AN HISTORICAL OVERVIEW

OF

MEMBRANE STRUCTURES

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INTRODUCTION;

To meaningfully seek the derivation of any special sector of building design and construction one cannot just look at the last ten years or the work of a few prominent architects. It is useful to look at past events which provide the ground for the development.

History as a science is inexact in the extreme. It is a continually altering body of data which we use as reference. Facts are facts , but selective bracketing can demonstrate patterns by which we operate in our work or home environments .

Construction , the field of designing , manufacturing and building is constantly bracketed to look at trends emerging as is seen by the content of magazines passing over your desk in any month.

The subject of this paper is the trend in the annals of structure towards lightness of construction , progressively with the passage of time.Specifically it looks at the source in design methodology and materials technology of Membrane Structures.

The thesis can be amply demonstrated by a comparison between the Pantheon in Rome (AD130) and Fullers Montreal Expo Dome (AD1967). Perhaps of more relevance to the paper is to continue the range to the Pontiac Silver Dome near Detroit built 1975.

IRON & STEEL DEVELOPMENTS;

To draw on historical material it's useful to look back on transitions and then see trends developing. There are a multitude of influences operating simultaneously and we could term our era *`Late Industrial Revolution Building Science'*. .Starting from 1779 with the first iron bridge at Coalbrookedale, we can encapsulate the modern age of new materials.

Fig 1 - Detail Coalbrookdale Bridge

Development in theory and practice of structure accelerated more after the development of mass produced iron castings and wrought works than at any time previously.

Great Britain's world dominance economically and militarily gave her the lead with many brilliant and innovative designers like Telford, Brunel and Stevenson etc. who commenced the golden age of engineers where building as a science separated from building as an art or craft.

Isambard Kingdom Brunel ,a monument of the time carried out a broad range of works including the Thames tunnel construction, railway and locomotive design including their stations, metal ships ,their propulsion systems and of course, bridges.

His *'hanging chain'* Clifton Bridge design at Bristol contrasts with the heaviness which typified previous works like the Saltash Bridge [1859]. The Clifton Bridge was completed as a tribute to him by his peers after his death.

He died before Bessemer developed the *blast furnace* in 1856 which made steel available to further the development of lighter and longer span structures by its improved material properties.

Fig. 2 - Isambard Kingdom Brunel

The Crystal Palace, perhaps the first fast-track project, also missed this milestone by a whisker. It was built by Paxton in 1851 - a dramatic demonstration of modernity with extensive use of skeletal metal members and glass infill. It's very close philosophically to contemporary methods, but it was built from cast iron.

Gustave Eiffel built his tower in 1889 and it contained 10,000 tons of steel and cast iron. It was then considered to be a temporary structure. One could observe that this was not a lightweight structure but by comparison, with say the Leaning Tower of Pisa, the conclusions are obvious, masonry versus spatial construction.

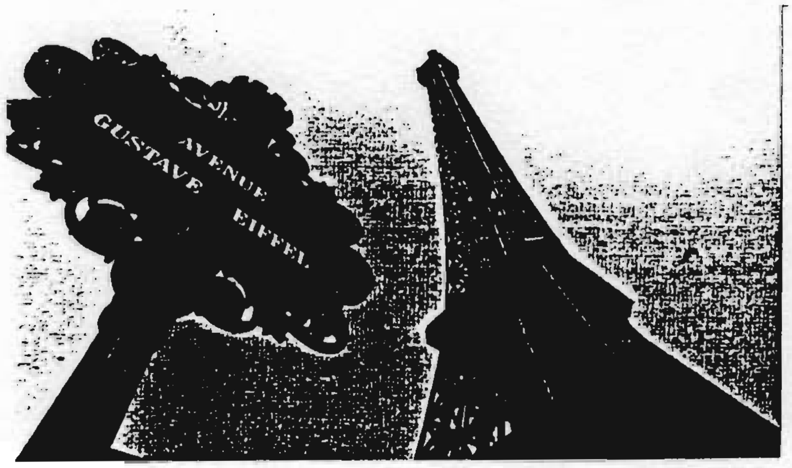

Fig 3 - Tour Eiffel

What drove this movement in structures from massive to lightweight were various factors.

