place in space distorts them greatly due the strong curvature of surfaces. From the manufacturing point of view, since the elements are supposed to be from aluminium with glass cover, those distortions were not acceptable. Several algorithms do the necessary geometry corrections so that the elements could be eventually manufactured and be functional. Some of them are:

2.1 Normal Deviation

This is the method that simply corrects the surface normal (vertical side of the parametric box) and straightens it up by equalizing the Y coordinates with the original point. In the single curved areas of surface this step is not needed, but in the double curved areas it is important for all points that define an element to be in the same line with their corresponding points in the element and on other elements in the same column.

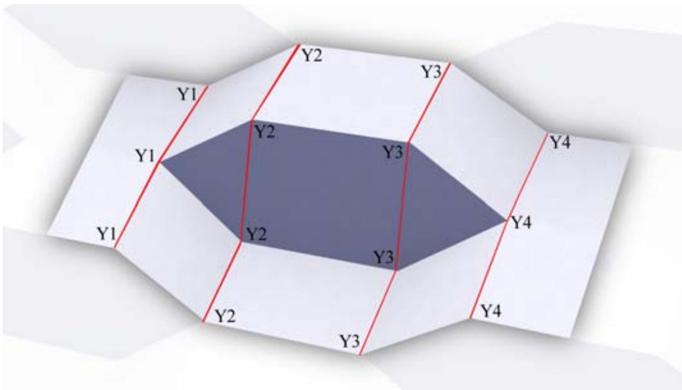

Figure 6: Normal deviation correcting algorithm (KHing)

2.2 Element Compare

Elements are "easily" fitted together in columns (at least their aluminium parts), however when they are next to each other in a row there can be a problem combining two elements that have different angles. That is why additional algorithm finds these cases and solves them by joining the separated ends together.

2.3 Glass Flattening

This is the name of the method that ensures that all glass parts are flat, for single and double curved parts of the façade. It consists of two separate algorithms:

2.3.1 Pre-Flattening

So-called pre-flattening prepares the elements by setting their edges parallel to their base axis. This process is shown on Figure 7 and that is how we ensure flatness of the one half of the glass tile.

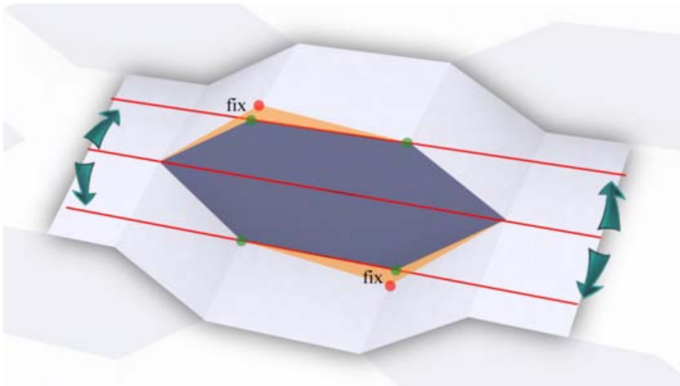

Figure 7: Pre-Flattening (KHing)

2.3.2 Flattening

In order to have the whole glass tile flat we lengthen the metal part on one side. One half of the glass is practically rotated around the separation line until it fits to the plane of the other half. There are two cases of flattening:
-In-Flattening is an easier method when the glass is bounded by two basic elements. The algorithm corrects only one element to fit the other.

-Side-Flattening is slightly complicated method involving not only elements in the same column but also the elements in neighbour columns. In that way 2 neighbour elements are corrected geometrically to fit 2 others since the “side” glass is not surrounded by two elements like “in” glass, but by 4 elements.
At the end we get absolutely flat glass parts in all elements regardless of the curvature of surface.

