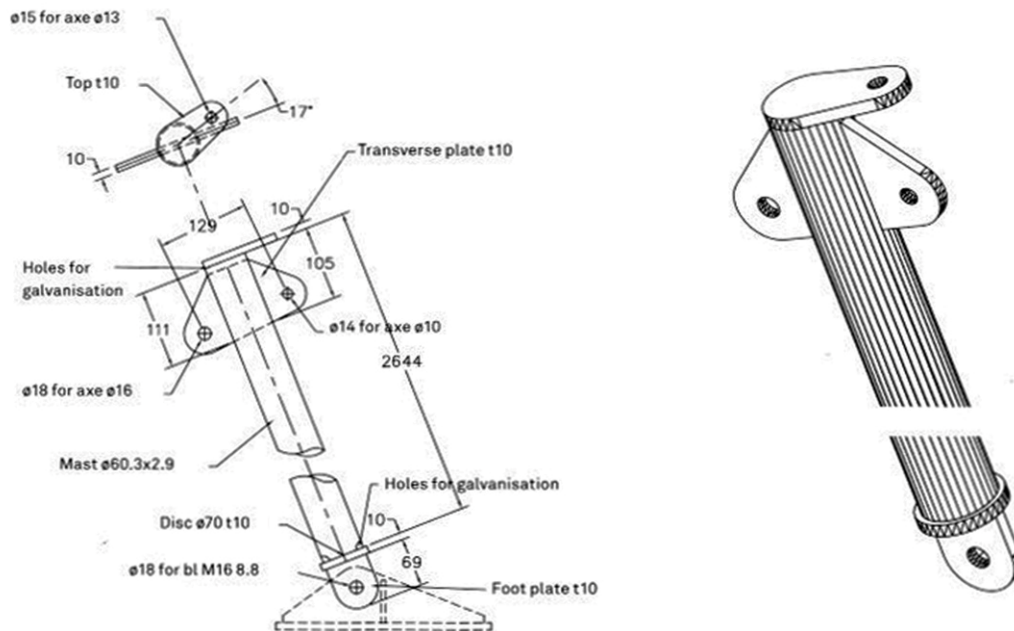


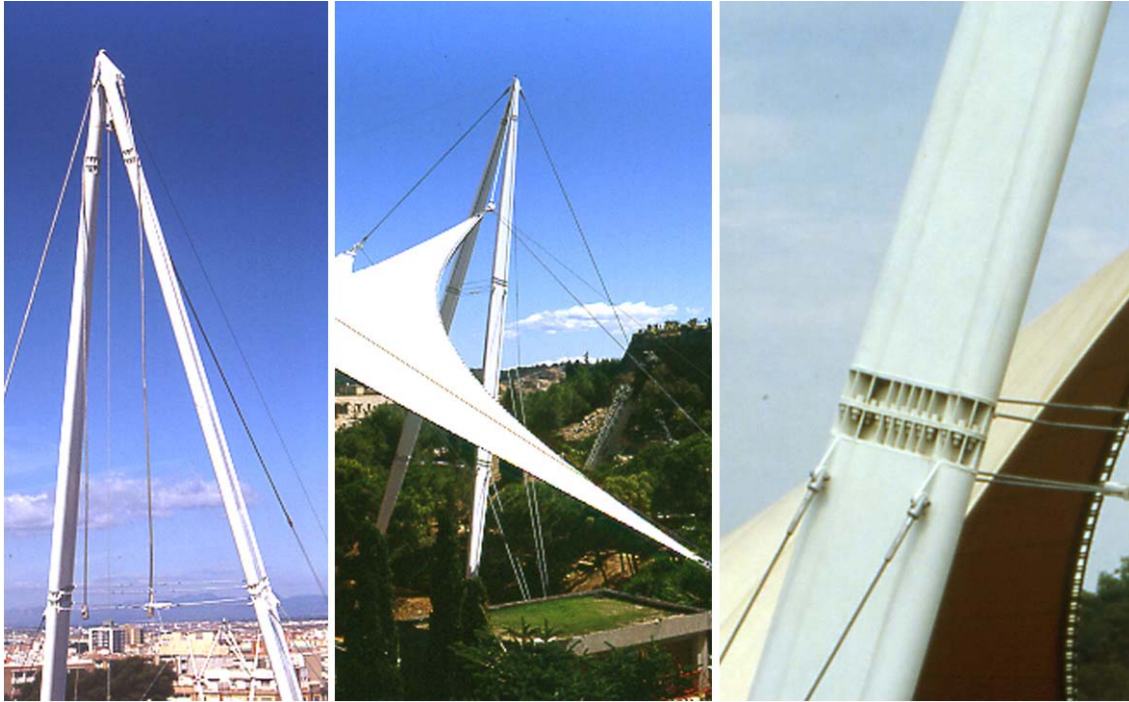
IMPROVING THE EFFICIENCY OF MASTS



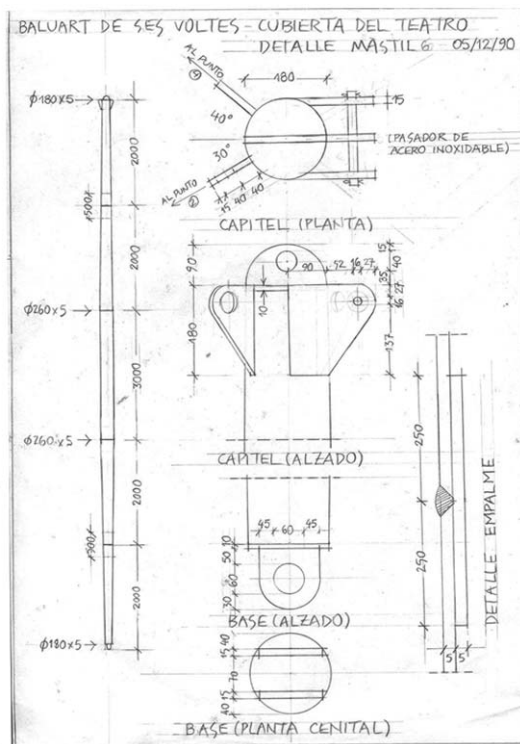
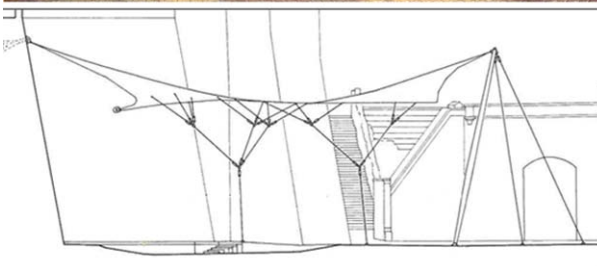
Masts accept different strategies to cope with over-dimensioning imposed by buckling on such long elements: cylindrical sections, avoiding protruding plates, tapering, trussing, tying, coupling and branching.



