Making double curved forms with the use of a 3D fabric.

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INTRODUCTION
Inflatable structures have seen applications in area such as rescue equipment, civil-, maritime- and aerospace structures. Applications are derived from unique advantages that inflatable structures offer. Inflatable structures provide: low structural weight, low storage volume, ease of deployment, and low manufacturing cost. (Ref. 9) For space applications these advantages result in significant mission cost reductions in some cases up to six times. (Ref 10). The requirements to space applications are very stringent because of high cost involved. Therefore research encompasses area to ensure a successful mission. Typical space research area membrane surface accuracy and deployment modelling.

Inflatable structures in civil engineering can be divided into two categories: air-supported structures and air-inflated structures. An air-supported structure can be regarded as a single membrane barrier structure i.e. only a single membrane separates the atmosphere from the internal atmosphere. The membrane is held in place by and internal overpressure. From the nineteen-sixties onwards these structures have been used for sport stadiums, air-houses, and exhibition halls. The following figure shows an example of an air-supported structure. Fig 1-2

Figure 1 and 2 Pontiac silverdome

The pontiac silverdome has got a 10 acre Teflon-coated Fiberglas roof. It was built in 23 months time at a cost of $ 55.7 million. The first game was played in August 1975.

Air-inflated structures are build up from an inflatable tubular support structure. The pressure in the interior is the same as the atmospheric pressure so there is no need for special air-locks. Typical applications for structures like these are emergency shelters. The objective of this paper is to demonstrate new possibilities of inflatable technology in civil engineering. The inflatable technology is used as a building method. A sandwich blob structure can be created using an inflatable mould or a double wall can be used that is inflated with foam. This paper focuses on the latter building technology.

BLOB ARCHITECTURE

The similarity between form active structures (Ref. 2) like tent structures and pneumatics on one hand and blobs on the other hand is so substantial that it is obvious that we should try to make a blob with the same techniques. In 1994 writes K. Michael Hays (Ref. 3) that in reaction to fragmentation and contradiction there is a new movement in architecture which propagates a combination not only in form but also between media like film, video, computers, graphics mathematics and biology. He recognises that architecture under the development of increasingly complexity of information and communication has chanced into information and media. This development has lead to a kind of smoothness, which is called blob architecture. Fig 3-4

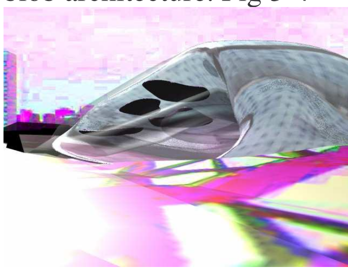

Fig 3 and 4 by Michael Bittermann Fig 5 by Eckert Eckert Architekten AG

The characteristics of a blobs are; smoothness, irregularity and having a double curved skin. Frei Otto already demonstrated the possibilities of influencing the form of pneumatic constructions by stretching nets and cables over it (Ref. 8). An other example of manipulating a tensile-form is the combination of cloth and a pneumatic structure in a blobby design. (Ref. 4) For instance in the floating theatre at the Expo 1970 in Osaka, designed by Yutaka Murata. One of the latest examples of transforming the form of a pneumatic construction is the tensile-structure for the Swiss pavilion (Fig. 5) The edges of the structure are transformed by using bending stiff elements.

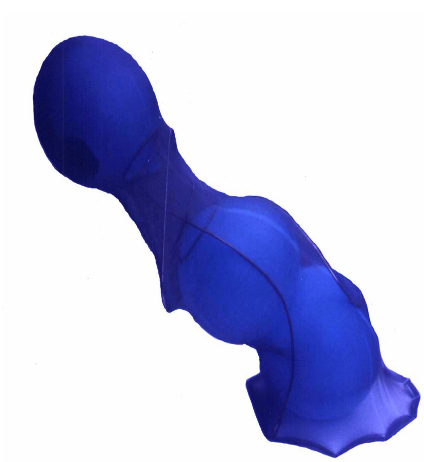

Figure 6,7 and 8 by Arno Pronk

At the Technical University of Delft we have formed a group who wants to take the challenge of finding a way to make blobs. This group exists out of Professors researchers and students. In our research we made a model from balloons and a wire-frame in a panty. In this way it is possible to make all kind of forms. (Fig 6-8) We did some experiments with the possibilities of this technology. After modelling the shape we rigidized the form with glue.

With some students we had a module dealing with the problem of realising a blob like structure. One of the designs (Fig 9) influenced the form of the pneu by making as much as possible strings at the surface of the pneumatic structure. The strings where grouped and bound to an inner frame. The principal of this pneumatic structure works like a parachute.
If at the opposite of the outside of structure is put an inner structure. And if the strings of both sides are bound together there becomes a sandwich.

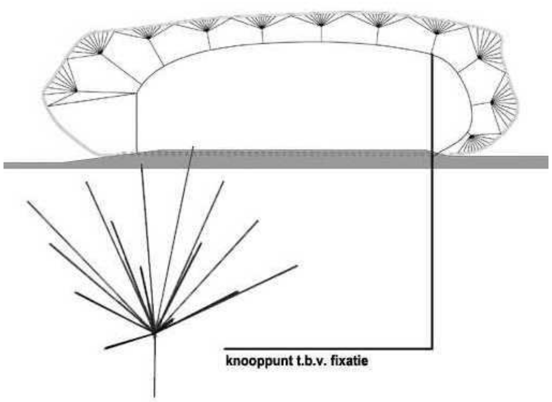

Figure 9 by Paddy Sienwerts

3D FABRICS

In order to inflate a dual wall structure, both walls need to be fixated. A 3D fabric provides a suitable way of fixating both facings. Vertical drop treads ensure that the distance between each facing remains constant.

