HAJ TERMINAL IN JEDDAH, SAUDI ARABIA, BY SKIDMORE, OWINGS & MERRILL

NEW INTERIORS THAT CATCH THE SPIRIT OF THE OLDER BUILDING THEY TRANSFORM
LEESBURG, VIRGINIA COUNTY ADMINISTRATION BUILDING, BY KDA ARCHITECTS
A SOPHISTICATED SHED, BY VENTURI, RAUCH AND SCOTT BROWN
BUILDING TYPES STUDY: THE WELL-BEING OF DESIGN IN THE HEALTH-CARE WORLD

FULL CONTENTS ON PAGES 10 AND 11

ARCHITECTURAL RECORD

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Horst Berger

TENT STRUCTURES: ARE THEY ARCHITECTURE?

In a word, tent structures have "arrived." They are now an accepted approach for major projects—as major as the Haj Terminal at the Jeddah airport in Saudi Arabia (above). This terminal, being built for Muslim pilgrims on their way to Mecca, is believed to be the largest (105 acres) covered area in the world.

In another sense, fabric tension structures have arrived because the range of building types where they are being used is expanding. Conceived originally as low-cost shelter for athletic events and exhibitions, fabric tension structures are beginning to be used for commercial buildings such as stores (RECORD, mid-August, 1979) and assembly buildings. The potentialities for the commercial sector are clearly evident in the enclosure for Florida Festival (pages 132-134)—a shopping/dining/entertainment complex at Sea World in Orlando, Florida, where the largest single piece of coated fiberglass fabric ever assembled (187 by 187 ft) hangs from a 90-ft-high mast to form a cone that, along with three other 50-ft-high cones and an inverted cone that comes within 16 ft of the floor, covers 60,000 sq ft devoted to food, merchandise and arts and crafts facilities.

In still another sense, fabric tension structures have arrived because designers can now have confidence in the technology—materials engineering, structural engineering analysis, and field erection—for the reason that manufacturers, engineers and erectors have had an intensive learning experience in the last eight years since the first permanent fabric tension structure was erected at La Verne College in California.

The technology would not have developed, of course, had there not been a mounting interest from architects and owners in low-cost, long-span enclosures with features not possible with conventional structural systems. One of these is the possibility of

Twenty-one tent units, high in the sky, and shading $10\frac{1}{2}$ acres, form the first module of a total of 10 that will provide an "oasis" for pilgrims on their way to Mecca. The terminal, which comprises two identical five-module sections, is designed for as many as 80,000 hajjis who may spend up to 36 hours at this terminal after they arrive at Jeddah.

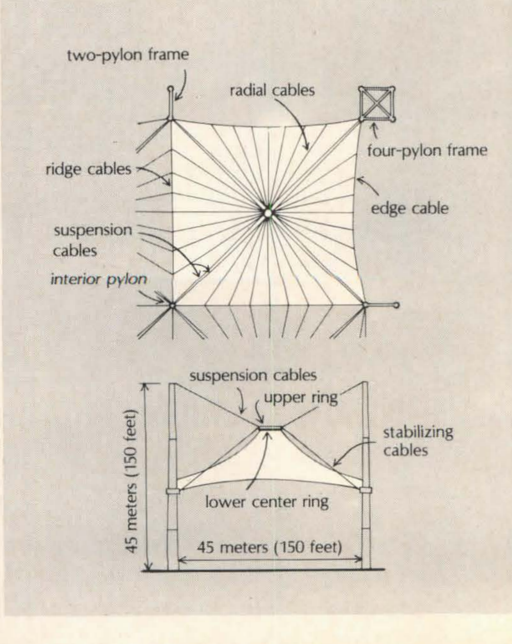
Horst Berger

visually stimulating shapes—shapes that can echo familiar forms (as in the case of the Haj Terminal that suggests a field of tents, but in the sky) or that attract attention and arouse interest (as in the case of Florida Festival).

