

Double-curved surfaces using a membrane mould

Ir. Arno Pronk, Ivo van Rooy BSc and Pieter Schinkel BSc

Ir. Arno Pronk, Assistant Professor
Product development
University of Technology
Eindhoven, Netherlands
A.D.C.Pronk@tue.nl

Ivo van Rooy BSc
i.v.rooy@student.tue.nl

Pieter Schinkel BSc
p.schinkel@student.tue.nl

Abstract

Since Leonardo da Vinci came with his idea for an adjustable mould to make three-dimensional curved surfaces people have been searching for a tool like that. This paper gives first the different moulding techniques that have been used to make three-dimensional surfaces with prefabricated elements. Then, the authors describe their own development of an adjustable mould. This moulding technique is based on the manipulation of elastic membranes by inflatables and other objects. The paper describes the way the elastic membrane is manipulated and gives the technical possibilities for making three-dimensional curvatures. In the conclusion we prove the feasibility of this technique and show composite elements that have been made for a three-dimensional curved façade.

Keywords: double-curved surface, adjustable mould, free-form design, fiber-reinforced polyester, façades, blob

1. Introduction

With the rise of the computer and 3D programs architects have more possibilities in designing “free-form” buildings. It is easy to use the computer as a design tool, but the translation to a real building is still very hard and expensive. The traditional production methods to make those free-form buildings lack behind and architects and engineers are forced to simplify their designs. Some well-known “free-form” buildings are the Kunsthaus in Graz and the railway station Innsbruck. The façades of these prestigious buildings have been produced using expensive moulding techniques which are, unfortunately, only available for exclusive projects. The problem is that every single part of the façade is

unique, which means that every part has to be produced using a unique mould. When there would be a mould technique available that is flexible, reusable and thus economically attractive, more projects could be realized with a unique double-curved façade.

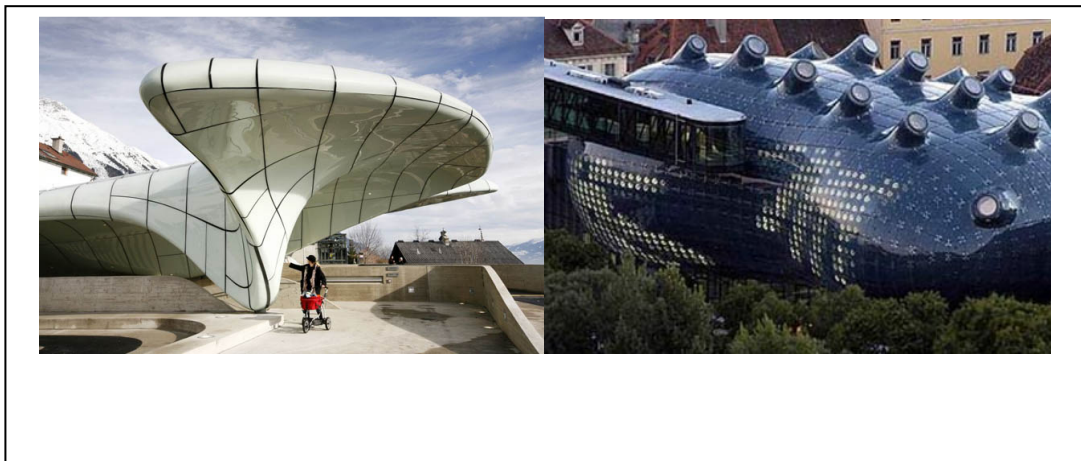


Figure 1a: Innsbruck railwaystation (Hadid)(left) and the Kunsthhaus in Graz (Cook/ Fournier)(right)

1.1. Mould techniques

Moulding techniques for this purpose can be divided into three different categories, as in Van Helvoirt, 2005 [1]:

