

## 3D Adaptable Building Skin: An Invention for Freedom in Shape of Façades.



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### KEYWORDS

Skin, inflatables, flexibility, adaptability, façades

### ABSTRACT

This paper sets out to develop a principle on which a façade element can be deformed in shape. By using a flexible structure with cables, small bars and inflatable tubes, which together form a woven pattern, a 3D freedom of deformability results. The façade element can be manipulated and deformed in shape at will. By studying the structure of the human skin, a pattern was discovered and translated into a constructive principle. The façade element can be applied in single curved and double curved surfaces, both concave as well as convex. Moreover the different elements in the structure are constantly in equilibrium with each other. Through this; great freedom in form is achieved. This principle will create many new possibilities in architectural design.

### 1 Human Skin

Research into the structure of human skin led to the discovery of a structural pattern which can be used for façade elements. Human skin is very elastic and deformable and for that reason it is interesting to investigate it from a constructive perspective.

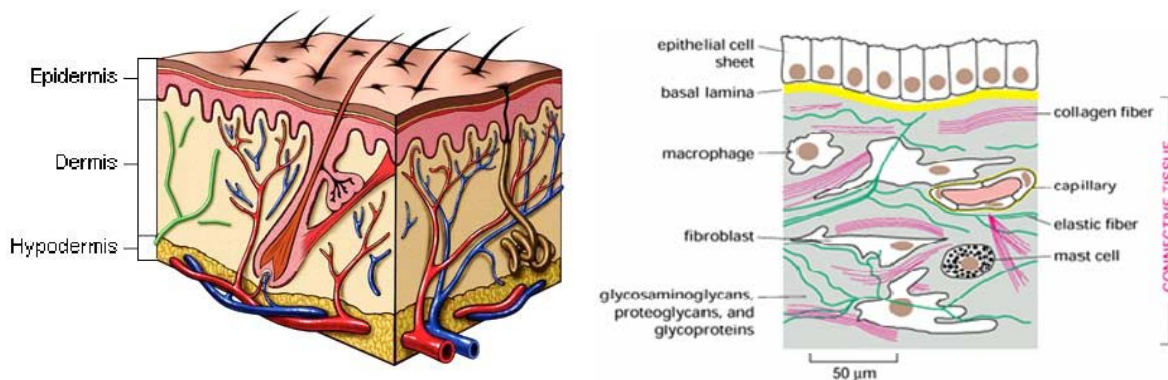


Figure 1. 3D view of the layers of human skin. (Source: Alberts e.a., 2002)

Figure 2. Schematic Cross-section of human skin. (Source:Alberts e.a., 2002)

Human skin consists of three layers: the epidermis, the dermis and the hypodermis (figure 1). The dermis is the structural layer and absorbs all the deformations. The structural behavior in the dermis is determined by a cooperation of elastin fibers, collagen fibers and the extracellular matrix. The elastin fibers take care of the elasticity and the ability of reshaping the human skin. The collagen fibers take

care of the ultimate strength and finite strain. The structural behavior of these two fibers is shown in figure 3. The red line indicates the cooperation of the fibers and characterizes the structural properties of human skin. When deformation occurs, the elastin fibers are tensioned first. They will stretch till the collagen fibers are straightened and the tension forces will be taken by the collagen fibers. The extracellular matrix lies between these fibers. This layer consists of a dense mass of fluids which keeps the fibers in the dermis layer in place. In this way the cooperation of the fibers in the chaotic pattern in human skin is organized. By analyzing these properties and studying the structure, an analogy was developed for a constructive façade element. 3D Adaptable Building Skin has the elasticity as well as the 3D deformability of human skin.

