On Convertible Structures: Two Design Proposals for a Retractable Roof (Or How the Movement Shapes the Roof).

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Paper

1 Convertible Structures – definition and principles

Architecture striving for the creation of lasting values can nevertheless generate ephemeral qualities. Sensitive to contemporary architecture, fluctuation in the structural morphology can be performed amongst conventional measures like change in utilization and conversion by the means of: polyvalence, mobility, adaptability and convertibility. This paper will focus upon the convertibility of architectural structures, which refers to the alteration in the structural form, adapting to different functional requirements, weather conditions or even aesthetic expressions. This will be exemplified in the following by two design proposals developed for retractable roofs.

As essential characteristic, movement will govern the principles of convertible structures [Otto 1972]. In a classification by stiffness a distinction is made between flexible systems and rigid mechanisms. The low stiffness in a substantial part of flexible systems allows for a higher freedom of movement: bending, rolling, folding and bunching. Rigid mechanisms are moved without deformation of their elements, the movement being induced in discrete points: hinges, scissors, pulleys or gear wheels. They adhere to more severe morphological principles and stricter motional sequences.

2 Design Proposals for Retractable Roofs

The following proposals were developed by the authors as part of a research project on convertible structures at the Technical University Berlin, Institute of Architecture, Department of Structural Design and Analysis. Representing first attempts based on the principles of convertible structures: flexible system and rigid mechanism, they could be raised as paradigms for convertible structures. Currently they are undergoing parametrical studies by the author with the objective to identify and term their morphology, to qualify their structural behaviour and motional sequence, to optimize their structural efficiency and to develop adequate detailing and actuating devices [Sill 2005].
3 Retractable Membrane Roof

As an example of a flexible system this structure is based on the combination of the geometry of a starwave tent with a radially transported and centrally folded membrane. Both principles were developed separately by Frei Otto [Otto 1972], [Otto 1976] and the latter subsequently refined [Schlaich et al. 2003], [Blaser 1999].

The retractable roof enables the convertibility through negligible bending stiffness in the membrane. The new development of this proposal relies in the shifting of the structural system from a prestressed radial strut-and-cable-system during the opened roof to a radial arrangement of prestressed cable trusses while the roofing is closing, where the hangers are substituted by the membrane spanning pointwise between the low restraining and high supporting ridges.

Figure 1. Perspective views of the retractable membrane roof: folded (left), tensioned (right) and corresponding dual static system (below, sectional views): radial spoke-system shifting towards radial cable trusses where the membrane acts as hangers

Figure 2. Actuator mechanism: winches pull trolleys carrying the membrane along the radial stationary cables
Based on the precedent engineering research at the Technical University Berlin, this enhanced system of a retractable membrane is currently adopted in a last year project from one of their architectural students at the Technical University Berlin. There it plays a key role in a design proposal for a retractable membrane roof to provide rain protection for an existing open air theatre [Klaus 2006].

The critical analysis of the existing open air theatre and of its use concluded in the need for temporary rain protection. The main challenges occurring with the application of this convertible system to the theatre roofing consist in the definition of the architectural concept for the roof with its integration into the context of the protected historic garden, the adaptation of the structural system to the existing circular stage and the concentric auditorium, the structural design and detailing, the materialization and dimensioning.

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4 Foldable Dome

The following system exemplifies the second type of convertible structures: the rigid mechanism. Based on the principle of a foldable structure, the foldable dome can fold and unfold to provide weather proofing.

The substantial innovation is the equidistant span between the pinned supports due to an elaborate geometry integrating fold and counter fold and unlike the well-known foldable chinese paper lantern, the triangular meshes remain planar without wrinkling during folding. The folding occurs through rotation in the ball joints in the case of reticulated shell or in hinges in the case of plates. The degree of freedom of the dome reduces to DOF = 1, simplifying the deployment. By retaining the single DOF with the actuator device during folding and blocking it in fixed states, a controlled and stable folding mechanism is obtained. With the triangulation of the reticulated shell this delivers structural stability throughout the integral motional sequence. With isostatic support condition appropriate to shells, triangulation of all meshes and all nodes being three-dimensional ball joints, the folding of the dome will cause no strain and stress in the grid members. The cladding of the dome could be realized in rigid panes fixed to the triangulated grid: e.g. transparent glass or translucent synthetic material underlining the character of the rigid mechanism.

This convertible structure is based on the combination of two simple folding structures: ‘fold’ and ‘counterfold’ according to figure 6 and figure 7 and their additive repetition.

The unfolding of structure in figure 6 reacts with an increasing span AE to the opening of the variable angle (CBD). In contrast to this an increasing opening angle (CJD) leads at the folding structure of figure 7 to a larger span AE.
The changeable spans are of disadvantage in the use for the purpose of convertible domes. But through a dexterous combination of both folding structures according to figure 6 and 7 in one more complex folding system (figure 5) the antagonistic effects can neutralize each other.

The main characteristics of the new system are its foldability, the constant span for a certain range of opening angles, the serial extensibility and a single degree of freedom. The constant span allows for simpler and controlled support conditions in terms of load bearing and manufacturing. The folds of the systems are correlated in the global system in this special constellation by the means of the hinges at their edges. Given the isostatic external support conditions of the structure according to figure 5, the movement in the system can be reduced to one single degree of freedom. Therefore the opening sequence of the retractable folding dome can be generated by a single actuator. The convertibility could be activated by a linear drive e.g. a pneumatic or hydraulic cylinder connecting two adjacent nodes. Alternatively a rope hoist can be employed.

5 References