1. The static mould. The most common mould of this kind is the EPS/PS (polystyrene) mould which has been 3D formed using a CNC cutter. This technique has a high accuracy but produces a lot of waste material.
2. -The reusable mould, for example a mould made of clay or sand. There is no waste material and therefore the method is a lot more environmental friendly. It is labour intensive and cannot be used in all circumstances.
3. -The flexible mould. This type of mould can be used for a lot of differently shaped elements because the mould will form itself to the elements that will be produced. Examples of this kind of mould are the FlexiMould by Boers [2], and the adjustable mould by Rietbergen & Vollers. The mould contains a field of height-adjustable pins. Each pin can be set into height individually using a computer-automated machine. The pins are covered with a polymer to smoothen the surface. It is important to avoid that the pins give a local distortion of the surface. The downside of these flexible moulds is the high investment. These expanses can only be gained back when a large amount of elements will be produced using this particular mould.

1.2. Flexible mould using a membrane

To avoid the high investments in a complex bed of pins and to avoid the problems with local distortion of the surface the authors developed an adjustable mould without pins in the surface of the mould. Instead of the pins they used the capability of doubly curved membranes to make a stable surface. There are three ways in which doubly curved membranes can be used. The first is to apply much curvature. The more curvature the surface of the mould has the more stable it will be. The second way to make a stable surface is to pre-stress it and the third is to support the membrane with overpressure by using an inflatable. Every method has his own characteristic forms. Combining the different possibilities leads to an endless number of surfaces that can be made in this way. (A.D.C. Pronk en R. Houtman (2004) [3]).

In this way the benefits of a flexible mould (adjustable to a lot of different elements) are combined with the benefits of a reusable mould (no waste materials and lower investment costs).

The first step of this research was to make one panel on a pre-stressed membrane with an inflatable underneath to test the technique. The result can be seen in Fig.1b

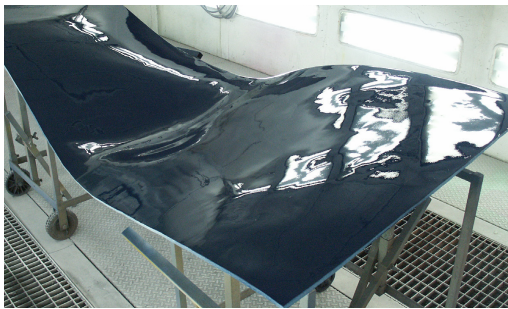


Fig.1b first panel

The second step was to develop an adjustable mould and a mock-up model of a façade. This mock-up consists of 12 double-curved panels of 600x600mm. They will form a small piece of a façade. The boundaries of the part will be kept straight making it possible to fit the mock-up model into an existing, flat façade.

2. First step: 3D design of a façade

The first step in the production process was to design a façade with the help of 3D drawing program. The authors used Rhinoceros 4 because of its NURBS modeling support. NURBS are mathematical described functions that represent a surface or a spline (edge). A façade will be designed using these functions instead of vertices and polygons to fully control the surface of the façade. The authors developed a plug-in to get specific information about the height and angle of specific points of the designed surface. This data is necessary to adjust the mould in the right position.