Important amongst them were cost and science.

The really big breakthroughs in computer techniques were not to occur until more recently but from the middle of last century to 1900 was a very fertile time in the western world where the industrial revolution moved into a higher gear.

Western world economies were booming; expansion was phenomenal ;throughout the world colonies were being developed and new markets created. Transportation systems pushed contact across the world and products were interchanged massively with little opposition from trade barriers. Resistance was largely suppressed by colonial wars and Europe, with America emerging, dominated the world economically and politically.

THE TWENTIETH CENTURY;

With new high strength materials, the emerging engineer class rapidly developed innovative new ways to build longer and bigger. The high rise building construction boom began some time in the late 1800's with Sullivan's Wainwright Building in St. Louis using the first complete steel frame. Before 1920 in New York, the first 50 storey building had been constructed. By 1932 they were over 100.

Meanwhile metallurgy and chemistry developed side by side and developers as ever sought cost effective ways to turn buildings into profitable operations.

Architects at the turn of the century were fed and inspired by a new awareness of international destinations made possible by the increased speed of travel and its ready availability. The influences of Japan, China, Mesopotamia and Egypt was strong upon the designers' palette. *The Art Nouveau and Art Deco* period grew from these and we can see the legacy of this still today.

The streams of construction were extremely diverse as experimentation continued unbridled.

The beginning of the century saw air travel commencing, initially using massive air ships. Specially designed lightweight structural frames were required to reduce the mass and enable the lift equation to balance with their highly flammable hydrogen contents.

Fig. 4 - Art Nouveau Style

Pier Luigi Nervi moved in one direction with in situ and pre-cast concrete constructions of extraordinary, elaborate minimalism to reduce the bulk of previously executed works.

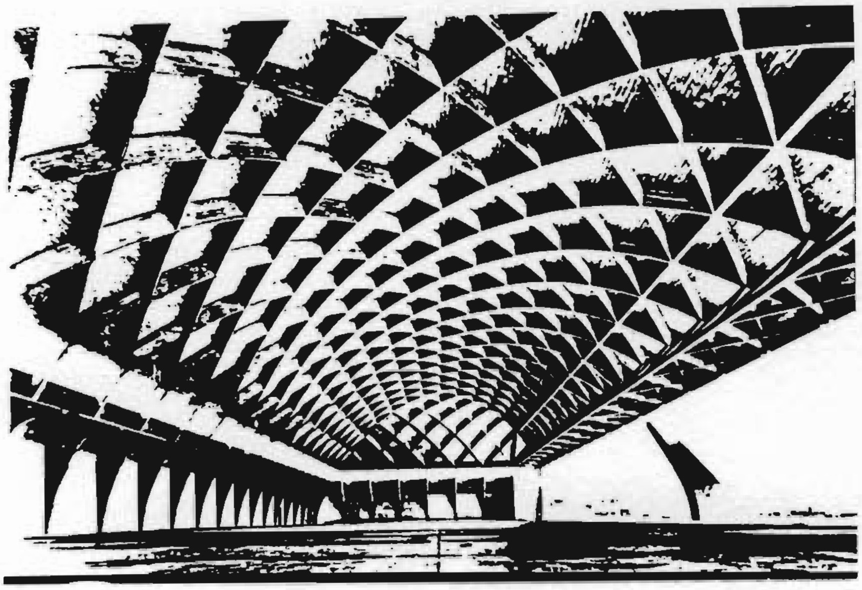

Fig. 5 - Nervi Hangar [ROME]

Two wars came and went in Europe leaving devastation in their wake. Reconstruction followed with the first of the industrial revolution dirt floor factories being swept away by the bombs and artillery barrages. The new factories which replaced them were modern, long span buildings. These wars gave impetus to industry to design buildings, bridges and military equipment in lighter and lighter materials to fight a war across an entire hemisphere. Hot riveted ship construction disappeared and welding developed as the technique during that period.