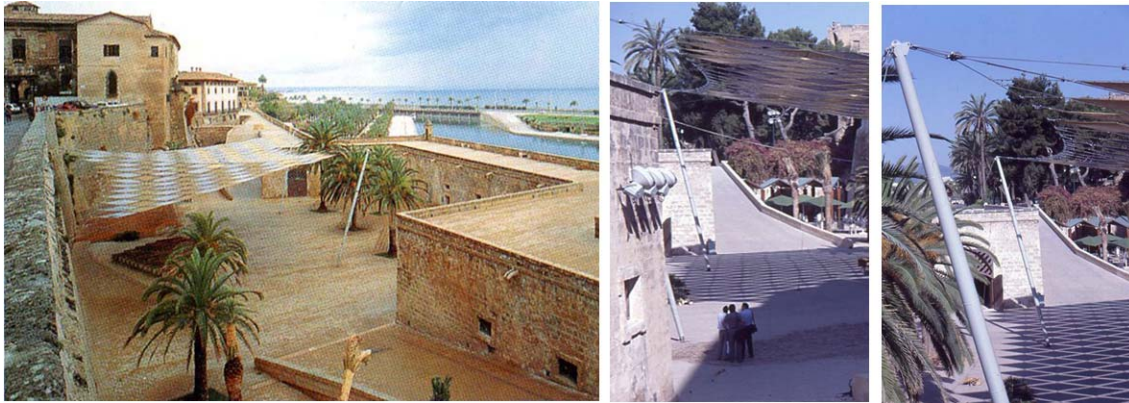
Circular hollow steel sections are efficient in compression and torsion, minimal surface area to be protected, minimal wind resistance and availability. They are equipped with welded components that allow at the bottom end a pin-joint connection and at the upper end, a set of lugs connect to the membrane.