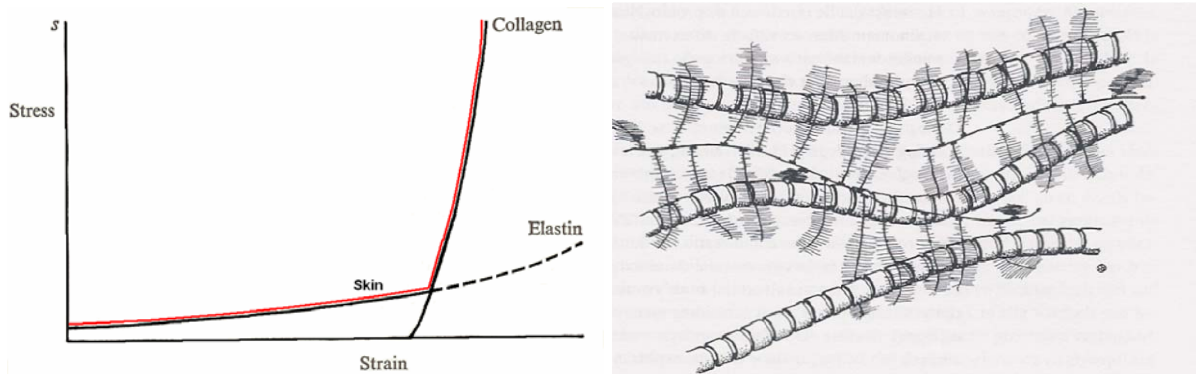


Figure 3. Structural behavior of the collagen and elastin fibers in human skin.(Based on a graph in Gordon, 1978)

Figure 4. Pattern of collagen fibers type I and type IX. (Source: Alberts e.a., 2002)

## 2 Translation to a constructive façade element

In order for the project to succeed as a commercial venture, the constructive façade element must be easily manufactured, constructed and maintained at low cost. To achieve this, the chaotic skin structure was schematized to a regular pattern. By scale model studies (figure 5), it was possible to design this 3D structure. In the cross section (figure 6), we see a hexagonal structure which is made up of small bars connected by cables. The cross section can be expanded in three directions. The façade element can therefore be adapted to different boundary conditions. By putting more cross sections after each other, a composition is created which can function in two dimensions. When putting a same set of cross sections at right angles through the previous set (the red dots, figure 6), a three dimensional structure is generated. The cross sections don't have any contact in both directions and are not yet capable to cooperate. In the open spaces of the structure, inflatable tubes are placed which will establish the cooperation between all the structure elements. The cross sections are never directly mutually joined. This leads to a façade element with elasticity and freedom of deformation.

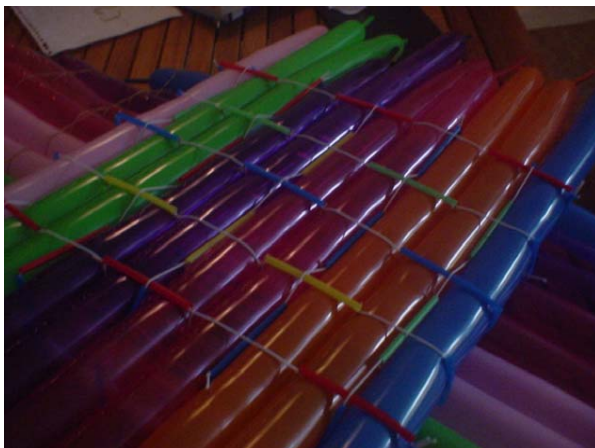


Figure 5. Scale model with three layers.

