The Form Studies Unit

Carleton School of Architecture

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Structural Topology #4, 1980

Abstract

This paper reports the past work, present projects and future plans of the Form Studies Unit at Carleton University. The Unit is dedicated to the study of geometrical-topological, structural-mechanistic and energy-related aspects of architectural morphology.

The description of the work done since 1973 has been grouped under the headings of networks, polyhedral chains, four-hinged frames, tension-compression networks and curved surface polyhedra. Rochester House and Gatineau Yacht Club illustrate the application of some morphological ideas developed by the Unit.

Topologie Structurale #4, 1980

Résumé

Cet article fait état du travail achevé, des projets en cours et à venir du Form Studies Unit de l'Université Carleton. Cette Unité se voue à l'étude de differents aspects; géométrique-topologique, structural-mécanistique et énergie reliés à la morphologie architecturale.

La description du travail accompli depuis 1973 a été groupée sous les titres de réseaux, chaînons polyédriques, élément à quatre axes, réseaux tension compression et surface polyédrique courbe. La Rochester House et le Gatineau Yacht-Club illustrent l'application de certaines idées morphologiques développées par l'Unité.

The Form Studies Unit at Carleton University (Ottawa, Ontario, Canada) was instituted in 1973 to organize the search for morphological origins, methods and essence of architecture. Geometric-topological, structural-mechanistic and energy related aspects of architectural morphology are under study. A form language and vocabulary is evolving which has been tested in the authors' works and in student projects. The Form Studies Unit offers six undergraduate courses, two each in the areas of geometry, structures and energy. Research and Development projects are undertaken by graduating students who have acquired a concentration in form studies. The Unit has also done research in collaboration with other universities such as Carnegie-Mellon, Pittsburg (Rooney 1979).

The Form Studies Unit has about 3000 sq. ft. of laboratory space with a wide range of model building and testing equipment. There is a special laboratory for precision model building. The Plastics and Wood Workshops of the School of Industrial Design are also available and have been used for mould building and vacuum forming.

Review of Past Work

Our work started with the study of geometric order of points, lines, planes and curved surfaces in space. Works of (Coxeter 1973), (Fuller 1975), (Fejes-Toth 1964), (Emmerich 1970) and (Burt 1966) provided fundamental and significant insights. Further contact with the works of (Le Ricolais 1973), (Baracs 1972), (Critchlow 1969), (Pearce 1978), (Williams 1972), (Wells 1970) and (Wachman 1974) was very useful.

The following is an illustrated list of various research, development and design activities in the Form Studies Unit:

1. Networks: Starting with strictly regular 2D and 3D networks, the search for semi-regular networks of varying connectivity and density has gradually progressed. Major effort has been directed at search for 4-connected networks which are subsets of regular 8-connected networks (**Figure 1**). Each of these seven subnodes was systematically assembled with itself to achieve a large variety of 4-connected networks, many of which were completely new to us (**Figure 2**). Currently 4-connected subnodes of 12-connected networks are being studied and future work to study hybrid aggregations of various 4-connected subnodes is planned. A measure of network regularity based on notions of entropy and information theory has been proposed but needs further theoretical development. (Haider 1977).

2. Polyhedral Chains: These are ordered aggregations of convex polyhedra attached face-to-face following a regular or semiregular network. The polyhedra in a chain belong to either of the two subsets: nodes and connectors.

The lines connecting the centroid of a node polyhedron to those of all the immediately surrounding neighborhood node polyhedra form an acceptable regular or semi-regular network. Between two node polyhedra there is one connector that has one common congruent

