Exploring the Design and Fabrication of Inflatables

"The Taming of the Shrew"

Bob Martens, Wolf-Michael Tschuppik
Vienna University of Technology

Abstract

The building materials that help designers or architects achieve their goal of defining and enclosing space are usually concrete, steel, glass or wood. For these materials designers have both empirical data gained from experience and at times complex calculation methods enabling them to use them in their designs in a tangible, reckonable and, consequently, almost risk-free manner. It seems obvious that creating a design with well-known building materials will lead to more or less predictable outcomes. This is a good reason for investigating a design process dealing with air-filled building-elements. Architectural structures look completely different when one employs a "building material" which has not been subjected to either detailed investigations or sophisticated calculations. The "Smart_Air" Design Studio was devised to take a closer look at the unusual building material "air," which we have only just begun to explore, and to make it the centre of a focused design exercise. The objective was to use "air" or, rather, pneumatic technologies, to arrive at structurally sound solutions for enclosing space, which could be considered a "roof" in the widest sense of the term.

Introduction

The Design Studio project presented in this paper opens up a broad range of potential applications for so-called inflatables (air-filled structures). The various projects defined highlight for anyone perusing them not only the non-permanent aspect which seems inherent to air-design, but also the chronological sequence of setting up and dismantling such structures. The projects often imply transient architecture, which might exist for as little as a few hours or even minutes: a structure erected at the push of a button and just as quickly collapsible. In this way, architectural design becomes truly portable. It can eventually fit into a shopping bag, be made smaller or larger. The results of such an exercise can be represented only on the basis of a ground plan and side elevation supplemented by computer models and model studies, which document the reflection process that went into the design. Once the model has been sewn or glued together and filled with air, it can ultimately be tested for its load-bearing capacity. After all: if it does not take loads as a scale model, it will certainly not take loads at full scale either. Building with air may not be a "weighty" matter but it still involves complex procedures dictated by the use of a building material that has attracted little attention of late. This paper presents two different types of air-filled structures. This approach, then, creates a kind of simple typology. On the one hand, there are the single-skin air supported structures and on the other hand, there are inflatables using an inside "core" making the structure much more stable. (Details will be explained in section 3). This Design Studio project was conceived in co-operation with a company whose know-how helped in refining it as it progressed. Thus possibilities and limits for the designs were much more readily identified. Construction oriented discussions at the beginning of the project helped the students to create potentially realizable visions because the project was embarked upon from the outset with the intention of translating some of the designs into practical reality.

To introduce working with air—not always a pliable medium—and to facilitate a strategic approach, this paper describes some evolutionary steps that have occurred in the field of pneumatic structures until today (section 2). The next section presents five designs by students involving various media and analyzes the processes that led to the final outcome (section 3). Section 4 explains the typical steps involved in the assembly of a structure on the scale of 1:1, and section 5 presents a number of conclusions.

Related Efforts

As early as the 1950s, the controversial artist *Yves Klein* set out to explore inflated structures and made attempts to translate his ideas of building with air into reality (Noever and Perrin 2004). In the 1960s, the Viennese architectural scene produced many new related ideas, some of them inspired by the since legendary *Archigram*. Provocative pneumatic creations emerged which had mainly one intention: to unsettle established architectural thinking. Examples that come to mind are the "Children-Clouds" by the *Missing Link* group, which were meant to insinuate themselves in conurbations like living organisms, or the balloon-like rooms for one or two daring dwellers created by *Laurids Ortner* and *Coop Himmelb(l)au*. A common denominator of these inflatable bubbles was that they always involved a great deal of innovation and raised the curiosity of passers-by and on-lookers. The atmosphere was highly charged with a spirit of experimentation. In 1974, *Frei Otto* and the *Institut für leichte Flächentragwerke* (Institute for Lightweight Structures), which he directed, presented the first preliminary edition of his *Air Hall Handbook* (Drüsedau 1983) which was published nine years later in its final version. The handbook contains a great deal of great expertise and information on how to create, sew together, calculate and inflate air-supported constructions. *Robert Kronenburg* (2002, 2003) places pneumatic structures in the context of transportable and mobile objects and architecture. Nowadays we know a great variety of uses to which air-filled structures of different sizes are put. Inflated halls for sports or temporary exhibitions and inflatable furniture are a well-known feature of today's world. A recent example is the Allianz Arena by *Herzog and De Meuron* (weblink 2006) which received great coverage in architectural journals: 2,760 air-filled membrane panels constitute a 66,500 sq.m. shell that represents one of world's the largest eye catchers. The individual panels range in size between 7.5 and 40 sq.m.