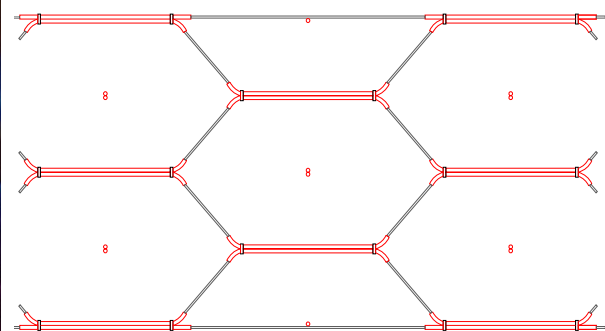
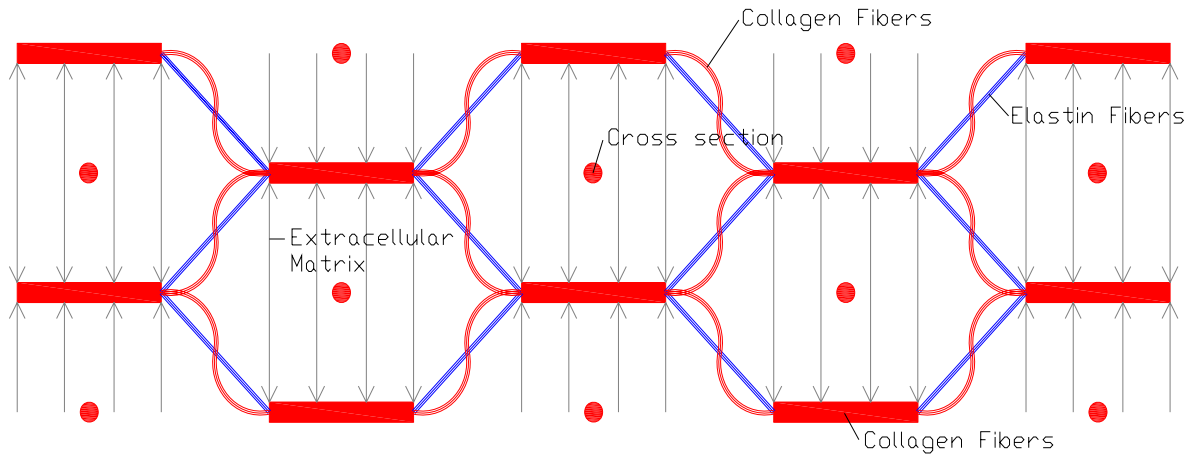


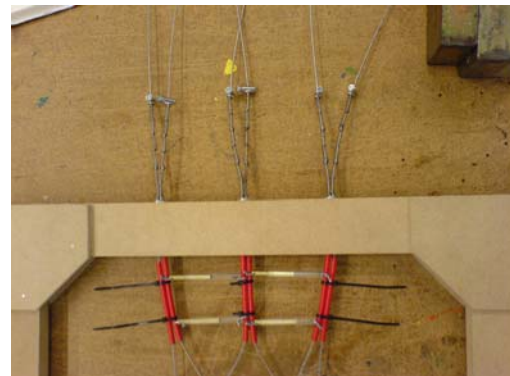
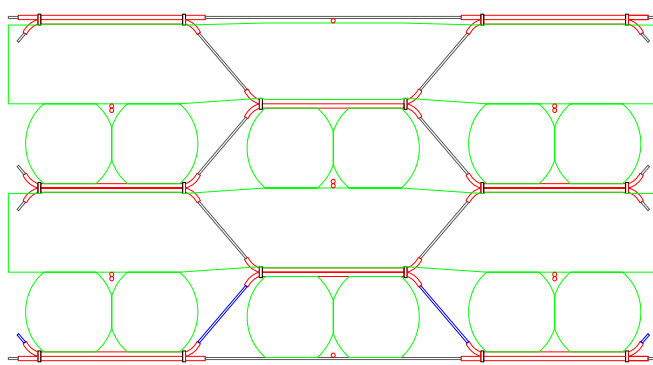
Figure 6. Cross section of cables and rigid pipes.

Figure 7 shows a two dimensional translation of a structural mechanism which meets the structural behavior of human skin. When this cross section is pulled out at both sides, the grey arrows will keep the red horizontal bars in place. Horizontal deformation is possible by the elastic properties of the blue cables. When the deformation becomes so large that the red curved cables are stretched, the system has reached its finite strain. Finally these elements are translated into structural materials at a makable scale. The red dots indicate the same cross sections which are woven at right angles through the cross section in figure 7. In this way a three dimensional system is created.



*Figure 7. 2D translation of a structural mechanism which meets the structural composition of human skin.*