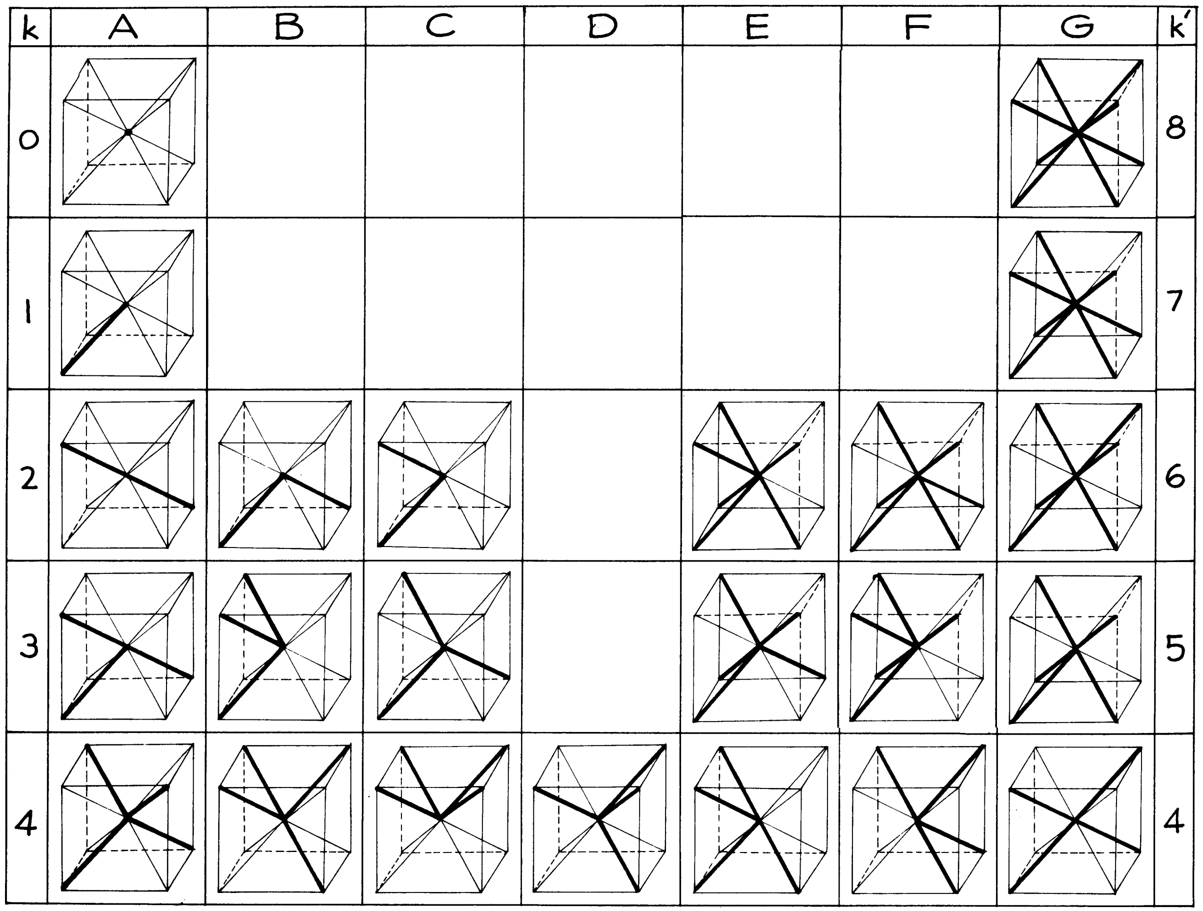
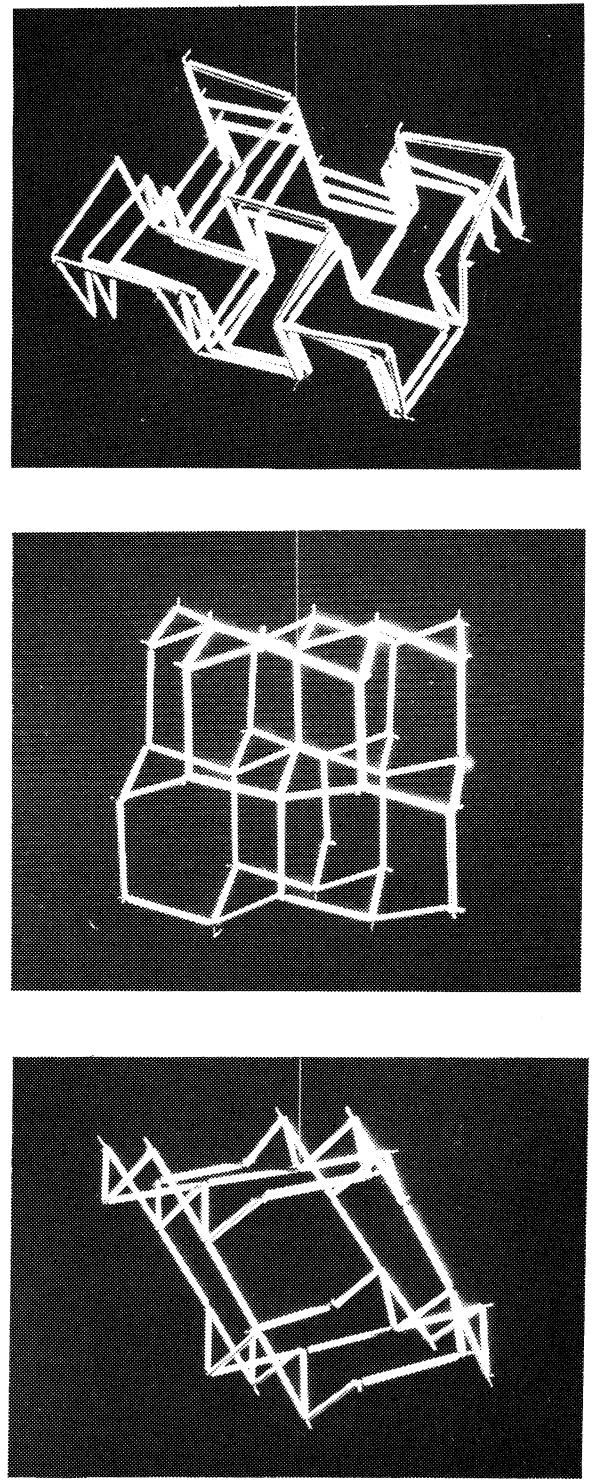


