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## 建筑拉伸膜的前景

### VISIONS FOR TENSILE MEMBRANES IN ARCHITECTURE

TEXT: © PROFESSOR R. LARRY MEDLIN, ARCHITECT  
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高效的轻型结构在建筑中的运用是一种必然趋势，能达到在大跨度悬索桥和极小曲面应用时相同的效果。这些效果依赖于能拉伸成一定弧度的材料及其联接组件的拉伸膜结构，最大限度地减少附加在支撑结构上的覆盖物造成结构体弯曲或重力加载，这就给设计师提供了一个几乎可以忽视覆盖物重力的独特设计机会。本文将就这方面展开探讨。

#### 改变大跨设计寿命的优势

拉伸膜结构应用于规划与设计，能改变大跨度结构的使用寿命或使用期限。适宜的膜结构材料和组件的持续发展能使构筑物的继续或更长期使用的目的得到保证。这种结构在 1967 年蒙特利尔世博会的德国馆（见图 1，建筑师：Gutbrod, Otto, Kendel, Kiess, Medlin；工程师：Leonhardt, Andrae）得到了应用。该馆由一系列钢索网支撑，上面覆盖着一层薄薄的织物。设计完善的作为永久屋顶的索网结构连同绝缘木板和石材现存于施图加特大学第二学院（见图 2，建筑师：Otto, Medlin, Burkhardt, Kugel, Rasch）建筑研



图 1. German Pavilion at Expo 67 Montreal, fabric membrane suspended below steel cable network.

1967 年蒙特利尔世博会德国馆，钢质网状结构上覆盖着纤维膜。



图 2. ILEK Stuttgart permanent structure – interior view of wood ceiling decking attached to steel cable net.

斯图加特 ILEK 结构：铺设在索网结构上的室内木质天花板。

究所内，作为轻型结构和建设实验之用。

近来，亚利桑那州图森市的伊迪丝球馆自适应康乐中心（业主：图森市公园和娱乐部，建筑师：Burns-Wald Hopkins，制作者 / 安装：纽约 Bird Air Amherst）一种非常简单的结构与此类似。该结构只有三根屋肋，弧形边缘连接着缆线，上面覆盖着单层聚四氟乙烯涂层的玻璃纤维膜（见图 3.1、3.2、3.3）。这种聚四氟乙烯玻璃纤维膜具有

