RIGID EDGE, BUILDING ATTACHED MEMBRANE STRUCTURES. CASE STUDY: AMADO ROOF STUCTURE, TECHNION-ISRAEL.

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Space structures are those that owe their structural performance mainly to the way their material is distributed in space. Paradigmatically, their design is dominated by the desire to minimize the amount of invested material and energy in their construction. Therefore, space structures are causal and could be rationalized, analyzed and optimized.

Structural Morphology is mainly concerned with:

1. Investigation of causal structural forms and in particular with the least-effort-stress structures, and the process and dynamics of their form generation;

2. The study of the structure of space, its order, periodicity and organization (and their inhibitive constraints), in relation to the structures which inhabit it, to promote the understanding and manipulative skills required in the process of their design.

When comparatively evaluating cost-effectiveness of space structures, it is their relative adherence to the above mentioned defining characteristics, namely: the mode of their material distribution in space and the level of their periodicity and its manipulation for the attainment of a far-reaching rationalization and industrialization of the process of their realization which count most.

Of course structural design may aspire to reach an art form level, but this is beyond the scope of this discussion.
When it comes to pre-stressed fabric membrane structures, two main alternative design strategies are considered:

1. The "free form" (cable perimeter) membrane structures, best epitomized by the German Pavilion in Montréal Expo (Frei Otto – 1976).

2. The "rigid edge", modular membrane structures. And, of course, some hybrid, cross-gene mutations.

Pneumatic membrane structures, because of their completely different mode of structural behavior, are excluded from this discussion.

In this paper the authors would like to stress, based on experience of more than 25 years, the relative circumstantial (cost affective) advantages of the "rigid edge" conceptual approach to design and realization of membrane space structures, especially when in highly constrained urban built environments.

The "free form" design strategy, morphologically characterized by a two layer distribution of point wise supports (upper points supported by mast poles and sometimes by arched rigid elements or otherwise) which determine the spatiality of the structure, and a peripheral cable edge system, responding to membrane tension forces, imposed by the stability-rigidity requirements of the overall structure. It is at its best when in open (natural) environment, as a free floating unenclosed pavilion space. When, because of programmatic constraints, the interior must be column-free, it must revert to edge supported solutions. In order to preserve required membrane curvature levels, the masts become considerably higher, or, if not, and to compensate for the reduced curvature, it leads to much higher stresses and pre-tensioning, in the wake of which the whole design and construction process must undergo a significant shift in the direction of rising complexity and costs.

It affects structural analysis, cutting patterns, detailing, materials, masts and anchorage solutions and erection techniques. Especially, this approach reaches a higher level of conflict in a closely knit urban environment, where free forms could not harmonize with the crystalline like morphological space regime.

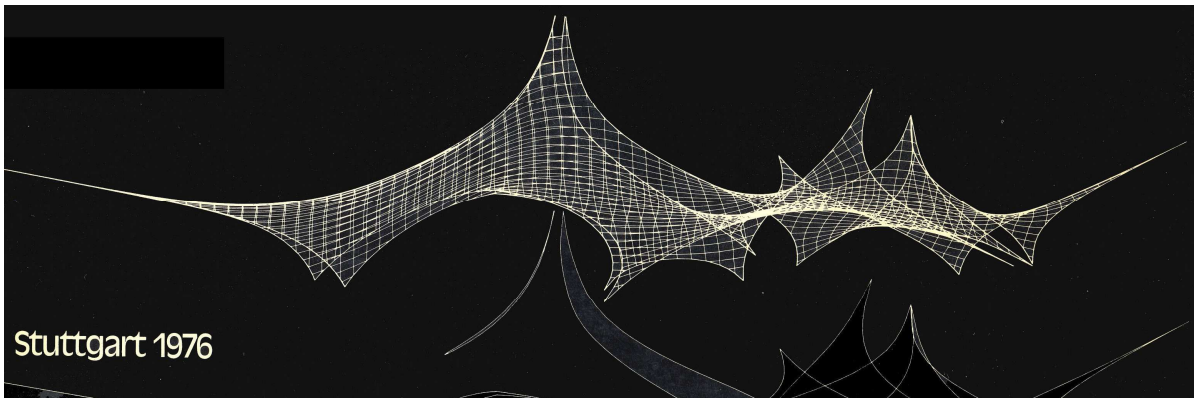

Fig. 1 – Free form design imagery – by Frei Otto

In contrast to "**free form**" design approach the "**rigid edge**" design strategy starts with a different set of rules, which affect the design outcome on the macro and the micro-detailed scale.