Figure 1



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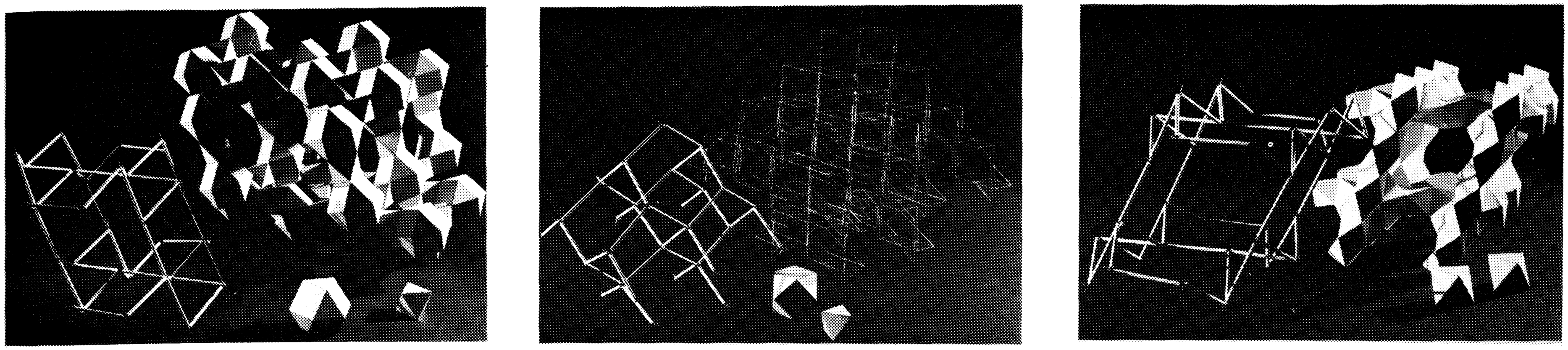