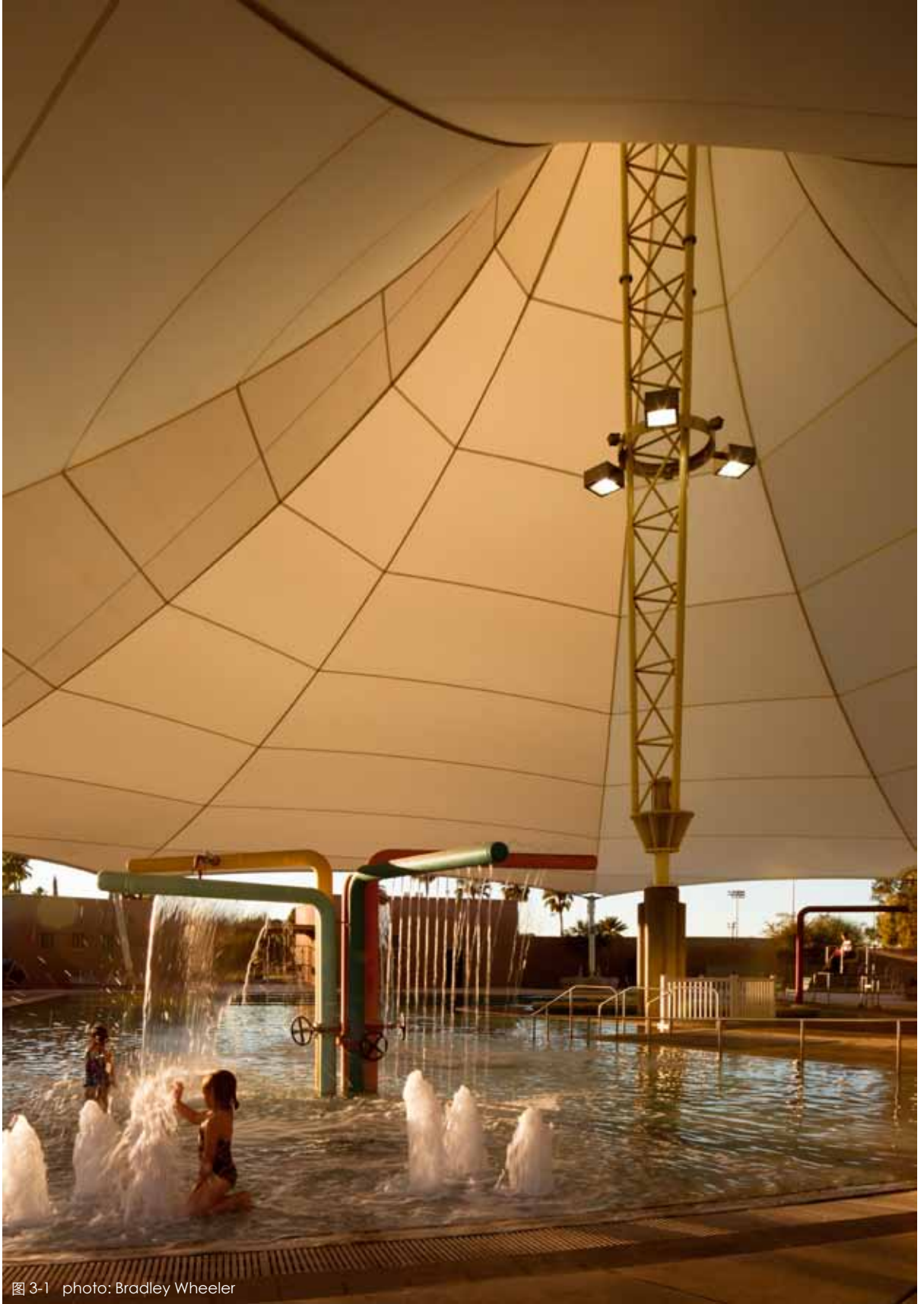


图 3-1 photo: Bradley Wheeler

图 3. Adaptive Recreation Center, Tucson – teflon coated fiberglass, stronger more durable fabric.

图森市自适应康乐中心：非常耐用的聚四氟乙烯涂层玻璃纤维物。

三十年或以上的使用寿命。三个泳池和环绕四周的休憩甲板上笼罩着一个伞形结构，半透明的覆盖膜给泳客提供一个选择阳光或阴影的机会，从而营造一个舒适的微环境，并对泳客在全年中避免太阳辐射过量提供庇

护。作为一个户外环境，泳池区与周边公园建立了一种强烈的视觉联系，而无需积极的环境控制体系。此外，该中心已初见成效，周期成本得到了节约，该项目的绿色建筑目标是非常前卫的。利雅得市中心主要的南北

街道，以及东西向比邻的高层建筑和周期性的冷却塔覆盖着类似的材料，从而营造出一种舒适的户外空旷的微环境（见图 4，建筑师：Rasem Badran, Amman, Jordan; Abdelhalim Abdelhalim, Cairo,





图 3-2. photo: Bradley Wheeler

Egypt; Jim Batchelor Arrowstreet, Cambridge, Massachusetts)。

预制件具有非常大的潜力，易运输、架设等。如果是必须的话，拆除或移动膜结构会适度地缩短它们的使用期限或预期使用寿命。比如，有一种拉伸膜，曾在密苏里州克莱顿市的圣路易斯县广场（见图 5，声学家：Christopher Jaffee）的一次圣路易斯交响乐团中午演出中，有过一次独特的成功表现。Walter Susskind，这位交响乐指挥，表达了他对膜结构的无比喜悦。这些膜结构在演出的前一天晚上架构在比邻的建筑物和广场的结构体上，第二天就拆除了，仿佛随着音乐旋律的停顿而悄然离去。

在 Tucson Mercado 的一条南北向的小巷内，竖立着一系列类似拉伸膜的檐篷，作为遮阴之用。膜结构有限地吸收来自邻近建筑物和道路的热量和太阳光反射，从而在夏天的 Mercado 创造出一个舒适的微环境（见图 6，设计、制造、安装：亚利桑那大学建筑学院夏天工作室以及图森市规划署 J. Hand）。附近的图森艺术馆馆长钦佩这样的安装，并连续几年在每年的艺术展览节上，让社区志愿者搬迁三个檐篷，重新安装在博物馆的广场上（见图 7）。

东非 Eritrea 的 Massawa 的滨海农场（见图 8，项目总监：Carl Hodges），一种原始的遮阴体系被开发出来，作为工作与农场员工交流之用。该项目的两个目标得以实现：80 个直径 20m 的圆形虾池周边环绕着阴影，最大程度地利用当地劳

动力和材料。一种众多的本土编织草席用来作为拉伸膜构成元素。该结构的其他部件为农场内可利用的再生材料，或在首都 Asmara 的国家再生材料交易市场获得。照片很好地揭示了出色的缝纫技术，农场女工为该结构的织造做出了贡献。

另一拉伸膜的使用实例就是，在亚利桑那西部的 Yuma Palms 购物中心中心景观广场，澳大利亚生产的紫外线保护网布，被整合成一个线性拉伸膜系统，覆盖在两侧比邻商店的人行道上（见图 9，业主：Westcor Development Partners, Phoenix; 建筑师：Ellerman & Schick Architecture/ Planning, Phoenix）。使用寿命十到十五年的高密度聚乙烯 (HDPE) 织物，比前面提到的使用期限更长的覆盖膜的初始成本更低。尽管购物中心的中轴线是西南—东北向，游客总是有走在树荫或阳光下的路径选择。在 Yuma 非常炎热的夏季，遮阴的凉棚和周期性的冷却塔营造出一个宜人的备受欢迎的微环境。

亚利桑那州图森市的 Flowing Wells 社区中心（见图 10.1、10.2，业主：Pima County Natural Resources, Parks and Recreation; 建筑师：Poster Frost Associates; 制作者 / 安装：International Tension Structures, Gilbert, Arizona），一组四幢的会议或活动建筑，周围环绕着一个花园式的中央庭院。每幢建筑的外墙安装着大型的玻璃幕墙，庭院景色可一览无余，其特点是公共艺术雕塑与景观一体化。这种对自然景观的开放极大地促进了中心内的社区交互感。为了保证图森市的温差不过大，即保证太阳直接辐射不会造成不良眩光以及白