The A shaped main mast of the "Camp de Mart" Auditorium (h=38,4 m) consists of two pin-supported poles joined at the top. They are made of 2 CHS \varnothing 323,9 x 8,35 mm connected by two continuous welded plates with variable height to get a tapered profile. They are tied to the outside by stays. Two additional guy cables on both sides are connected at intermediate points along their length. Where the intermediate guys are connected to the poles, a horizontal tie cross-bracing consisting of steel rods (\varnothing 24 mm) joins the pole tubes. To simplify the transport, the poles are subdivided and assembled onsite through bolted connections not protruding from the profile of the section.



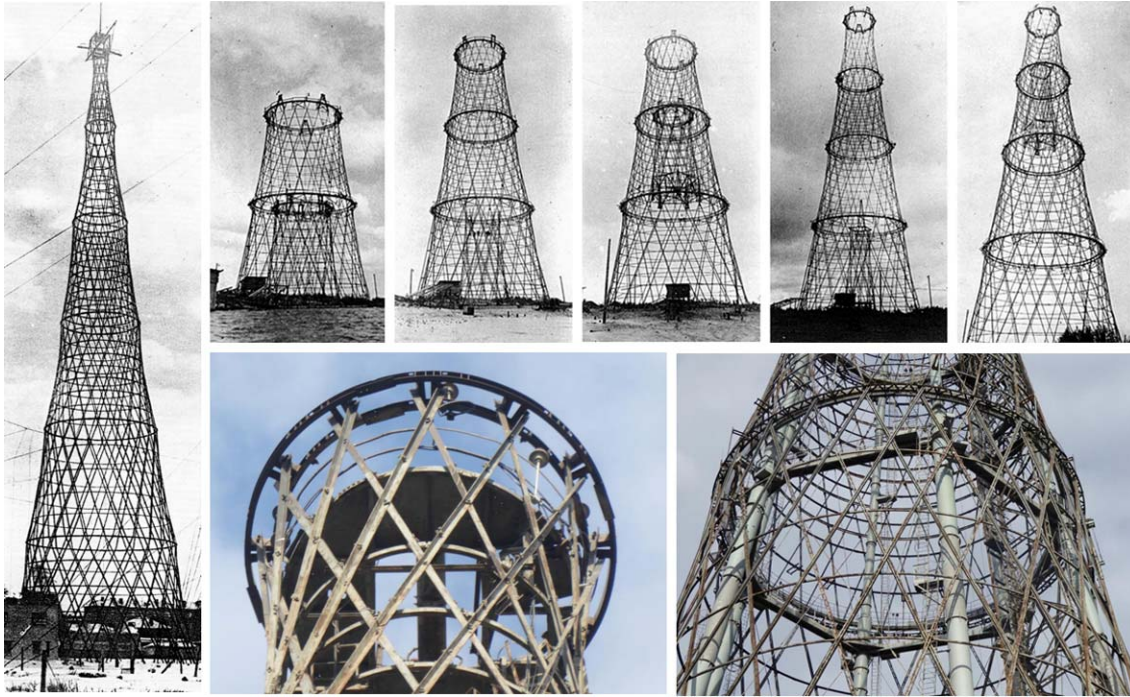
A small outdoor theatre in an open space in the former moat beneath the gothic Palma de Mallorca cathedral has been covered with a protective awning. It consists of a system of cross wires spanned between peripheral cables. The lozenge-shaped openings thus formed are filled with pieces of polyester fabric held in position by spiral spring clips.



It is fixed by cables to plates anchored to the city wall and to two hinged masts held in position by cable stays. To keep the awning as rigid as possible, it is attached to the ground via tree-like cable systems that can be adjusted by means of turnbuckles (DETAIL 6/1994). Notice the tapered masts that prevent from looking oversized compared to the whole structure and the site.