Studio Project: Framework Conditions

Whether or not the topic of inflatable architecture should be seen as new seems much less relevant than the question of how architects should approach building with air. After all, they lose a number of well-known parameters, for air can neither be touched nor can one really build with it. Specific tools are required for the designer to be able to imagine this substance which needs to be enclosed before it can be touched or seen, and tools are required to handle it with a view to load-bearing capacity and design. One could say that the participants of the Design Studio project were confronted with a "big nothing" which they needed to tame in one way or another. And as we are going to see this resembled in many cases a taming of the shrew.

It seems advisable to start with a short introduction to the problem of designing inflatable constructions. In principle, encased air has the tendency to expand evenly in all directions. In other words, air-filled shells seek to assume the form of a ball. If designers do not want a spherical shape they must take certain preventive measures. One way of manipulating form consists in giving the cover specific shapes. Not unlike the fashioning of a suit, the final shape is the result of making some areas longer and others shorter. Another possibility is developing the shape from the inside by sewing in many thin threads that hold the desired contour in place. In this case one speaks of a "core" that holds the structure together from the inside.

In addition to these two general possibilities, the designer must also choose between a system that inflates the structure in one, terminal step (like an air mattress or a balloon) or a system where a permanently operating blower keeps the structure in shape by providing a steady supply of air. While the former provides higher air pressure and rigidity, the latter allows quick size increases or reductions even of large-format inflatables. Making these fundamental decisions is an integral part of developing inflatable structures for the designer, as are developing an idea, a function and an appropriate shape for the structures.

The modern-day teaching of architectural design involves a many-faceted approach using structures made of paper, digital structures and sometimes "real" artefacts which are supposed to help the students get closer to the objective of realising an architectural object on the scale of 1:1. Architectural studies should provide the possibility of gathering experience in a wide variety of media. An idea gives rise to a first concept which then will undergo a number of steps before realisation is achieved. The training must pay sufficient attention to this process of implementation and transformation and make sure that students get to practice it. The approach is the same as with any empirical test series. It involves developing, testing and, if necessary, binning the result and starting all over again. Using air as a building material also implies finding appropriate designing and testing tools. Standardised solutions such as off-the-shelf CAD wall and ceiling elements are certainly unsuited for this type of work. Therefore every idea requires the designer to find a solution for how to verify or disqualify the imagined outcome. If this is purely a question of design, a freely computer-generated form may be sufficient. In order to test load-bearing capacity and designs for connections, students will need to fashion some kind of model made of fabric or balloon material.

The first models of air-filled structures are made of pipe cleaners, balloons or stuffed fabric bags/cushions. In addition, the computer helps the students settle on the final shape for the elusive inflatables. We found, however, that structures which were very easy to set afloat on the computer screen sometimes took a hard knock once they were turned into physical models. The working process therefore always required a scale model because this was the only way of testing actual behaviour under realistic conditions.

The five exemplary projects described in the following pages illustrate a necessary route to be followed when taking a designer's approach to such an intractable building material as air:

In his design "Stadtausschnitte" ("city views," fig. 1a-c) Michael Murauer wanted to generate an image of air caught in a structure and translate the substance of air into an object that can be entered. "Stadtausschnitte" is an object conceived for urban areas to be used by passers-by as a kind of over-dimensional viewing device. The openings in the shell provide "framed" views of the surroundings for the viewer inside. Individual openings can optionally be closed by membranes.

In this case, Murauer developed the initial idea on the drawing board. He used studies to examine the respective impact and the desired overall shape. Since the target geometry was highly complex, he built no scale model at this stage but, rather, implemented the structure on the computer by CAD to provide a choice of patterns. The scale model finally produced was merely a concluding step and due to the complex geometry had to be simplified in a number of ways.

Arno Ebner developed an additive system of large format "Pillow-Modules" designed to provide large-scale roofing for open-air events (fig. 2a-b). Easy transport and fast assembly and disassembly make the "Pillow-module" seem an adequate choice for events planned at short notice. The circular openings which give the roofing system its characteristic shape also serve to connect the upright supports and to integrate various additional elements such as loudspeakers and lighting elements. Ebner first developed this idea as a small-scale conceptual model which helped to clarify structural conditions and provided information about how to add and link elements. He used a three-dimensional computer model as the basis for a more in-depth study of materials, colour and the design of individual details. The larger "hardware" models made from PU foam or cardboard served to test structural properties and the stability of the system.