图 3-3 photo: Bradley Wheeler

天热收益和晚上热损失，在设计出庭院和空旷的天空之间，一组六个拉伸膜遮阳棚覆盖在庭院上。与 Yuma Palms 中心相同的高密度聚乙烯网状织物在此得到应用，各遮阳棚允许冬季有少量的阳光间接射入，同时阻挡了高热量的夏日阳光。作为 Flowing Wells 社区中心的“心脏”，庭院中花园式的空旷景观与成熟的树木的结合运用，营造出了全年舒适的微环境。

### 自由的空间定位

实际上，行人道上伞形的遮阳膜是一种覆盖在轻质金属框架上的拉伸膜，这种金属框架可以方便地随意搬移、倾斜，甚至倒置。同样，相对透明和为数不多的拉伸膜结构组件附载在弯曲或使拉伸膜扭曲的结构体上，从而达到一个虚拟的独立的重力荷载。

在空旷的场地上，三个结构相似的拉伸膜结构被安置和定位在一个空间中，满足了不同规范的要求，从而说明该设计的潜在意义。从概念上而言，单个拉伸膜是通过向上的曲面支撑和向下的曲面抑制反向拉伸来得以定型和固定的。这些乙烯涂层的聚酯织物预期有二十年的使用寿命。作为 Phoenix 市民广场 Solar Oasis 项目的一部分，“夏日邀请”（见图 11，亚利桑那大学环境研究实验室主任：Carl Hodges）展览所使用的拉伸膜是通过桅杆和停在北侧的货车来悬挂的。从东西向看，朝下的曲面好似高悬于夏日天空中的一道弧。朝上的曲

面，拉伸膜的边缘是从南面低处开始，然后向上延伸，超出货车的顶部，延伸到悬挂在桅杆上的弧形缆线边缘。把拉伸膜设计成向上“倾斜”，充分利用了从南向北上升的拉伸膜下贯穿该空间的自然对流的微风。加上比邻的冷却塔和其他被动冷却技术，该展览展示夏日下午户外环境温度经常超过 110° F (43° C) 时，Phoenix 市中心舒适的户外环境。

亚利桑那北部自然大峡谷西部游客集散中心（见图 12，建筑师：Richard Fe Tom, The Architecture Company, Tucson；结构工程师：Caruso Turley Scott；拉伸膜制作/安装：Fabric Structures, Inc），朝下抑压的弧面也呈东西向，仿如划过夏日天空高悬于头顶的一道太阳弧。此外，由于该设施建于延伸至峡谷西部边缘的一条狭窄的土地上，4, 500 英尺 (1,372m) 下面科罗拉多河蜿蜒环绕，因此拉伸膜下徐徐微风向上吹拂，经解说或餐饮区贯穿整个区域。遮阳与微风的综合作用使温度常常在 25°F (13.9°C) 内，远远低于拉伸膜下相邻的其他区域的温度。朝上的南北向的曲面在南面山峰抬伸，指引着游客进入该设施内，同时容许较低的冬日阳光照射进拉伸膜下的活动区域。

现在的图森市动物园（见图 13.1、13.2，业主：City of Tucson Parks and Recreation Department，建筑师：Burns Wald-Hopkins，制作/安装：Shade Concepts, Irvine, California），入口区进行了重建和设施加固，昭示了“绿色”建筑理念，并塑造了作为动物园独特的身份标识。设计改造后，





图 4. Riyadh City Center exterior spaces cooled with fabric membranes and cool towers.

利雅得市中心外部空间温度由于覆盖了织物膜和安装了冷却塔而有所降低。



图 5. Stretch fabric temporarily suspended from adjacent buildings shades St. Louis Symphony during mid-day concert.

圣路易斯交响乐团中午时分的音乐会上，临时使用的弹力织物膜延伸了临近建筑物的阴影。

东西向分布的礼品屋、票房和洗手间呈弧形排列。大部分拉伸膜高悬于狭窄的功能建造物的南部边缘。延伸至北面最大面积的拉伸膜布设在欢迎入口和主要面向游客的最舒适的户外区域。这样也延伸了比邻售票窗口的阴影区域，并扩大了下午的阴影区域，同时串联了增加的动物园游客。拉伸膜的曲面主要都是按照朝上弯曲的方法来布设的，朝下的曲面则高悬于东南面的东部，并俯冲向西北部的西部最低处，这样拉伸膜顶部约 70% 的雨水排入蓄水池。售票厅的屋顶也朝这个方向倾斜，向下喷流的雨水倾泄，成为临近蓄水池的一道景观。这些水源的组合在入口区的西北侧形成了持续密集的水帘和高悬而空旷的景观效果，从而使夏日夕阳呈现炫目的光环。该公园的入口与伊迪丝球馆自适应康乐中心（见图 13.3，本文之前陈述部分）比邻，位于图森市的 Reid 公园附近，同一需改建和景观规划区域。夜晚，两者都是借助园内那种类似于中国大型灯笼的大型织造物笼罩的照明物来间接照明的，这种照明物常用于夜间活动。年终假日时节，晚上动物园也是开放的，动物园的照明也因一种名为“zoo lights”的庆祝活动而通宵达旦。众多图像投射到拉伸膜上，拉伸膜充当了这种活动的投影屏。