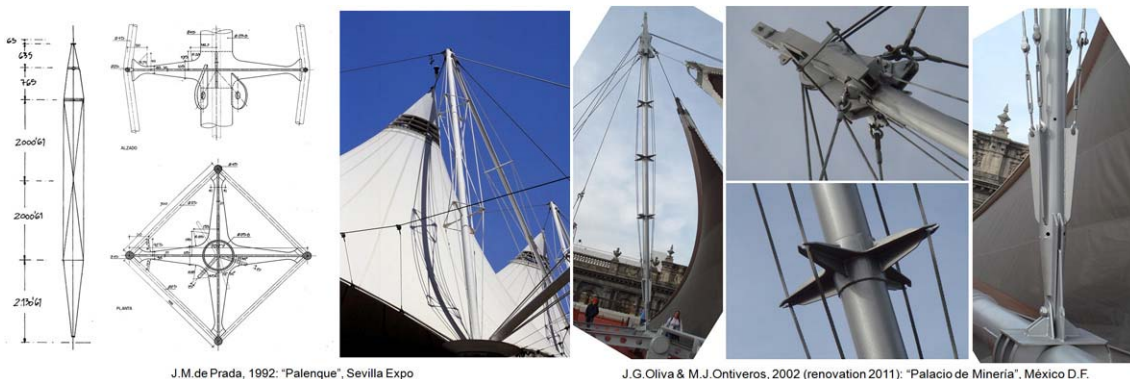


Trussed masts are common in travelling circuses to reduce weight, facilitate assembly and lifting from the ground.



A spectacular case of lightening is that of the Shukhov Tower, a landmark in the history of structural engineering. Known as the Shabolovka Radio Tower, it was built between 1919 and 1922, rising to the height of 148 m. It was originally designed to be 350 m high but steel shortage made it impossible. It consists of six stacked hyperboloids, which have the property of being constructed out of entirely straight segments. For the construction Shukhov employed his own original method of telescopic assembly.

Today, the structure suffers from corrosion and, in addition, it sits close to the center of a growing Moscow. Demand for land, coupled with its poor condition and lack of public access, have led to the looming threat of demolition. In 2014, architects, preservation groups, and members of the local community, rallied to protest against a plan to dismantle the tower and re-erect it at a new location. The 2016 World Monuments Watch joins their voices in calling for continued vigilance in the fight to save this icon of modern Russian history.

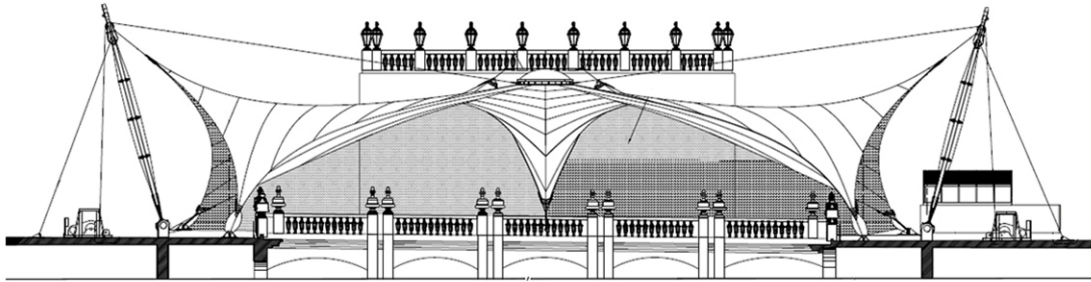


J.M.de Prada, 1992: "Palenque", Sevilla Expo

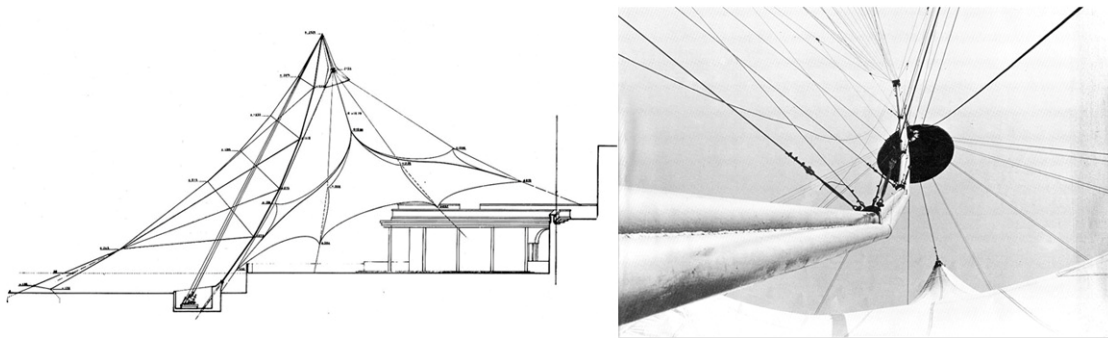
J.G.Oliva & M.J.Ontiveros, 2002 (renovation 2011): "Palacio de Minería", México D.F.

The "Palenque" in Sevilla opted for tying. Cross-trees 10 mm thick and ties \varnothing 25 mm lighten the mast by reducing the buckling length from 7,60 m to 4 m so that a CHS of 115 x 7 mm is enough. It is a way to save steel and to prevent the mast from looking oversized.