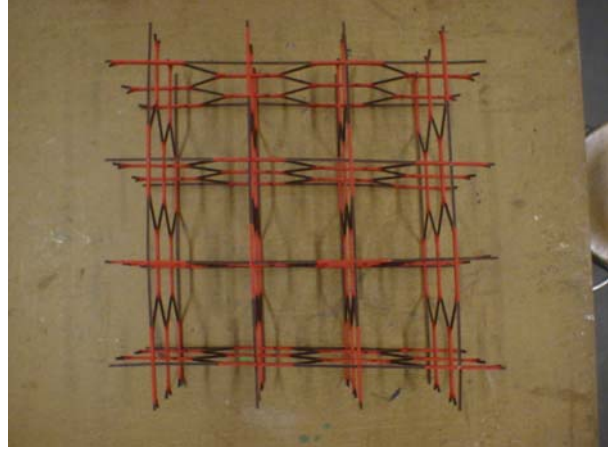
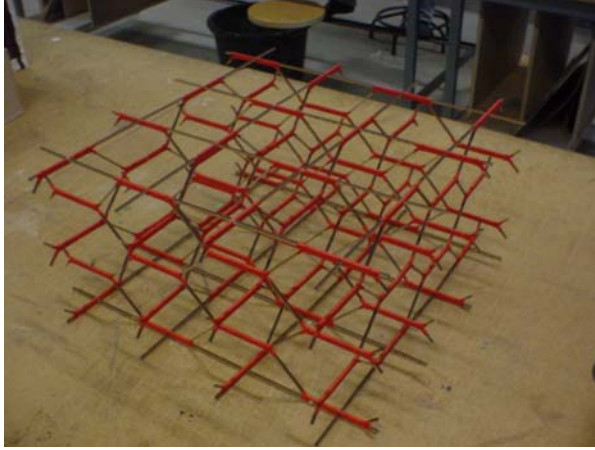
To give the façade element properties comparable to human skin; inflatable tubes, steel cables, rigid pipes and springs are used. The inflatable tubes represent the properties of the extracellular matrix by their resistance in pressure. The steel cables, rigid pipes and springs represent the cooperation of the collagen and elastin fibers. In a structural sense figures 8 gives a cross section of the pattern. The red beams are rigid pipes and the diagonal cables are steel cables. The rigid pipes are hollow so the steel cables can slide through them. In the geometry of figure 8, six cables are used. Four cables in the body and two cables on the outside. The cables on the outside are straight. The cables in the body are woven like for example the blue cable starting at the left hand side under through the rigid pipe and going upwards through the second rigid pipes and going downwards through the next rigid pipe and so on. This weaving pattern gives the façade element much more freedom of deformation. At the end supports each cable is hold by a spring. The spring limits the ability to deform. When the cross section is deformed, the tension caused by the spring will become higher in case of geometrically non linear behavior. The structural mechanism must be pretensioned by the springs or it will become kinematically undetermined. The behavior of the façade element is now comparable with the structural behavior of human skin as shown in figure 3.



*Figure 8. Cross section of the pattern .*

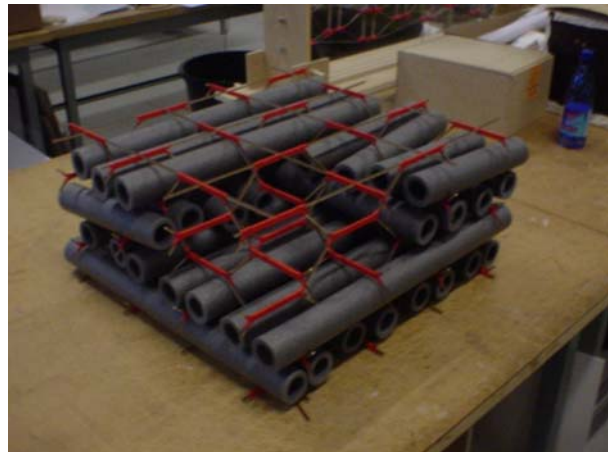
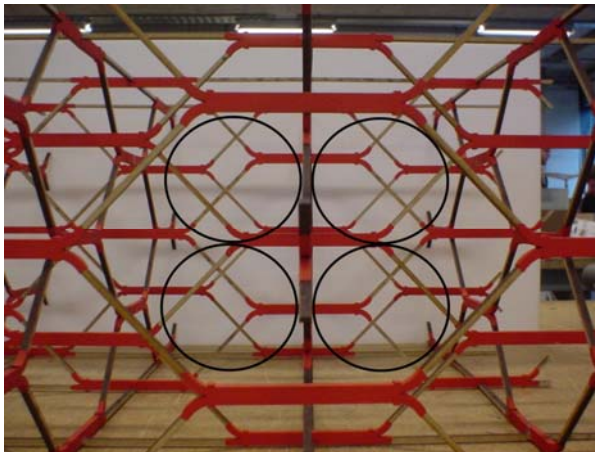
*Figure 9. Springs at the end supports give the cables elastic behavior.*