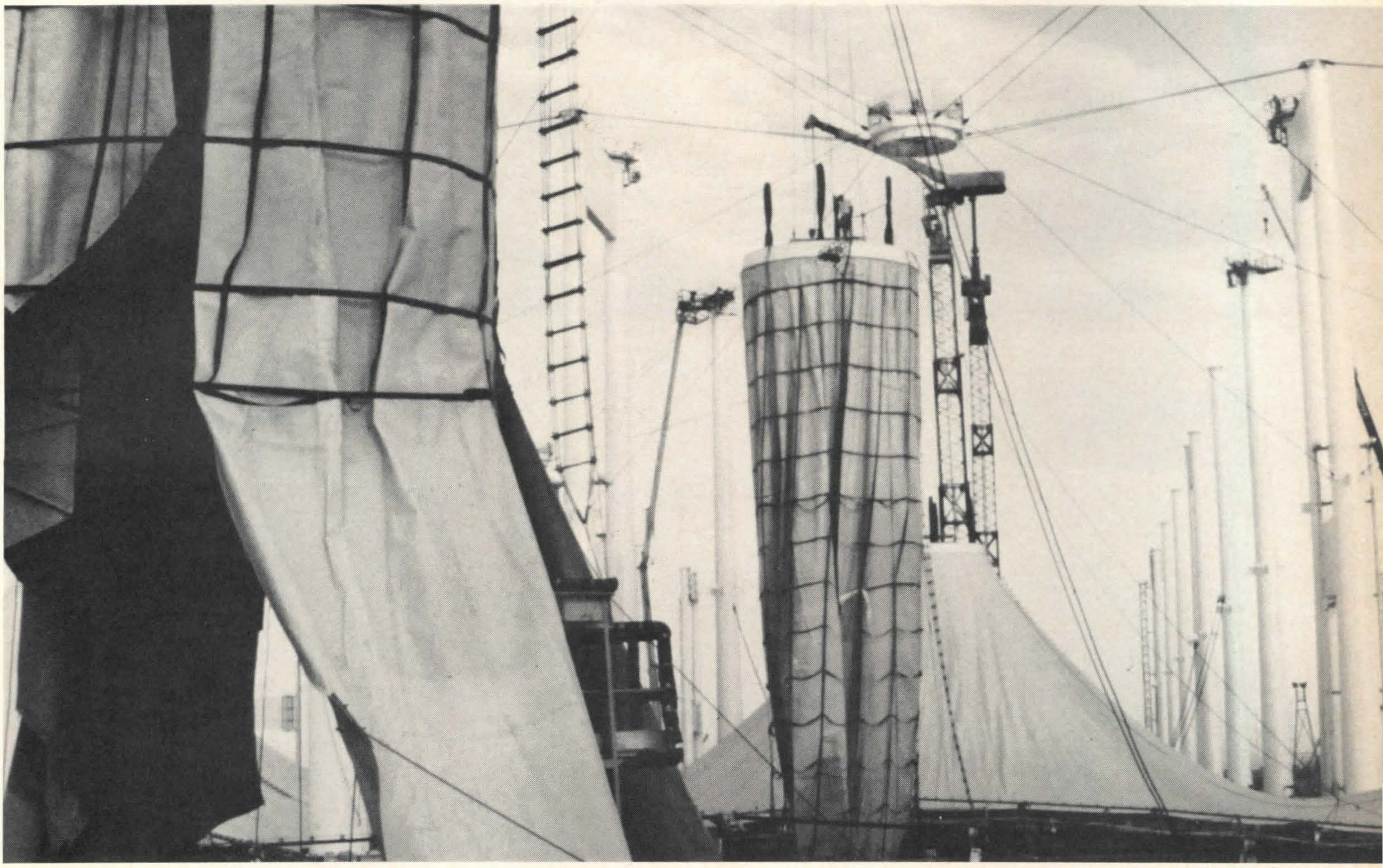
Though the fabric has little thermal insulating value in the usual sense, the tradeoffs between thermal energy exchange and "free" light could make fabric-roof buildings more economical to operate than conventional ones, according to mechanical engineer Karl Beitin of Geiger Berger Associates. A bonus—not in the economic equation—is the visual and aural contact that occupants of these buildings have with the outdoors—movement of sun and clouds can be discerned; rain can be heard.

If architects are to take full advantage of the unique properties of fabric tension structures (defined as mast-, arch-, or frame-supported rather than air-supported), they need to realize that there are some very

Robert Brand



The "skyhooks" for the tents are steel rings hung from suspension cables which are draped from single pylons in the interior of the module, ladder-like double pylons at the module edges, and four-pylon towers at the corners. Marching along in 1000-ft rows, these pylons seem to echo the columned arcades of mosques that the hajjis may visit.



William Ling photos

special engineering disciplines that should be considered. Form and tensioning of fabric roofs have very significant effects on structural stability, avoidance of flutter and vibration, resistance to imposed loads, ease of fabrication and erection, and—when all these factors are taken into account—cost of the structure. (Cost of fabric tension roofs currently is on the order of $16 to $18 per sq ft of area covered, say engineers and manufacturers. Use of a double-fabric roof adds from $3 to $5 per sq ft to that cost.)