#### 便利的适应性和可移植性

就像传统的帐篷，拉伸膜自身的张力能够释放，从而可容易被重新包装，运输和重新安装在一个或多个不同的地方。纽约现代艺术博物馆展馆的结构（见图 14，轻型结构中心 - 华盛顿大学建筑学院：St. Louis, Missouri, Medlin, Schoeller, Fotsch, Bolazina, Cohen, Havland, Lemberg, Peterson; 制作 / 安装：Stromeyer GmbH, Konstanz, West Germany）就是一个很好的例子。由于使用了一种乙烯基涂层的聚酯膜，形成了一种半透明的效果，从而过滤了阳光，减少了眩光，因而这种结构常用于半户外的环境。夜晚，拉伸膜笼罩的空间下的照明光线反射或散射到拉伸膜上，成为注目的焦点及晚会活动的中心。展馆最初用于现代艺术博物馆的特别活动，随后被当作拉伸膜结构的典范，并用做 Ludwig Glasser 策划的一次“Frei Otto 作品”展览的展馆。后来，多伦多的安大略艺术馆以及芝加哥的科学和工业博物馆的一些类似公园般更开放的场地中的展览和展示活动中，都使用了这种装置。这些装置中，展馆周边的开敞场地中可系统而灵活地放置一些展板，以充分利用现有场地的景观及交通格局。展览时间结束，这些被安装和使用过的装置，又在伊利诺伊大学校园内靠近芝加哥环路的多功能馆使用了好几年。到后来安装这种装置时，拉伸膜安装人员在安装过程中非常娴熟，当电影摄制组制订的摄影棚搭建时间定下来后，在摄制组到来时，他们能在几分钟内快速升降这些拉伸膜。

亚利桑那大学百年校庆活动中，安装了一种双层针织弹力织物，并通过三个锚固点、一辆大型拖车顶及场地周边地面一些小的固定点来固定。这种同时具备三个自由矗立的拉伸膜棚、众多展板、一个演出和展示平台的安装方法，被称为可搭建或拆卸的“亚利桑那精神”式展览（见图 15，设计、制作、安装：学院全体教职员及环境研究实验室，弹力织物顶棚：Medlin, Bogan, Frazier），并能在几小时内做好运输准备。这种百年校庆期间的展览装置还安装在图森



市和凤凰城的购物中心、郊县集市、亚利桑那州博览会，三次亚利桑那大学的集会吸引了超过400万的参观者。

在密苏里州堪萨斯城的皇冠中心广场（见图16，工程师：Irv Engel；制作/安装：纽约的Membrane, Bird Air, Buffalo；伞形棚：纽约的Feller Scenic Studio Bronx, Irvin Industries, Lexington, Kentucky），搭建了一个乙烯涂层聚酯拉伸膜展馆，该展馆由两个75' x 75'的方形组成，他们能单独或一起使用；十个直径30英寸的伞形结构和各种支撑结构，安置在广场的较高点和较低点，以适应更广泛的各种社区活动。这些活动包括车展、船舶展、牲畜交易、珍贵图书展以及街道艺术表演；音乐喜剧表演；迪斯科舞蹈或电影放映；复活节游行、狩猎和各种不同种族和文化的各类活动。

在模块化的拉伸膜系统，每个模块的曲面是沿着边缘高低交替的，在弧线朝下较低点的模块之间，采用人体“S”弯脊线的方式使每个模块相交，穿过一个中心节点或弧线到达高的节点。基本体系包括交替支承的内部模块、一个体系终端模块和另一端人入口处向上抬升的模块。这种体系可通过搭建在Pasadena作为Rose and Super Bowls（见图17，业主/制作/安装：加州洛杉矶Academy Tent，结构顾问：伦敦Michael Barnes）娱乐场地的一组六个模块的组合得到印证。

这种体系最简单的安装方法就是将入口和终端模块联接起来。借助一个由当地人志愿建造的舞台和隔音设施以及音响系统，这种模块组合起来就可用作大时空音乐节和新世界交响乐夏日之家（见图18，声学专家Christopher Jaffe）的演奏厅。迄今为止，这套体系最大跨的装置是在南加州汽车展上，有22个模块。

### 拉伸膜的转换性

拉伸膜可收缩、拉伸和反复收缩性能以及可拉伸成不同外形尺寸的弹力膜性能，在某种程度上能适当地提供可变性和重塑性，以适应不同变化的情形。利用这种潜能是亚利桑那建筑学院两项最近的研究课题的目标。借助于在Alvaro Malo教授带领下的新兴材料技术领域工作的机会以及其他教师的研究成果，Brent Vander Werf进行了一项名为“适合遮阳的弹性体系”的研究，并将此作为他的硕士论文。Vander Werf开发了一种双向稳定模式的自我调节的遮阳体系，该模式在两个稳定的位置移动，开启或关闭附着一种弹力织物的球形透光孔。作为范例，在亚利桑那大学太阳能十项全能项目（见图19，之前《中外建筑》2010年第二期即106期介绍过）东边的窗户上安装了这种体系。该体系能自动适应不断变化的日光和热能的转变，容许阳光的照射或提供遮阳。

另一个在亚利桑那大学同一领域的研究生Nicholas Johnson，目前正在对一种弹力面料膜的形态的可变性潜能进行研究，该形态可在两个拉伸膜交界处的边缘进行“S”形弯曲。通过升降支撑拉伸膜的最高的尖点，拉伸膜结构可在升起时让阳光进入和降低时提供遮阳间转换，以适应不同的光照强度和环境温度条件（见图20）。

尽管早期的人类使用了帐篷，但膜结构已经改变了其使用用途和条件。目前全球都在关注材料、能源和其他资源的有效利用，遵循尊重甚或采取有助于自



图6. Stretch fabric and adjacent buildings shade The Tucson Mercado. 图森市 Mercado 弹力织物膜和临近建筑投射的阴影。



