We speak of true spatial systems only if the spatial effect also serves functional, i.e. load-bearing purposes. 'Closed' systems such as spoked-wheel or rotation frameworks do not require tie-back to the foundations since they balance out the acting forces with the ring connection and closed 'force bends', e.g. as tensile/compression-ring structures.

This applies also to spatial frameworks which, apart from horizontal wind forces, exclusively transfer vertical normal forces to the building. The second group of spatial systems are cable nets or true membrane structures in which the material (PTFE/PVC/PES) functions as statically effective primary structure and is not merely employed for weather-protection purposes. Lightweight stadium roofs are susceptible to vibration and can be agitated through wind (or earthquakes, rock concerts, etc.). The prestressed roof elements must therefore always be reversely curved (negative 'Gauß' curvature, U. Peil) and designed sufficiently strong as horizontal tensile forces approach the infinite and are, quite likely, not resisted by the material (cable net or membrane).

High (pylons) and low points should alternate; guy cables should continue the tensile direction of the form.

Saddle shapes are also hypar surfaces, which can be formed by two reversely spanned parallel cables in the direction of curvature. At evenly distributed loads these are parabolic or hyperbolic. The obligatory pretensioning of cable nets has to be secured by tensile foundations. We may assume that lightweight membranes or cable net structures bury a similar mass into the ground as needed for compression-stressed frameworks.

A hyperbolic paraboloid is created when a cylinder formed by parallel lines is twisted around its central axis. Such shapes can be formed by almost any type of material capable as straight-line generatrix (e.g. timber shells, etc.). The cables in a cable net structure run parallel to the edges.

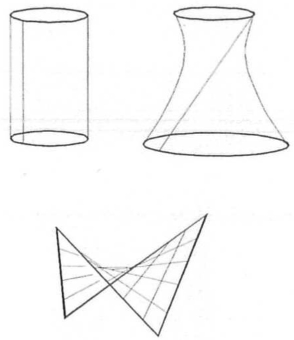
Spoked-wheel structure

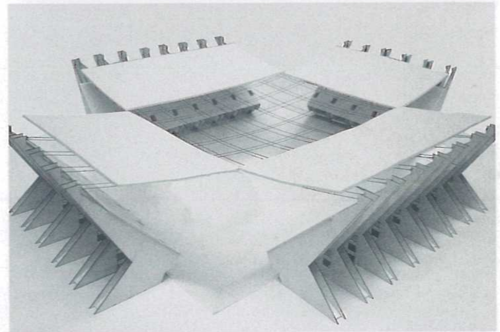
The large spans typical for stadium construction can be realized most economically as ring-cable roofs. The covering structure of Gottlieb Daimler Stadium in Stuttgart (1993), designed by engineering practice Schlaich Bergermann and Partner, has become a prototype worldwide, which has since been taken further and, in some instances, significantly altered. The principle of a horizontal spoked wheel was employed in the new-build and conversion of four of the twelve World Cup stadia in Germany. Normally, there is a pressure ring on the outside, which functions like a bicycle rim with a hub at the centre taking up all bearing and stabilizing cables.

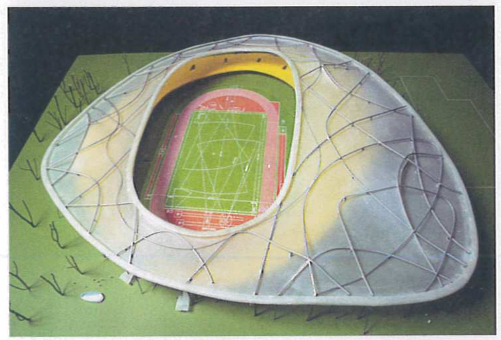
Two types A/B are distinguished: Stabilizing cable *above/below* the suspension cable.

Since precise horizontal forces may become infinitely strong, the suspension cables have to run at an optimized pitch. If the main cable is above the stabilizing rope, it runs outward at the top and inward at the bottom. The geometry is thus elevated on the outside and shallow on the inside (cf. Stuttgart, Hanover, Hamburg). Frequently, weather protection is required only for the spectator areas; the tensile ring is designed as a hollow hub, leaving the stadium interior uncovered.

With the suspension rope in a low position, the structure is flat on the outside and high on the inside. The stabilizing cable for reversed loads (suction) runs above and is fixed to the hub (cf. Frankfurt). A spoked-wheel structure is capable of covering large areas without columns placed







502 **Schematics**
Hyperbolic paraboloid/cable net (U. Peil)

503 **Intersection of trusses**
Guiseppe-Meazza-Stadium Milan, Italy

504 **Crossed suspension cables**
RWTH-Aachen, Taha Anwar, summer term 2005

505 **Cable-stayed pneumatic roof structure**
Tokyo Dome, 'Big Egg'

506 **Spatial framework on diagonal supports**
Draft: athletics stadium Chemnitz, 1995