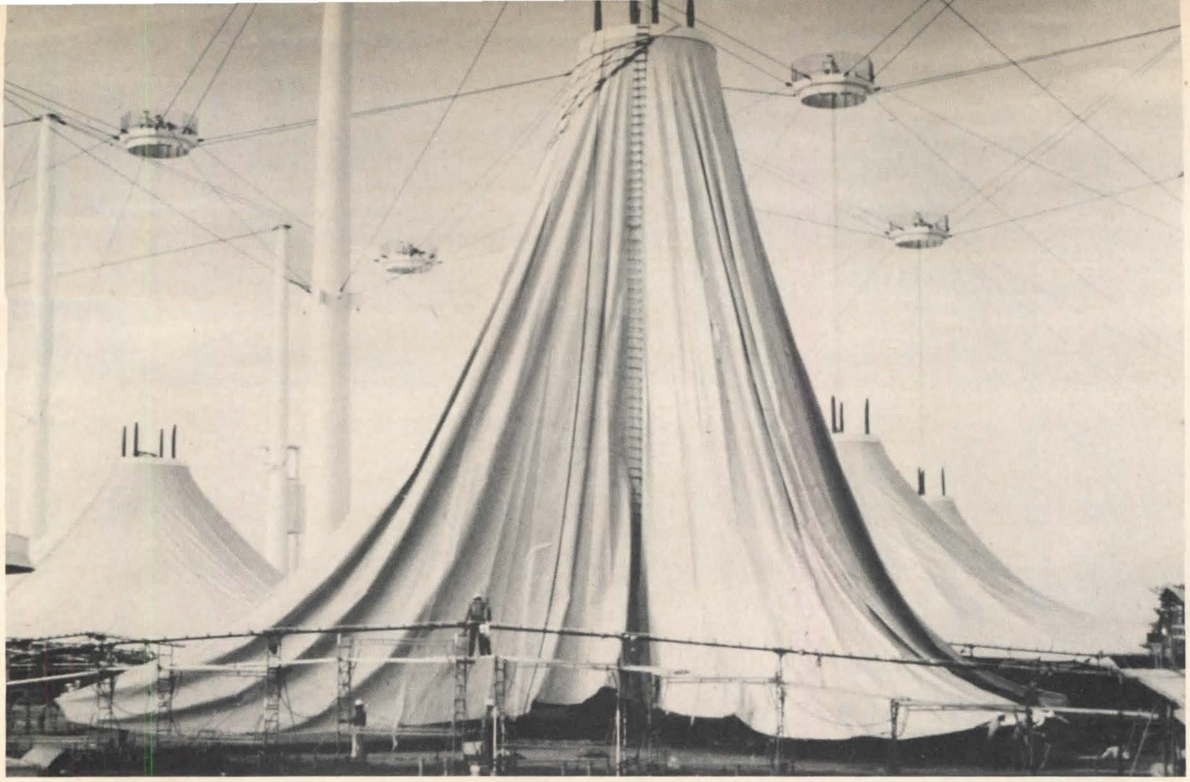
Nevertheless, as with any building tool, fabric tension structures are not suitable for all occasions. Feeling close to nature, with separation provided only by a tent-like skin, may not be a desirable attribute if what occupants want is the security of a "cave" or a "den." Further, the architect may want a more anonymous enclosure than is provided by fabric tension structures. But if the positive attributes of these spectacular enclosures do fit the program, then there is a myriad of shapes possible through a repetition of and/or mixing of basic forms.

Sometimes, the architect may choose—as did Skidmore, Owings & Merrill in the case of the Haj Terminal—to make a very strong design element out of the support structure. Whether viewed by a hajji (pilgrim) as he arrives by plane, or when he walks down the archlike passages between modules (21 tent structures), the Vierendeel-type pylons on the long sides of each module may evoke some of the monumentality and dignity of the mosques the hajji may visit during the holy season.