The "Tetrapod" designed (fig. 3a-c) by Jürgen Fedele di Catrano aims at combining the benefits of pneumatic architecture with those of modular units and thus develop an air filled "building block" with a maximum of conceivable uses. The chosen shape of the Tetrapod makes it possible for the individual elements to lie or stand in any desired position. The basic elements also allow for a multitude of combinations. In addition, the individual parts of the basic elements

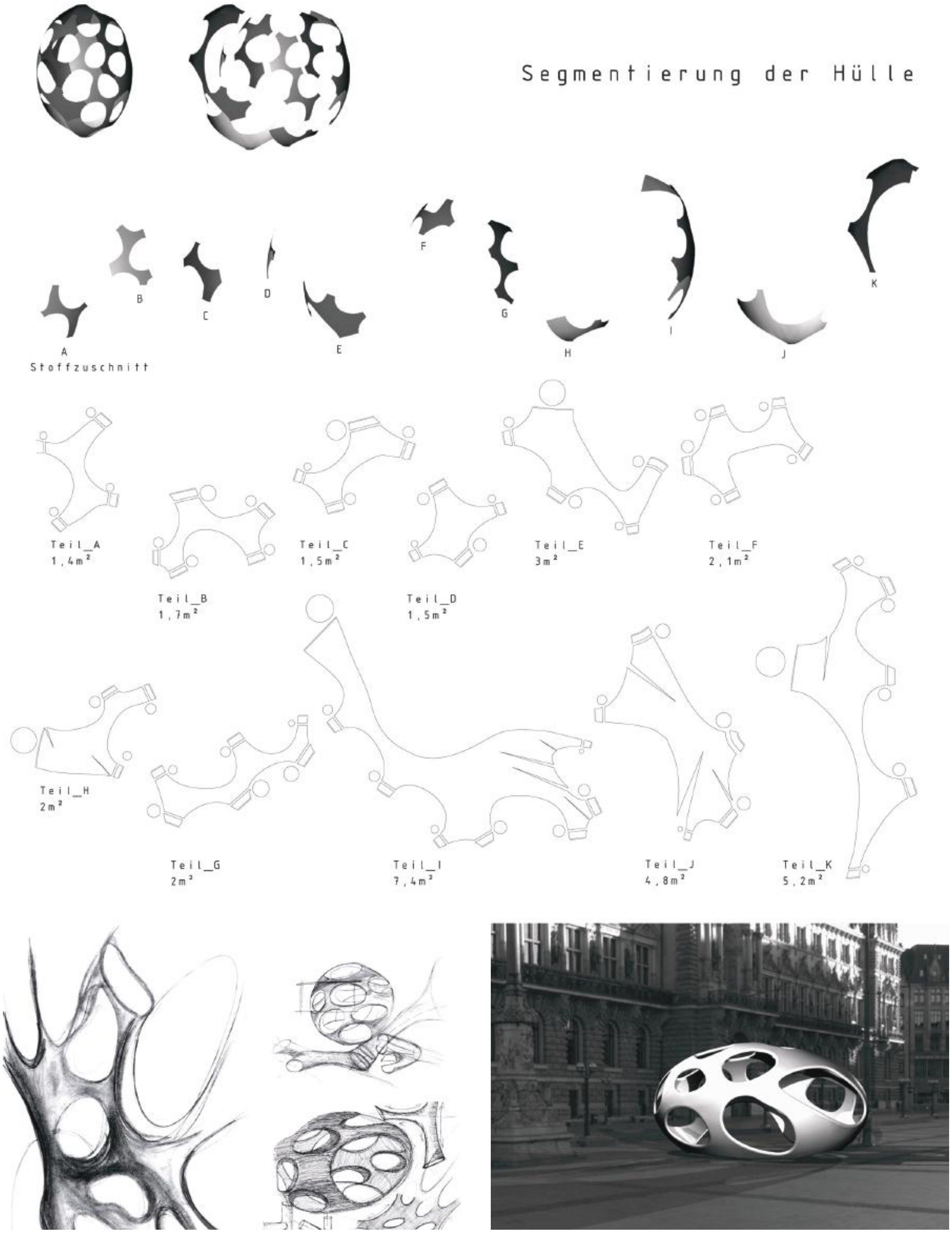

Figure 1a-c. Stadtausschnitte (city views): drawings, patterning sheets and the final shape.

