IMPROVEMENT OF STRUCTURAL MEMBRANES

Progress is being made in the understanding of the appropriateness of membrane structures that are much more efficient than bending solutions based on trusses and cantilevers. But many designs do not take it into account to the point that membrane structures frequently end up being covered conventional steel structures. However many designs assume an appropriate design based on lightness, avoiding bending by following the load paths with the right combination of curvature and depth. They improve the behaviour of the structure reaching some successful achievements, such as:

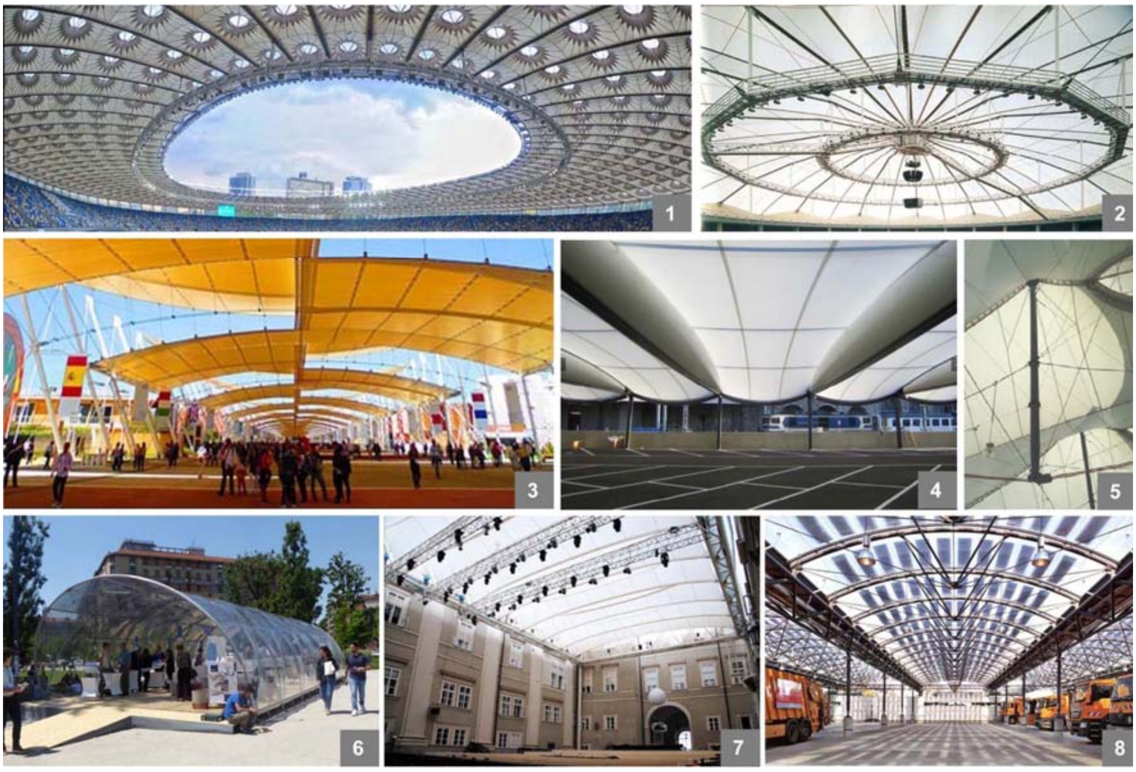

Figure 1: improvement of structural membranes

1.1 Spoked-wheels. Gmp Architects with Hightex, 2011: Olympic Stadium, Kiev.

1.2 Cable-domes. H.C.Chen & Associates with Geiger Engineers, 1993: Tao-Yuan County Arena, Taiwan.

1.3 Cable-beams. Majowiecki Structures, 2012: EXPO Walkways, Milano.

1.4 The Tensairity system and large inflatable structures. Luscher Architects with Airlight and Canobbio, 2004: Garage Park, Montreux.

1.5 Flying masts. A.Erickson with H.Berger, 1990: San Diego Convention Center.

1.6 Active bending. TextilesHub POLIMI with form TL and Canobbio, 2019: TemporActive Pavilion, Milano.

1.7 Retractable roofs. Kugel Architekten, 2012: retractable roof for the Salzburg Residence courtyard.

1.8 Environmentally performing and energy harvesting. Ackermann & Partners with Taiyo Europe, 2011: Carport Roof, Munich.

