3D adaptable building skin: an invention for freedom in shape of façades

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

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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 shape of 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 is capable of 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 that’s why it was interesting to investigate it from constructive perspective.

Figure 1. Schematic view of the layers of human skin. (Source: Molecule Biology of the Cell)
Figure 2. Schematic Cross-section of human skin. (Source: Molecule Biology of the Cell)

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 stresses and deformations. The structural behavior in the dermis consist mainly of 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 speaks for the structural properties of human skin. When deformation occurs, the elastin fibers will first take in the primarily tensions forces. They will stretch till the collagen fibers are lie straight, now the tension will be taken by the collagen fibers. The extracellular matrix lies between these fibers. This layer consists out of a dense mass of fluids which keeps the fibers in place in the dermis layer. This way the cooperation of the chaotic pattern of the fibers in human skin is met. 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 of Structures, or why things don’t fall down by J.E. Gordon)](image)

![Figure 4. Pattern of collagen fibers type I and type IX. (Source: Molecule Biology of the Cell)](image)

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, installed and exploited 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 bounding conditions. By putting more cross section one after another, a series exists which can function two dimensionally. 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 capable to cooperate yet. 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 gives the façade element elasticity and freedom of deformation.

![Figure 5. Scale model with three layers.](image)

![Figure 6. Cross section of cables and rigid pipes.](image)

A.B. Suma 3D Adaptable Building Skin
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 at both sides, the gray 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 exists.

![Figure 7. Literal translation of the structural properties of human skin.](image)

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 structural behavior of the cooperation of the collagen and elastin fibers. Figures 8 gives the pattern of a cross section. 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 left under through the rigid pipe and going upward through the second rigid pipe and going downward 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 cables is hold by a spring. The spring limits the ability to deform. When the cross section gets deformed, the tension caused by the spring will become higher for 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 now meets the structural behavior of human skin as shown in figure 3.

![Figure 8. Translation to a constructional pattern.](image)  
![Figure 9. Springs in the end supports give the cables elastic behavior.](image)
Study the geometry of the façade element, a scale model has been produced. As seen on 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 right angle per layer over one another as seen in figure 13. This way local surface loads can be absorbed three dimensionally and distributed through the façade element.

![Figure 10. 3D scale model of the cross sections of cables and rigid pipes.](image1)

![Figure 11. Top view of the 3D structure of cables and rigid pipes.](image2)

![Figure 12. The hollow cylindrical corridors through the 3D scale model of the façade element.](image3)

![Figure 13. Isolation tubes as inflatable tubes in the 3D scale model of the façade element.](image4)

### 3D Adaptable Building Skin

The above mentioned 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 is also capable of local deformations. 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 higher than the façade elements thickness.
4 Research of structural behavior

Research project carries 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

Since years many designers have been searching for a façade element whose shape can be manipulated. Elements with adaptable shape promise great freedom in architectural design. This becomes possible with this façade element. Using this façade element which can be used for large surfaces and can deform into many different shapes, 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 and faces, texts 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 outward 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 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 endless.
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.

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8 References