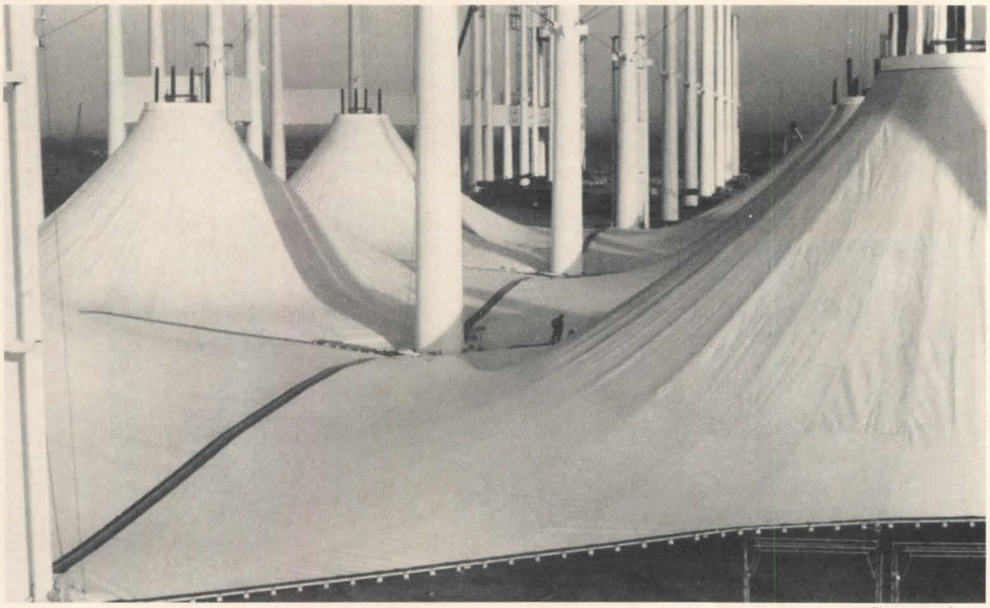
The Haj Terminal and the Florida Festival pavilion are both bench marks—but with different "main ideas." The first illustrates the influence of program and architectural viewpoint on form and engineering design; the second, the contribution of engineering finesse and imagination to formgiving and economical use of materials.

The Haj Terminal had to be huge because the number of pilgrims from Islamic nations coming to Saudi Arabia during the 70-day hajj season is expected to swell to two million, most of whom are expected to come through this airport to be taken by bus to Mecca and from there to the plains of Meena and Arafat. There will be two terminal units 1,050 by 2,250 ft, each comprising five modules of 21 tent units (three units by seven units). The two large terminal units will be separated by a landscaped mall and each will have arrival processing buildings (the only facilities to have air conditioning) along the long sides where aprons are provided for aircraft.

In a talk last year in Europe before a group of engineers specializing in lightweight structures, shell structures and long-span structures, Dr. Fazlur R. Khan, partner in Skidmore, Owings & Merrill, the firm that



The half-acre tents are hoisted by cables dropped from the upper suspension ring to a mate at the top of the tents. Nylon nets around the tents prevent damage to the fabric from wind during the time the tents are hung but not tensioned. Prestress is induced into the tent membranes for structural stability and strength by means of electric jacks. All 21 tents in a module are tensioned simultaneously. When the right tension has been attained, the two rings are bolted together. The open rings allow natural ventilation for air changes and create a breeze for comfort. Visitors say the shaded space is amazingly cool.