图7. Tucson Mercado fabric sails temporarily relocated at the Tucson Museum of Art plaza. 图森市 Mercado，临时铺设在图森市博物馆艺术广场上的织物遮阳棚。



图 8. Using native materials, workers fabricate prototype for shrimp pond shade system at the Seawater Farm, Massawa, Eritria, East Africa.  
东非 Eritria 的 Massawa 海水农场，利用自然材料，工人们建造的虾池遮阳系统原型。

然环境再生的建造方式，并在制造拉伸膜结构的材料和技术方面得到显著改善，这一切都表明：拉伸膜结构在未来的使用将充满无限的潜能。

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Highly efficient lightweight structures are the end result of applying the same principles as those used in the largest span suspension bridges and in near minimal surface soap films. These principles are employed in relation to prestressed tensile membrane structures with tensile-edge arcs and guys that minimize members loaded in bending and/or compression with associated buckling. This creates an almost gravity-defying “lightness of being” offering designers unique opportunities that will be discussed

in this article.

### Advantages of Varying Life Span Design

Tensile membranes can be planned and designed logically for varying life spans and/or periods of use. The continuing development of available membrane materials and assemblies has enhanced projects intended for continuing or more permanent use. Such development was evidenced by the progression of a fabric membrane supported by a steel cable net in the German Pavilion at the 1967 Montreal Expo 1 (Architects – Gutbrod, Otto, Kendel, Kiess, Medlin; Engineers – Leonhardt, Andrae), and refinement of this cable net structure to an insulated wood decking and slate as a permanent roof at the Institute for Lightweight Structures and Experimental Construction, at the University of Stuttgart 2 (Architects – Otto, Medlin, Burkhardt, Kugel, Rasch).

Recently, a similar system was simplified to a single layer Teflon-coated fiberglass membrane with

only three ridge and perimeter-edge arc cables at the Edith Ball Adaptive Recreation Center in Tucson, Arizona 3.1, 3.2, 3.3 (Client – City of Tucson Parks and Recreation Department, Architects – Burns-Wald Hopkins; Fabricator/Installer – Bird Air Amherst, New York). This Teflon/fiberglass membrane has the life expectancy of thirty years or more. Serving as a large umbrella-like structure above three pools and surrounding deck area, the translucent membrane offers bathers a choice of sun or shade, along with a comfortable micro-environment and shelter from excessive solar radiation throughout the year. As an outdoor environment, the pool area provides a strong visual linkage with the surrounding park and does not require an active environmental control system. Moreover, the Center has achieved significant initial and lifecycle cost savings, and the project's green building goals were advanced. A similar material covering the main north/south street in Riyadh City Center, together with tall adjacent buildings on the east/





图 9. At the Yuma Palms Shopping Center HDPE mesh fabric canopies along both sides of the outdoor mall insure that a shaded walkway is always available. Yuma Palms 购物中心, 高密度聚乙烯网状织物膜铺设两边街道商店外面的人行道上, 保证行人在阴影中通行。

west and periodic cool towers, creates a comfortable outdoor micro-environment in the desert. 4 (Architects – Rasem Badran, Amman, Jordan, Abdelhalim Abdelhalim, Cairo, Egypt, Jim Batchelor Arrowstreet, Cambridge, Massachusetts).

The potential to prefabricate, easily transport, erect and, if desired, dismantle or move membrane structures makes them appropriate for shorter use/planned life spans. For example, a stretch fabric membrane had its own successful debut at a mid-day performance of the St. Louis Symphony at the St. Louis County Plaza, Clayton, Missouri 5 (Acoustician- Christopher Jaffee). Walter Susskind, the Symphony Conductor, expressed his pleasure over how the membrane, which had been tied to an adjacent building and plaza structure the evening before and removed the next day, was able to move gently in rhythm with the music.

A series of similar stretch fabric canopies erected over a north/

south alley provided shade for the Tucson Mercado. In addition, the membrane afforded limited heat absorption and re-radiation from the adjacent mass of the buildings and road, thereby creating a comfortable micro-environment in the summer for the Mercado 6 (Design, Fabrication, Installation, The University of Arizona School of Architecture Summer Studio, and City of Tucson Planning Department – J. Hand). Curators at the nearby Tucson Museum of Art admired the installation, and for a few years community volunteers relocated three of the canopies in a re-oriented configuration at an annual art exhibition festival on the Museum's plaza 7.

At the Seawater Farm in Massawa, Eritrea, East Africa 8 (Project Director – Carl Hodges), a prototype for a system of shade canopies was developed by the author working with the Farm staff. Two objectives of the project were achieved: the provision of a ring of shade around the perimeter of 80 twenty-meter in diameter circular shrimp ponds

and the maximized utilization of local labor and materials. An adaptation of native woven straw mats was used for tensile membrane elements. Other components of the system were all recycled materials available at the Farm or obtained at the national recycling bazaar in the capital of Asmara. The photo of the prototype development reveals the excellent sewing skills that the women workers at the farm contributed to the fabrication of the structures.