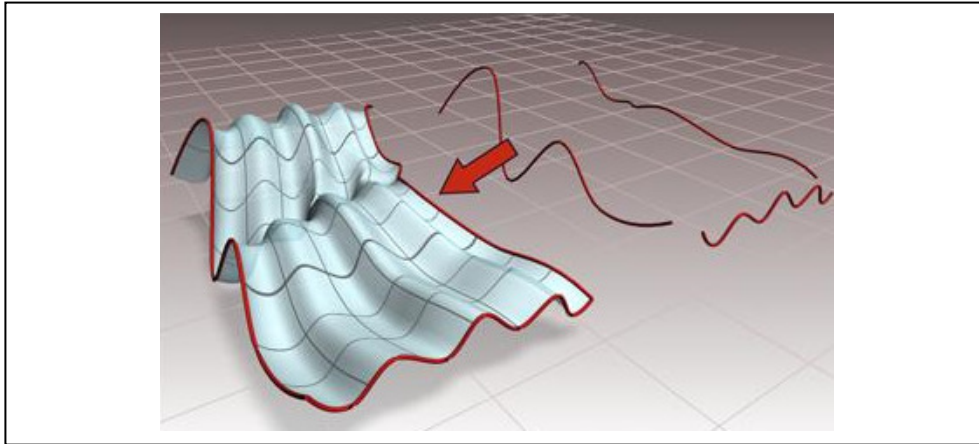


Figure 2: A NURBS surface created from three splines

3. Second step: Adjustable mould

Like been said, the mould is based on the flexible and elastic properties of a membrane stretched over an edge. The edge (the boundary of the mould) is fully adjustable, using a specially designed system. As can be seen in the Figure 3 the edge consists of several height-adjustable bars placed in a grid. In this chapter all parts of the mould will be discussed.

3.1. Height-adjustable bars

The bars support a boundary that is formed like a spline. In mathematics, a spline is a special function defined piecewise by polynomials. Each polynomial is defined between a knot, and the bars represent these knots. The spline will flow gently along the height-adjustable bars.

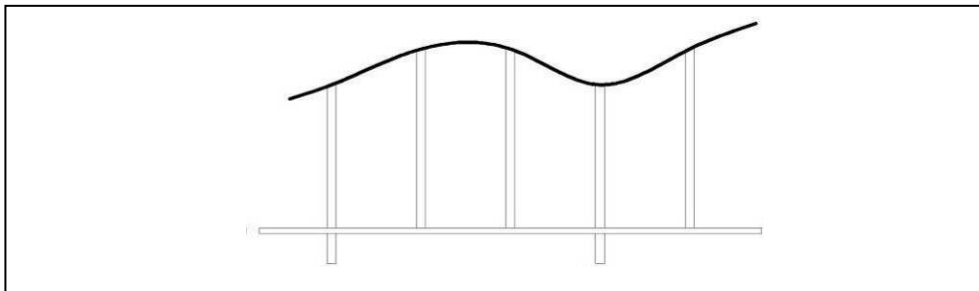


Figure 3: The boundary is placed on top of the bars to form a spline

The size of the mould is 1200 mm x 1800 mm. Therefore it is possible to make 6 panels of 600 mm x 600 mm. The mock-up façade consists of 12 panels. So the 12 panels will be produced in two shifts. To have a close fit between the edges of the two shifts we have to force the membrane in the right position and angle. Therefore a special rubber edge has been designed that guarantees a smooth transition between two production cycles (and two elements of the final façade). This edge consists of an EPDM rubber, flexible beak that can be placed into the desired angle. This angle is the transition angle between two elements. The beak will push the membrane gently into the right angle. The result is a fluent transition. On top of the membrane a counter bar and rubber edge will be pushed on top to guarantee a nice transition when the rubber comes from a higher angle.

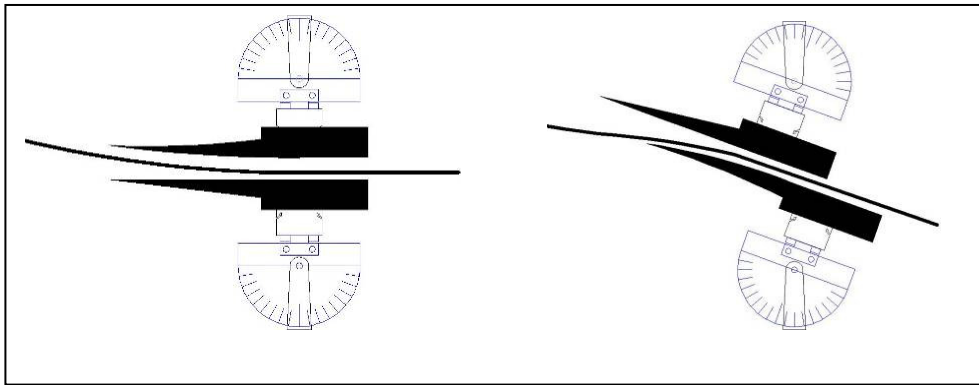


Figure 4: The rubber beak placed on top of the bars

3.2. Stretching the membrane

To hold the bars in place a steel structure has been made. This steel structure does not only support the bars but is also used to pre-stress the membrane. Figure 5 shows the steel structure, the bars are represented in blue, and the rubber beaks are black. The green beams are used to fix and stretch the membrane. They can also be placed into different heights at the corners. The maximum surface that can be created in once time is 1824x1216mm.