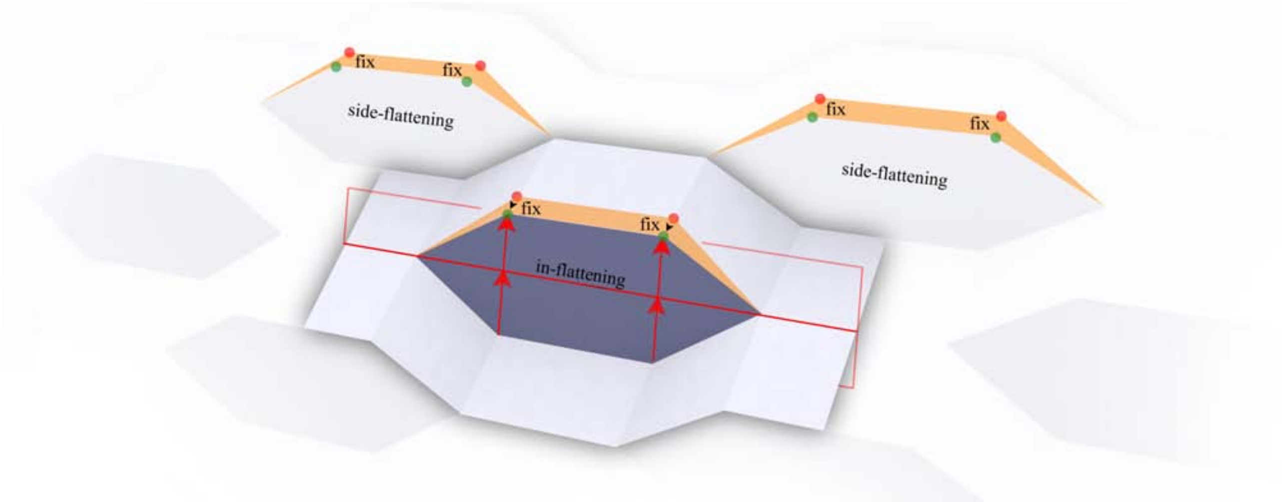

Figure 8: Flattening (KHing)

2.4 Angle Correction

Due the manufacturing restrictions there are angles between metal and glass parts that are not easy to produce. That is why another method searches for the minimal angle allowed and if it finds elements that do not fit into limits it rotates the glass until minimal angle is satisfied.

2.5 Element Drawing

When all elements are changed, internal list of their correct coordinates is being used for drawing them so we can have a nice visualization in Rhino.

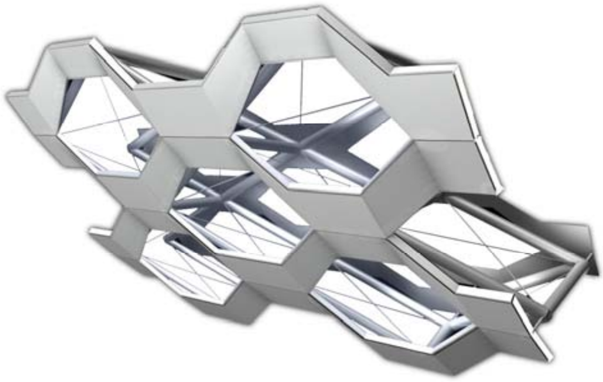

Figure 9: Element with construction (without glass) (KHing)

3. Analysis

Speaking in numbers, we are talking about more then 25.000 elements on one surface, hence more then 50.000 elements on both (inner and outer) parts of a facade. We could say that in the double curved regions all elements are different, but the question “how different” arises. Are we speaking in terms of centimetres, millimetres or maybe even micrometers? Each element has a set of “characteristics” - the lengths of its sides and the angles between different parts. By connecting all these parts we do have a little tolerance in their dimensions that can be fixed within the width of a fugue. Hence, the question is: “Can we compare elements (their parts) and create groups of them, such that for each group one element can be made and the differences between that one and the others in the group can be bridged by fugues. That is how we can manufacture the same element for the whole group and fix the differences “manually”.
The result of the script we made is an Excel file showing the elements and groups they belong to. Elements are marked with unique names so that they can be identified in space. This Excel table is then used back in Rhino to graphically present these groups within separate layers. It was a surprise how many elements could fall into the same group within very small tolerances (about 1-2mm) for the dimensions of the element parts.

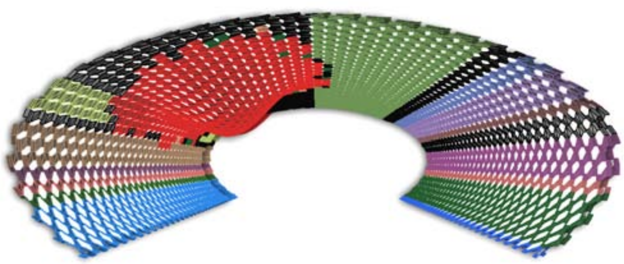

Figure 10: Analysis – different groups (KHing)

Conclusion

The greatest challenge was to develop a system of element definition in space and controlling practically every single element if we want to. All the variations in form and type of an element as well as the constant changes and “evolution” of the structure led us to it. Deadlines provided pressure that provided additional scripts for efficiency enhancement. Of course, experience showed us the advantages of predefined forms and integrated structural and aesthetic design, however, this project where those two conditions weren’t satisfied and where the structure evolved with every step along the way new ways of thinking were slowly developing. Today parametric design programs are conquering the market and moving in that evolutionary direction of thought, but still, they are used for some basic design development. We had to produce heavy steel and aluminium parts without any space for errors in our geometry. That is why we developed our own scripts and dealt with the specific problems of this project by creating specific algorithms.

The question remains if we are able to have software that will give us the needed control over structure, that will enable us to control every element in the way that we want to, or do we have to get used to the fact that in the future, for these kinds of projects, programming and code developing becomes an important part of architectural design and even architect’s area of expertise.