In another instance of tensile membrane usage, UV-protected mesh fabric manufactured in Australia was integrated into a linear system of tensile membranes covering walkways adjacent to shops on both sides of a central landscaped mall at the Yuma Palms Shopping Center 9 (Client – Westcor Development Partners, Phoenix; Architect – Ellerman & Schick Architecture/ Planning, Phoenix) in western Arizona. The High Density Polyethylene (HDPE) fabric, with a life expectancy of ten to fifteen years, has a lower initial





图 10-1 photo: Bradley Wheeler

图 10. At the Flowing Wells Community Center, Tucson, a grouping of tensile mesh sails and landscaping provide shade and reduce glare, thereby creating a comfortable year around microclimate.

图森市 Flowing Wells 社区中心，一组网状的拉伸膜遮阳棚和优美的自然环境为行人提供了阴影，减少了太阳眩光，从而在该小环境范围内营造出了常年舒适宜人的氛围。

cost than the more permanent membranes previously mentioned. Even though the central axis of the shopping center is oriented southwest to northeast, visitors always have a choice of walking along a path in the shade or sun. During Yuma's very hot summers, the canopy shade and periodic cool towers create a much-welcomed tempered micro-environment.

At the Flowing Wells Community Center in Tucson Arizona 10.1, 10.2 (Client – Pima County Natural Resources, Parks and Recreation, Architect – Poster Frost Associates; Fabricator/Installer – International Tension Structures, Gilbert, Arizona), a grouping of four meeting/activity buildings surround a central courtyard/garden. Large glass areas in the facades of each building provide unobstructed views into the garden, which features a public art sculpture integrated with the landscape. This openness to the natural scene fosters a strong sense of community interaction within the Center. To insure that Tucson's intense, predominately direct solar radiation does not cause undesirable glare and daytime heat gains and night losses between the designed courtyard and

desert sky, a system of six tensile membrane sails covers the courtyard. Constructed of the same HDPE mesh fabric employed at the Yuma Palms Center, the sail grouping was configured to permit some indirect sunlight in the winter and to block out most of the higher overhead sun in the summer. The combination of the courtyard garden's desert landscaping and mature trees has created a comfortable year-round micro-environment as the heart of the Flowing Wells Community Center.

#### Freedom of Orientation in Space

In its essence, the pedestrian umbrella is a tensile membrane stretched over a light metal framework that easily can be carried overhead, tilted or even inverted. Similarly, the relative lightness and the limited number of members of a tensile-membrane structure loaded in bending or buckling enable tensile membranes to attain a virtual independence from gravity.

On a grander scale, three structurally similar tensile membranes configured and positioned in space to satisfy different programmatic criteria illustrate the significance





图 10-2 photo: Bradley Wheeler





图 11. At the “Summer Invitation” Phoenix Civic Plaza, the tensile membrane is shaped to create cool breezes under the canopy.

Phoenix Civic 广场的 “夏日邀请” 活动中，拉伸膜的铺设营造出了幕棚下微微清凉。

of this design potential. Conceptually, each of these basic tensile membranes is shaped and stabilized by counter-acting tensions of an upward supporting surface curvature and a downward restraining surface curvature. Their vinyl-coated polyester fabrics have an anticipated twenty-year life span. As part of the Solar Oasis project at the Phoenix Civic Plaza, the "Summer Invitation" 11 (The University of Arizona Environmental Research Lab, Director – Carl Hodges) exhibit membrane is suspended from masts attached to a trailer van on the north side. Running east/west, the downward surface curvature parallels the high overhead arc of the summer sun across the sky. The upward curvature, which starts low at the southern edge of the membrane, rises upward beyond the top of the van to cable-edge arcs suspended from masts. This orientation "tilts" the membrane upward and creates an advantageous natural convective breeze under the membrane rising from south to north through the space. With adjacent cool towers and other passive cooling techniques, the exhibit demonstrates a comfortable outdoor environment in downtown Phoenix in the summer, when afternoon ambient air temperatures often exceed 110°F (43°C).

At the Hualapai Nation Grand Canyon West Visitor Facility 12 (Architect – Richard Fe Tom, The Architecture Company, Tucson; Structural Engineer – Caruso Turley Scott; Membrane Fabricator/Installer, Fabric Structures, Inc.) in northern Arizona, the downward restraining surface curvature is also oriented east/west to parallel the high overhead summer sun's arc across the sky. In addition, because the facility is atop a narrow spit of land that extends from the canyon's west rim, around which the Colorado River meanders more than 4,500 ft (1,372m) below, breezes rising upward and across the land form are channeled through an interpretive/dining area below the membrane. The combined effect of shading and breezes frequently results in a 25°F (13.9°C) lower temperature under the tensile membrane compared to adjacent exposed areas. The orientation of the upward, north/south surface curvature, which is raised at the southern apex, invites visitors into the facility and admits lower winter sun into the activity area under the membrane.

At the existing Tucson Zoo 13.1, 13.2 (Client – City of Tucson Parks and Recreation Department; Architects – Burns Wald-Hopkins; Fabricator/Installer – Shade Concepts, Irvine, California), the entry area was





图 12. At the Hualapai Nation Grand Canyon West Visitor facility, the fabric membrane is shaped to shade summer sun, but admit lower winter sun.

