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A Hyper-Roof Concept For Low-Cost Housing

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by

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Introduction

The goal of a single house set off on a private piece of land for every family is an architectural doctrine that is widely subscribed to in many parts of the world. With the present uncontrolled rate of population growth, continued adherence to this doctrine will lead to a worldwide urban sprawl of disastrous proportions. Housing construction based on this principle is characterized by retention of archaic fabrication methods and by the combination of escalating costs and declining workmanship that is also observable in other products of our industrial age. These trends seem inexorable unless an abrupt change is made in our approach to housing construction.

On the North American continent the Los Angeles area might be cited as an example of what the "single-house" concept leads to in a rapid-growth city, while metropolitan Toronto is an example of an alternative approach employing high-rise apartments and condominiums to avoid having all the land occupied by single-family houses. In this paper, a new approach to low-cost housing projects is proposed. The concept is to enclose an entire complex of closely packed, privately owned houses, community recreational facilities, and auxiliary mechanical equipment under a single, transparent hyper-roof. The overall objectives are efficient utilization of space, preservation of the principle of private ownership of one's house, and creation of a climate-controlled recreational area for year-round use. As an example, a complex for housing 10,000 people in an area of about 160 acres is used to study the structural and economic feasibility of the proposed system.

Structural Forms for Roof

Large-size super-roofs measuring one or two miles in diameter and covering entire cities have been proposed by Fuller [1]* and by Zuk [2] and have been mentioned with increasing frequency by architects and city planners. Although the diameters attained in recently constructed free-span roofs are still in hundreds of feed rather than thousands, it would seem that the diameter of 2980 ft. required to enclose a circular area of 160 acres is not an impossible goal. As a structural form for the proposed hyper-roof, the following contenders are considered in this paper: rigid frameworks; inflatable membranes; cable-suspended roofs; and a semi-rigid dome presently being studied at State University of New York at Buffalo.

Rigid frameworks such as the geodesic dome proposed by Fuller [1] have been used extensively for large radomes. As an example, Weiss [3] has described the radome enclosing the Haystack radio-astronomy antenna at Tyngsboro, Massachusetts. This structure, sketched in Fig. 1, was designed by Lincoln Laboratory. It can be described as ~~nine~~-tenths of a sphere, 150 ft. in diameter, with a trapezoidal hexacontahedron geometry. Employing hollow aluminum members 3 in. by 5 in. in cross section and 9 to 15 ft. long, the framework is made up of 930 triangular panels of 15 different shapes and is covered by 1/32-in.-thick fiberglass-reinforced polyester. Special design requirements for radomes leading to this configuration include a random orientation of the metal members to prevent biasing in the interference pattern and a thin skin to minimize the amount of interference. By extending the principles embodied in the Haystack radome, it has been possible to consider a metal-space-frame radome that is 560 ft. in diameter and eight-tenths of a sphere as an enclosure for the proposed NEROC radio telescope. Under the less restrictive design criteria for a roof over a housing complex, it would seem that space frameworks could reach diameters of a few thousand feet.

