

A PROTOTYPE OFFICE BUILDING

Submitted in partial fulfillment of the requirements  
for the Degree of Master in Architecture on August 20,  
1956.

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ABSTRACT

Title of thesis: A PROTOTYPE OFFICE BUILDING

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” In this School we encourage the students to develop both common sense and passion and within those two virtues to learn to search for facts, to understand techniques, to coordinate results, and finally to synthesize them in clear and creative expressions.”

Dean Belluschi

An aircraft factory or an automobile assembly line is a marvel of technological and scientific achievement. The architect is lagging in the ability to utilize effectively the methods of science and technology. Architecture is still in the handicraft stage. Observe a bricklayer at work; or a carpenter; or a plumber.

Construction of a tall building is a little more advanced. But even there, as the building rises from the base, it is as if an one story building has been multiplied many times. It does not reflect the forces acting on it and the success of a building architecturally is usually determined by its skin deep-cosmetic treatment of the facade. It is a two dimensional structure.

But architecture is a three dimensional art. And the mind begins to wonder if a space construction enclosing space and at the same time integrating the services of the building could not be employed. The structure has been three dimensional in medieval times - couldn't it become once more?

My thesis is an attempt at application of a space frame to a tall building.

Cambridge, Massachusetts  
August 20, 1956

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Dear Sir:

As partial requirement for the degree of Master in  
Architecture, I submit my thesis, "A Prototype Office  
Building."

Respectfully submitted,

Algimantas Zemaitis

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THE PROBLEM

To design an office building of approximately 300,000 sq. ft. of floor space in an urban high land value area. The building is to have efficient core arrangement, approximately equal rentable floor space on top and bottom floors and column free interiors. The structure should be fabricated in a factory employing methods used in industry and reducing the amount of work to be done on the site to a minimum.

## STRUCTURE

Typical conventional framing first runs all loads in one direction to the beam, in another direction to the girder and then transmits them at right angles to the column. While this division of labor, at first glance, appears reasonable, the total of all loads carried by all members of the structure actually represents a multiple of loads to be supported. In other words, we do not have an actual division of labor; rather, we are faced with a 'superimposition', a duplication and triplication of labor. And so to frame a typical 20' x 20' bay in steel for a 200# floor load requires from 10 to 15 lbs. of steel per sq. ft. The same bay could be supported with only 3 to 5 lbs. of steel if it were designed in three dimensions. More than that, a space construction shares loads between at least three supports to avoid concentrated stresses at any one of them, making "the strength of the whole greater than the strength of its parts since the entire frame acts to relieve high local stresses." <sup>1</sup>

The space-truss used in the structure is an Octahedron-Tetrahedron Truss as developed by Buckminster Fuller. It is made up of tetrahedrons as modular units. The tetrahedron, enclosing the least space with the most surface, is the stiffest form against external pressures. Here is Fuller's own explanation of the truss:

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<sup>1</sup> See Space Frame Design-Symposium, Architectural Forum, February 1953.

"In the Octahedron-Tetrahedron truss, three planes of beams and their triangularly binding edge patterns rotate tepee-wise positively and negatively to non-redundant ridge-pole fixity, and with such symmetry as to result in radial distribution of all loads from any one loaded vertex through the neutral axil of all the edges of the system precessionally differentiated as either pure compression or pure tension stresses, metered at even rates, because edge vectors are identical in length, precessing further into positive and negative radial and circumferential waves, excentric to the loaded vertex and the stress distributed positively and negatively throughout those adjacent vertexes surrounding any one loading center, and which wave distribution in all directions precesses into tensile action the concentric series of rings around the originally loaded vertex. The increasing succession of concentric rings which continually redistribute the received loads act in themselves as unitary systems with an increasing number of excentrically distributive vectors, after full dispersion loads come to symmetric reconcentration at supporting area in direct pattern reversal.

"The four planes (of the Octet Truss) comprise a system and what were previously individual beams, and therefore free systems in themselves, are now fixed components of a larger tetrahedromal system which latter is inherently nonredundant because it is the minimum fixed system. Ergo, all of those previous individual free system beams are now converted into one non-redundant complex of basic systems...

"The nonredundance of the larger associated complex of tetrahedra is occasioned by its precessionally induced self-differentiation of functions, when loaded at any one vertex, in such a manner that every member acts in axially focused pure tension or pure compression, and with the subsequent loading of any next adjacent vertex inherently induces comprehensive reversal of all the system's pure tension into pure compression functions and vice versa, - that is to say, it is dynamically nonredundant.

