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PERMANENT ARCHITECTURAL FABRIC STRUCTURES: RETROSPECTIVE AND PROSPECTIVE VIEWS (1990)

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I. INTRODUCTION

Exploited by nomadic tribes almost from the dawn of civilization, the use of fabric to provide mankind with shelter from the natural elements of sun, rain, wind and snow is an architectural design strategy whose origins are lost in antiquity.

However, the tactical elements for its fuller exploitation relative to other engineering options have only recently been explored, refined and commercially resolved. These elements are as new as the discovery of high performance polymers, methods for their incorporation into advanced composites and the development of a computerized methodology for the analysis of their non-linear, time-dependent viscoelastic behavior. These elements have finally come together over the past twenty years to lend credibility to the concept of permanent fabric architecture.

In a very real sense, it is arguable that the development of a theoretical basis for the various aspects of this technology, its acceptance by the design professional community, and the establishment of a credible commercial base for its implementation represent a watershed in the exploitation of this strategy which has gained substantial momentum over the past twenty years. It may be plausibly argued today that significantly fuller exploitation of the "structural fabric option" can be expected in the built environment of the twenty first century.

It is not my intention, today, to offer an in-depth discussion of the many aspects of technological advance which came together to create this watershed. They are both too numerous and too complex for so brief a presentation. And as importantly, you will hear from others at these proceedings of such advances.

Rather it is my intention to share with you, from the vantage point of an active participant, a sense of the unusual circumstances, the single-minded dedication of a development team, and the manner in which incentives were provided to encourage early commercialization of the concepts based upon laboratory findings of technical feasibility. I will try to draw from the experience of these past twenty years the apparent trends to the continued advancement of various aspects of the technology, and its embodiement in specific applications. Lastly, I will comment on the even "greater expectations" initially envisioned which remain as a challenge to future generations of scientists, engineers and entrepreneurs.

II. HISTORICAL RETROSPECTIVE

In anticipation of the World's Fair which came to be known as EXPO '70 some twenty years ago, design professionals all over the world were commissioned to facilitate the "architectural statements" which have become the hallmark of such events. This particular fair, however, came to be recognized as a real challenge insofar as the relatively sandy soil of the site at Osaka, Japan exhibited a limited load bearing capability. Consistent with this condition, the entire fairground became an extravaganza in fabric architecture.

It was at this fair that a young American engineer was able to realize his expectations for a structural fabric option he had envisioned: an air-supported structure with its inherently long, clear spans but without its typically bulbous envelope due to the presence of a grid of restraining cables anchored in an earthen berm. The United States Pavilion based upon this design was not only a "visual success", readily distinguishable from the other more typical fabric structures, it was the technical success hoped for as well: its aerodynamic envelope performed exceptionally well in typhoon winds.

That engineer, the late David H Geiger, exhilarated with this engineering success returned to the United States convinced that the limited applicability of fabric structures to temporary facilities could be substantially extended to a broad range of permanent structural applications, including domed stadia, field houses, arenas, atria and even office parks. However, a requisite element to render this conviction viable to him was the definition of a coated fabric with a range of properties superior to the PVC coated fibreglass employed at Osaka. It was his perception that the combustibility, long term weatherability, and light transmission/soil resistance of the coated fabric could be substantially improved upon.

Armed with his reputation as a successfully innovative engineer, a well articulated sense of materials performance, his entrepreneurial instincts, and the zeal of a missionary, David Geiger launched a compaign to seek support for the development of such a fabric, and its installation on a project in the United States to prove its feasibility.

It had occurred to Dr Geiger that a fabric of woven fibreglass coated with polytetrafluoroethylene (PTFE) was the most likely genre of coated fabric which might prove suitable in such application. In an effort to define an incentive for major producers of these materials to support his objective, Dr Geiger sought the assistance of the Educational Facilities Laboratory of the Ford Foundation. Its Director, Dr Harold Gores, had been instrumental in funding the grant which had lead to his concept of a low-profile fabric structure as exemplified by the U S Pavilion in Osaka. It now seemed timely to explore anew its adaptability. Through the efforts of Dr Gores, the Presidents of two small colleges were inspired to make available two projects, already contemplated as fabric structures, to test the feasibility of the yet-to-be-defined improvement in coated fabrics sought by Dr Geiger.

It was this exceptionally bold offer providing real world, multi-million dollar "laboratories" for proof of the technology that caused both E I DuPont and Owens-Corning Fiberglass Corporation to take a serious interest in the development. Each of these companies agreed to explore the viability of the concept in their laboratories and examined the issue of combustibility, weatherability, and durable translucency.