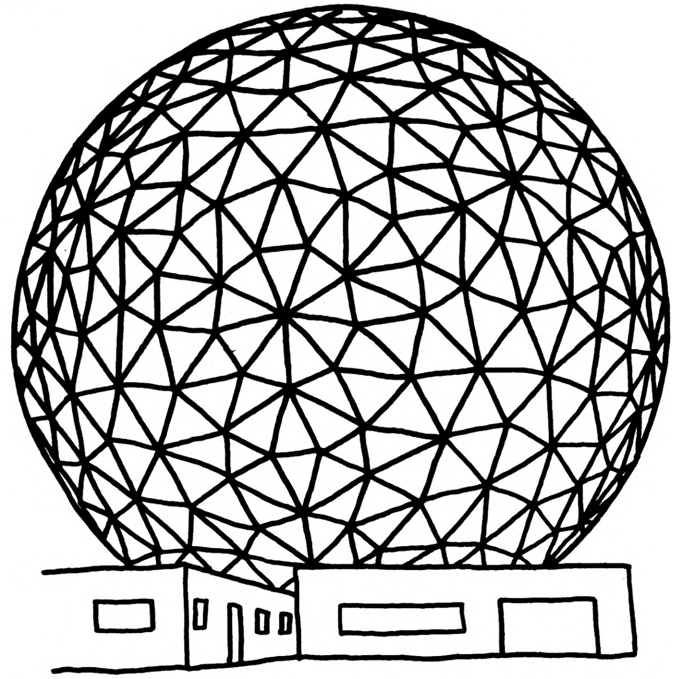

Fig. 1. Haystack Radome at Tyngsboro, Massachusetts

Inflatable structures have received considerable attention as a result of the expanding need for specialized structures in the space age [4,5]. Both the single-wall type with pressure elevation inside the enclosure and the dual-wall type pressurized only within the wall have reached advanced stages of development, and diameters of several thousand feet are quite conceivable. Because of the need for foolproof mechanical equipment to maintain the pressure elevation, it would appear that this principle has at present too many disadvantages to be suitable as a hyper-roof for a housing complex.

Cable-suspended roofs have experienced a very rapid growth in importance in recent times [6,7]. A typical arrangement employing a compression ring and a tension ring and a single set of cables is sketched in Fig. 2. According to Bethlehem Steel Corporation [6], spans of 150 to 300 ft. are feasible for single-curvature surfaces with two sets of cables or for double-curvature surfaces with one set of cables (as in Fig. 2). Spans of 200 to 400 ft. are possible for

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*Numbers in brackets designate references at end of paper.

double-curvature surfaces with two sets of cables. According to the American Iron and Steel Institute [8], the Oakland-Alameda County Arena has a cable-suspended roof with a diameter of 420 ft. The proposal of Zuk [2] is for a diameter of one to two miles with a central tower and two sets of cables. Although he states that technology is not yet to the point of making his idea realizable, it would seem that stepping up to a diameter of a thousand feet or so might be possible in the near future.

The structure being studied at SUNYAB is a semi-rigid dome composed of an array of wide, shallow members prebuckled into intersecting prestressed arches as shown in Fig. 3. The method of attachment of glass or other transparent roof panels to the framework is visualized as suspension by a family of circumferential cables. Other arrangements are also possible, e.g., "rigidizing" the skeleton by horizontal ribs in place of the suspension cables. A preliminary computer analysis has been carried out by the author to determine the behavior of a single prestressed arch made from a buckled strut and under the action of simple loads [9]. It shows that the prebucked arch is capable of carrying a significant amount of vertical load and suggests that a dome made up of such arches may be a very promising contender for large-span hyper-roofs.

