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Autor: Levy, Matthys

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The Lightest Retractable Roof
Toiture escamotable ultralégère
Das leichteste einziehbare Dach

Matthys LEVY
Principal
Weidlinger Associates
New York, NY, USA

Matthis Levy, a Swiss born civil engineer graduated from Columbia Univ. with MS and CE degrees. He is the designer of the Georgia Dome in Atlanta, GA, and New York's Javits Center and other structures built around the world.

SUMMARY
Tenstar Domes with cable networks rigidized using tensegrity concepts can be adapted to a wide variety of configurations. For the Georgia Dome, completed in 1992, an oval plan was covered with a teflon coated fiberglass membrane stretched over a triangulated Tenstar Dome. Alternate configurations have now been proposed for roofs spanning as much as 360 m and one scheme includes a retractable oculus that greatly enhances the usefulness of a facility by providing all-season, all-weather protection for special events combined with the advantage of natural daylighting for sporting events.

RÉSUMÉ
Les coupoles Tenstar à réseaux de câbles raidis selon les principes Tensegrity sont adaptables à de nombreuses configurations. Ainsi, une membrane de fibres de verre revêtue de téflon et tendue au-dessus d'une coupole Tenstar subdivisée en triangles a permis de couvrir la surface ovale pour le Georgia Dome achevé en 1992. L'auteur propose d'autres formes pour les toitures de portées supérieures à 360 m; un projet de toiture comporte une membrane escamotable offrant une protection permanente par tout temps aux manifestations spéciales, avec éclairage naturel pour les rencontres sportives.

ZUSAMMENFASSUNG
Sogenannte Tenstar-Kuppeln aus Seilnetzen, die nach Tensegrity-Prinzipien versteift sind, können einer Vielzahl von Bauformen angepasst werden. Für den Georgia-Dom (1992 fertiggestellt) wurde eine ovale Grundfläche mit einer Teflon-beschichteten Fieberglas-Membrane überdacht, die über eine in Dreiecke unterteilte Tenstar-Kuppel gespannt ist. Es sind Konfigurationen für Spannweiten bis 360 m in Diskussion. Ein Konzept beinhaltet eine einziehbare Dachhaut, die durch die Kombination eines jahreszeitunabhängigen Witterungsschutzes und natürlichem Tageslicht die Verwendbarkeit einer Anlage für spezielle Veranstaltungen bedeutend erhöht.

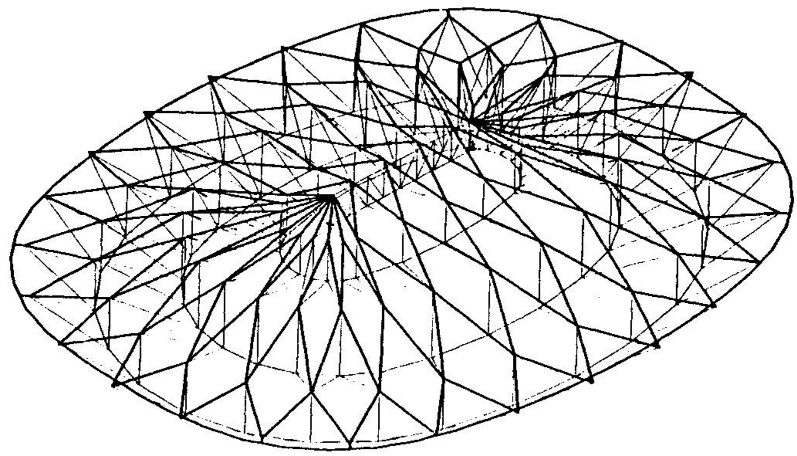
1 Introduction.

The first historical retractable roof was the canopy over the coliseum in Rome and was more like a horizontal curtain hung from a series of parallel ropes strung between the top of the stage house and the back of the stands. It served more as a sun shade rather than a weatherproof cover because of its numerous open joints. Thirty years ago, a modern retractable roof was built in Pittsburgh consisting of a number of orange peel sectors supported along the edge on a circular track and in the center of the arena, from a cantilevered arm. The roof, apart from being very expensive, suffered from mechanical problems and is now permanently shut. When the Toronto Sky dome was completed in 1988, modern technology and sophisticated computer analysis dealt successfully with the mechanical difficulties that had plagued the Pittsburgh structure and its temperature and deformation dependent deformations. However, the cost issue remained as that structure exceeded $400 million dollars. The Toronto Sky dome and recent Japanese retractable domes have been constructed as rigid, heavy, steel structures, either spanning across an arena or cantilevering from the edge.

The Tenstar retractable dome[1] offers another approach based on the principle that a cable structure that remains in place over the opening is virtually invisible and totally transparent. By introducing a structure that supports a retractable roof, a lightness of structure is achieved that is directly proportional to a "lightness" of cost.