The "Palacio de Minería" in old downtown Mexico City is considered a masterpiece of Latin American neoclassicism that has to be preserved. To provide shade and protection from the rain, a cover has been designed and built.



The schedule included the requirement of not altering neither the existing structure nor the external look, meaning that no structural elements of the roof might be seen from the streets. This requirement implied that the intervention had to be very light and the height of the masts limited. It is why the masts, 9 m high, are pinned and prestressed with ties to reduce buckling and section.



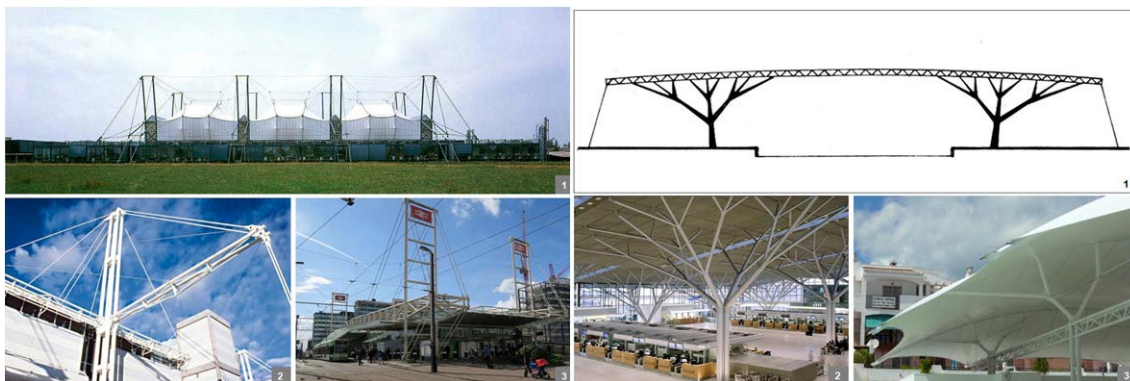
R.Taillibert & S.du Château with L.Stromeyer, 1965: Open air theatre, Cannes (IL 5). The 28,5 m long and 25,5 m high mast consists of a welded bundle of thin-walled steel piles (3 x Ø130 mm). Only one of the three pipes stands on a base plate at the foot of the mast. The mast is given a parabolic-polygonal curve in anticipation of the planned direction of buckling. Each polygonal point is guided from behind by 4 cables in two levels. The effective static buckling length of the mast is reduced on the mean by 5,60 m from the total length of the mast to the interval of the polygonal points by this new structural method.

Tensegrity structures are free-standing pin-jointed networks in which an interconnected system of cables are stressed against a disconnected system of struts. Principles and analysis are documented in papers, articles and bibliography, but few practical applications have been realized and known. K.Snelson first attempts were models and sculptures with such simple detailing that do not apply to building structures.

Instead, the Messeturm in Rostock, a tensegrity tower 62,3 m high, may be compared to the flexible "Needle Tower II" in Otterlo, 30 m high, designed by K.Snelson. The difference in height involves differences in design and realization. More than twice the height requires a substantial increase in rigidity, that is obtained connecting the compression elements and fixing their joints. The result can still be considered a tensegrity structure as it keeps being an interconnected system of cables stressed against a system of struts.



Each node receives two CHS (273 x 12 to 40 mm) in compression, 2 diagonal cables \varnothing : 50 to 75 mm and 2 horizontal cables \varnothing : 30 to 50 mm. The cable ends are open spelter sockets pinned to the gusset plates (for the diagonals) and end plates (for the horizontal cables). The end plates are bolted to create a fixed connection between struts, that limits the total deflection of the tower during storms.



Coupling or clustering the masts make them thinner. Slim tubes look more elegant than a single bulky cylinder. **1** M.Hopkins 1985, Schlumberger Research Laboratory, Cambridge. **2** Ph.Cox 1988: Darling Harbour Exhibition Centre, Sydney. **3** A.Brookes 1992, East Croydon Station, London.

Branching the masts reduce spans and buckling lengths. **1** A space latticed slab provided with multiple supports from below. The free buckling lengths are reduced by arranging the supports like branches of a tree. (C.Roland, 1970: "Frei Otto. Tension Structures". Praeger Publishers, New York). **2** gmp Architekten, 1991: Stuttgart Airport, Terminal 1. **3** C.J.Jiménez with

Ch.García-Diego, J.Llorens, H.Pöppinghaus and T&P Construcció Tèxtil, 2007: Almuñécar Aquarium.