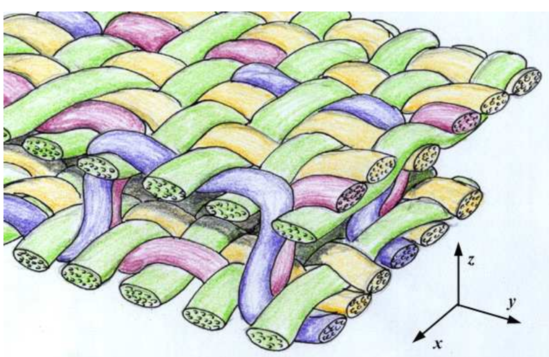

Figure 10 3D fabric layout (Holtsmark, 2001) Figure 11 Goodyears Inflatoplane

The picture above shows a layout of a parabeam 3D fabric. (Ref. 5) The distance between each facing can be varied to suit the application. When both facings are coated, an airtight space is obtained which can be inflated by either air or foam. Goodyear already produced an inflatable aeroplane using rubberised airmat in the mid nineteen-fifties. It is an example of the high-performance applications of a 3D fabric. (Ref.1)

Inflation of a 3D fabric can be done by a variety of media such as air, water or foam. A sandwich construction can be created when foam is used as an inflation medium. Research to use of foam inflation methods has been applied in space industry. (Ref. 7) In aerospace-engineering foam inflation is a way of rigidizing the structure to prevent the need for inflation gas for longer periods of time. A variety of foams can be applied but main requirement to the foam is that it has a long reaction time to allow for controlled inflation of the product. The inflation strategy should be such that the entire product is filled with foam.

Another group of students looked at the 3D fabrics. This material is used in lightweight-structures since a long time (Ref. 6). Pneumatic use of 3d fabrics is mostly used as a plane structure. We looked at the possibilities of making single and double curved forms by cutting out small pieces at one site of the fabric one side is becoming smaller as the other one and the result of that is a curved form. After fixing the cutting parts together we got the following result. (Fig.12-13) By cutting out a small part in the middle we also cut through the strings in that part. As a result of that the surface of the structure gives a bubble at the other side of the cut-out.

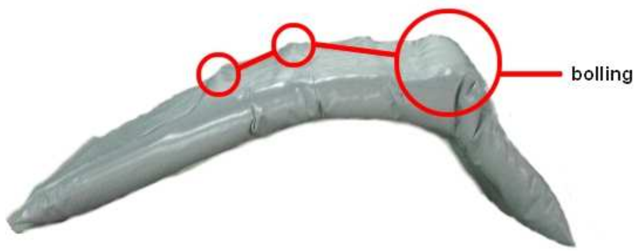

Figure 12-13 by Alex de Ruiter, Jasper Felsch and Haiko Cornelissen

A DOUBLE CURVED 3D FABRIC
After this experiment we studied the possibility of making a double curved model. The 3d model of the blob is generated with the software package EASY (Fig 14). The boundary of the blob is at one horizontal plane, which creates a total flat area when only prestress in the membrane is applied. To influence the shape of the membrane in a form-active way, the surface is loaded with normal pressure during formfinding. The pressure is not equally distributed on the surface, which creates the desired organic shape (Fig 14).

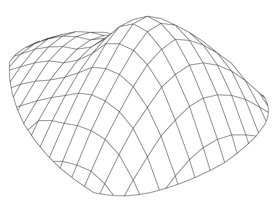

Figure 14 by Freek Bos

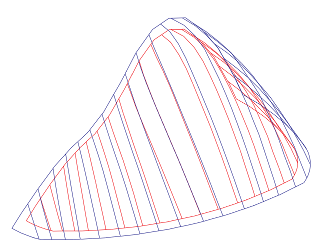

Figure 15 by Rogier Houtman

The material that is to be used has a double layer structure, so the model used to create cutting patterns should have a double layer structure too. The distance between the two layers has a fixed length of 100 mm. To model the inner layer, the outer layer is scaled in such a way that the inner layer approximately is 100mm away from the outer layer. Because the shape is not a sphere, the distance of each point to the centre is not the same and therefore the position of the innerlayer is only approximated.

The cutting patterns are determined by means of geodesic lines. Because geodesic lines can have many positions on spherical-like shapes, only half of the blob shape is used to create the patterns. Afterwards they are mirrored to obtain the full cloth. Picture 15 shows the result of the 3d cutting patterns.

The 3d patterns are transformed into 2d strips by means of the Cut&Grow procedure of EASY. The result of this is a set of individual strips which in normal situations are welded together to form the surface envelope. In this case, while using the 3d fabric, a different approach is taken. The fabric is not actually cut into the different patterns. The strips are shifted as much as possible towards each other, which gives a pattern layout according to fig 17. The remaining gaps between the strips are folded away and covered by a straight strip of fabric. By doing this, the fibres in the fabric are not cut trough and consequently at the other side of the fabric no bubbles occur like the ones in picture 12. Picture 18 shows the result of the experiment. The inside of the blob looks as we aspected. The outside is less smooth. A reason for this can be the fact that the scaling of the outer fabric was not completely appropriate and consequently the outer fabric is too large.

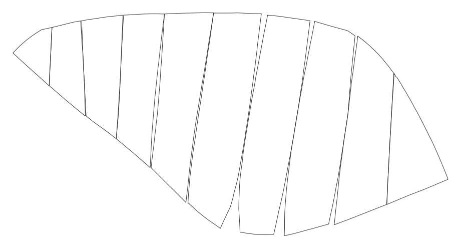

Figure 16 making the cutting pattern

Figure 17 by Arno Pronk

Figure 18 inflating of the model

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