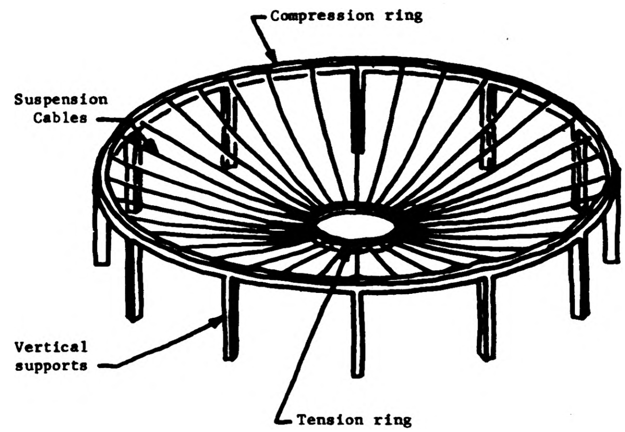

Fig. 2. Cable-Suspended Roof

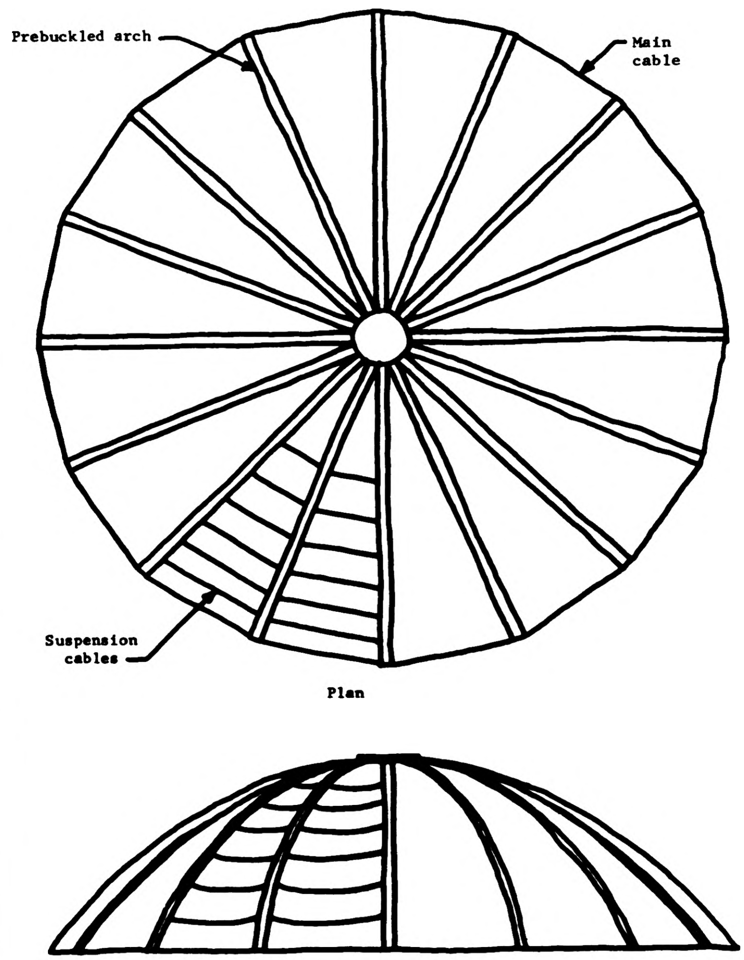

Fig. 3. Semi-rigid Prebuckled Dome

Interior Layout

With the arbitrary assumption of 5 persons per house, the sample complex being considered will contain 2,000 houses. It is visualized that each of these will occupy an area of 900 sq. ft. and will contain three living levels: the upper, or "ground", level would consist of a sun room occupying, say, 225 sq. ft. and a patio or garden occupying the remaining 675 sq. ft.; the middle level would have all 900 sq. ft. devoted to housing space and might include bedrooms, bathrooms, and study. The lower, or "subterranean", level could use 450 sq. ft. for kitchen, dining room, and lavatory and the remaining 450 sq. ft. for car storage, etc.

Certain community-owned facilities will form a part of the space enclosed under the hyper-roof, and it is envisioned that these will also occupy three levels. The upper level could contain foot paths, fountains, groves, and recreational facilities, the middle level utility lines, power plant and centralized mechanical equipment, offices, and shops, and the lower level access drives, community parking, and car service area.

A schematic diagram of vertical space allocation showing interaction between the privately owned areas and the community-owned areas as in Fig. 4. Since the 2,000 houses will occupy an area of 1,800,000 sq. ft., while the total enclosed area of 160 acres is about 7,000,000 sq. ft., there will be about 5,200,000 sq. ft. of community-owned area. This works out to about 26% or 42 acres private and 74% or 118 acres public.