The over-riding morphological approach is to consider the overall structure's geometry as a crystalline ordered lattice of closely packed polyhedra, with periodic modular fabric membranes, stretched and attached to the lattice's "**rigid edge**" spatial polygons, to produce a continuous fabric membrane medium. It facilitates a Lego-like assemblage of hyperbolic, saddle shaped Modular membrane units, with enough design flexibility to fit into a constrained, spatial built environment. By manipulating module proportions, the curvature values could be arbitrarily adjusted to produce low-tensile stresses and thus saving on every stress-induced aspect of the structure.

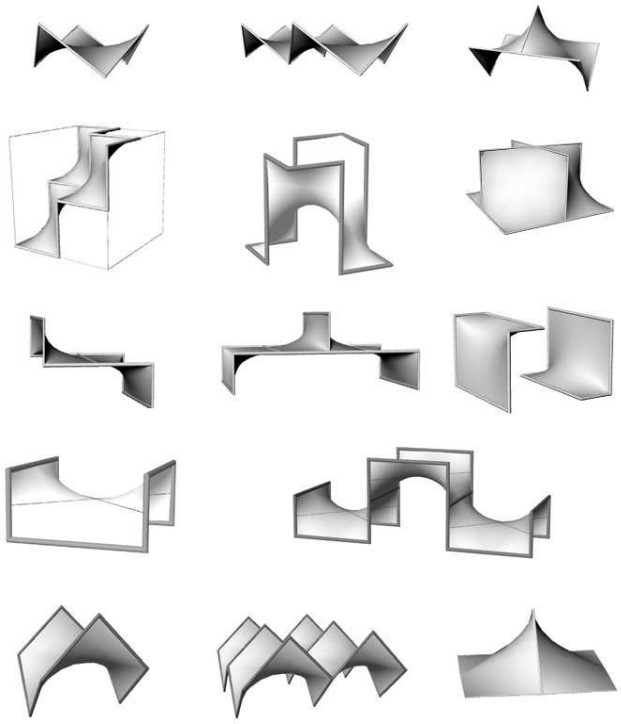

Fig. 2 – Lego like, orthogonal membrane units

Detailed Description of the "Rigid Edge" Approach.

- The membranes due to the relatively low inner stresses (because of the higher curvature levels) may adhere to wide range of reinforced P.V.C. fabrics, generally supplied by the current industry, namely – P.V.C. sheets with polyester or nylon fibers, with the appropriate thickness (weight) to meet the prescribed requirements.

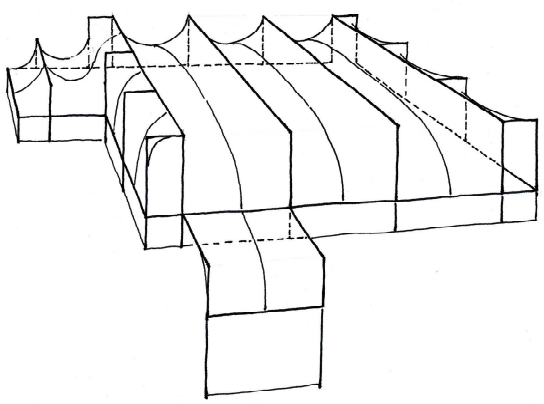

Fig. 3 – The Amado membrane roof structure – the overall orthogonal assembly composition of rigid-edge membrane units.

- The skeletal lattice structure is solved to conform to the overall space given constraints, inclined mostly to “orthogonality”, and to generate the straight (aligned) perimeters of the modular membrane units and fenestration facades. Standard industrial metal profiles are employed, complemented with specially designed and produced metal sheet components, as required.