Post-war reconstruction heralded a new boom which has perhaps only ended now, although geopolitical shifts in Eastern Europe may extend this. The United States initially lead the world in technology and military power while its designers took a fresh approach to *lightweight structures.*

SADDLE SURFACES EMERGE;

Engineer **Fred Severud's** firm was instrumental in inspiring works which were part of the genesis of membrane structures. **Mathew Nowicke** [architect] with **Severud**, built the saddle shaped Raleigh Arena in North Carolina in 1952, extensively using cables.

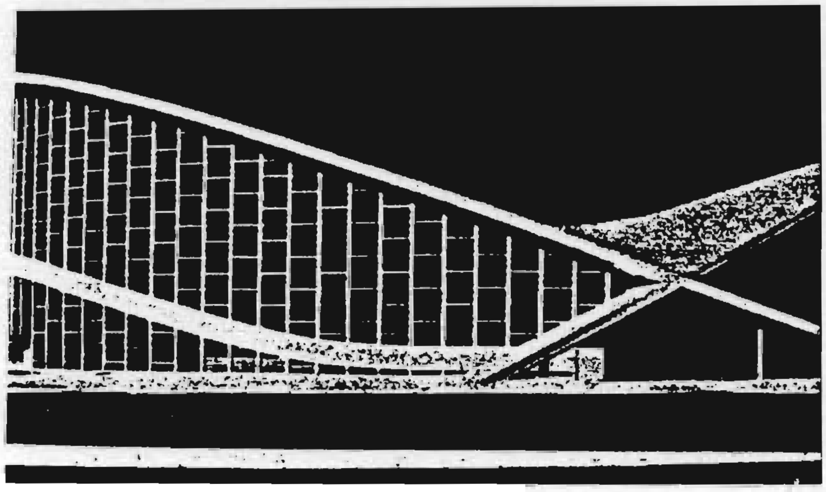

Fig 6. Raleigh Arena

In 1956, **Eero Saarinen** with **Severud**, built the TWA Terminal in New York, again a classical precursor to membrane forms as we know them.

Fig. 7 - TWA Terminal [NEW YORK]

Both **David Geiger** and **Horst Berger** worked in the firm and both became legends of design, the former in superdome pneumatics, the latter for long span tension structures. Sadly, **David Geiger** is now dead and last year **Horst Berger** rejoined the firm where he now works.

In Australia in 1955, **Peter MacIntyre** with **Kevin Borland** (architects) designed the Olympic Swimming Centre, followed in 1958 by the more purist Myer Music Bowl by **Yencken and Freeman. Irwin Johnston** were engineers on both.

In 1961, **Kenzo Tangye** and **Koji Kameya** designed inspired stadia for the Tokyo Olympics. These were all major structures utilizing curved, sometimes anticlastic surfaces so familiar to tent structures of today.

Fig. 8 - Tokyo Olympic Structures [JAPAN]

They became a guiding light to the next generation. They had in common an extrapolative engineering approach to design and all were clad in somewhat traditional forms.

DEVELOPMENT OF TENT STYLE;

Meanwhile, quietly in Germany and in the U.S.A., Frei Otto and Walter Bird were separately working on developments using flexible fabrics. Otto developed through a productive long term working relationship with Peter Stromeyer, principal of an old firm of tent makers in Germany.

Wally Bird started in 1946 with his first air supported Radome. He and his group painstakingly worked through the principles of flexible structures with the assistance of the U.S. mililtary and their developing needs for an extensive radar network covering the north west flank of the United States to give early warning of a potential attack from the cold war enemies.

Fig 9.- Atoms for Peace-Birdair

While pure sources in architectural history are generally blurred, one could almost draw clear lines between Wally Bird's early work and the resulting field of pneumatic structures while similarly recognising Frei Otto as the precursor of the tensile tent structure.

