Moveable membranes - smart solutions in the field of architecture

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Abstract

In a world of growing and changing demands on buildings and building envelopes, moveable elements help to increase the possible usage of the buildings and to enhance the corresponding characteristics. Over the last decades, an increasing number of projects that include moveable components have been carried out successfully and even more will follow. Projects, which have been completed so far, range in size from small to large scale and reach up to over 10,000 m² in retractable surface. Adaptive façades, retractable courtyard covers and deployable roofs for sport stadia are just a few examples for different kinds of system, which react actively to environmental demands or respond to a specific user requests. The paper describes the basic principles for the conceptual layout of retractable membrane structures. Besides detailed knowledge on material behavior and structural systems, also a comprehensive design approach spanning from architecture, structure to mechanical and electrical engineering is mandatory. To showcase the concepts, some of the recent works by schlaich bergermann partner are presented.

Keywords: membrane, deployable, retractable, movable, driving technology, adaptivity, folding, pneumatic, lightweight

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1. Introduction

schlaich bergermann partner has been working on innovative movable structures for more than 30 years. This includes several fields of engineering and construction like retractable bridges, CSP-technology and movable roofs and facades for concert halls, court yards and sport facilities.

![Figure 1 Courtyard City Hall Vienna 2: Black Sea Arena Batumi (© schlaich bergermann partner, Zooey Braun)]

The demand for smart buildings with adaptive components is growing from year to year, since they increase the possible usage options and functionality of a building significantly. Retractable roof or façade elements are often implemented in projects of all sizes, to, for example, flexibly protect a space from environmental conditions, enhance a certain user comfort or react on different utilizations. A deployable roof, for example, can transform an outdoor stadium into a mega multipurpose indoor arena within minutes. From an operational point of view, this creates valuable possibilities and helps to successfully run the venue. However, there are of course numerous technical and coordinative challenges that come with designing these structures. Its integration within a building or a fixed structure requires detailed planning and coordination between the involved collaborators, starting from the conceptual layouts, planning, fabrication, construction, developing prototypes until final commissioning. From an aesthetical point of view, it is important that the structural design and mechanical engineering for the retractable elements are developed in close consideration of the overall architecture and appearance of the respective building or space. Therefore, innovative engineering solutions are required using appropriate materials.
2. Adaptive lightweight structures

Lightweight structures are very efficient structural system. The use of low mass materials, such as textile membranes or cables, reduce the overall loads and forces in the global structural system significantly. Since most of the elements are in pure tension and not in bending, the cross sections can be fully utilized leading to a very economic design.

The combination of the lightweight principles and adaptive approaches provides a great opportunity for modern architecture with unique demands to their functionality. A smart structural system in combination with the use of lightweight materials simplifies the driving technology significantly and reduces the overall energy consumption during operation. Various structural concepts are possible using moveable elements. However, the geometry of the supporting structural system must be carefully developed and designed for different configurations, so that beside the structural integrity, the movability of the retractable elements is given under all relevant loading conditions.

The relevant demands on the lightweight membrane materials have to be evaluated on a project specific case. Beside the mechanical properties that are required for the structural design, also further characteristics need to be considered, such as fire resistance, optical parameters, durability in the specific environment, foldability and distinctive folding patterns and the amount of moving cycles during the expected life time – just to mention few of them. A proper material selection in combination with proper design and detailing is important to ensure a durable adaptive membrane structure. Specific material tests are usually required to verify in advance the material before it can be implemented in the project.

3. Moving principles

In most cases retractable membrane structures can accommodate two main configurations: In deployed condition the membrane is either mechanically or pneumatically prestressed and covers a certain space. In this condition the membrane is subject to full environmental loads such as wind, snow, etc. In the second configuration the membrane is subject to full environmental loads and parked. Between these two configurations a defined driving process happens while the membrane is being folded and moved. Using flexible textile membranes or cables allows for the application of folding patterns that reduce the size of the overall system from fully deployed to the storage position. Typical reduction factors are seen in a range from 1/20 to 1/100. The differentiation of driving technology and stressing technology is a key point for large retractable membrane structures in keeping the mechanical driving system simple, reliable and economical. Long distances for travelling require small forces and can be performed in a fast way using winches, whereas short stressing lengths require significant higher forces that can be realized by hydraulic systems.
A movable building component with its associated loads results in a significant variation of boundary conditions for the structural design of the component itself but also for the supporting structure. Various possible configurations and scenarios during the movement process must be considered and well analyzed, assuring that the system is stable and safe not just in the final configuration but also in all intermediate steps. In case just limited loads are allowed during the movement process, it is required to implement a smart monitoring system that is linked directly to the controlling system of the driving technology.