  The skeletal structure is globally stabilized through the employment of tension cables and relatively simple tensioning accessories. In a final performance mode' the membrane medium may be perceived as a substantial-to critical contribution to the overall stability and stiffness of the structure, although, according to the author's professional experience, it is wise to stabilize the space lattice structure so it could perform independently of the membrane medium, for various construction dismantling – maintenance reasons, as necessitated by local membrane failures and the like.

- Rigidity and stiffness of the skeletal structure generates the right conditions for incorporated fenestration façade solutions, to provide for hermetic closure and the sought climatic control of its interior. Accordingly the peripheral elements are solved so as to conform to the structural and functional requirements, imposed by the façade design considerations and the attached membranes.

Fig. 4 – The Amado membrane roof structure – the overall orthogonal assembly composition of rigid-edge membrane units.

- Edge solutions of the membrane modules, simplified as they are by the lowered tension forces, must give an answer to the tensioning and sealing-waterproofing problems. A system of edge-wise screws is employed for pretension and controlling the distance between the membrane’s edge perimeter and the structural steel beams, and when combined with suitable steel sheet gutters, provide for the drainage system, which carry the accumulating rain water through the structural components all the way and beyond the structure’s bounds.

- The nature of the "rigid edge" conditions enables to reduce significantly the required dimensional tolerances, and coupled with the reduced modular sizes and periodicity involved; insure critical simplification of the membrane's design, their cutting patterns and the process of their manufacture and assembly-erection on site.

Aesthetic Design Considerations:

No doubt that the "free form" approach, in the hands of design masters, can lead to striking aesthetic-architectural results, with projects that turn into a focus of international appraisal and a merit to their creators and to their surrounding landscapes. In more limited landscapes and especially in tightly built environments, imposing as they are debilitating design constraints on every inhabiting structure, the design horizon may be critically hampered, resulting in numerous projects which should not have been realized at all.

The design horizon of the "rigid edge" approach is not as limited as envisaged by the general uninitiated design community. In some contrast to the "free form" design prospects, characterized, as it is, by free, flowing organic forms, the "rigid edge" imagery is more periodical-symmetric-rhythmic, crystalline in nature, building on the complementary formal imagery of the skeletal lattice metal structures, glass facades and the modular curving membrane medium with its characteristic response to light.

What is required of the designer who decides to venture into this field, besides understanding of the technicalities and structural behavior, is also a cultivated mind and intimate acquaintance with the body of knowledge relating to ordered space lattices, periodic hyperbolic surfaces, "saddle polyhedra" and their close packing, and in general, the resulting insights which enable a designer to manipulate matter and space for structural effect and cost effectiveness.

Case Study and Previous Projects

The "rigid edge" approach may be convincingly demonstrated and represented by the recently accomplished project: the 'Amado Membrane Roof Structure'(Figures 1 & 2), enclosing a lobby-foyer space of about 750sqm, of the faculty of Architecture and Town-Planning, at the Technion, Israel Institute of Technology, in Haifa, Israel (Korren-Shani, with Burt being involved in the preliminary design-2005), but not before mentioning some of the other related projects, of the same approach which were designed and constructed over the past 26 years.

All of the membrane structures were realized on sites which were already operative, without critically interfering with their routine function.

Ortogonal, rigid edge assembly composition of membrane modules of past projects: (Fig. 5-10)

Fig. 5 - Floris Pavilions, (1750 sqm); Burt, Kent, Glassman; 1980.

Fig. 6, 7 - Carmiel commercial center, (3500 sqm); Burt, Grossman, Shani; 1987.