Fig 10 - German Pavilion [MONTREAL]

Otto teamed up with Rolf Gutbrod to win major competitions. A milestone in the development of membrane structures was the cable net supported German Federal Pavilion for an Expo in 1967 in Montreal, an event which also featured Buckminster Fuller's equally brilliant geodesic dome. At about the same time, the I.L. [Institute for Lightweight Structures] in Germany began its life in the full scale model of part of his Expo structure.

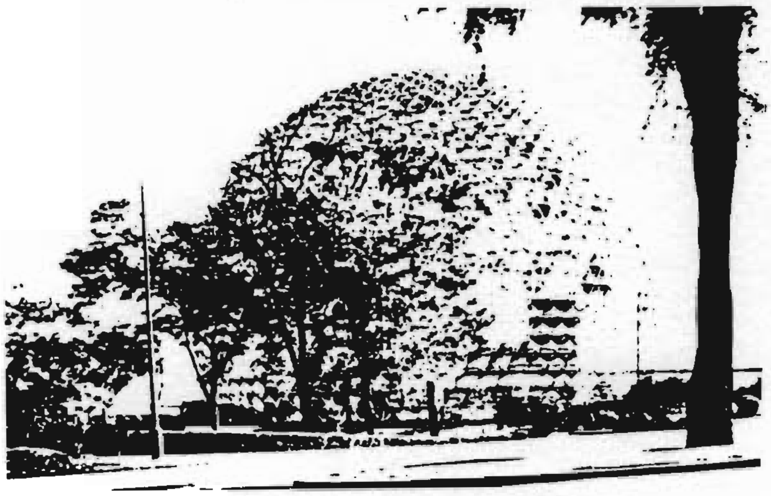

Fig 11 - Fuller Dome [MONTREAL]

Computational techniques for analysis or surface determination were, if in existence at all, only in their infancy and these structures were generated and formfound by a laborious method of model making and measurement supplemented by an ingenious but complex method of photogrammetry. Despite this arduous process, the work produced created sensations.

The Munich Olympics Stadium in 1972 designed by Otto and Gutbrod and built by Behnisch and Partners, using Leonhardt and Andra as engineers, created an international yardstick for excellence in curved surface structures which remains today.

One could be forgiven for considering the post-war period as the *tensile era* if only in exposition and Olympic structures. Surely they have dominated in these fields.

German designers and practitioners received sustained support for innovative curved membrane forms from the *Federal Garden Exhibitions* which were held across Germany regularly. These featured the emerging German technology and in particular , tent structures.

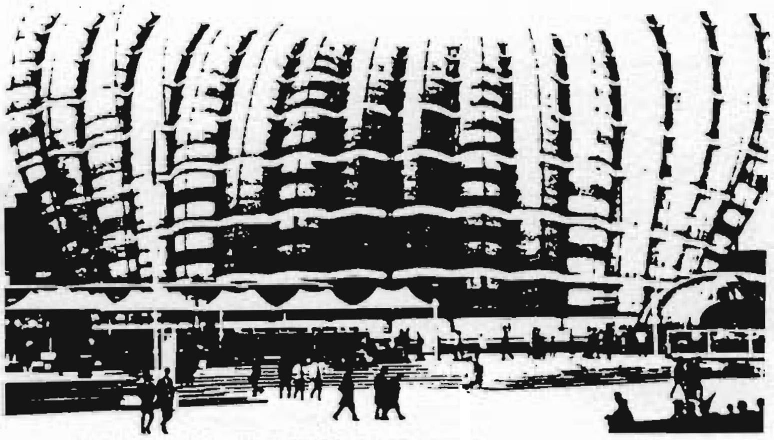

Fig. 12 - Fuji Pavilion EXPO 70 [OSAKA]

Meanwhile the Japanese fabricators who had visited Germany to look at these developments , launched onto the international stage with gusto in 1970.

Expo 70 marked the emergence of a dynamic industry which has since become almost pre-emminent in the world.