Figure 3

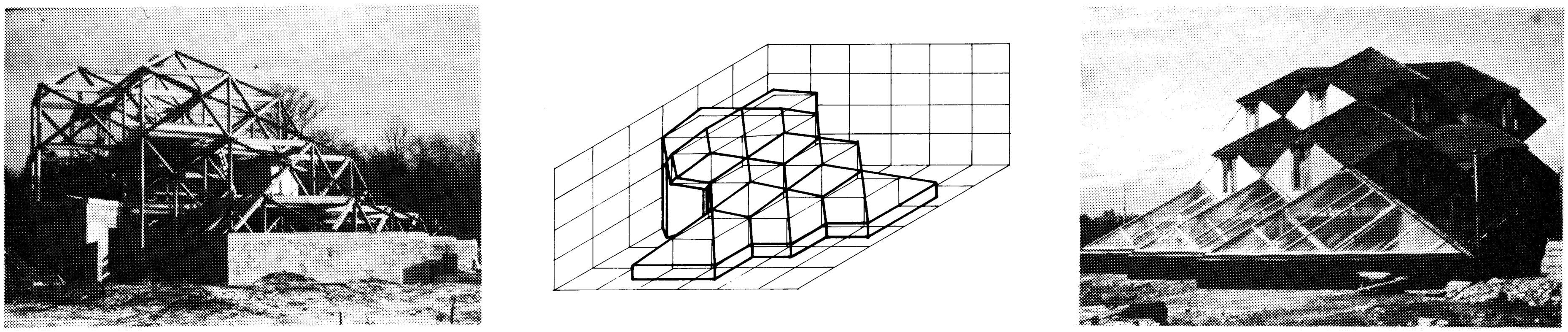


Figure 4

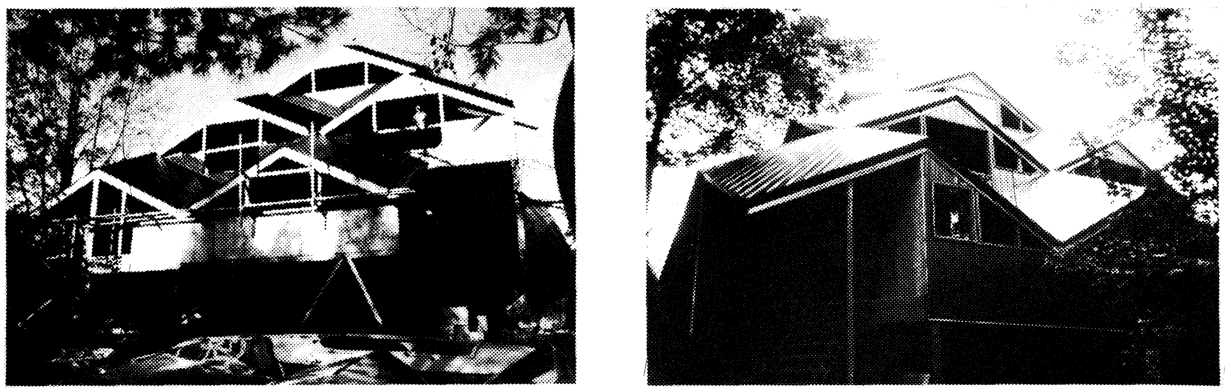
chain face with each node polyhedron. A k-connected network will result in a k-connected polyhedral chain.

Generalized conditions, relating the properties of polyhedra and networks, that are necessary for chaining, have been developed. Indices like the space-partitioning index, the surface-volume index, and the periodicity of joint types provide a comparison of the architectural potential of various polyhedral chains. The nature of the polyhedral chains, in contrast with infinite polyhedra, is much more easily understood, provides the freedom for selective manipulation and distortion of spaces, and thus has higher potential for being used by design professions (**Figure 3**): (Haider 1975), (Haider 1977).

3. Rochester House: This is a passive sun-sensitive building with an indoor pool and a greenhouse. Its structure is a hybrid of 8-, 4-, and partial 6-connected networks. The geometry has been vertically scaled down to make the spaces more efficient. The structure may also be described as a spatial checker-board of vertically squashed cubes with body-centred diagonals, or as a close-packing of semi-regular rhombi-dodecahedra (**Figure 4**). Morphologically it may be described as a network to live in. The building has a high degree of geometric and structural periodicity in that the joints are derived by simplification of a single 14-connected parent joint; there are only two member sizes and only one standard triangular panel (**Figure 4**). Gatineau Yacht Club is another project that is based on the same geometric discipline (**Figure 5**).

Rochester House and Gatineau Club are the most striking examples of our triple foci of geometry, structure and energy.

4. Four-Hinged Frames: A three-hinged arch (or frame) in a plane derives its rigidity from a virtual triangle in that plane, formed by lines connecting the three hinges. A hinge in this case is a joint between two or more members in a plane such that there is no resistance to rotation with respect to one another in that plane. Complex planar rigid arrangements may be achieved by hinging together straight members or bents as long as a non-trivial rigid planar pattern is achieved by the imaginary lines connecting the hinges. A planar bent is a structurally continuous non-straight member that is completely contained in a plane. Extending this con-



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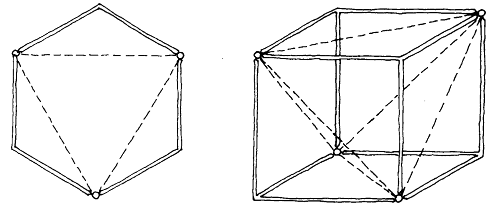


Figure 6

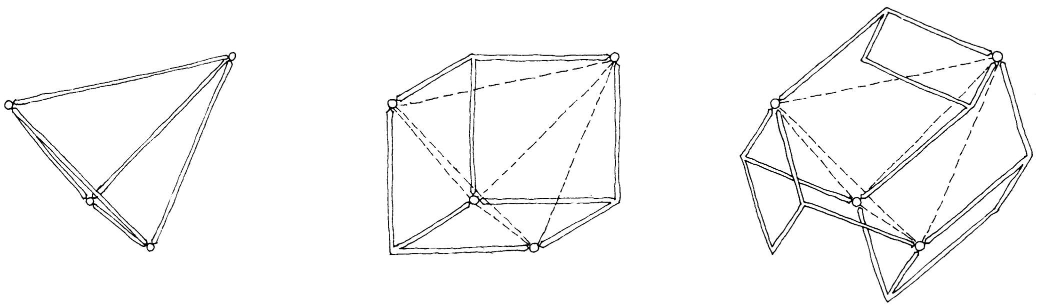


Figure 7

cept to 3D space, rigid structures may be created by a hinged aggregation of spatial bents as long as a virtual network created by connecting neighboring hinges is rigid. A hinge in this case is a universal spatial «ball and socket» joint allowing freedom of rotational motion to all connecting members. A spatial bent is a structurally continuous assembly of members that cannot be contained in a single plane.