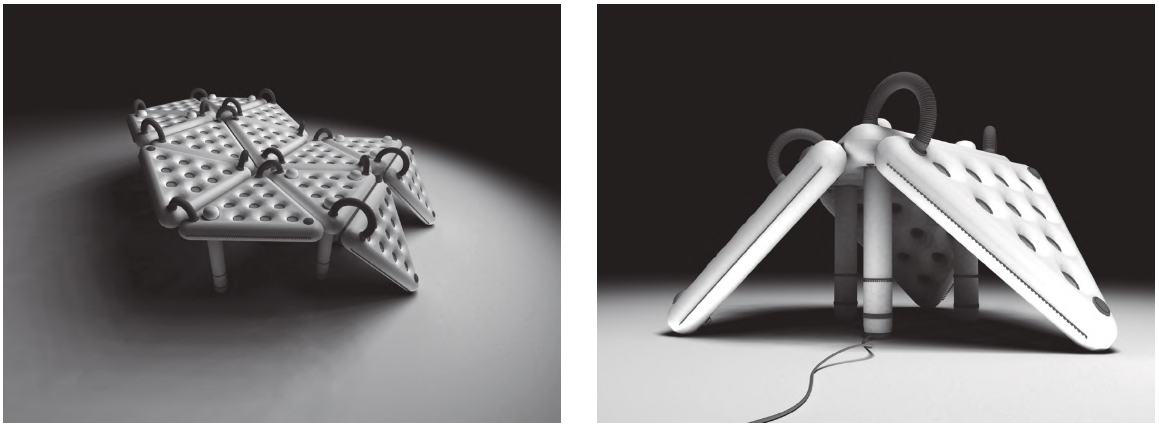

Figure 2a-b. Pillow-Module: modular connection of individual elements.

can always be replaced in case of damage.

In this project, air-filled models provided the explanatory basis for modifications throughout the entire design process. At a very early stage of the project the student even built two-layer models to test the relationship between the outer skin and the core. This meant