1.2 The System.

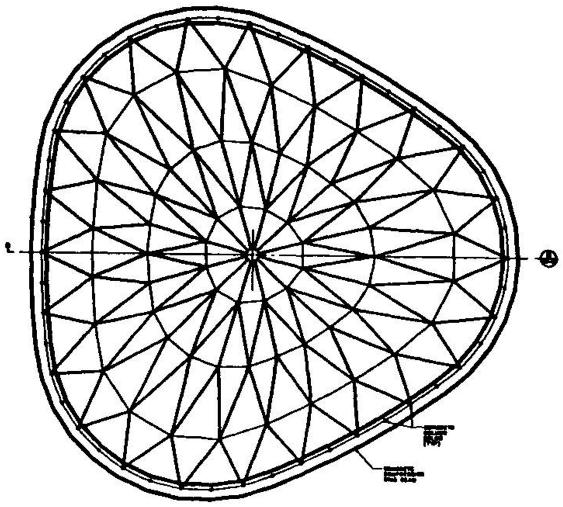
The first Tenstar Dome was completed in Atlanta in 1992 and consists of a 240m by 193m fabric covered oval dome. It was based on the tensegrity concept proposed in 1954 by the American original, Buckminster Fuller. This structure consisted of ever smaller annular rings, rigid in their

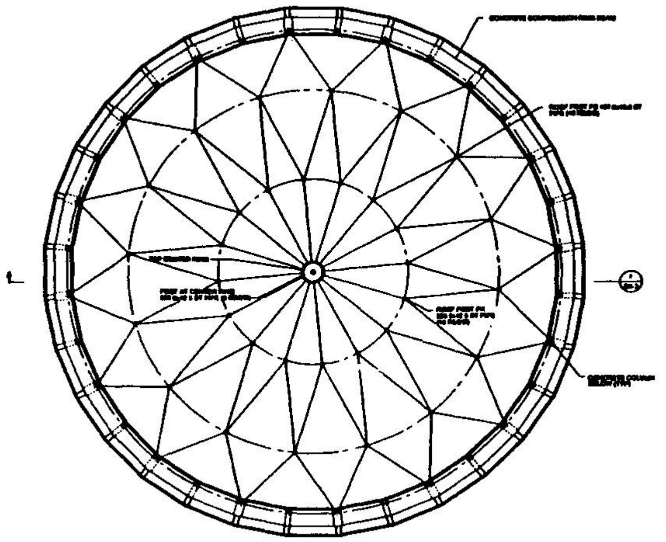


[1] Patent Pending

vertical planes, connected to each other with cables running from the top of the large ring to the bottom of the next smaller ring. He described it as a structure in which islands of compression reside in a sea of tension. Structurally, it can be described as a radially oriented succession of discontinuous trusses in which the bottom chord is a series of hoops tying together all the trusses.

In the Tenstar Dome, each node is braced by triangulated cables forming, on the top surface, a continuous net. The resulting arrangement is an extremely stiff structure in which the stiffness is obtained both from the triangulation and the prestress necessary for a cable net. The total dead weight of the resulting structure, including its fabric cover is an incredibly low 0.3 kN/m^2, less than one half the wind suction load specified by most building codes as well as the required live load.



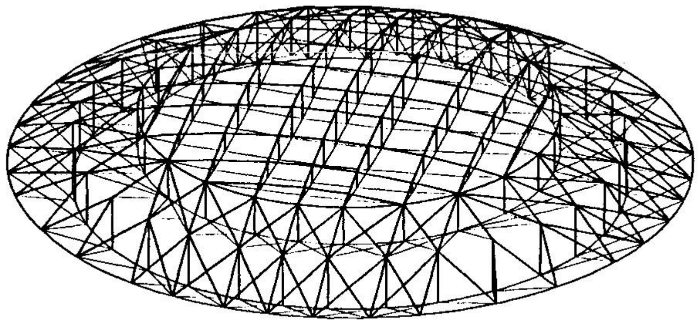


The system allows and incredible variety of alternative configurations: the plan may be a circle, a curved triangle, or an oval; the covering material may be fabric or a rigid metal deck; openings in the roof may be introduced leaving only an annular ring to cover grandstands and most exciting of all, a retractable roof can be devised.

2.1 The Retractable Option.

The retractable option we have studied offers the lightest weight and concurrent lowest cost roof of this type developed to date. The scheme consists essentially of a cable dome with parallel cables on the top surface to which parallel tracks are attached. The spacing of the cables is of the order of 15m which renders this sparsely populated cable grid relatively invisible to the spectator looking up at the sky. Nevertheless, the spacing is small enough to permit a lightweight truss structure to be designed to ride on it. This movable roof is assembled from a series of separated triangular trusses, linked to each other in the direction of travel in the manner of a caterpillar. In the orthogonal direction, the sections are connected with spring loaded rods to allow rotation and some lateral displacement. This concept permits the moving roof to adapt to a deformable cable supporting structure.

By accepting the minimal visual impingement of a cable net, an extremely lightweight movable roof structure is possible compared to the heavy, trussed, and often cantilevered movable roofs that have been built.