"This unitary systematic nonredundant complex provides a total floor system with higher structure performance abilities than engineers could possibly ascribe to it thru any conventional structural analysis means when predicted only upon the behaviour of its several parts, in which it is axiomatic to conventional engineering, that if "horizontal" those parts are beams,-- for the total floorability by such conventional engineering could be no stronger than the single strongest beam in the plural group and their prediction falls short of the true behaviour of the octettruss by many magnitudes, for in true mathematical fact no 'beams' are left in the complex; that is, there are in it no members loaded at other than polar terminals.

"Stresses are equally distributed to all members in relation to their distance from a point load and consequently are distributed in concentric circles, which facilitates analysis of the structure.

"Indeterminate structures such as these prove highly economical because all the structural units and their connections are standardized throughout, and each distributes loads proportionately to all other units.

"Consequently, if high local stresses occur at any one point they are relieved by the rest of the frame, and although stresses at some points may exceed nominal stated limits, the collapse load of the whole structure is considerably greater." <sup>2</sup>

In order to make a natural connection with the truss the straight members had to meet the truss at an angle. Those members crossing each other in diamond shaped patterns make the entire outside wall act as a column. Some of those members are made heavier, forming stacked large octahedrons, bracing the structure against the wind and taking most of the load, while the lighter members act primarily in tension and reduce the bending moment at the outside column connections with the slab. Those lighter members are capable of withstanding compression stresses if put in compression by the force of the wind.

The interior columns are centered around the core and help to relieve the span. During construction they form a stack from which the floor trusses are lifted in place.

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<sup>2</sup> Quoted from a letter of January 8, 1955, to Patent Counsel to Geodesics, Inc. and Synergetics, Inc., by R. Buckminster Fuller.

PREFABRICATION AND ASSEMBLY

Development of space-frame depends largely on development of new fabrication methods and easier erection on the site. For years the use of conventional post and beam framing (and subsequent waste in additional weight of steel) has been justified on construction labor. With welding this need no longer be true.

"Welding has made such progress that on many and perhaps most buildings it should permit savings of at least 15% on the steel structure. Some of these savings from welding will come from continuity in design; some will come from cheaper connections".<sup>1</sup> Presently it is possible to seal by welding as many as 250 cans per minute - a process requiring great precision. It seems reasonable to assume that welded connections done with adapted machinery in a shop under controlled conditions could compete favorably in price with standard bolting techniques used in conventional framing despite the fact that the number of connections is greater.

Larger sections of the truss could be erected out of steel rods in a continually flowing band, cut at desired lengths and attached to other sections on the site. The members could be pre-bent continuous steel rods similar to the ones used for webs of open web steel joists.

Working out a connection is a subject for Master's thesis in itself. However, if welding on the site proves to be impractical due to the number of welds, one of three already worked

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<sup>1</sup> "How to Cut the Cost of Steel Framing", Architectural Forum, vol. 101, September 1954, p. 151.

out methods may be tried:

1. Connectors as developed by Konrad Wachsmann;
2. Connector plates similar to the ones used in Unistrut;
3. Connector as used by B. Fuller in the Rotunda dome. Of

this he says:

"My Ford Dome solution was through emphasis of edges, and economical employment of surprise advantages to be derived by use of low-cost aluminum roll sheets and high-speed stampings of same, and surprise (approximately double) strength accruing to micro tolerance of end fixity riveting specifications, practically obtained by pre-punching of rivet holes, through machine guidance, at tolerances of hole diameters and relative positioning, infra-visible and ergo impossible to previous on-the-job, craftsman layout techniques.

"I have a large portfolio of photographs of true models demonstrating surprise techniques in joint, edge and face solutions, and combinations thereof, developed throughout recent years. Most of these solutions I reduced to practice in full-scale components employable in man-usable structures." <sup>2</sup>

The columns would come in sections full story high. The floor slab would consist of diamond shaped panels the underside of which would be slightly concave in order to transmit the load to the truss at the vertexial ends of the struts. Those panels would be removable for access to mechanical installations. The

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<sup>2</sup> From a letter by R. Buckminster Fuller to Patent Council of January 8, 1955.

outside wall - stamped lightweight insulated aluminum panels wedged between the floor and the ceiling - would form a module of vertical mullions to meet the interior partitions.

In erection a lift-slab technique would be the most practical. The six central columns would act as a shaft from which the trusses, erected on the ground or intermediate floors, would be hoisted. The side structural members would be inserted after the floors are in place.

#### FIREPROOFING

"Despite vigorous denials the news is now beginning to leak through the screen of industrial atomic secrecy that massive doses of gamma radiation have been harnessed to make an ordinary soft sheet of plastic stronger than the same thickness of today's structural steel and so resistant to heat that it could be used in the after-burners of jet engines; i.e., so resistant to heat that in building it could be used naked without fireproofing." \* But until that day will come the buildings will have to be fireproofed conventionally.