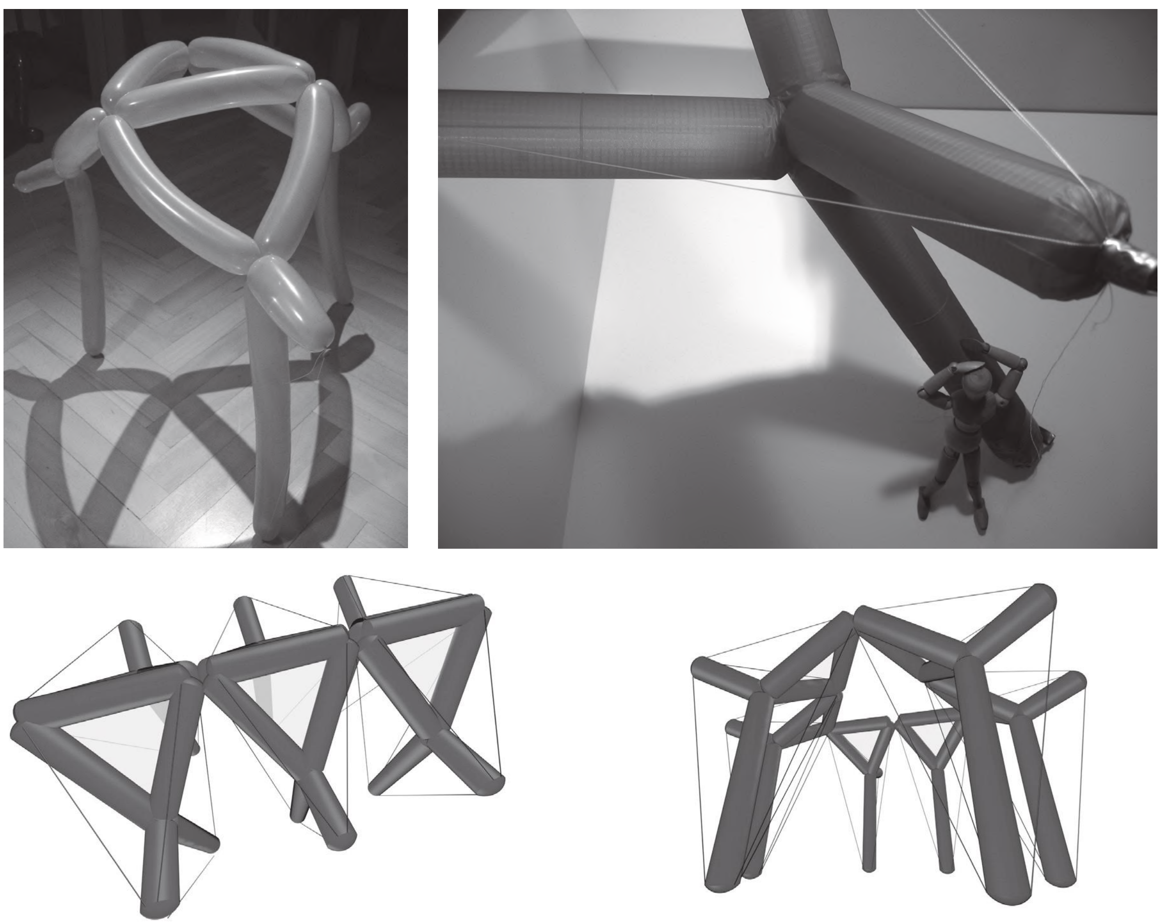

Figure 3a-d. Tetrapod: Development of the unit and composite supporting structure.

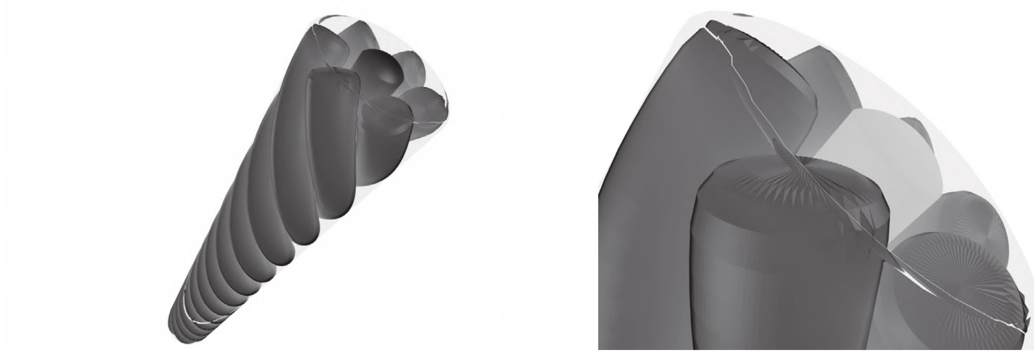

Figure 3e-f. Tetrapod: Experimental variations on the main column element.

that Catrano could test the pressure conditions and shaping almost as well as with a full-scale unit. The fact that the structure and the material aspects were represented in a realistic way from the beginning probably contributed to the very convincing result, also in terms of depth of detail.

The "Triangul.AIR" (fig. 4a-b) roof/wall element designed by Hakima Hariri consists of a pneumatic frame that can be folded in six points and a cover composed of triangular shapes. The design allows three of the frame's folding points to form a 90° angle while the other three folding points can be bent into random angles. Different types of covers and the possibility to print information on certain parts of the "sail" allow for a great variety of indoor and outdoor uses.

Hariri replaced the simple initial paper and cardboard models with a model consisting of stuffed fabric cushions. Only then was it possible to get a realistic sense of the necessary dimensions and fashioning of the linking elements. Developing the patterns and testing them on the model, also with a view to stability, helped gain the insights necessary for a full-scale prototype of the item.

"CoolDown" (fig. 5a-c) by Florian Scartezzini can be set up very quickly and serves as a city version of the canopied beach chair. It invites passers-by to relax for a moment and take a rest. This pneumatic object can be erected very rapidly and easily

