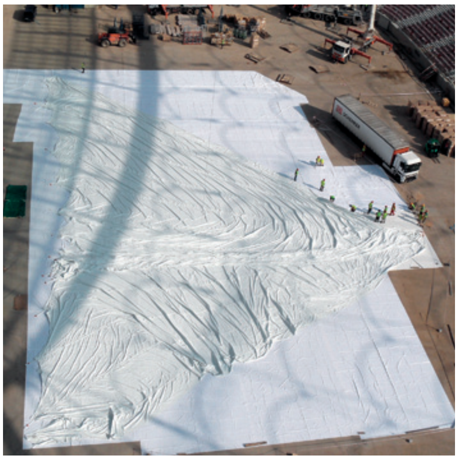
Modern Adjustable Membrane Roofs in Warsaw and Vancouver

Jan Cremers, Gregor Grunwald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Membranes are of ever increasing importance in the construction of stadiums today. Flexible materials of this kind are used for such roofs in probably the majority of cases – for new structures as well as for conversions and refurbishments. In some projects, they are specified not just for the roofs, but for the facades as well. In addition to the protection they provide against the weather, the internal daylight conditions they allow are of growing significance. This helps to stimulate the growth of grass and to reduce the potential for aggression, but above all it allows high-quality television images – with an absence of columns and an even lighting quality with limited contrasts.


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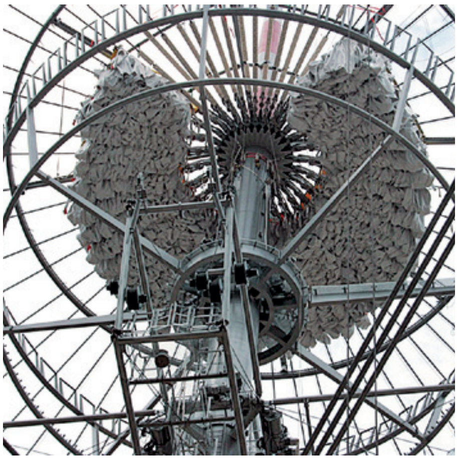
One of the principal advantages of flexible membranes is their translucence, usually with a high degree of light diffusion.
The typical geometry of stadiums and the requisite absence of columns result in large spans. For this purpose, planar bearing structures subject to tensile loading have been developed in recent decades. These offer economical solutions through the use of very light and translucent membrane materials. The light appearance of early solutions was mostly bought at a high price, however: the structures were rear-anchored with massive foundations.
Today, “spoked-wheel systems” are largely used, commonly based on the model of the membrane roof in Stuttgart (1993), which was developed by the engineers schlaich bergermann und partner (sbp).
In the meantime, membranes have been subject to an aesthetic change. Instead of having large, continuous areas, the structures are segmented by the radial cables that are used, with a corresponding stabilization of individual sections and the repetition of smaller units; e.g. through the use of arches between the radial cables (see interview with Volkwin Marg, page 570).
One special subgroup of the spoked-wheel form is that in which, in addition to a fixed roof in the outer areas, there is a separate structure at the centre that can be drawn together as a further covering.
This allows events to be programmed throughout the year independently of the weather, while the translucent material nevertheless ensures daylight conditions even in a closed state. Important forerunners of larger-scale flexible membrane structures of this kind and to this scale are the stadium in Saragossa (1989) and the Commerzbank Arena (Waldstadion) in Frankfurt (2005), the engineers of which were also schlaich bergermann und partner.
For decades now, the Hightex company has been active in this field. Examples of its work include fixed roofs for arenas in Stuttgart, Busan, Abuja, Berlin, Robina, Johannesburg, Cape Town and Kiev as well as movable (sliding/folding) roofs in Rothenbaum, Hamburg, and in Wimbledon and Warsaw.

Warsaw National Stadium
Following the competition in 2007 for a new National Stadium in Warsaw, a roof structure was built according to the spoked-wheel principle. The closable inner section allows the stadium to be used all year round – not just for football – and regardless of weather conditions (ills. 1–5; see also page 620). Cable trusses laid out in radial fashion are fixed between the central hub, a cable ring over the edge of the playing field, and a peripheral outer compression ring. The radial cables extend from the upper end of the raking support, or from the compression ring, towards the centre of the stadium, intersecting each other in cast nodes (ill. 5) and linking up with two elevated ring cables. The outer roof area, stretching over the entire grandstand to a line above the edge of the playing field, is the section of the cable structure that provides permanent covering. Inserted in the segment bays between pairs of lower radial cables are nine steel arcs (ill. 5).
These act as stabilizers in part areas, and they form the edge geometry of the roof membrane, which in this section consists of PTFE-coated glass-fibre fabric with an overall area of approximately 55,000 m^2.
Prefabricated at works, the individual membrane sections were hoisted into position on the structure, unfolded and fixed over the arcs to the compression ring, as well as to the radial and ring cables, where they were subject to tensioning.