Hualapai 自然大峡谷的游客集散中心的遮阳设施中，织物膜的铺设带来了夏日的阴凉，并且容许冬日有少量阳光射入。

redeveloped to enhance facilities, demonstrate “green” building considerations and create a more significant identity for the zoo. A remodeled building arcing in plan from east to west houses a gift shop, ticketing operations and restrooms. In general, the configuration of a tensile membrane provides an overhang above the south edge of the narrow facilities building. The largest area of the membrane, which was extended to the northeast, creates an inviting entry and the most comfortable outdoor area facing the primary visitor approach. This also extends the covered area adjacent to the ticket windows and expands the shaded area in the afternoon in tandem with the increase in zoo visitors. While the primary upward curvature of the membrane is oriented toward this approach, the downward surface curvature is highest in the east southeast and slopes downward to its lowest point on the west northwest, where about 70% of the rainwater that falls on the membrane roof is drained into a cistern. The ticket facilities building roof also slopes in this direction and drains in a downspout to a landscape near the cistern. These combined sources of water have generated and sustained a dense lateral and overhead desert landscape on the northwest side of the entry area, which screens the most intense later afternoon summer sun. The

zoo entry and the Edith Ball Adaptive Recreation Center 13.3 (previously discussed in this article) are located in close proximity to each other in Tucson's Reid Park, within the same redeveloped site and landscape plan area. Both are indirectly illuminated at night and loom large, glowing like gigantic Chinese lanterns within the park, which is frequently used for evening activities and events. During the year-end holiday season, the zoo is open and illuminated in the evenings for a "zoo lights" celebration. Images are projected onto the tensile membrane, which serves as a marquee for this event.

#### Facilitation of Adaptability and Portability

Much like a traditional tent, the pre-stressing tension of a tensile membrane can be released, thus permitting the structure easily to be repackaged, transported and re-erected at one or more different sites. An exhibition structure for the Museum of Modern Art in New York 14 (Lightweight Construction Center, School of Architecture, Washington University, St. Louis, Missouri, Medlin, Schoeller, Fotsch, Bolazina, Cohen, Havland, Lemberg, Peterson; Fabricator/Installer – Stromeyer GmbH, Konstanz, West Germany) is a case in point. Formed using a vinyl-coated polyester membrane with appropriate translucency





图 13-1 photo: Bradley Wheeler

图 13. The Tucson Zoo entry fabric membrane is shaped to direct almost all rainwater to a cistern, where it is stored to irrigate landscaping.  
 图森市动物园入口安装的弹力膜结构，直接积聚所有的雨水到蓄水池，并在蓄水池上形成一道优美的瀑布景观。



图 13-2 photo: Bradley Wheeler

to filter sunlight and reduce glare, this structure facilitated a semi-outdoor daytime use. At night the membrane reflected and diffused electric light that illuminated the space below and created a special emphasis and definition of place announcing an evening event. The pavilion was initially used for MOMA special events and then as a demonstration tensile membrane structure and pavilion for an exhibition of “The Work of Frei Otto” curated by Ludwig Glasser. Later, the pavilion and exhibition were re-installed in more open park-like areas at the Ontario Art Gallery in Toronto and the Museum of Science and Industry in Chicago. In these settings, the openness of the Pavilion's perimeter permitted the placement of the flexible system of exhibition panels to take advantage of each site's existing landscape and circulation patterns. When the exhibition schedule was completed, the structure was installed and used as a multi-purpose activity pavilion on the Chicago Circle campus of the University of Illinois for several years. By the time of this final installation, the tensile membrane erection crew had become so adept at the process that when a film crew arrived after the scheduled final raising of the pavilion, they quickly lowered and re-raised the membrane in a few minutes.

For the Centennial celebration of the University of Arizona, a double-knit polyester stretch fabric was suspended from three posts anchored into the top of a large trailer van and small posts and guys about the perimeter below. This system, together





图 14

图 14. An exhibition structure designed for the Museum of Modern Art, New York courtyard was also exhibited in Toronto and two locations in Chicago.

纽约现代艺术博物馆的庭院中设计的展览结构，也运用到了多伦多和芝加哥的展览活动中。

图 15. The University of Arizona Centennial Exhibit travelled to sites in every county in Arizona during the Centennial year.

亚利桑那大学百年校庆所布设的展示结构在校庆期间发展到了亚利桑那每个郡县。

图 16. At Crown Center in Kansas City, Missouri umbrellas and dual module pavilion structures can be deployed in several configurations to accommodate a wide variety of community events.

密苏里州堪萨斯城的 Crown Center，伞形的拉伸膜和双模块结构搭建的展示结构，进行了多种灵活的组合，从而适应了各种各样的社区活动。



图 15

with up to three additional free-standing tensile membrane sail structures, exhibition panels, a stage and exhibition platforms called the "Arizona Spirit" exhibition 15 (Design, fabrication and installation by faculty, staff and students, School of Architecture and the Environmental Research Lab, stretch fabric canopy – Medlin, Bogan, Frazier) could be set up or taken down and prepared for transport in a few hours. During the Centennial year the exhibition was installed at shopping centers in Tucson and Phoenix, every county fair, the Arizona State Fair and on The University of Arizona mall three times attracting over four-million visitors.

At the Crown Center Plaza in Kansas City, Missouri 16



图 16





图 17. A modular pavilion can be set up with two or more modules to accommodate small to very large events.

模块化的展示结构可由两个或多个模块组合搭建，以适应小型的或更大型的活动。



图 18. Modular pavilion set up as a music pavilion for the Big Sky, Montana Music Festival.