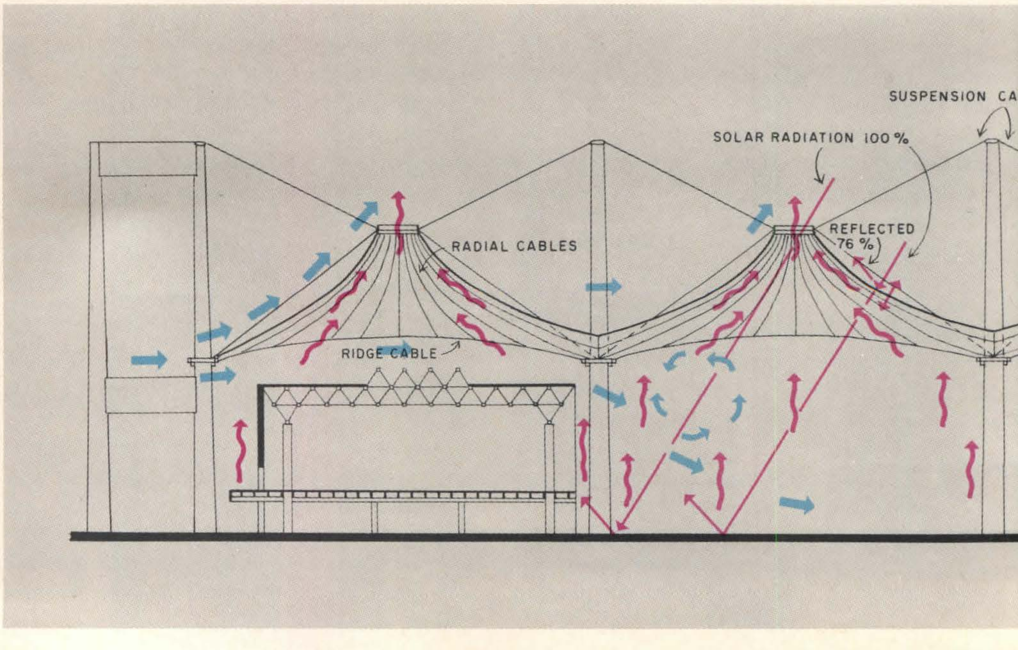


William Ling photos

designed the Haj Terminal, stated that while the fabric-roof terminal may not be architecture in the traditional sense of a building, it is indeed a grand space in the sense of a total environment. The first impression on the pilgrims from an architectural point of view, he said, probably will be this 20th-century expression of the ancient forms they are going to see most of their stay. Thus the structural/architectural form becomes more relevant than just another opaque large roof.

SOM decided that though traditional tents have center posts, these should be eliminated because, with 80,000 pilgrims milling about, they did not want a proliferation of columns to obstruct their flow. This made the support structural system somewhat more expensive, because central poles are a more direct approach. The total cost was still only $17.50 per sq ft or a total of $80 million.

The architects experimented with many



Robert Yarnall Richie

simple models and found that "fantastic variations in shape" could be achieved by simply changing the elevations of the peaks and the spans. But the architects, says Khan, wanted to keep the shape and form *absolutely simple*. Also they wanted to develop the form in a way that the entire hajj processing terminal into which the planes disembark people could be built underneath one of the tent rows. This was accomplished by starting the bottoms of the tents 65 ft above the ground, and letting them soar up to 115 ft, where they are attached to support rings, which in turn are held in the air by cables that rise to the top of the pylons at 148 ft. The over-all plan was developed in modules of three by seven bays, with open space between modules straddled by double-column frames to carry the lateral forces of the suspension cables. The steel rings at the top of the tents were left open because it rarely rains, and a wind tunnel test with smoke indicated that continuous ventilation could be expected. Visitors report that being under the roof is like being in a forest: it is cool, breezy and pleasant, yet open and light—even on unpleasant days in the hot desert.

As is usually the case, simplicity of form was not achieved without some hard work along the way. SOM, whose client is the Ministry of Defense and Aviation of the Kingdom of Saudi Arabia, had its engineers developing the structural criteria for the project, performing an engineering analysis, planning for and evaluating the tests on an aero-elastic model that was tested at the University of Western Ontario by Alan G. Davenport, and checking out the two-tent prototype that was built at Owens-Corning Fiberglas' research grounds at Granville, Ohio.

Advice on patterning, fabricating and packing the tents for shipment was the role of Walter Bird's firm Birdair, now merged with Chemfab, a manufacturer of industrial coated fabrics. Because the fabric, which is 1 mm thick, should not be creased, Birdair developed careful packing and handling procedures. Patterning itself is quite an engineering art, because compensations have to be made for stretch of the fabric in warp and fill directions when prestressing forces are applied, so that the forces remaining after final tensioning are what the engineer designs for to resist loads.

Owens-Corning Fiberglas, as roof contractor, engaged not only its own construction specialists, but also outside specialist engineering firms to develop the techniques and equipment for hoisting and tensioning the fabric structures—no small problem considering that the prodedure is to tension all 21 tents in each module simultaneously. And, as tensioning is being completed in one module, work must proceed in the adjacent module. Chemfab wove all the fabric because they had the largest loom available. Owens-Corn-

Les Stone

ing coated and fabricated half (105) of the half-acre-size tents and Chemfab did the same for the remaining half.

Hochtief, the West German general contractor, has the monumental task of getting the first section done—including all services and structural elements under the tents—by this fall.

The visual simplicity, and hence the interconnectedness, of the tent structures made engineering analysis by computer more complex and time-consuming than if the tents had been center-pole supported and designed as independent units. Each terminal section is one very large roof, with all units being interconnected. Thus the structure is a very large indeterminate system with ripple effects from unit to unit and module to module. Tension or load applied to one tent is induced into surrounding tents and masts. This meant that Horst Berger and his associates at Geiger Berger had to develop a very large computer model to simulate the behavior of this indeterminate system, and the largest computer storage system in the country had to be used to perform a comprehensive engineering analysis, which was part of Geiger Berger's contract as structural engineering consultants to Owens-Corning Fiberglas.