However, as essential as laboratory research was to confirm the desirable performance of PTFE coated fibreglass composite, the existence of actual projects on which feasibility was to be demonstrated placed a time constraint upon the determination. In the case of fire performance, it would also be necessary to obtain code approvals for the proposed structural format. Moreover, it would be necessary to develop commercial relationships with not only a weaver and a coater, but to designate an engineering fabricator/installer at the earliest possible date in order to meet the proposed construction schedules.

With what in hindsight can only be described as the most serendipitous of decisions, the Chemical Fabrics Corporation was identified as an appropriate coating partner for such a development given its wide coating equipment, and Birdair Structures Inc was identified as the most experienced and technically capable fabrication engineering company from the point of view of evaluating and fabricating new composites. Ultimately, the Chemical Fabrics Corporation had to invest in weaving equipment to supply its requirements for wide woven fabric, a decision technically supported by Owens-Corning to meet the schedules for commercialization. In short, it possessed precisely the entrepreneurial instincts which would later be required to address the markets as well as the products for fabric construction. As many of you know, CHEMFAB ultimately acquired Birdair Structures and presently operates it as a joint venture.

In effect, a loosely defined development team had come into existence whose sole objective was to define and commercially produce, for realworld evaluation, the PTFE coated fibreglass fabric envisioned as the key to exploitation of structural fabric strategies in permanent construction.

Through closely coordinated action, the accomplishments of this team were such that by May of 1973, - barely two years after work had begun, - the first project based upon the newly developed fabric was under construction at LaVerne College in California. This tension structure was quickly followed by a low-profile, air-supported structure at Milligan College in Tennessee. Both became useful laboratories for the evaluation of the technologies they represented from both a materials and design point of view.

It is probably of some significance to note that this particular mode of development commercialization resulted in an acceptance of the technology to the degree that a ten fold scale-up in plan area occurred within two years as a domed stadium was undertaken, and of one-hundred-fold as the "shaded village" known as the Haj Terminal in Jeddah was undertaken five years after that. There have been few introductions of a new building technology which can boast such acceptance, and fewer still that owe their inspiration to the vision of a single individual. This is not to diminish the significant technical contributions of others such as Walter Bird who guided the fabrication and installation, or of OCF whose experienced approach to code compliance and construction services became an imperative, nor that of DuPont who assumed the role of integrator and served as technical conscience for the team, and certainly not that of CHEMFAB's John Cook whose "can do" posture colored every decision. Rather it is a tribute to the character of David Geiger who brought them all to concerted action.

III. APPARENT TRENDS

Nearly twenty years after completion of those prototypical structures offered as a technical proof, PTFE coated fibreglass remains the material of choice in permanent fabric architectural.

It is instructive, however, to note the various structural applications to which they have been put, and even more instructive to note the subtle changes in project appearance as the design professional community has increased its involvement with their use.

Indeed, it is not likely that such involvement has heralded the modification of the coated fabric itself to enhance its aesthetic appeal, while a greater understanding of its micromechanical structure may facilitate the design of composites with exceptional mechanical efficiency.

1. Structural Format and Construction Methodology

Stadia have been perceived as constituting a significant opportunity for permanent fabric architecture from the earliest days of development. This has certainly proven to be the case with a dozen now in place and another in progress. Not surprisingly, many of these are in the United States, but there is a major stadium or field house on every continent with the exception of Africa and Antarctica which boasts a roof of PTFE coated fabric.

Many such stadia are designed as air-supported structures (e.g. the Burswood Island Superdome in Perth) providing the most economical, clear-span structural format. A desire to provide shaded seating with an open-air playing field, however, has lead to "diadem designs" such as the International Stadium Riyadh, and the recently constructed stadium in Rome which was host to the World Cup Soccer Championships last month.

Other stadium designs have relied upon a tensioned cable net and flying trusses to provide a fully enclosed, clear-span at a premium cost relative to an air-supported structure, but which is not dependent upon pressurization for structural integrity. A dome of this type has been constructed in Korea and another, based upon PTFE coated fiberglass, has been proposed for the city of St Petersberg, FL, while a third has been proposed for the city of Atlanta.

While very early construction methodology contemplated the use of helicopters to install cables, it has generally been found that winches, hydraulic jacks, spreader beams, and large cranes are more appropriate to the task of installing the rings and cables of the stadium roof. This is an area of technology development for which experience has, not surprisingly, proven to be the best teacher.