Figure 2: "Velarium", movable fabric roof, "Colosseo" Flavian Amphitheatre 80 AD

Figure 3: Studio Tecnico Majowiecki, 1990: Rome Olympic Stadium

The progress in the understanding of the appropriateness of membrane structures is led by lightweight large-scale sport stadium roofs started in 80 AD in Rome (figure 2) and resumed in 1990 also in Rome (figure 3).

Figure 4: Rhode-Kellermann-Wawrowsky with Bollinger & Grohmann, 2011: Municipal Stadium, Gdansk.

Figure 5: Arat Siegel und Partner Architekten with Eiffel Deutschland and sbp, 2011: Mercedes Benz Arena, Stuttgart.

Since then, large-scale sport stadium roofs have expanded all over the world imposing the tensile bicycle wheel (figure 5) as a much more efficient structure than bending solutions based on trusses and cantilevers (figure 4).

Cable domes (figures 6, 7)

The cable dome was developed by David Geiger. It consists of six main components:

a) The outer compression ring resists the pulling force of the radial ridge cables and first row of diagonal cables.

b) The central tension ring acts in tension resisting the pulling force of the radial ridge cables and the last row of diagonal cables.

c) Top-chord radial ridge cables pushed up by the posts.

d) Compression posts between hoops and radial ridge cables, pushed up by the diagonal cables.

e) Circular (in plan) tension hoops joining the bases of the struts.

f) Diagonals cables pushing up the posts and the central tension ring.
In addition, valley cables tension the membrane and provide doubled curvature.

Figures 6,7: Geiger Engineers, 1990: Tropicana Field (former Suncoast Dome), St.Petersburg.

Figures 8,9: G.Stowell, Architect with form TL and Canobbio, 2010: The sports canopy for the National Tennis Centre, London is a wide-span membrane which consists of five Tensairity beams with membrane panels in between.

Figure 10: Maco Technology, 2014: The Ducati hospitality tent is also based on Tensairity beams which span 12 m.

Figure 11: S. Dubuisson, Architect with Tentech, 2014: Inno-wave-tion exhibition pavilion, a combination of a tensile compression ring with Tensairity.

Tensairity

The Tensairity structure is a reinforced air inflated beam combining minimal weight with a high load bearing capacity. Three cases are shown in figures 8 to 11.

Active bending

Another improvement of structural membranes has been active bending. It is the structural principle of the traditional umbrella, in which bending is used to set the shape from elastic members such as beams, plates or slender rods which are initially straight and unstressed. Because of the geometrical and mechanical properties of the active (bent) members, bending-active structures are lightweight and stiff enough due to the curved shape acquired by the active elements[1] (figures 12 and 13).

Figure 12: Institute of Building Structures and Structural Design, 2011: an innovative membrane structure for a schoolyard roofing comprises 7.5 m long, elastically-bent fiberglass rods (in pockets) for the pre-stressing of the membrane.

Figure 13: C.Mazzola & A.Zanelli with Form TL and Canobbio, 2019: "TemporActive Pavilion", an ultra-lightweight temporary structure consisting of bending active GFRP arches, a restraining system made of stainless steel cables, and an ETFE translucent membrane envelope.

Retractable roofs

Sometimes it is not convenient for the roof to be permanently installed so that the architectural configuration is not altered or the lawn is allowed to sunbathe. For this purpose, retractable roofs have been developed, such as the one shown in figure 14 and figure 15,

Figure 14: gmp Architekten with sbp, 2011: National Stadium retractable roof, Warsaw.

Figure 15: N.Kugel, 2012: Salzburg Festival retractable roofTentech,

where a centrally located courtyard becomes a weather proof venue, protected by the retractable membrane, opening and closing automatically within minutes. The protected buildings remain unaffected, only minor horizontal forces are anchored at the facades.

NOTES

1 J.G.Bessini, 2021: "Form-finding and performance of bending active structures". PhD Dissertation, Universitat Politècnica de València. Available at: *https://riunet.upv.es/handle/10251/165575#*