For the engineering analysis of the Florida Festival structure, essentially the same program was used, but computer calculations were simpler because the solution was for a finite fixed roof. The movement of the masts and the edges was finite. The perimeters of the tents were tied to fixed edge beams, and the masts, set on bearings, are allowed to rotate at the bottoms. This provided a finite system because the whole roof moves as a unit when loaded by wind.

The problem presented to design architect Basil H. M. Carter, who at the time was with the firm of Robert Lamb Hart in New York City, was to design a facility to house a marketplace containing 45 different food and merchandising unit buildings in a semi-tropical setting. Because the owner wanted to grow a wide variety of native plants and trees, including a 40-ft palm tree, plant consultants advised the architect that a fabric with at least 18 per cent light transmission would be required (in contrast to the normally used 6 to 8 per cent). Getting 18 per cent light transmission was achieved by Chemfab through use of a more open weave, a different yarn and a new combination of resins for the coating. Measured light levels have come within a few per cent of what lighting consultant Howard Brandston predicted in his daylight studies for Basil Carter. Levels have been as high as 750 fc on a clear spring day and 150 on an overcast spring day. During the day the fabric has a very luminous appearance, and with 18 per cent light transmission it can be bright at times.

The design concept of the fabric tension

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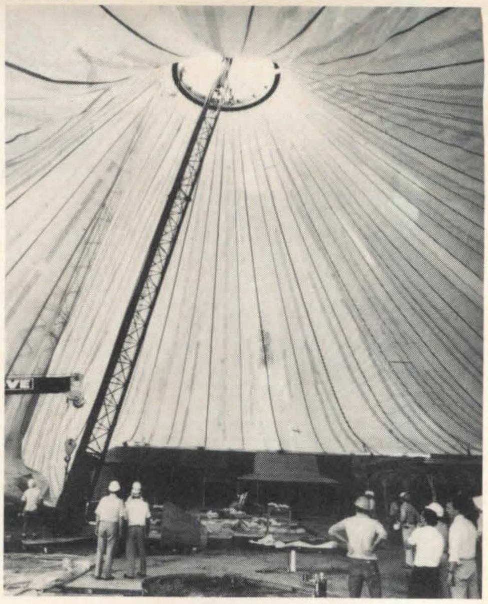