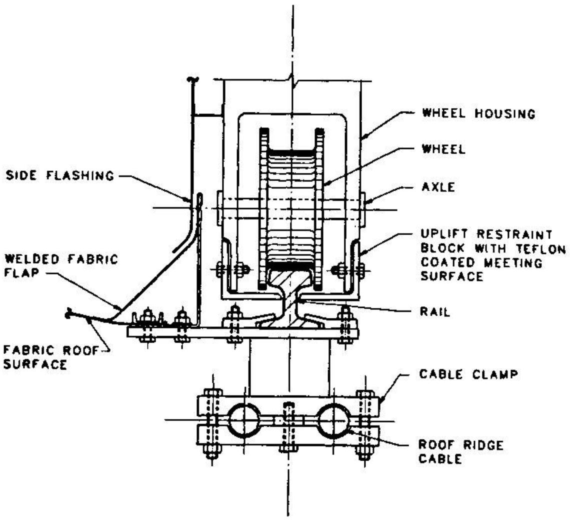


2.2 Alternative Configurations.

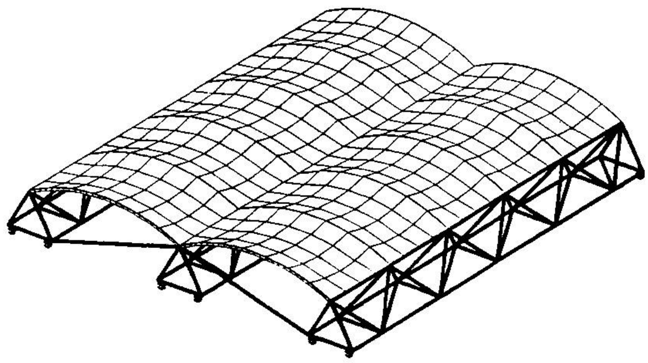
Two types of these retractable roofs have been studied: An oval roof with a rectangular retractable oculus; a round roof with four petal-like retractable sectors. In both cases, the retractable sections are arranged for the greatest simplicity and ease of operation and maintenance.

Because the retractable roof sections are lightweight, the bogies and operating mechanisms including wheels, housings, motors are all scaled accordingly and are lightweight. Two operating systems have been considered: A cable driven system with fixed motors located on the compression ring. A wheel driven system with built-in small horsepower electric motors directly geared to the wheels on the operable section.

At the meeting stiles of the roof sections, a weatherproof interlocking device has been proposed. As the sections approach each other, a cam displaces a spring loaded cap on one section that then overlaps a curb on the other section.

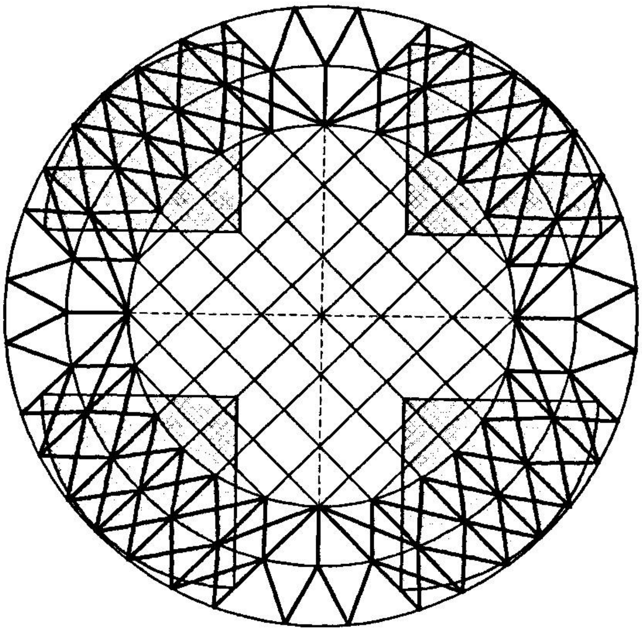


WHEEL HOUSING DETAIL

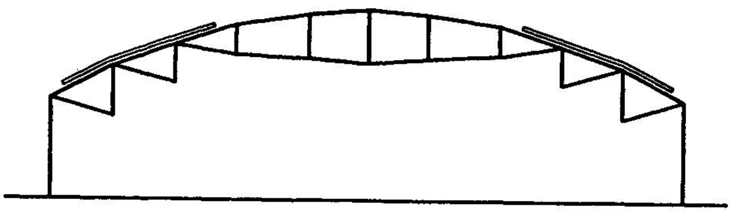


ISOMETRIC VIEW

The fixed portion of the roof can be covered in fabric using the hyperbolic paraboloid panels used on the Georgia Dome or can have a rigid covering of metal panels supported by steel joists. The movable roof panel can similarly be covered in fabric using saddle shaped panels between sprung arches or can have a rigid metal covering. There is an inherent advantage in using fabric as the roof covering because it obviates the need for a separate waterproofing membrane that, because of the flexible nature of the roof, needs flexible joints, all of which are sources of potential leaks. On the other hand, in locations where insulation and the need to support large snow loads are important, a rigid roofing material may be more appropriate.



ROOF CABLE LAYOUT PLAN
OPENED POSITION



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