The most basic arrangement like this has been called the four-hinged frame, the four hinges indicating a tetrahedron as the virtual rigid network (**Figure 6**). All rules of rigidity (Baracs 1975) (Rosenberg 1979) may be applied to this virtual network and then the real structure may be derived by deviating from the virtual lines as long as no new hinges are created in the physical structure. This realization has provided two new areas of search for ordered form:

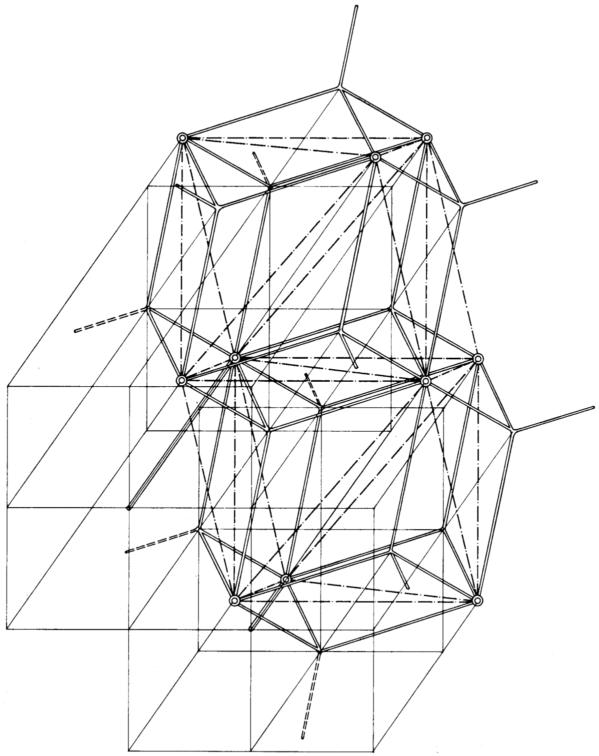
a. Distortion of hinged networks or polyhedral chains that are rigid. The topological connectivity of the hinged network is maintained but each previous hinged line is distorted into a bent. Enclosed spaces and tunnel systems will change their form and relative sizes and can thus respond to architectural or other design requirements (**Figure 7**).

b. Structures of much lower density are achieved by a hinged aggregation of 4-connected spatial rigid subnodes of the 6-, 8- and 12-connected networks. There is great freedom in synthesis of the overall form.

An application of this concept in housing is illustrated in **Figure 8**. The stable structure is obtained as a hinged aggregate of 4-connected spatial bents made of 4 steel tubes meeting at a rigid joint. The overall rigidity is indicated by the virtual 12-connected spatial network (virtual octet truss) yet the real structure is only a 4-connected network providing spatial openness of considerable architectural value. The double layer enclosure has energy-saving potential which is under investigation. Housing patterns on plane and sloping sites, low-technology and cultural appropriateness for some South American countries is currently being studied.

5. Tension-Compression Networks: Post-tensioning techniques have been combined with the geometric-structural study of networks in two ways:

a. The cable is used as an uplifting mechanism to achieve longer spans and as a double spiral envelope to achieve torsional stiffness. This concept was explored in an experimental study of polyhedral chains as long-span systems (Haider 1976) (**Figure 9**). More recent work has aimed at the search for torsionally stiff light-weight spans to act as support structures for solar collector arrays on roof tops of existing buildings. The double spiral achieved by a tubular steel network and geometrically compatible cable system is used to increase this spanning capability, minimizing support points on existing roofs (**Figure 10**).



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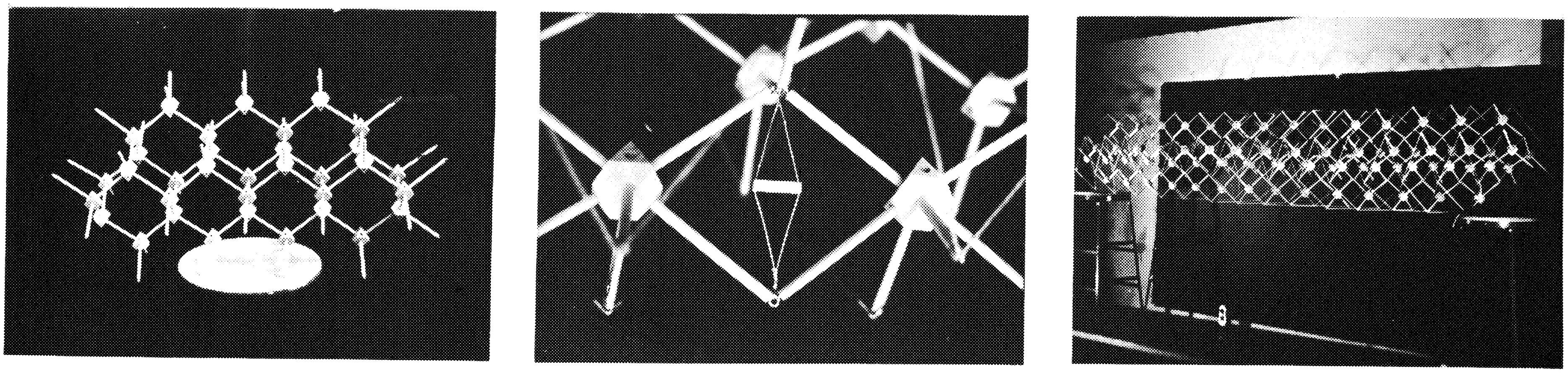
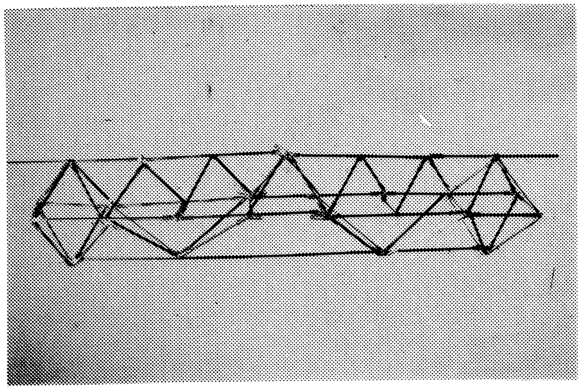