模块化结构搭建的展示厅成为了 Montana 大时空音乐节的音乐演奏厅。

(Engineer – Irv Engel; Fabricators/ Installers – Membrane, Bird Air, Buffalo, New York; Umbrellas, Feller Scenic Studio Bronx, New York and Irvin Industries, Lexington, Kentucky), a kit of parts has been created, consisting of two 75'x 75' tensile membrane, vinyl-coated polyester pavilions, which could be used together or separately; ten 30' diameter umbrella structures and various supporting elements, which could be deployed on a lower and/ or upper plazas to accommodate a wide variety of community activities. Events held included auto, boat, livestock, rare books and sidewalk art shows; music and theater performances; a discotheque/ cinema; an Easter parade and egg hunt and various ethnic and cultural events.

In a modular tensile membrane system, the surface curvature of each module was enhanced by alternating high and low points along the edge and across each module by employing "S" curved ridge cables between the modules that arc downward to the low points, pass through a center inflexion point and arc up to the high points. The basic system consists of alternating hand interior modules, a module that closes the end of the system, and a module that raises upward to provide an inviting primary entry at the opposite end. This type of system can be seen in a grouping of six modules that was set up in Pasadena as an entertainment venue for the Rose and Super Bowls 17 (Client/Fabricator/Installer – Academy Tent, Los Angeles, CA; Structural Consultant- Michael Barnes, London).

The simplest configuration of



the system is joined entry and end modules. Together with a stage and acoustical shell built by local volunteers and a sound system, this arrangement of modules served as pavilion for the Big Sky Music Festival and the summer home of the New World Symphony 18 (Acoustician – Christopher Jaffe). The largest deployment of this system to date was 22 modules for a Southern California Automobile Show.

### Transformability of Tensile Membranes

The ability to tension, release and re-tension membranes and the capability of stretch fabrics to be stretched to different overall dimensions offers the potential to transform or reshape structures, as appropriate, in response to changing conditions. Objectives using this potential were the subject of two recent studies at The University of Arizona School of Architecture. Working in the Emerging Material Technologies area under the leadership of Prof. Alvaro Malo and with other faculty, Brent Vander Werf conducted a study "Elastic Systems for Compliant Shading Enclosures" as his Master's thesis. Vander Werf developed a self-regulating shading system using a bi-stable capacitor mechanism that moves between two stable positions to open and close eye-shaped apertures to which a stretch fabric membrane is attached. A prototype of the system was installed in the east window of The University of Arizona SEEDpod Solar Decathlon project 19 (previously reported in the 106:2010/02 issue of Chinese & Overseas Architecture). The system automatically responds to changing sunlight or thermal conditions to admit sunlight or provide shade.

Another University of Arizona graduate student working in the same area, Nicholas Johnson, is currently studying the transformation potential of a stretch fabric membrane shaped using an "S"-curved ridge between two membrane segments. By raising or lowering the membrane apex points at the supporting masts, the membrane configuration can be transformed from being raised and open to sunlight to being lowered to provide shading, as is appropriate for varying sunlight intensity and ambient temperature conditions. 20.

Since humankind's early use of tents, membrane structures have been adapted for changing uses and conditions. Current global concerns for efficient use of materials, energy and other resources, along with a manner of building that respects or even contributes to regenerating the natural environment, and significant improvements in materials and techniques for creating tensile membrane structures, all suggest limitless potential for their future utilization.

**【About the Author】** R. Larry Medlin is an architect/lightweight structures consultant and Professor of Architecture at The University of Arizona School of Architecture and he worked on all the projects in this article. Other principals and key participants are listed for each project. He can be contacted at: [rlmedlin@u.arizona.edu](mailto:rlmedlin@u.arizona.edu). See more of his work at: [www.RLarryMedlinTensileStructures.com](http://www.RLarryMedlinTensileStructures.com)



图 19. Self Regulating Shading System installed in east window of The University of Arizona Solar Decathlon Project. 安装在美国亚利桑那大学东边窗户上的太阳能十项全能项目中的自我调节遮阳系统。



图 20-1

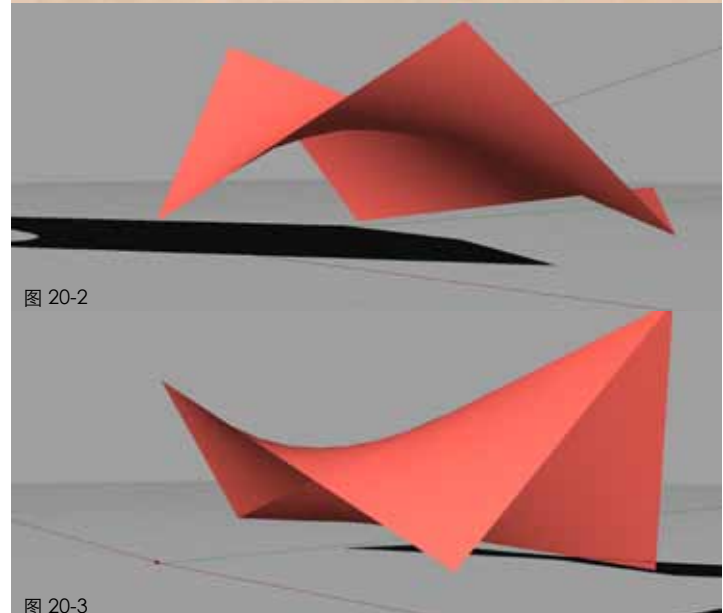


图 20-2

图 20-3

图 20. Current studies for a Transformable Membrane at The University of Arizona. 亚利桑那大学目前正在研究的一种可变性拉伸膜。