2. Large Atria and Skylighting

Another architectural format which lends itself well to fabric structure is that of skylighting, particularly on a large scale such as the atria of a modern hotel, town centre. or mall.

The evolution of design format for a shopping mall is readily evidenced in this slide sequence illustrating an older, outdoor strip mall in Miami prior to retrofitting with a skylight corridor, and after such treatment using PTFE coated fabric. Note that the fabric itself may be employed to create decorative effects through layering in which the inner layer represents an acoustical treatment also based on PTFE coated fibreglass.

Success in such application lead logically to the use of such skylighting strategies in upscale malls such as the one at Sherwood Gardens (Canada). The effect at night when lit internally by reflected light is dramatically distinct from that during the day when lit by transmitted light.

Note also the trend to combine transparent (glass) and translucent lighting elements (PTFE coated fibreglass) in a single treatment. An impressive atria utilizing that concept may be seen at the Hyatt Regency near the San Francisco Airport. Visual contact with the outdoors is established while maintaining the dominance of diffuse translucency associated with PTFE coated fibreglass.

Since seams are a natural consequence of materials produced in finite widths, they have provided an interesting challenge to the designer with a keen eye for aesthetics.

One option, which has been well explored in Australia, is to harmonize the seams within its complex structural framework as at the Myer Centre in Brisbane. A particularly pleasing design involved the first use of circumferential seams in a modular barrel vault as shown here at Melbourne's Chadstone Shopping Centre. There have even been designs which exhibit no visible seam at all by concealment behind a structural member.

3. Sculptured Statements

Some of the most visually exciting designs are those such as the Canada Pavilion in Vancouver which set out to create a specific visual impression, - that of a fleet of sailing ships at a mooring.

Such mood setting sculpture lends itself readily to houses of worship such as St Anne's Church in Seaford, Australia.

It seems likely that the use of fabric architecture will continue to be imaginatively employed by designers to create an ambience of light and sculptured form. And it is almost certain that colors or tints will be brought more into vogue by such designers. The technical feasibility of colour and decorative effects are demonstrated in the unique structure sculpted for Qantas Airline, complete with logo.

4. Micromechanical Modeling

While designers have been busy finding new ways to incorporate structural fabrics into new uses while creating more visually pleasing effects, material scientists have been devising models for the theoretical characterization of coated fabrics and the experimental verification of their structural capabilities.

The term coated fabric itself has begun to give way to that of flexible composite, particularly at Chemical Fabrics Corporation which has long recognized the distinction. Its research over the past several years has been aimed at selectively deploying both thermoplastics and elastomers, as well as alloys of such polymers within a fibrous network of equally well defined geometry and composition.

Its objective has been to develop a sufficiently good understanding of the micromechanical behavior of a flexible advanced composite to permit the design of more mechanically efficient composites with minimal compromise of other critical properties such as weatherability, combustibility, solar-optical behavior, and surface energy.

The benefits of such modeling are expected to lead to more efficient mechanical designs of composite materials themself, as well as to a greater degree of design freedom when incorporating them into structural systems.

IV.

There are at least two potential features of permanent fabric architecture which remain to be achieved in the future. One relates to the scale of construction, while the other relates to the ability of such a structure to generate its own internal environment.

These are in at least some sense related since if the latter could be achieved, its execution on a reasonably large scale would be highly desirable.

First suggested in 1968 by Nickolaus Laing, the principles are deceptively simple. By selecting composites which could accept solar gain during periods of insolation (day time) but which would exhibit minimal thermal loss at night, after a period of about twelve days, a subtropical microclimate would be developed within such an enclosure even at the latitude of Newfoundland. Such a system would utilize fossil-derived fuels only for "control systems".

conversely, by rejecting solar gain during daylight hours and utilizing the black body behavior of the night sky to radiate thermal energy, a refrigerated internal environment could be obtained even in the Sahara - again with minimal use of fossil-derived fuel.

The structural aspects seem well enough in hand given the scale already achieved (Haj terminal). But the thermo-optical switching mechanisms (materials) have yet to be defined.

It's an idea whose time has surely come given the need to utilize renewable energy sources and to minimize the production of green house gases.

Furthermore, it is interesting to contemplate the relatively low costs likely to be associated with elimination of the primary weathering loads of UV radiation, extreme temperatures, rain and wind from the materials of construction inside such an enclosure. Perhaps there is an even greater architectural opportunity within such an enclosure, but at least for now, the focus is on the enclosure itself.