 Figure 9



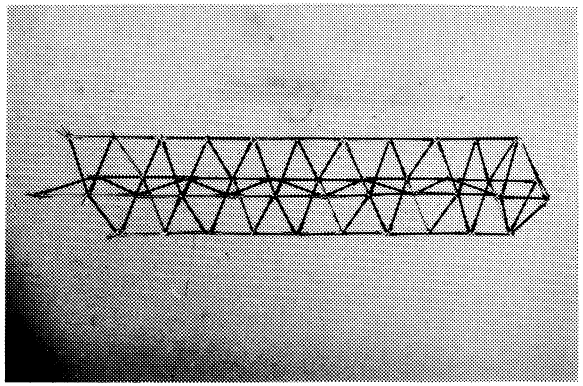
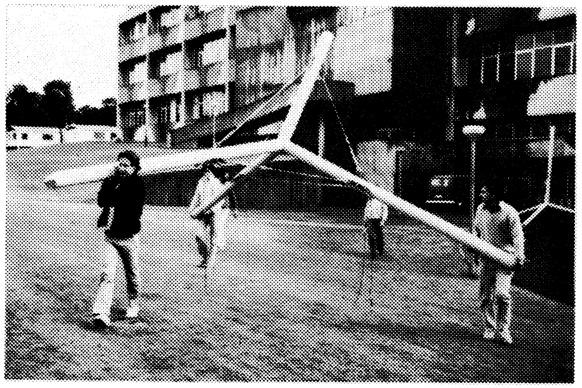
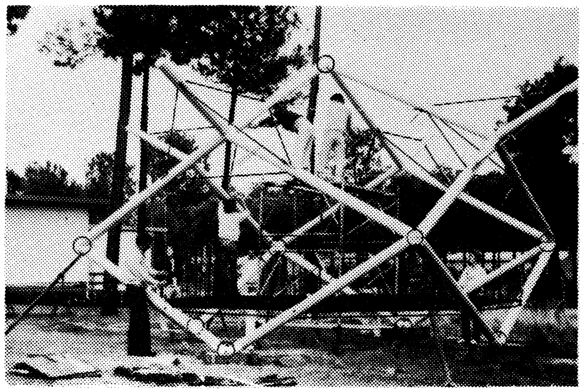
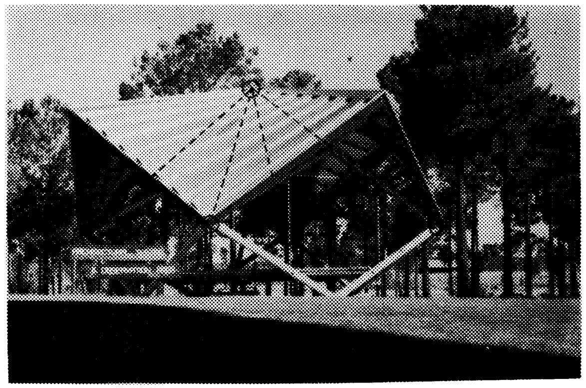


Figure 10

b. A convex triangulated polyhedron of pretensioned cables is used to compress spatially radial members that connect the vertices to the centre of the polyhedron. If any superimposed axial force in a pretensioned cable is such that the net force is still tension within allowable limits, and if the deformations are small, then this pretensioned cable may be considered as a tension-compression member that maintains its length. Thus a convex triangulated polyhedron of such pretensioned cables, along with radial members connecting the vertices to the centre of the polyhedron, create a rigid assembly. During Strutt's visit to Western Australia Institute of Technology, Perth, an experimental pavilion structure was built to test the feasibility of this idea (Strutt 1979). A rigid joint was achieved by using 4 round wooden members