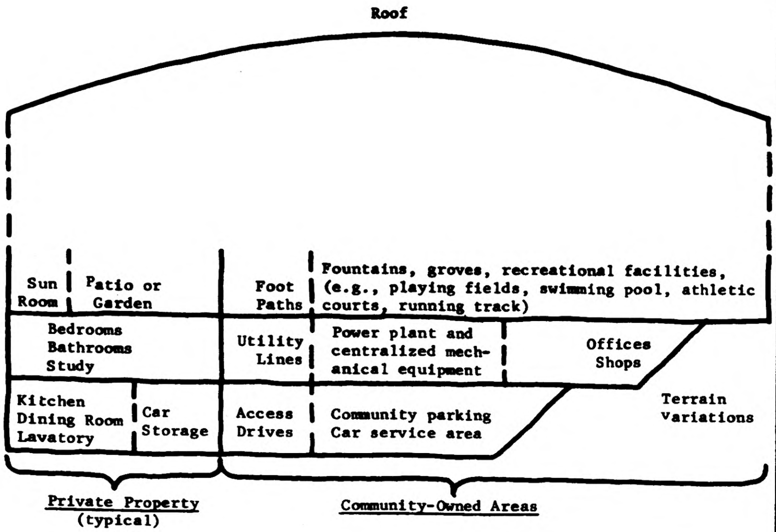

Fig. 4. Schematic Diagram of Space Allocation

To decide on the spatial arrangements in the horizontal direction, it can be assumed that the houses will be rectangular in plan, will be mass produced, and will be surrounded by reinforced-concrete walls. They can then be packed into "blocks" of about ten houses each (two rows of five) which are set off so as to allow access to every house on the upper and lower levels.

Since the dome will be weatherproof, the roofing, insulation, and waterproofing requirements for the housing units will be considerably simpler than in conventional housing. Acoustically, however, each house should be as completely insulated as possible.

Economic Analysis

A very rough cost analysis in U.S. or Canadian dollars as of 1970 can be carried out as a means of investigating the economic feasibility of the proposed scheme. Since very little experience is available in the types of construction employed here, the unit figures must be regarded as very tentative. With that in mind, the total costs of various parts of the system are as follows:

Roof:	
$2.50/sq. ft. of enclosed area x 7,000,000 sq. ft. =	$17,500,000
Houses:	
($5.00/sq. ft. of floor space x 1575 sq. ft. = $7,880/house) x 2,000 houses =	$15,800,000
Land:	
Private: ($5,000/acre x .0206 acres = $103/house) x 2,000 houses =	$ 210,000
Community: $5,000/acre x 118 acres =	$ 590,000
Development of community-owned property, including initial cost of centralized mechanical equipment:	$ 5,000,000
TOTAL	$39,100,000

If this entire amount must be borne by the house purchasers, that makes the cost to each $19,500. Each owner must also pay a monthly fee for maintenance of the roof and community-owned property, as well as paying for utilities on a usage basis. Thus, it would appear that this housing is not yet in the low-cost category. If it is assumed, however, that the roof is financed out of public monies as part of an urban-development program, the cost to the house purchaser is reduced to $10,800.

Mechanical Equipment

The centralized mechanical equipment for the proposed housing complex must include air-conditioning equipment capable of keeping the entire space enclosed by the roof at a controlled temperature, ranging, say, from 60°F daytime temperature in winter to 80°F daytime temperature in summer, as well as controlling humidity, filtering out dust, etc. The utilities to be input to each house would include warm air (in winter) or cool air (in summer) for finer adjustment of temperature level, hot and cold water, electricity, and gas (probably purchased from the local utilities companies), communications (telephone and mail, radio and television signals), and provisions (possibly via an automated centralized distribution system). Output from each house would include wastewater, refuse, and outgoing communications. Water must be available for the vegetation under the roof, and drainage routes must be provided for this water.

Sociological and Psychological Aspects

The effects on human behavior of living under a common roof with many other persons is difficult to predict with existing sociological and psychological models. It would seem intuitively that there would be both beneficial effects such as enhanced community spirit and deleterious effects such as loss of feeling of privacy. Certainly there would arise greviances of various kinds, and some mechanism should be built into the organizational structure of the community to resolve these quickly and fairly.

Conclusions

The foregoing study indicates that there are many aspects of the proposed concept that are still in the stage of uncertainty. But it does suggest that a hyper-roof approach to low-cost housing may be feasible, and it is at least possible that such an approach may lead to a much more successful type of low-cost housing than has been achieved in the past.

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