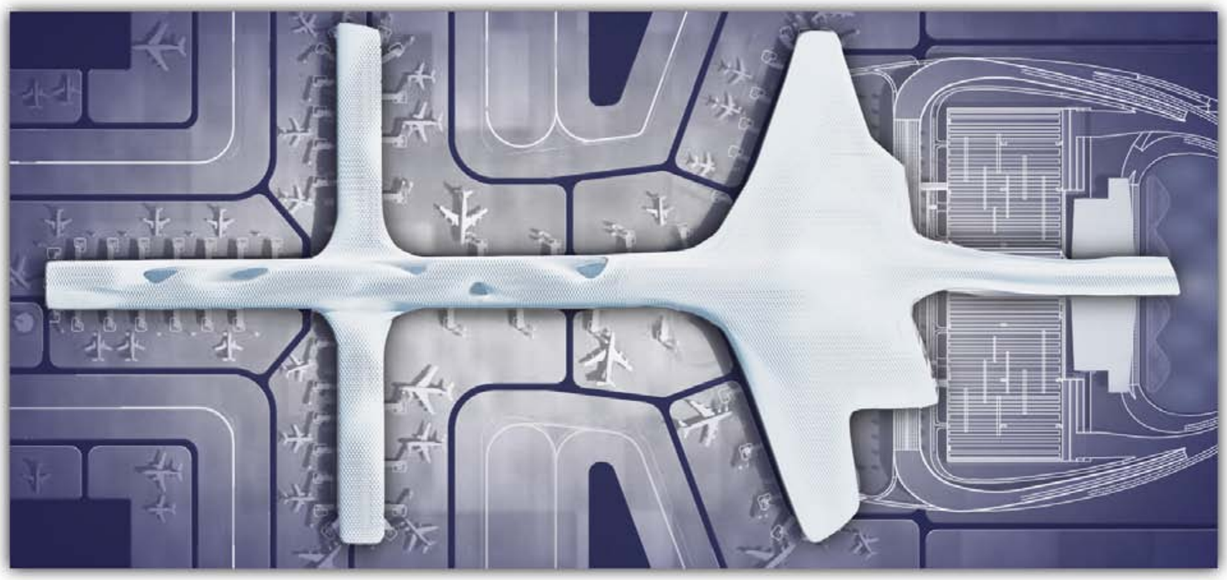

Figure 11: 300.000 m2 of double curved surface (Fuksas studio rendering)

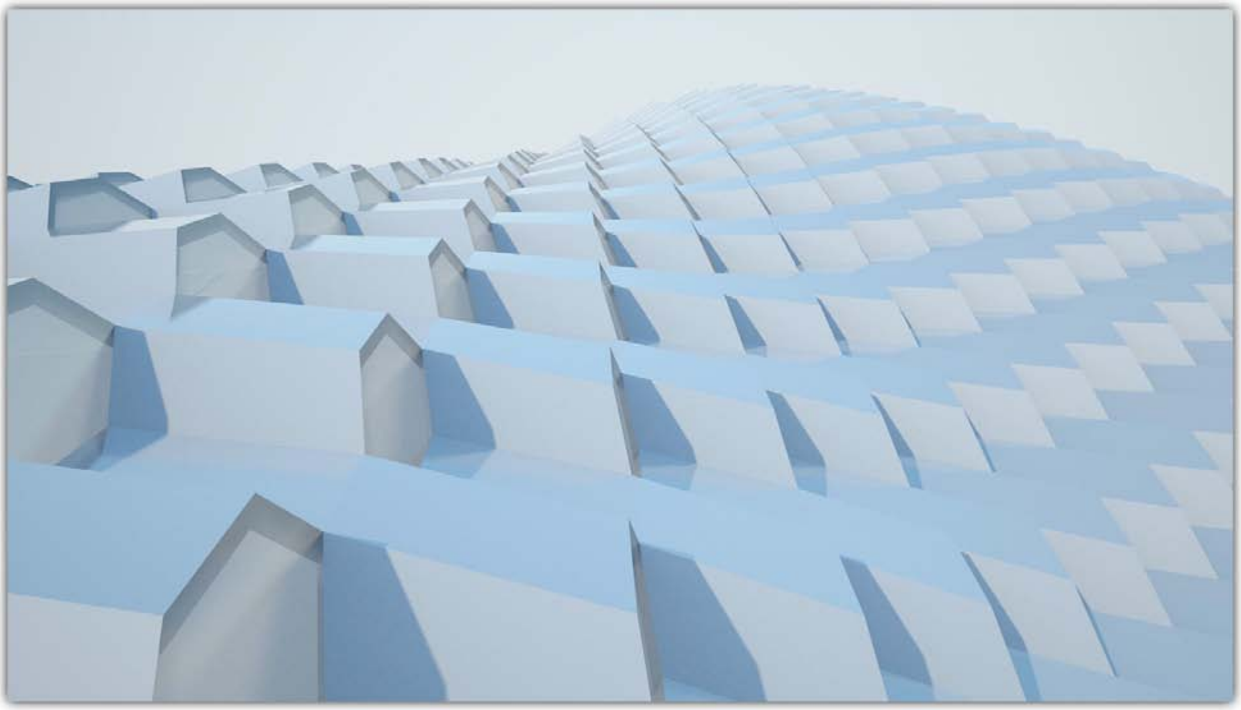

Figure 12: Facade generated over double curved surface (KHing)