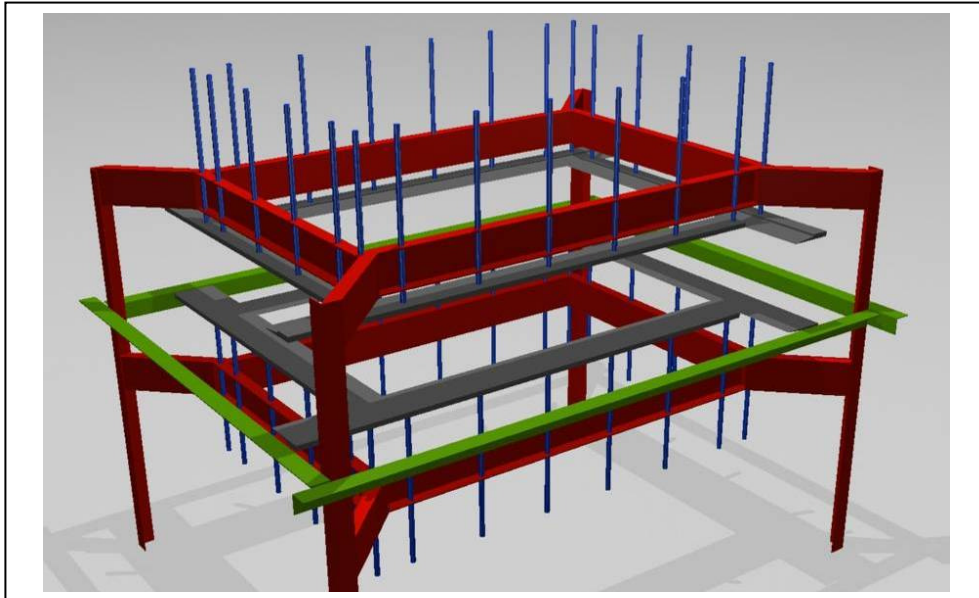


Figure 5: The steel frame of the mould

It is important to stretch the membrane (a PU-foil) over a continuous length. The authors used an innovative system developed by Buitink Technology. At four sides of the membrane an inflatable tube is placed. By raising the pressure in the tube the form of the cross-section changes from a lens to a circular form. In this way the membrane is stressed by the change of the form of the tubes.