The variable roof in the middle
The oval inner area of the stadium above the playing field can be covered by a second structure. A 70-metre-long “flying” central column or mast is suspended by four cables from the lower radial cable. The column is held in its middle by 60 axial cables that extend upwards. Fixed to the lower part of this mast is a travelling “membrane garage” (ill. 4). After lowering this unit, the roof membrane within can be unfolded outwards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1–5 National Stadium, Warsaw; architects: gmp, JSK Architects; structural planning; schlaich bergermann und partener (sbp); general planners: Alpine Bau Deutschland, Hydrobudowa Polska; cable construction: Cimolai, Hightex; membrane construction: Hightex
1 A quarter of the 10,500 m² membrane comprising the movable inner roof prior to the heat-sealing of the four sections on the cable structure
2 One of a total of 60 hydraulic tensioning devices at the junction between the movable and fixed sections of the roof; 18 mm laminated-safety-glass roof (2× 8 mm)
3 Carriages on radial cables with electric cable winch
4 The inner roof with 60 radial cables
5 Sealing the PTFE-coated glass-fibre membrane of the fixed section of the roof at the cast nodes of the cable construction

Bibliopraphy:
Knippers, J., Cremers, J., Gabler, M., Lienhard, J.: Construction Manual for Polymers + Membranes, DETAIL / Institut für intern 1ationale Architekturdokumentation, Munich 2010

along the 60 radial cables by means of 15 fixing points that glide lineally. These "gliding trolleys", as they are called, are attached to the membrane by means of radial straps. The carriages fixed to the edge of the membrane are drawn outwards by electrically operated cable winches, and the gliding trolleys are pulled behind (ill. 3).
By virtue of different drawing speeds along the individual axes, the carriages engage simultaneously with the hydraulically driven, self-locking tensioning construction.
This guarantees the power-operated final tensioning of the membrane when it is unfolded. Drawn into its ultimate position, it is pretensioned axis by axis, so that it can bear the requisite loads and protect the stadium from the effects of the weather. The entire process takes about half an hour. The joint between the fixed and movable sections of the roof is closed by a 10-metre-wide glass covering fixed to the radial cables. This glazed construction is situated immediately below the membranes and is drained by virtue of the fact that it slopes towards the outside (ill. 2).
The membrane of the sliding section of the roof consists of a PVC-coated polyester fabric, a translucent material that is capable of repeated movement, folding and unfolding. In the outer areas where the loads are greatest, so-called "type 4 material" was used. In the central area, a somewhat lighter "type 3 material" was sufficient. On close examination, a slightly different degree of translucence can be determined between these two materials.
The sliding roof was prefabricated in four parts at works (ill. 1), delivered to site and joined together in position on the roof to form a larger area roughly 10,500 m² in extent. For this purpose, a stationary welding machine was used, hung temporarily from the cable structure. The straps consist of polyester and have a tensile strength of up 40 tonnes.
A close investigation of their long-term, stretch and creep behaviour was necessary


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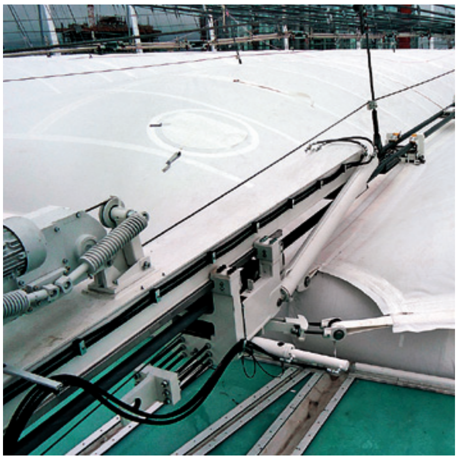
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to determine the requisite stress path of the travelling roof.

BC Place stadium, Vancouver

In the BC Place stadium in Vancouver, a travelling roof also ensures that the operation of the facilities remains flexible and independent of weather conditions. Erected in the early 1980s, the Airdomes arena could accommodate 60,000 spectators. Its pneumatic roof, stabilized by increased internal air pressure, is now being replaced by a new form of roof construction based on the principle of a prestressed spoked wheel. The new image of the stadium is dominated by 36 peripheral columns that rise high above the structure and which accentuate this location for various events in the imposing skyline of Vancouver (ill. 9). The tiers of seats are covered by a single-layer membrane consisting of PTFE-coated glass-fibre fabric. The centre of the roof can be opened and closed by means of a two-layer pneumatic cushion structure that is unique in its nature and size.