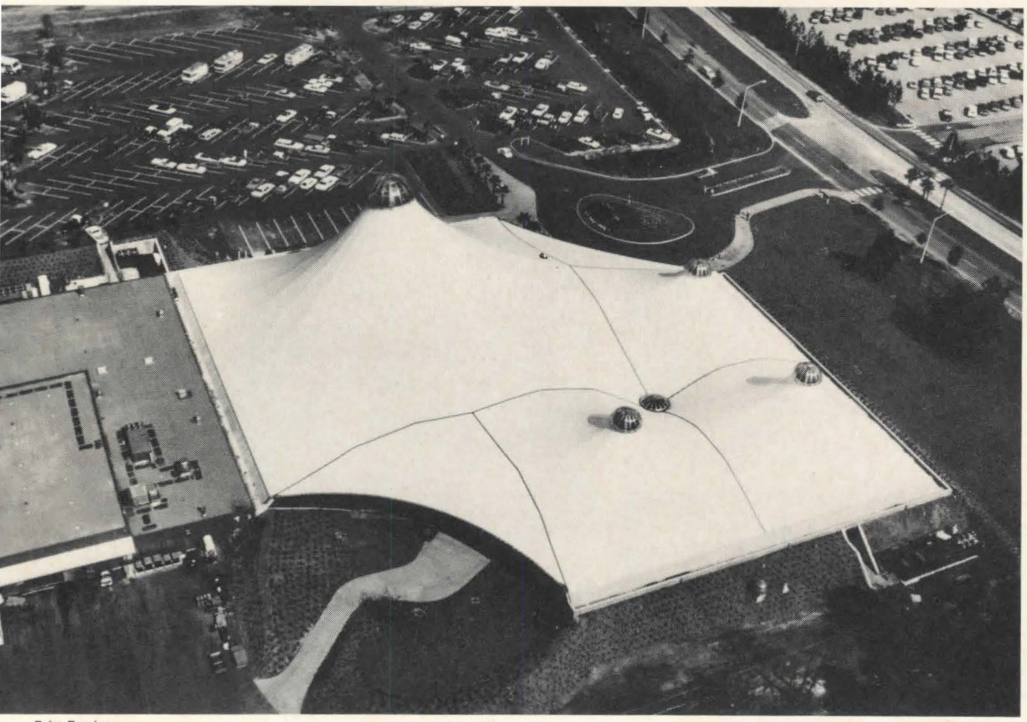

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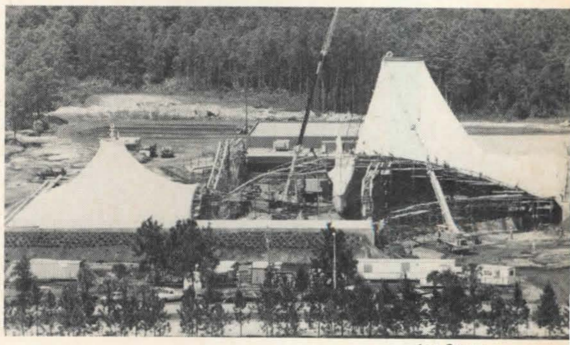
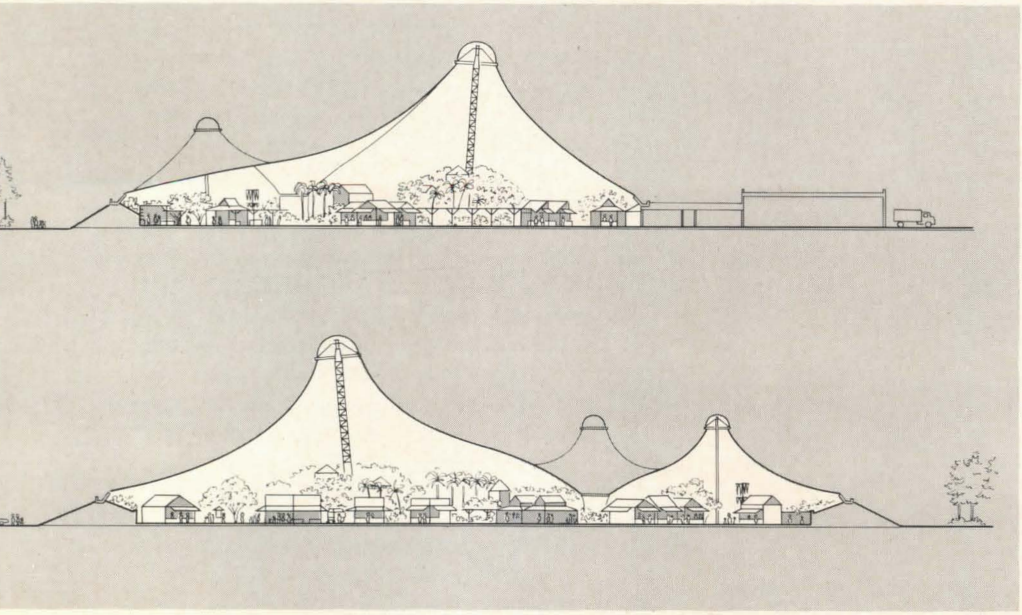


Les Stone

Geometry of the Florida Festival structure is two large squares intersecting at the corners. Raising the edges of the large 90-ft-high cone made possible an inverted cone at the intersection of three 50-ft-high upright cones. The small cone with two edges held down by the edge beam was erected first. For the 90-ft cone (top), a crane outside hoisted the ring, while one inside lifted the mast.

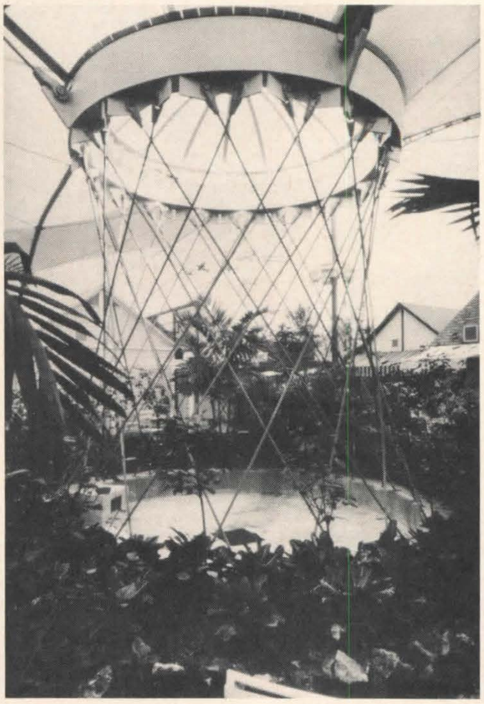


structure developed from a plan layout by Basil Carter of two intersecting rectangles, which engineer Horst Berger modified to two intersecting squares, in turn divided into seven squares, each equal in area to one-fourth of the large intersecting squares. Berger's first suggestion was two large tents. Next he proposed one upright tent and one upside-down tent. But this required lifting the edges around the upside-down tent, and in turn resulted in the development of three small tents around the upside-down tent.