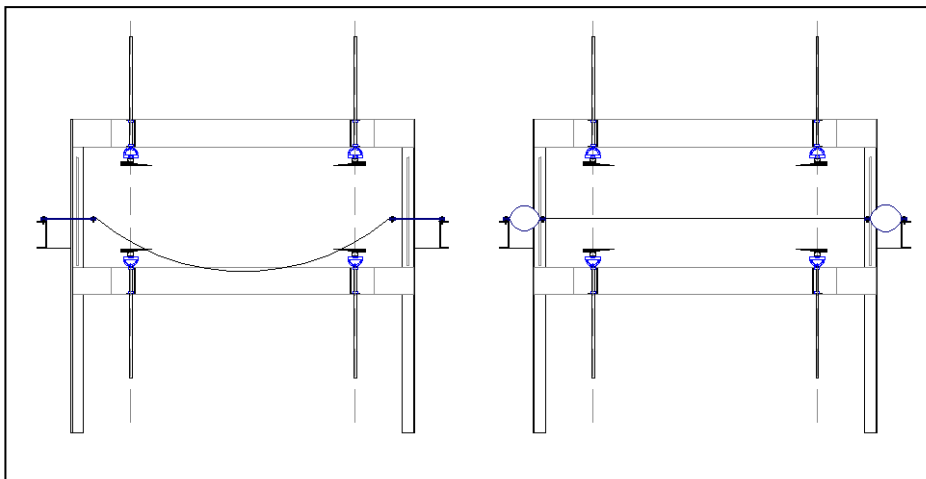


Figure 6: Cross-section of the mould, the inflatable tubes stretch the membrane



Figure 7: The mould: in white the membrane attached to the black tubes

3.3. Manipulating the membrane

When the membrane has been spanned between the adjustable boundaries the shape can be manipulated by using inflatables. The balloons can be placed underneath or on top of the membrane to push it gently into the right shape. Using the 3D designed façade the surface can be investigated to see if it is necessary to manipulate the membrane, how big the balloons need to be and where they need to be placed.

4. Third step: Production of the façade elements

The façade elements that have been produced are made of fiber-reinforced polyester. This material has a lot of advantages over traditional materials. It is very light and because of the fibers very strong but still flexible. Polyester will become hard after adding a fastener, and a catalyst. The last one will start the process of hardening.

4.1. Vacuum injection

To produce real façade elements using the adjustable mould the vacuum injection method should be used. This production method is suited very well for the mould because it is possible to press a balloon on top of the membrane while producing. Besides, the method is very clean. First, on top of the membrane several layers of glass fibers are placed. These fibers make sure the panel will be strong to resist stress. A special finish layer is also placed to give the panel a smooth surface. The layers of glass fibers are sealed with a vacuum bag.

This bag is air proof fixed on the edges of the mould. It is really important that the entire package is air tight. On one side of the package air will be sucked out by a vacuum pump. On the other side the package is connected with a bucket full of prepared polyester resin by a tube. The vacuum pump sucks all polyester into the glass fiber package and makes sure it will be spread evenly. This process takes up to one hour, after that the polyester panel needs to harden over time (up to three hours, depending on the temperature).

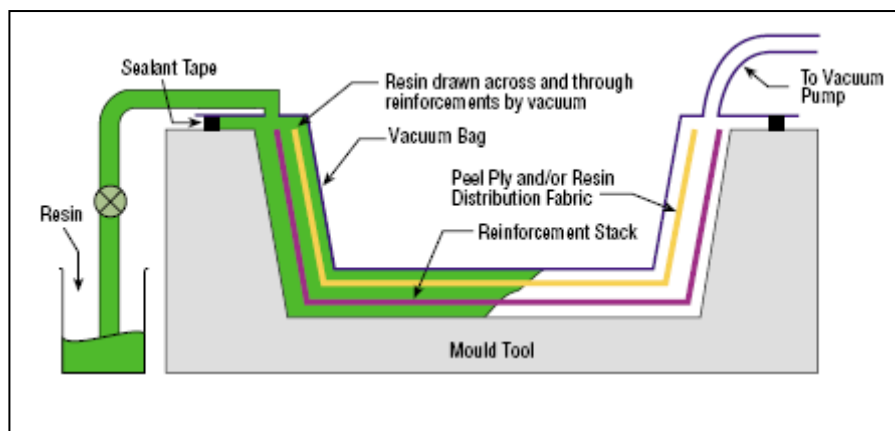


Figure 8: Vacuum injection method (SP Guide to composites [4])