Locally held Expos in Japan which regularly expect a gate of millions of persons , have become the equivalent of the German Garden Shows. These Expos display an array of spectacular light weight structures including some of the more inventive membrane forms yet built

At the 1970 Expo , the *US pavilion* (Geiger engineer) unveiled a new form of long span air structure utilising a low profile cable net restrained membrane fixed to a perimeter berm. This structure opened the door for the super dome stadia built through to the middle of the 80's mostly in the United States. These spectacular and monumental structures provided the low cost , light weight solution to roofing football grounds and other sporting facilities in climates where snow and rain prevented normal activities.

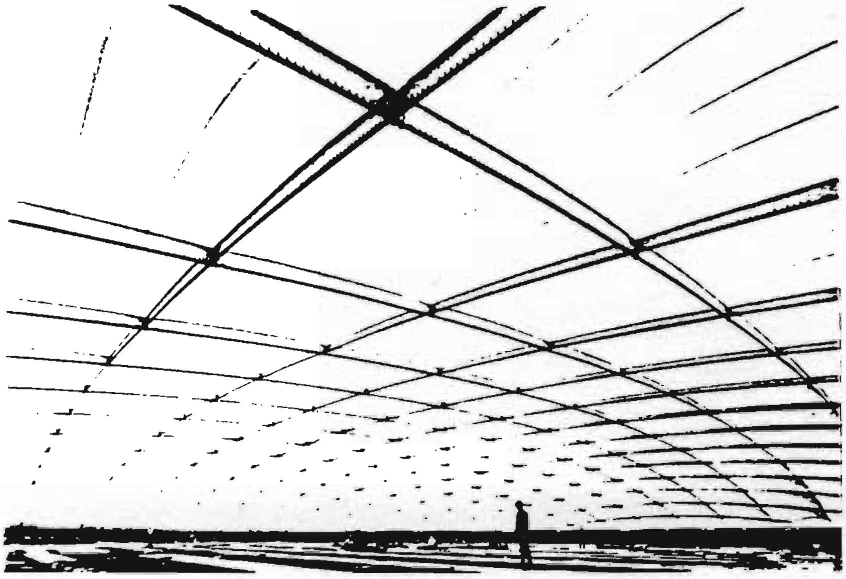

Fig 13 - US Pavilion EXPO 70 [OSAKA]

The use of the structures has been largely limited to the USA although the *Burswood Resort* in WA is a small version. The technology is now being applied in Japan and when rules regarding grass playing fields change in Europe , we can expect to see stadia roofed there in a similar manner.

MEMBRANE MATERIAL PROPERTIES;

The technology of designing and building membrane structures has been directly influenced by the materials available for use at any time. During the short history designers have constantly sought more durable and generally improved materials for use in structures. One of the intrinsic problems has been the relatively minor share that architectural fabrics has of the total market for composite fabrics.

Until the industry developed there were few manufacturers who would invest the necessary funds into R&D to produce materials which the industry sought. A classic chicken and egg problem.

Being the traditional material used on tents and awnings , *canvas* was used on most early works. Membrane structures now owe much to the craft of tent making ,the history of which stretches back into the obscurity of pre-history. This industry produced Circus tents of gigantic proportions up to the present day .It has traditionally supplied military organisations with temporary accommodation on a large scale.

Fabrication and construction methodology of the new prestressed tents , which were made by the existing industry ,carried the signature of previous techniques of construction. As the industry moved more into the mainstream of the building industry and distanced from temporary event structures , it required a new set of techniques , specifications and skills to accommodate the new demands of truly engineered structures.

Early work in air structures for radomes needed a gas tight membrane which excluded canvas immediately. Ottos work in tension structure design called for membranes which could accommodate higher loads than canvas and better tear strength. Light weight synthetic fibres were trialled with *Polyester* being the most used for the ensuing three decades.