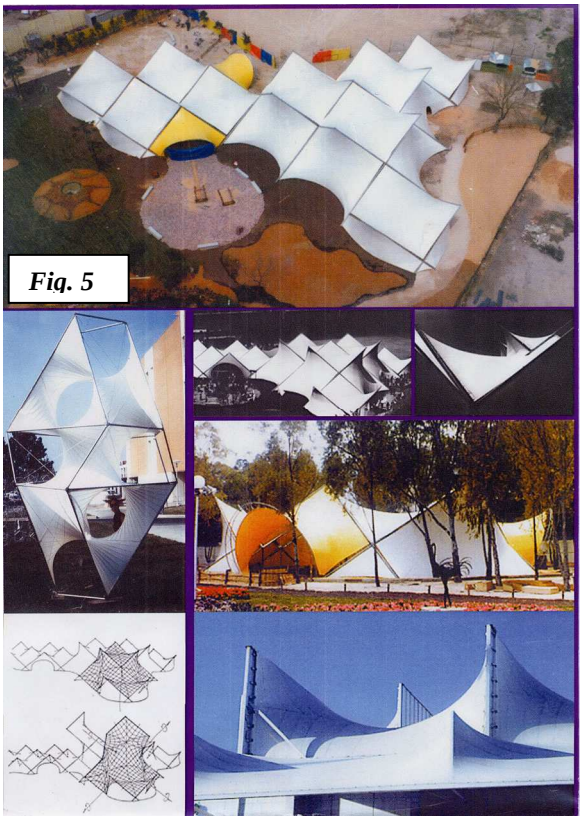

Fig. 6 – Interior view

Fig. 7 – Exterior view

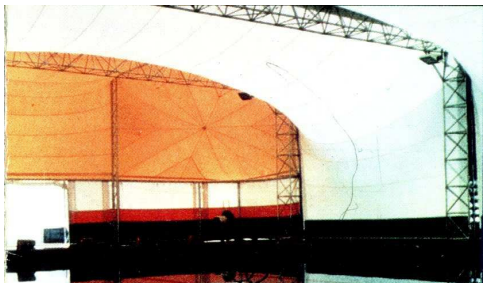

Fig. 9 - Holon Swimming Pool, (1400 sqm), Burt, Kent, Glassman; 1983.

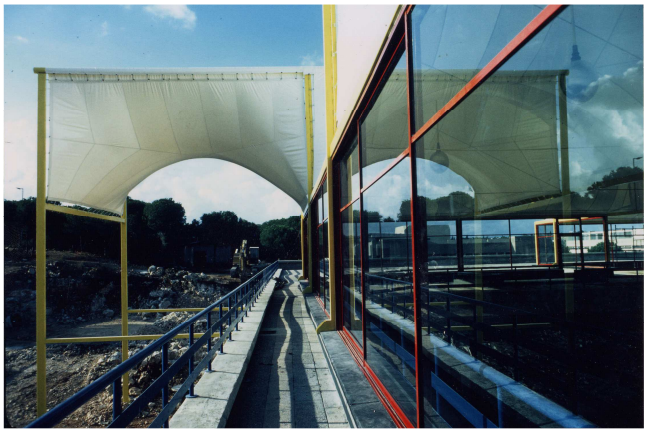

Fig. 8 - Amado Roof structure (first version), (750 sqm***); Burt, Kent, Glassman; 1985.***

Fig. 10 - Karion –commercial center, Kiryat Biyalic, (***1500 sqm), Burt, Grossman & Shani; 1988.***

The Amado Roof Structure Case Study – Recent (2005) Version

The membrane structure which was defined from the outset as a '**low-cost enterprise',** had to conform to a rigidly imposed programmatic and site conditions within a grip of an orthogonal building geometry, with a dictate of a column-free interior prearranged space, constraints on structural height and imposed orthogonal morphology on the steel support structure and the fabric membrane modules.

The realized membrane roof structure is very characteristic of the rigid-edge design approach and clearly demonstrated the inherent technological and structural advantages of its morphology.

Fig. 11 – Amado roof membrane structure – interior views

Fig. 12 – Amado Roof; Exterior view of the rigid-edge orthogonal composition of membrane units and glazed facades.