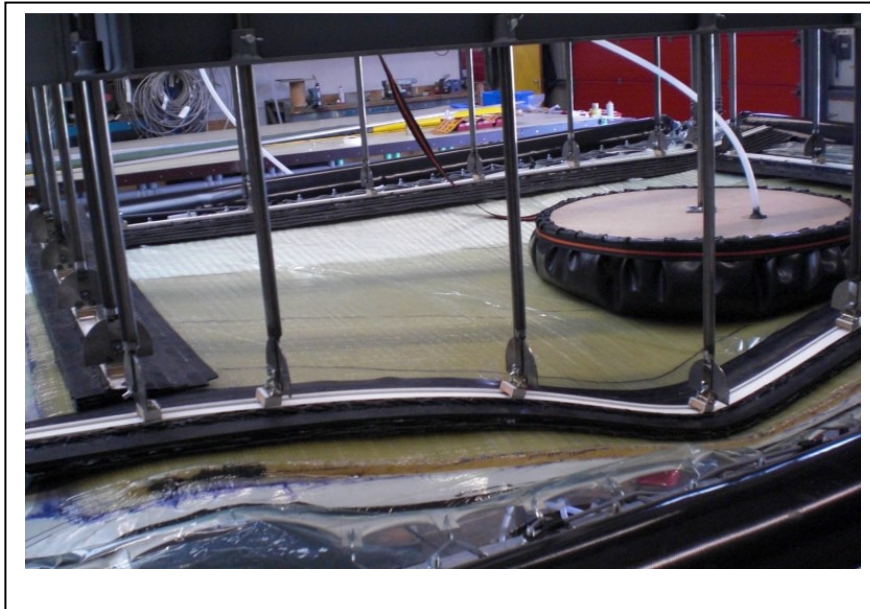


Figure 9: The mould during an injection

4.2. Finishing the panel

The produced polyester panel is now ready to be finished. It can be cut into the desired dimensions. To test the mould a mock-up model has been made that uses panels of 600x600mm. Each production cycle will produce 6 of these panels. They can be cut using a saw or even a water or laser cutter. After sand rubbing the panels can be coated or painted. As in figure 10, the mock-up has been coated with a metal coating which gives the panels a rusted steel look.



Figure 20: The mock-up model that has been produced using the new production method

5. Final step: Fixation system to back structure

After the panels have been produced and finished they are ready to be fitted onto a back structure to form a façade. All panels are different; therefore the support system needs to be flexible as well. The distance between the panel and the back structure is different for each panel. Besides this problem, the panels also need to be adjusted in all directions. Therefore

a new system has been designed to suit the polyester panels and production method. The system consists of a U-beam that is attached to the back structure. Each panel has four fixation points that have been glued on the corners. These points consist of a ball joint so they can be placed in any angle. This ball joint is attached to a steel tube that will be slide into another tube that is attached to the U-beam. The upper tubes can be adjusted and fixed in all directions.

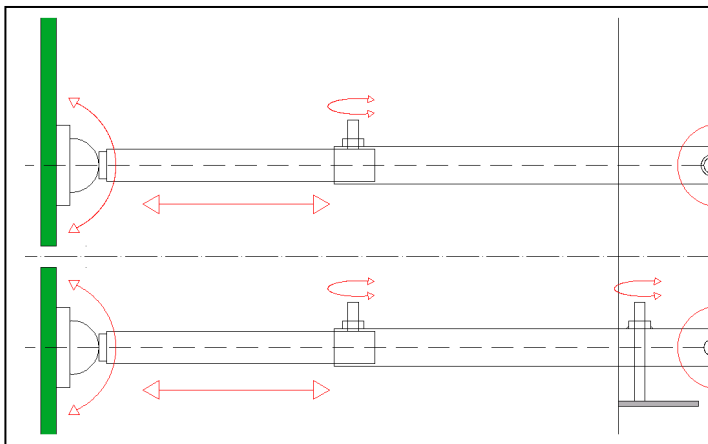


Figure 31: Fixation system

6. Future possibilities

The new production method has been put into the test and proves that it is possible to economically produce unique elements. It is possible to produce double-curved façade elements using a membrane mould. When the elements produced for the mock-up had been made in a conventional way the price would have been doubled. The main advantages of the technique are the low costs and the simplicity of the mould. It is also possible to optimize the process by the introduction of computer-controlled bars to speed up the adjusting time of the mould and the introduction of 3D monitoring to have a better control of the 3D surface.

7. Acknowledgement

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