A continuous ceiling of lightweight perlite or vermiculate gypsum plaster attached to the underside of the truss will satisfy most building codes. The columns will be fireproofed with 1 1/2" of perlite or vermiculate gypsum plaster sprayed on with a plaster pump. The floor slab will be 2 1/2" of vermiculate concrete.

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\* "Building in the Atomic Age," Architectural Forum, vol. 101, September 1954, p. 94.

With weight of less than 20# per cu. ft. this type of fireproofing adds proportionately little to the dead load of the building.

### MECHANICAL EQUIPMENT

The attempt has been to reduce the number of connections to be done on the site to a minimum and to integrate all mechanical equipment with the structure by utilizing the space within the truss.

#### a) Heating, ventilating and air-conditioning

Along the periphery heating and cooling would be achieved by using window type units thru which chilled water (hot water in wintertime) would be pumped. The air would be drawn from the outside. This system eliminates the need for large vertical risers and ducts but is effective in only approx. 18' deep area from the outside wall. The remaining area remains to be air-conditioned by ceiling diffusers. Since installation of ducts in the truss would be difficult, the duct system would be laid out in a shop and the truss welded around it. Completed sections would be hoisted in place leaving only 5 connections to be made on the site for each zone fed by a riser. The system would be composed of 6 zones serving 11 diffusers each. This permits the ducts to be smaller in diameter and allows a small portion to be shut off during repairs. All angles at connections would be 120° instead of the usual 90°, resulting in lesser resistance to air flow. The entire truss would act as a plenum for return air.

The utilities would be located on the top floor and in the basement.

b) Wiring

By restricting all ducts to the bottom portion of the truss the connections of ceiling diffusers to the duct system are made easier and shorter, and the top portion of the depth becomes available for conduits and telephone lines.

c) Plumbing

All soil, drain and major water supply pipes are located in the plumbing space. Smaller fixtures such as drinking fountains can be installed anywhere because the truss has ample space above ducts for pipes. Long sections of pipes can be slipped in place thru the top of the truss.

SUN, SOUND AND TEMPERATURE CONTROLS

A projection of the slab beyond the outside wall runs all around the building (to be used by window washers). In addition to the structural mullions a series of diagonal louvers, following the angle of the structural members, may be attached, especially to shield the western sun. Similarly, louvers extended only a few feet from the top would provide effective shading on the south facade. Such louvers are a natural extension of the panels covering the edge of the truss and not merely applied to the skeleton.

A 2 1/2" concrete slab, 2' air space (depth of the truss), and 1" continuous plaster ceiling would give sufficient sound insulation between floors. Partitions are 2" plaster partitions

with an average transmission loss of 38 decibels.

There are 6 temperature zones, each supplied by a different riser. Such a system would respond more quickly to the outside temperature changes. It is conceivable that, depending on the climate, the building could be heated on one side, cooled on the other and have some intermediate zones in between.

### PLANNING

The shape of the plan is best suited to large offices and bull-pen areas. None of the corners in the offices are less than 90° making cleaning and furniture arrangements easy.

The utilities, corridors, elevators and stairs are centered, equally accessible from all offices and resulting in an efficient core.

### POSSIBILITIES IN THE USE OF SPACE FRAME

The system seems to offer the following advantages:

1. The system is well adapted to fabrication in a factory.
2. All members in the truss are same length and all connections are identical.
3. Prefabricated sections would come with ductwork installed in them.
4. No scaffoldings are necessary.
5. Mechanical equipment is integrated with the truss.
6. The structure is much lighter, resulting in savings in steel, lighter deadload, and permitting greater heights to be attained.

7. The parts are lighter and easier to transport.

8. Unskilled or semi-skilled labor could be utilized on the site, permitting skilled workers to work in shops under all weather conditions.

9. The structure can be erected much faster than conventional framing.

10. The structure braces itself against the wind.

11. No interior columns are needed.

12. Equal distribution of rentable floor space top to bottom floors is achieved.

13. Expansion is achieved by addition of other similar units forming a honeycomb shaped cluster in plan.

The major difficulty in the use of space-frame lies in the connections. But finding a way to manufacture such a truss economically should not be too difficult a task to ask a push-button industry.

A building is not only an aesthetic, but also a mechanical and technological problem. Only an approach from basic ideas will result in most imaginative expressions. The architect must free himself of the role of designer of exteriors and selector of tasteful finish materials. He must provide new and advanced standards of building, keeping in mind the machine as an ever present factor. He must become an inventor and designer, dictating and making demands on industry. A master builder, with technology as his tool. Through this a more scientific architecture will emerge.

Perhaps this thesis will tend in that direction.

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