Physical properties of high strength , lightness and flexibility along with relative cheapness and ease of production turned the page of history forever away from organic fibres as the industry began the long and successful application of *PVC (Polyvinyl Chloride) coated woven Polyester cloth.*

1970 proved to be a milestone in development in materials as it pointed to a long span potential ,previously not applied. The US pavilion at Expo 70 had been fabricated from PVC coated , woven glass fibre , a departure from polyester which heralded a new era of flourocarbon coatings. The potential for enduring membrane structures was recognised and within four years the first structure was built from *PTFE (Teflon) coated woven glass fibre.*

La Verne College sports facility (1974) became the first structure built in this new material. Thus the industry moved further from its craft base with two materials available. Each held intrinsic advantages for applications in structure but now the designers could more completely select the engineering properties wanted for the specific project parameters.

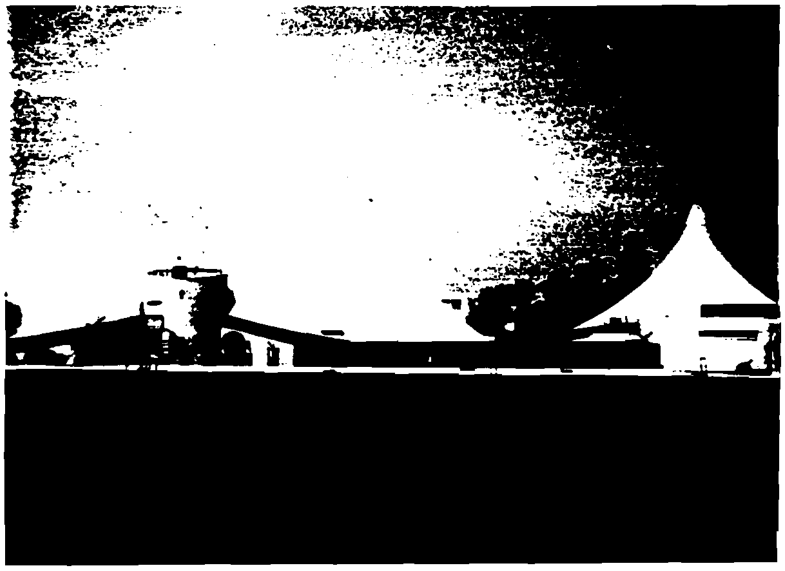

Fig 14 - La Verne College [LOS ANGELES]

Each fabrics particular properties brought about subtle and gradual changes in design methodology as the designers responded to fabrication limitations of new materials. The highly curved forms typical of the flexible , inexpensive PVC coated materials slowly gave way to lower curvature shapes which reflected the economies of panel cutting required by the much more costly PTFE/Glass fabric.

New *flourocarbon coatings on PVC* arrived to improve finish , durability and appearance. *Woven PTFE fibres (TENARA)* and extruded clear *ETFE film* sheet have begun new application areas in unworked parts of the market. In this country the capacity for providing large areas of shade has hardly been exercised.

WORLD MILESTONES IN MEMBRANES;

As the *Munich Olympic Pavilions* were to Germany , *Expo 70* was to Japan and construction of the *Pontiac Silver Dome* was to USA , while *Yulara* was to Australia and the *Haj Terminal* was to the world. Each of these were significant structural events which transcended parochialism of genre or country. They symbolised the reality of this soft shell stuff to those who previously considered it whimsy.