In an unfolded state, it can be inflated with compressed air to create a cushion that is stable in form. In this position, the mobile roof of coated PTFE fabric is designed to withstand snow and wind loads, and the two-layer cushion construction provides a certain thermal protection. In contrast to the sliding roof in Warsaw, the Canadian structure is in its normal position when closed. The mobile roof, with an oval layout, has dimensions of roughly 80 × 100 m in an extended state. Divided between 36 axes, the individual cushion bays are arranged in radial fashion about a central mast approximately 60 m above the playing field. The mast bears the load of the “garage” or parking space for the roof, into which the membrane can be folded (ill. 12).

In order to open the roof, the blower units installed round the central mast actively suck compressed air out of supply tubes in the cushions (ill. 10). Finally, the deflated membrane is drawn by motor via its sliding


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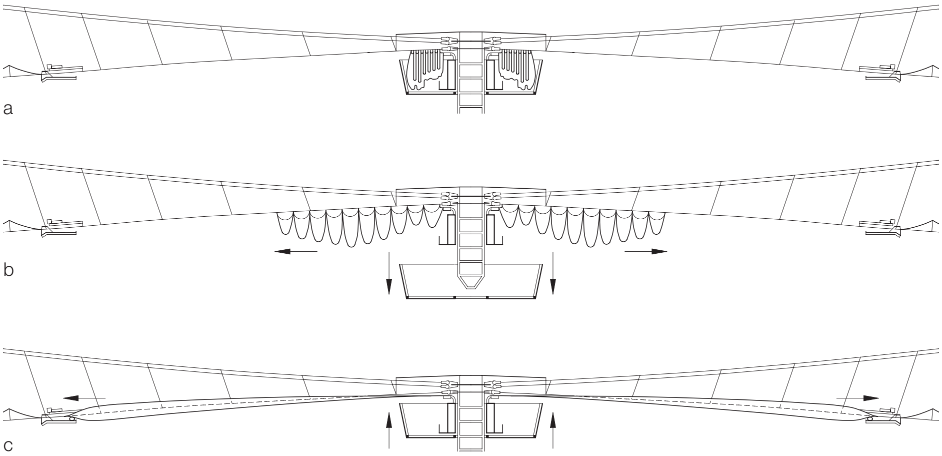

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mountings along the suspension cables. The membrane folds together into the middle and is protected by the upward travelling garage. When the roof closes, the membrane is drawn outwards on to the glass apron roof installed beneath the ring cable. Through the subsequent inflation of the cushion, the roof structure is stabilized. A radial sealing torus forms the outer closure of the movable membrane. With increasing air pressure, this closing element presses firmly on to the glazed roof, thereby creating the necessary seal for the structure (ill. 8). The process of opening or closing the more than 7,500 m² movable "blue sky roof", as it is known, takes just 20 minutes. It allows an all-year use of the stadium regardless of weather conditions. As a travelling cushion construction, it is unique in this form and with these dimensions.

Summary

In recent decades, flexible textile and membrane substances have firmly established themselves as a complement to "classical" building materials. Their use still offers designers considerable scope for differentiation, and their development is by no means complete.
Membranes can be seen both as a reference to the archetypal history of architecture and to efficient high-tech future-oriented materials. Permanent use in different climatic and cultural realms is possible, on the one hand because of the basic properties of certain materials, but also in view of the adaptable forms of construction. Membranes have a wide range of properties as well, not least of which is their light trans-mission. Furthermore, flexible materials – alongside rigid structures – allow movable, changeable forms of construction on a large scale. Other advantages accrue as a result of the very small masses that are involved: for example, membrane materials weigh between 0.4 and 2 kg per m². In comparison with alternative forms of construction, the weight per unit area is far lower as a rule, which can result in a reduced use of materials in the primary and secondary construction as well as in a smaller outlay for transport, assembly and the ultimate removal (ills. 6, 7). The overall energy balance for the entire life cycle is, therefore, advantageous in comparison with more solid forms of construction.
In principle, membrane structures, which are nearly always prototypes, show what a superior performance level can be achieved through a collaboration between highly qualified planning teams and the companies executing the work – an essential condition for innovation. This applies in particular to the transformable structures presented here in two outstanding examples.

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6–12 BC Place, Vancouver
architects: Stantec Architects
structural planning: schlaich bergermann und partner, Geiger Engineers
general planner: PCL Constructors
membrane construction: Hightex
The inner roof consists of coated PTFE fabric
8 Inner-roof cushions with pretensioning mechanism
10 Assembly of compression tubes within cushion
11 Stages of closing the inner roof:
a in open state;
b lowering the "garage", extending the membrane
c inflating the cushions

12