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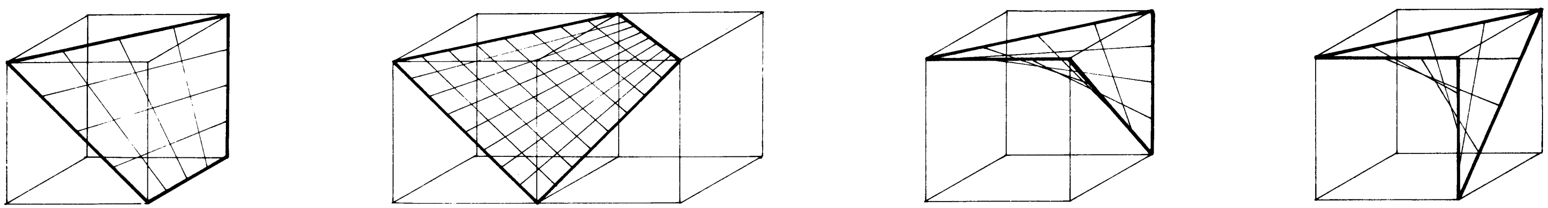
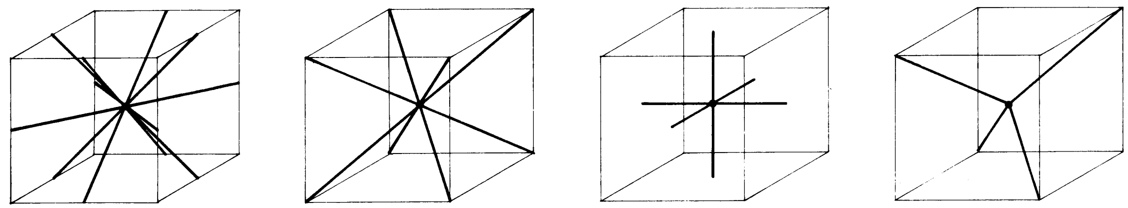


that butted against one another on precut faces and were compressed together by 6 pretensioned cables forming the convex tetrahedron. These rigid modular elements were then connected around a rigid virtual half octahedron (fixed square base), thus providing rigidity to the entire assembly. The square base of the half octahedron is part of a pin-connected spatial octagon which is rigid because of an octagonal rigid floor diaphragm and four-hinged formations that cannot have any translatory motion. The cable polygons around the external boundary joints are for stability during construction and are not needed in the end (**Figure 11**). Larger span and scale applications of this idea are under study.

6. Curved Surface Polyhedra: Systematic aggregation of curved-surface periodic elements from a cube (**Figure 12**) has generated many forms of architectural and of purely geometric interest. Most interesting among these are infinite polyhedra (Burt 1966). Because the 4-, 8- and 12-connected strictly regular networks can all be related to each other through the 6-connected cubic network (**Figure 13**) and because the periodic curved surface elements of a cube are obtained as spatial quadrilaterals using the edges and surface diagonals of a cube, we have found striking point-wise and in many cases line-wise congruencies between the networks and the curved surface polyhedra (**Figure 14**). Infinite curved surface polyhedra do not enclose space and in a purely geometric sense only partition the universal space. Numerous finite and infinite curved surface polyhedra have been developed at the Form Studies Unit (**Figure 15**).



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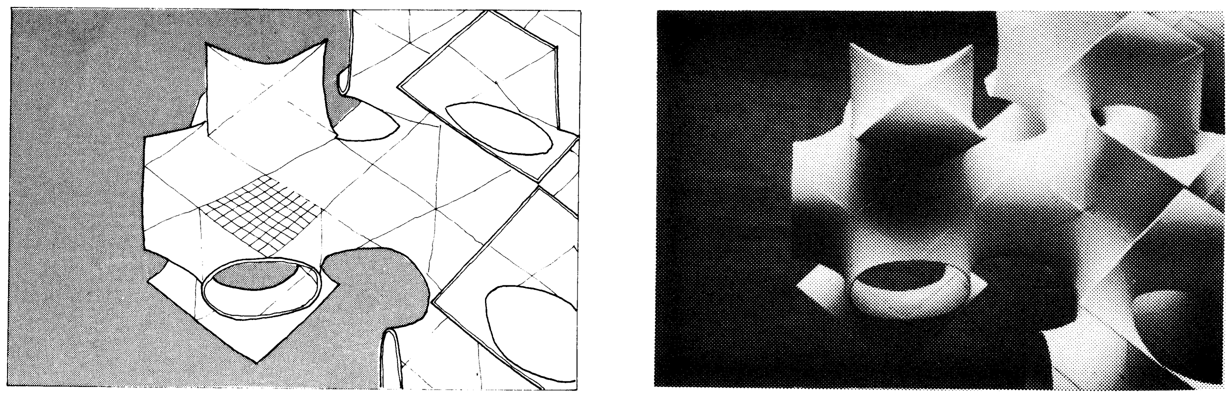