To study the geometry of the façade element, a scale model has been produced. As seen in figure 10 and 11, the cross sections are woven at right angle through each other. A complex system exists as seen on figure 10, but the top view of figure 11 shows a regular pattern of cross sections. Figure 12 shows the hollow corridors through the cross sections. These hollow corridors give the opportunity to place the inflatable tubes in layers as seen in figure 13. In this way local surface loads can be absorbed three dimensionally and distributed through the façade element.



*Figure 10. 3D scale model of the structure with cables and rigid pipes.*

*Figure 11. Top view of the 3D model of the structure with cables and rigid pipes.*

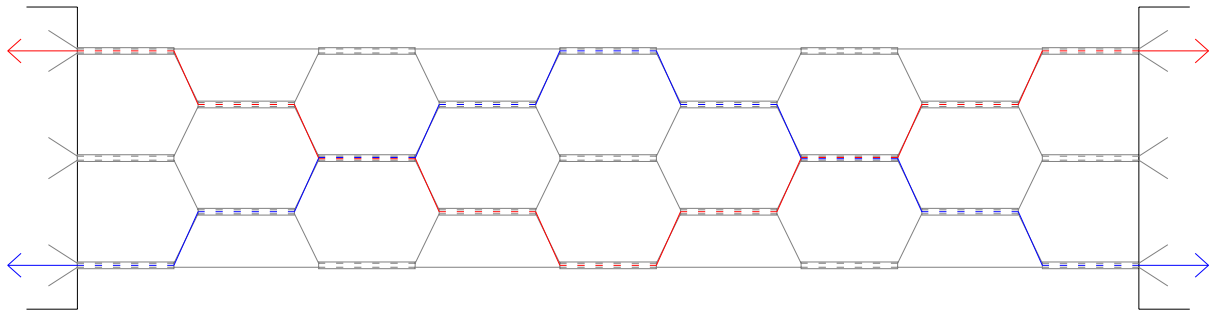


*Figure 12. The hollow cylindrical corridors through the 3D scale model of the façade element.*

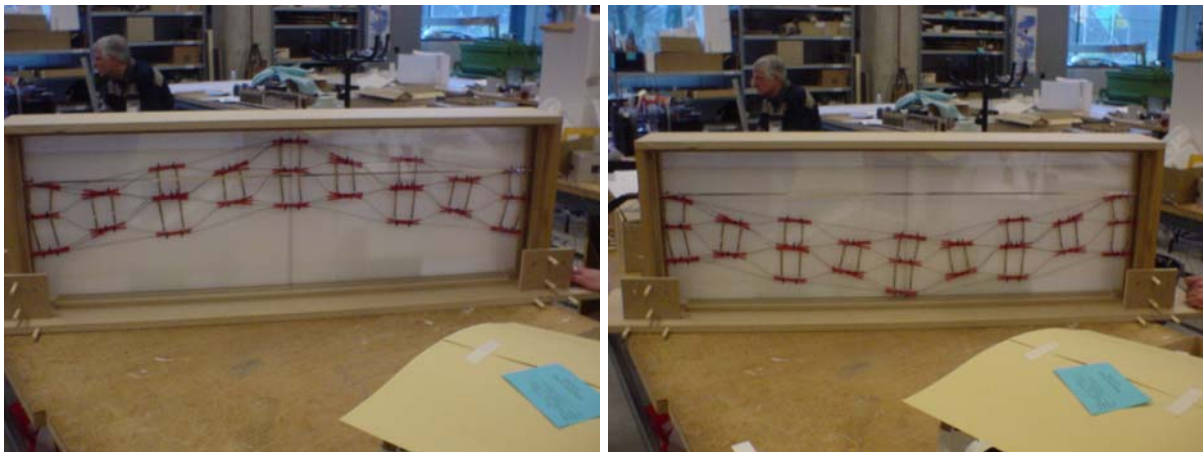
*Figure 13. Isolation tubes as inflatable tubes in the 3D scale model of the façade element.*

### **3 3D Adaptable Building Skin**

The above described structure can be deformed into convex and concave surfaces by varying the tension in the cables or pressure in the inflatable tubes. Using an extra cable which is woven through the cross sections, the façade element can also locally be deformed. Many deformations can be manipulated depending on the geometry and woven pattern of the extra cable. The most obvious configuration is shown in figure 14. The red cable causes an upward deformation as shown in figure 15 and the blue cable causes a downward deformation. When extra cables are used in a 3D system, many deformations become possible. Deformations are always curved and never more than the façade elements thickness.