In general, for mechanically prestressed membrane structures a continuous membrane is only able to fold if, during the retraction process, the distance between two supporting points will never be bigger than in the final deployed geometry. Furthermore, the effect of compensation and prestress of the membrane has to be taken into account. Therefore, different moving principles are possible for deployable structures: They are either based on linear movement, radial movement or swinging movements.

Below, some examples of projects that have been designed by schlaich bergermann partner in the past and that apply different moving principles are presented:

### 3.1 Linear movements

The shade canopy structure for the Barahat Al-Nouq Square in Doha is approx. 35 m wide and 90 m long. In each of the 30 axes two cables are spanning between two building structures on either side of the square. From the fully locked cables 36 membrane covered panels per axis are suspended creating 18 V-shaped folds. At the upper end of the V-shaped fold the panel is fixed to the cable with sliding trolleys that move during operation. In retracted configuration the panels are stored at the perimeter while the folds are nearly vertical.

![Figure 1 and 2: Barahat Al-Nouq Square in Doha (© schlaich bergermann partner, transsolar)](image-url)
In hot weather conditions, when the square needs to be shaded, the system is pulled to the other side of the square, opening the V-shaped folds and creating a zig-zag arrangement of the panels. The panels themselves are 2,70 m x 1,40 m in size and consist of an aluminum frame with a PVC coated polyester membrane cover. Various arrangements of folding – also different in adjacent bays – are possible and provide both adequate shading of the square and a unique visual appearance, too. The result is an elegant movable structure, which on demand can move within a few minutes.

3.2 Radial movements

In the last years, several large-scale convertible roofs have been completed, such as for the National Stadium in Warsaw and the BC Place Stadium in Vancouver. The moving procedure of the membrane roof of the National Stadium in Warsaw shows poetic engineering. Approximately 11,000 m² of PVC coated polyester membrane are supported by 60 single radial cables. The roof can be automatically deployed from the central parking garage along these cables. Electric winches move the driving carriage actively into the reach of the hydraulic stressing cylinders. The membrane itself is connected to the driving carriages and certain sliding carriages, which are all running on the primary steel cables.
Figure 4 and 5: Retracted and deployed roof at the National Stadium in Warsaw (© Marcus Bredt)

Figure 6 and 7: Driving carriage during movement, stressing units at perimeter (© schlaich bergermann partner)

The specific weather conditions in Vancouver can potentially lead to very high snow drifts and loads. To assure the all-year use of the 8,500m² retractable roof, which transforms the stadium within 10 minutes into a fully closed multipurpose arena, inflated and pressure-controlled cushions were integrated instead of a single layer membrane. 36 cushions with a max volume of 105 m³ are attached by sliding carriages to the lower cable of the cable girder. Radial Polyester belts between the cushions transfer the forces into the surrounding structure. They are mechanically stressed before the inflation of the cushion commences. Fluoropolymer coated PTFE fabric with extremely high translucency and excellent performance characteristics, especially in relation to the folding requirements, was chosen. The air pressure in the cushions is variable and responds to the respective environmental conditions. The standard pressure of 500 pa can be adjusted to max 2000 pa, based on load measurements of magnetic sensors at the primary steel cables and local climatic data input.
4. Future prospects

Various further movable roof structures that use textile membranes are currently under development and construction – often as a result of the continuing development of already implemented and well proven systems. For these retractable roofs, the very different and oftentimes extreme conditions like wind, snow, sun and earthquakes need to be taken in account. Every roof concept and every planning process is unique and needs to be designed and addressed differently to respond to the local situation. In this regard, different movement concepts and geometrical principles are applied, creating outstanding systems with unique appearances. As stated above, the demand for individual roof structures is yet to increase in the future.
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Barahat Al-Nouq Square: Architecture by Mossessian & Partners

National Stadium Warsaw: Architecture by gmp Architekten von Gerkan, Marg und Partner

References