Figure 14

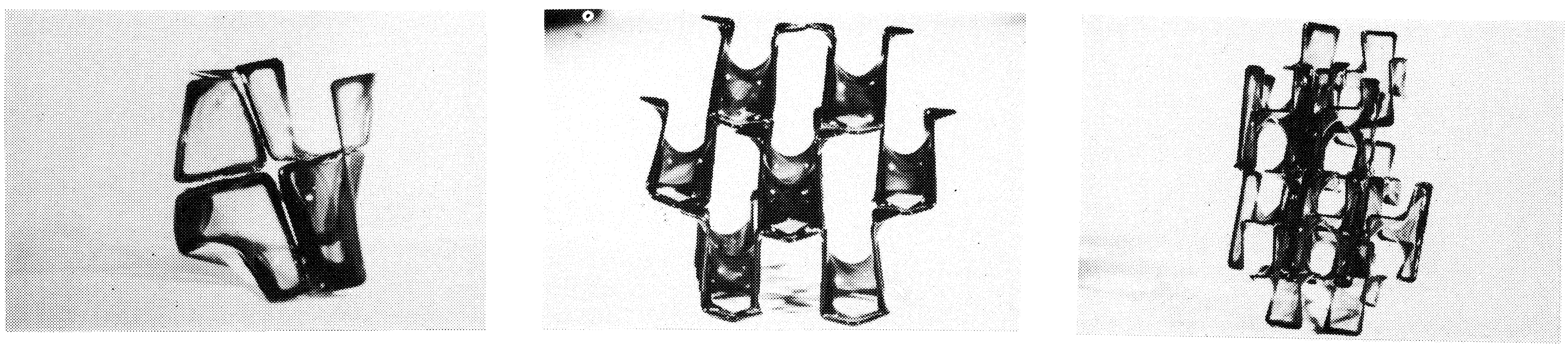

Figure 15

The most significant project emerging from this area of study has been the design of an undersea environmental laboratory (Strutt 1978). Of morphological significance is the fact that a 6-connected polyhedral chain using small rhombidodecahedra as nodes and cubes as connectors was accomodated inside the tunnel system of an infinite curved surface polyhedron based on a periodic curved surface element of 300° spatial index. The interstitial space could be divided into a 12-connected (octet) network with pointwise congruence between both the exterior curved surface polyhedron and the interior polyhedral chain. The architectural as well as structural potential of such a scheme is under study (**Figure 16**).

Conclusion

At the Form Studies Unit, we seek Beauty in Order. We are in search of transformations and juxtapositions of geometric orders to achieve Architecture. This is our first and only goal.

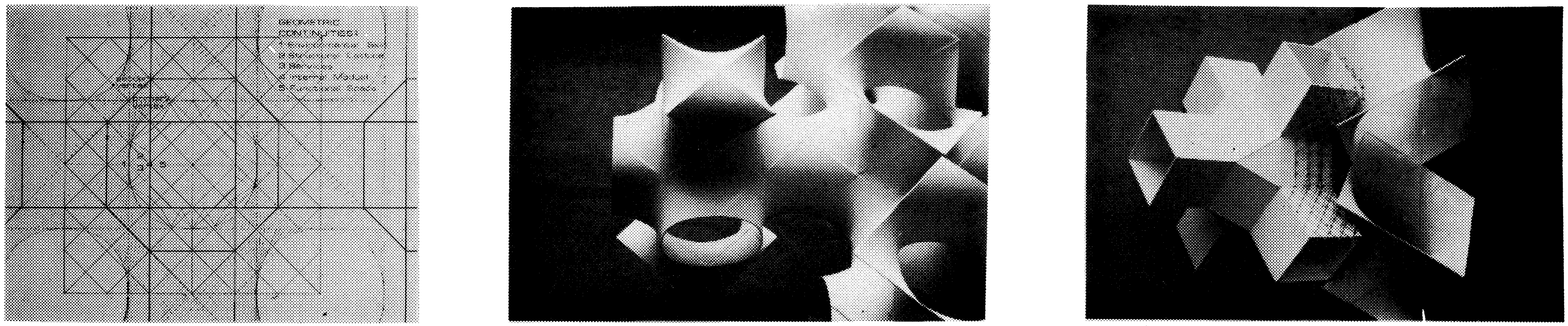

Figure 16

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