*Figure 14. Extra cables (blue and red) to cause deformations.*



*Figure 15. Scale model of a 2D cross section with upward deformation.*

*Figure 16. Scale model of a 2D cross section with downward deformation.*

#### **4 Research of structural behavior**

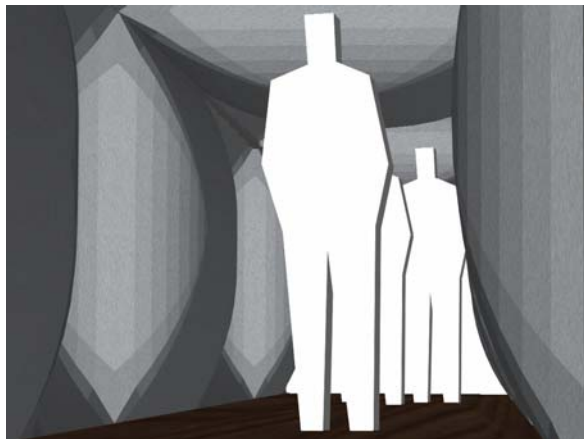
A research project is carried out to investigate the structural behavior of a two dimensional cross section. To meet the commercial market, the sectional geometry is set to 318 mm thickness and a span of 1950 mm in two orthogonal surface directions. Structural elements like inflatable tubes, steel cables and springs will be investigated and adjusted to the desirable behavior.

#### **5 Architectural advantages**

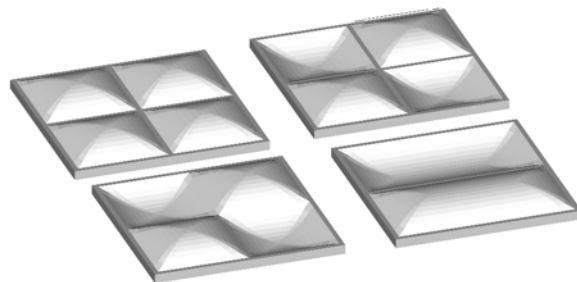
For long time many designers have been searching for a façade element whose shape can be manipulated. Elements with adaptable shape lead to great freedom in architectural design. Freedom in shape is possible with the proposed façade element. This façade element can be used for large surfaces and can deform into many different shapes, so a building can express itself in many ways. The building is thus able to adapt to its surroundings, or express different characters both inwards and outwards. Possible shapes on the façade are 2D and 3D waves, walking bulges, logos of firms, pictures, expression of scenes, text and names etc. The façade of a building constructed with this element, can even become a living organism, literally comparable with human skin. Even rooms and halls can grow or shrink and adapt to its internal circumstances. These spaces can be differently used and experienced. On the outside the deformations are also experienced and may result in a totally different meaning of the building. The outside deformations have a direct relation to the inside experiences. The freedom of shape is not the only advantage. By the great thickness of inflatable tubes, the façade consists almost entirely of stagnant air; the best thermal isolator. Also the choice of the top layer is free. The best solution would be an elastic fabric which can deform with the underlying façade element. This fabric may or may not be transparent or colored. The possibilities are infinite.



*Figure 17. A corridor can adapt to passing people. The width of the corridor with a plan width of two meters expands from 1.40 meter to 2.60 meters.*



*Figure 18. Inside experience of the corridor.*



*Figure 19. Several possible 3D deformations for façade elements.*

## **7 Acknowledgement**

Special thanks to Prof. Ir. F. van Herwijnen, dr. Ir. M. Bakker, Ir. A. Habraken and dr. J. Voorthuis for giving me the support and opportunity to develop my own ideas. This attitude is the right one for a university with ambitions for development.

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