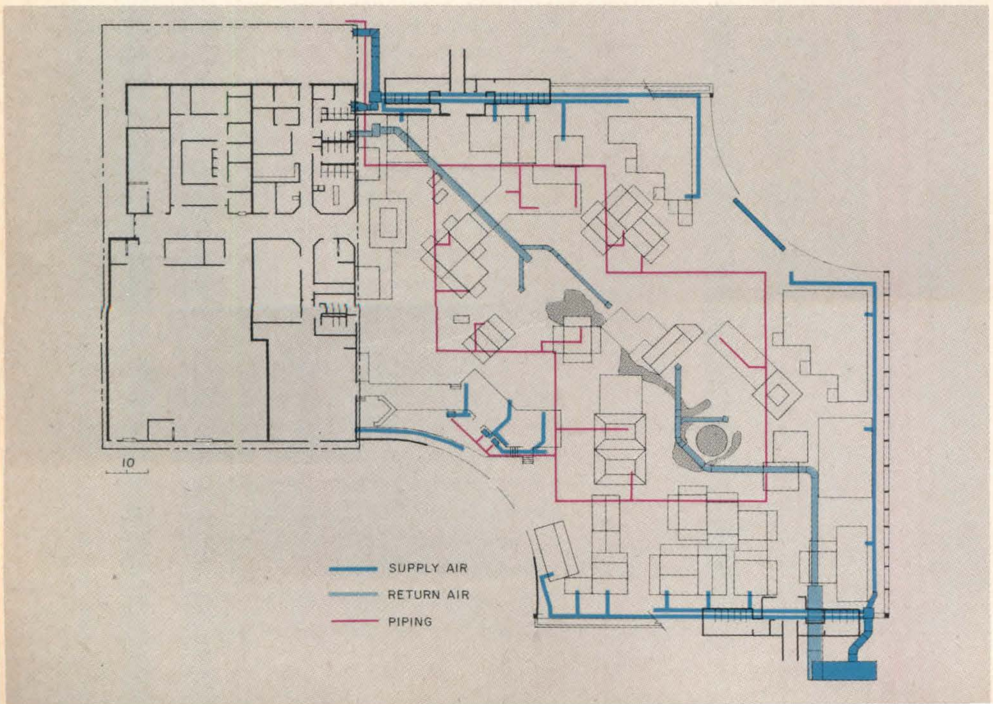
The structure is held up by one large and three small masts. It is held down in the center of the second main square (in plan) by the reversed tent module. The tent obtains stability from its anticlastic curvature and prestress. Wind load basically causes uplift, which is resisted by the edge support and the reversed cone. Loads in membrane structures are carried as much by deformation as by increase in stress, states Berger. In a good

The fabric has a light transmission of 18 per cent—the amount the landscaper felt necessary for the wide variety of tropical plants and trees. Visitors can sense movement of the sun and passing clouds, and they can see the sky through the skylights which admit shafts of sun for accent illumination. During a rainstorm, the rainwater drains through the tie-down ring of the inverted cone, creating an interior waterfall.

The air-distribution system was designed to stratify cool air so as not to waste it in the upper reaches of the cones. Air at the periphery comes from a central air conditioner. Return air is below grade. Booths are cooled with fan-coil units.



Robert E. Fischer photos



membrane structure, the absorption of load is mainly in deformation rather than stress rises. (For example, in Jeddah, where the hajj tents are under a prestress of 66 lbs/in., no stress rise is predicted under a 95 mph wind. At Orlando, the prestress is 45 lb per inch and a slight slackness is predicted in the big tent under maximum wind uplift.)

The significance of the new fabric tension structures in the world of architecture is clearly major. Horst Berger feels that the openness of space, the abundance of daylight, and the sculptural quality make for "a new architecture." Further, the space-enclosing function of structure takes on a new aspect. "Encapsulated space" was an expression of this, but is too limited; "megaspace" comes closer. A "modified environment" is more like it—fabric tension structures take the edge off the harsher expression of nature and make the environment livable with minimum materials and at low cost.