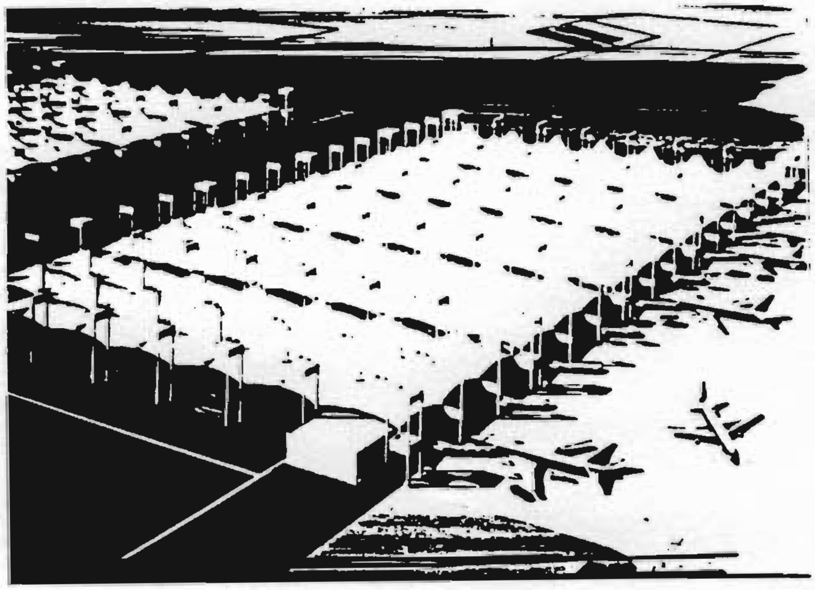

Fig 15 - Haj Terminal [JEDDAH]

Respectability flooded in and from that day to now Expos and Olympics , exhibition halls , swimming pools , shopping malls and atria are increasingly finding the quality which these indoor/outdoor forms lend to buildings.

By the early 80's sophisticated and dedicated computing techniques abounded so that not only analysis and shape finding but graphic imaging of these sculptural forms were possible and readily available. Specialist fabrication groups evolved usually from existing fabrication companies and designers emerged often from the influence of **Frei Otto and the IL team.**

Like any new field the apparent development is exponential in the earliest times and indeed spectacular works of stunning complexity and ambition were successfully undertaken with meagre facilities by todays standards. Pioneering stuff for sure.

Recent works have seen a maturation of application in structures such as **David Geigers** *cable dome system* which applied a form of Bucky Fullers *Tensegrity networks* tin conjunction with fabrics to roof structures at the Seoul Olympics and St Petersburg.

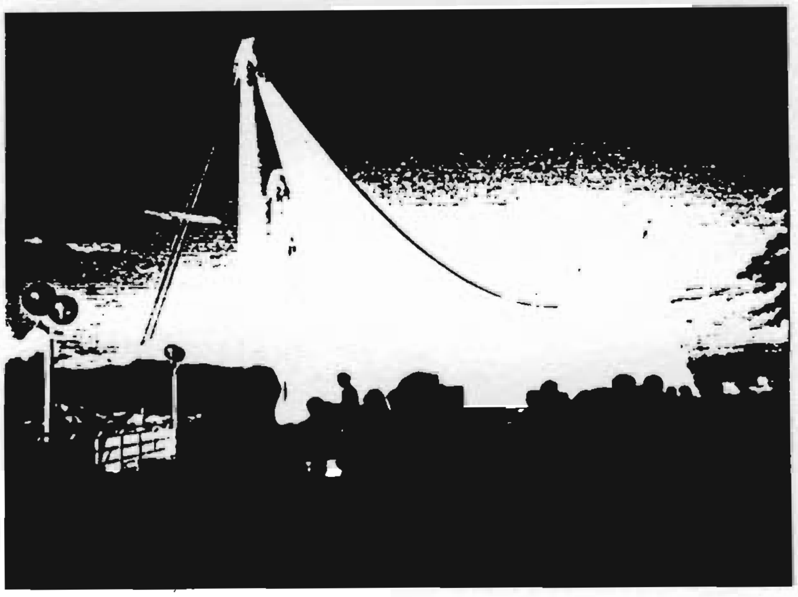

Fig 16 - Canada Place [VANCOUVER]

Vast areas of pneumatic pillow roofs have covered a tropical plant house at Arnhem in Holland using the revolutionary ET film and a forest of Tenara clad mechanised, auto opening umbrellas of 10 metres diameter have finished testing and are planned for use in Mecca. Barcelona will be another glittering array featuring the recent works of **Harald Muhlberger** and the new **Michael Barnes/David Wakefield** combination.

The recent Nuage Leger (light cloud) at the Grand Arch in Paris (**Peter Rice,Henry Bardsley,Ove Arup**) for the Bicentennial of the Republic presents membrane as major sculpture and in Japan , well that's where the next millenia begins.

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