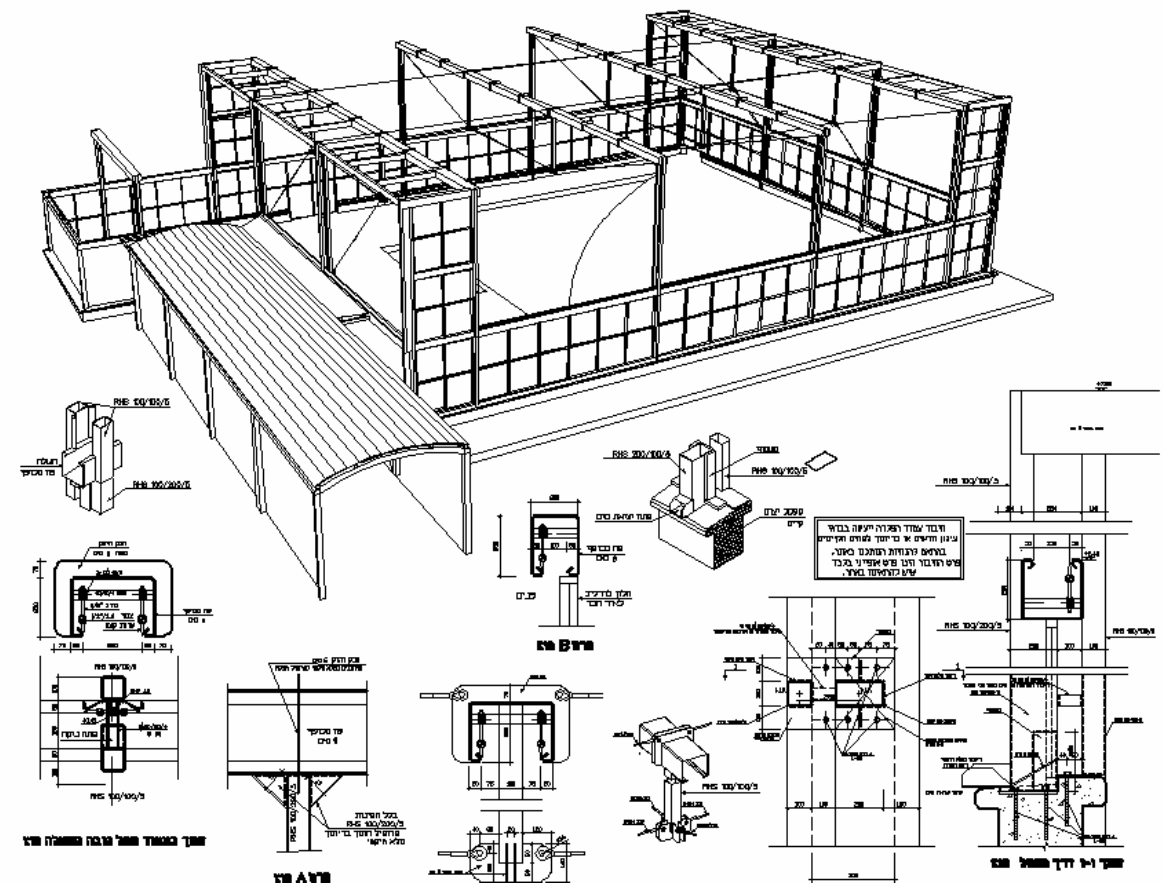

Fig. 13 – Amado Roof; View of the skeletal orthogonal structure and typical cross sections, tensioning devices and drainage solutions.

In Conclusion

The pronounced advantages of the "rigid edge" design approach are as follows:

1. High geometric periodicity of the membrane and the skeletal structure, resulting in far-reaching economical effectiveness through industrialization of the design, manufacture, and construction process.

2. Adherence to orthogonal geometries and "Lego type" modular approach of the membranes and their relatively small size, simplify significantly their form finding and cutting pattern solutions.

3. High curvature values of the modular membrane units results in a critical impact on all aspects of their structural behavior, leading to substantial reduction of stresses, cross section areas (weight) and material saving and subsequently - costs.

4. The approach affects positively all structural-architectural components and their harmonious integration: The membrane medium, the skeletal structure and all incorporated façade glazed features, and potentially reduces conflicts with the close-by built environment.

5. The "rigid edge" approach, if professionally handled, can lead to aesthetically satisfactory results, and even more so in a densely built, morphologically crystalline architectural environment.

6. All a.m. points, combined, contribute to this "rigid edge" design approach's attractiveness. Because of its pronounced simplicity and periodicity and structural soundness, it affectively reduces realization time and coasts.

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