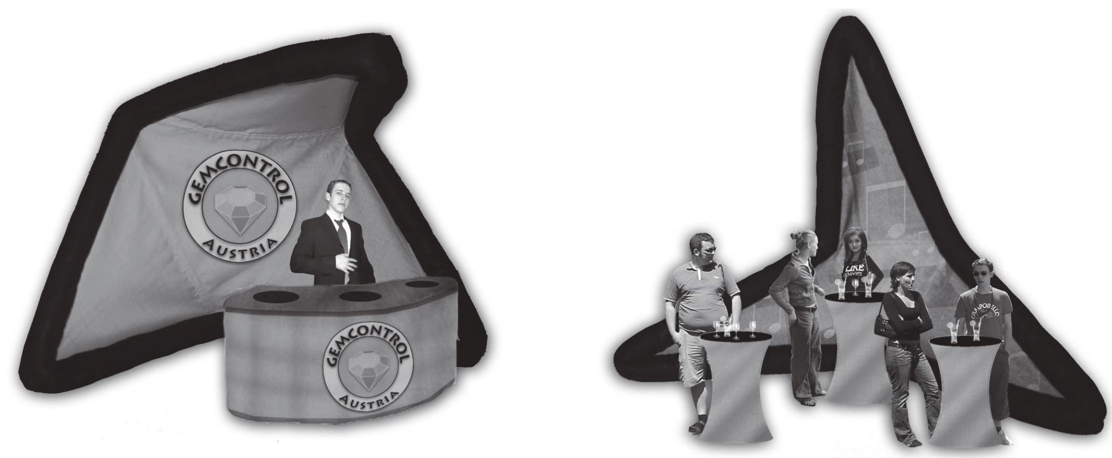

Figure 4a-b. Triangul.AIR: basic shape and changes made by bending individual points.

Figure 5a-c. Inflatable chair for the urban environment.

without a major investment of time or effort in any type of environment. Two tension rods are inserted into the lateral membrane walls and the cushions are inflated with air. Only the seating element is filled with water to ensure stability.

This is another project which was developed mainly on the basis of a model. The material used for the model was similar to PU foam. It provided a good impression of the shape in the individual project stages and also made it possible to settle stability issues. CAD was used to develop the patterning sheets and to visualise the total object.

The physical models turned out to be very beneficial for the development of the structures, since they revealed structural issues in a tangible manner, while computer-generated models offered great advantages for deciding on material, colour and the shaping of details. The students used both techniques to the same extent and considered them as an integral part of the design process.

Prototypes

The task set in the Design Studio was to use air as a building material by encasing it and create a roof that could carry loads. The design process involved questions of ease of transport, the construction venue, adaptability and outer appearance. The intention was that one or several designs would be translated into full-scale prototypes. This aim required the designers to ensure from the start that the dimensions were right for the respective assembly. A great number of questions relating to technical feasibility had to be settled. Hence, the experimental approaches had to cater to the laws of gravity and the scope of technical feasibility at a very early stage in order to be able to even think about translation into reality. Computer-generated patterning sheets detailing the segments of the skin (e.g. Triangul.AIR) were used as a basis for industrial cutting and sewing of the individual pieces. Figure 6 shows how closely the scale model resembles the full-scale prototype and how precisely the pieces were dimensioned. The use of different media in the design process certainly turned out to have been helpful in this respect.

The creation of the prototypes is still work in progress, since not all of the inflatables have been fabricated so far.

Conclusions

The Design Studio aimed at bridging the gap between design ideas and the artefact that was to be the end product. The process was about making the idea as palpable and presentable as possible. The idea had to be tested for its structural visibility and wherever possible checked for usability in a full-scale model. The work in such a Design Studio is necessarily an experimental process. Empirical knowledge can be gained from experience and observations in a cycle of trying out, changing, checking, etc. This is experimentation in the best sense of the word and, in short, a traditional way of empirical learning. Analysis leads to insights which are fed back into the draft. This is of particular importance because air is not easy to calculate and structures that encase it are not easy to describe geometrically. Geometry can describe the aspired form not with perfect but only with sufficient exactitude. And then there is the question of what happens if physical forces act on three-dimensional structures generated in such a way? What if there is wind or bad weather or a drop in air pressure? All of these factors make synthetic structures filled with air seem very intractable. In their specific way they elude the world of precise three-dimensional data that may have been there at their origin (patterning sheets). One finds that there is always a residue of incalculable or indefinable geometry left in each and every project. Until the moment when the pneumatic structure is produced, and more specifically until it is mounted, it

Figure 6. Triangul.AIR: 1:1 Prototype.

remains partly ungraspable. And perhaps it is precisely this aspect which makes many buildings made from air look so "alive" and natural, because in a true sense they physically interact with their environment.

Although work on the computer was an integral part of the work process, it cannot be said to have been the predominant medium, since the parameters involved in the projects were hardly known for long stretches of the project. A study of the interdependency between the generation of form and the use of adequate software is to be regarded as the focus for a future Design Studio. Meanwhile further prototypes are expected to be realized and evaluated in the near future.

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