INNOVATION OF STRUCTURAL FORM

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In 1927, Buckminster Fuller saw his life in crisis and was on the verge of suicide. He had failed in business and his young daughter had recently died. "I appeared in retrospect", he later wrote, "a black, horrendous mess…I seemed to have converted the opportunities to give in to negative waste." (He was always very dramatic and explained events in his life in a cosmic framework). Nevertheless, out of this crisis emerged a burst of creative energy and innovative thought starting with what he called the 4D House. Eventually we were treated to the Dymaxion (dynamic, maximum ion) house and car, both of which failed commercially although they had been touted as everyman's machines for living and transportation. The car turned out to suffer from some technical problems and was wobbly at high speeds. The house might have made an impact like so many flying saucers in the landscape. Unfortunately, Fuller acted uncharacteristically cautiously before releasing the design for production, perhaps because of a fatal crash of the first dymaxion car, and asked for more time for research. This resulted in production delays, the withdrawal of financing and the eventual failure of the manufacturing company. But, later Fuller developed geodesics and tensegrity that still surrounds us with domes and other structures. All these inventions were produced during inspired moments in the life of a creative genius. In other words, the driving force for creativity was internal but responded to external needs. In the case of the Dymaxion house, it was the need, after the Second World War for massive amounts of new housing that could benefit from technology transferred from the airplane manufacturing industry. In the case of the geodesic domes, it was the desirability of providing economic ways of spanning large spaces using industrialized components.

ECONOMIC FORCE

The search for economy and efficiency of production appear to be common to most innovative developments. Filippo Brunelleschi won the commission for the design of the dome of Santa Maria del Fiore in Florence in 1417 precisely because he proposed a novel method of constructing the dome without the need for expensive falsework. In so doing, he beat out another Florentine and fellow member of the Goldsmith's guild, Lorenzo Ghilberti, who was already famous for designing the magnificent bronze Gates of Paradise for the Baptistery. To demonstrate his concept to the committee examining the proposals, Brunelleschi built a brick model that convincingly revealed the feasibility of the erection scheme. Apart from the obvious usefulness of models in explaining technical ideas to a lay audience, this story demonstrates the advantage that innovation can bring in besting a better known colleague.

Each of the dramatic bridges that Robert Maillart built in Switzerland was the result of a design-build competition where cost was the single most important factor. The same can be said about the many structures that Pier Luigi Nervi built throughout Italy. His base of operations was a construction company and not a design organization, and he found economies in a new material, ferrocement, combining prefabrication and industrialized construction techniques. Of course, both Maillart and Nervi brought to their task a sensitivity for design that made their structures spectacular.

ANALYTICAL ADVANCES

More recently, the numerous innovative solutions to the design of skyscrapers (a better word than the more mundane designation: high-rise) developed by Fazlur Khan also had economic roots. Khan first sought a way of alleviating the so-called penalty for height which, as a consequence of the action of lateral forces, increases with height and requires ever-stronger structures. After the exterior cross-braced Hancock Tower in Chicago introduced the principle of tube construction that energized the whole building envelope in resisting wind or seismic forces and reduced the structural penalty, the bundled tube Sears Tower further refined the concept. Khan benefited in his ability to design the Hancock Tower from advances in the methods of analysis and in particular, the availability of the electronic computer as a tool for solving large problems involving thousands of elements and nodes. By thus providing the means to examine a vast number of alternative schemes and variations thereof, the computer frees the designer from tedium and allows his(or her) mind to roam and….perhaps to innovate.

NEW MATERIALS

A third engine for innovation, and I remind you that I have so far mentioned two, economic necessity and analytical advances, is the development of new materials. Before the Osaka Pavilion in 1970, fabrics were worn or were considered the stuff of hair raising adventures in the wild, or as a tent hanging precariously on the side of a mountain or as a nomad's home. The architects of the Osaka pavilion, Lou Davis and Sam Brody, were looking for a structure for the World's Fair that was both innovative and cheap. They had an idea for a four-domed balloon structure and called Mario Salvadori, a Columbia Professor who had a reputation in the design of thin shell roofs to help them with the design. Mario, for perhaps the only time in his long life, said he was too busy and recommended one of his students, David Geiger, for the project. With Geiger's help, the design evolved to the sliced pumpkin solution that revolutionized our concept of roof by substituting a soft, flexible fabric for the hard, rigid materials we had become accustomed to: wood, steel and concrete. The concept of a cable-reinforced fabric was not totally new. Late in the First World War, an English inventor, F.W. Lanchester proposed an air supported canvas roof for a demountable field hospital with ropes as reinforcement. His idea never took form but in the early nineteen fifties, stronger and more reliable fabrics were developed and inflatable roofs began to appear. At the same time, Frei Otto stretched fabric between the wires of a web or from poles to create a virtual catalogue of roof shapes. His first canopy structure built in 1967 in cotton and later replaced with PVC coated polyester was characteristic of the pole supported structures he espoused. Of course, his net structure for the 1972 Munich Olympic Park is better known for its intricacy than for its economy.

After Osaka, Geiger designed a number of air inflated domes using the recently developed teflon coated fiberglass fabric that offered long life, self cleaning characteristics and great strength. Air supported stadium roofs sprouted like mushrooms in our urban landscape and appeared in Pontiac, Minneapolis, Syracuse and even Tokyo. Several of these early domes suffered deflations as a result of storm damage. In most cases the failures could be attributed to faulty operations resulting from operators decreasing pressure when they should have increased it and also because axes were used to break-up ice on the roof causing punctures. In this way, Geiger learned another lesson of innovation, the hazard of failure. It was the same lesson that Fuller learned two decades earlier and that the master builder of Beauvais Cathedral discovered seven centuries ago after a spectacular collapse of the main vaults of the choir as he was raising the gothic arch to new heights.

A flood of other examples of innovative structures suggest themselves: The roof dish designed by the Uruguayan engineer, Leonel Viera for an arena in Montevideo; the bicycle wheel roof for the Utica arena designed by Lev Zetlin; the hyperbolic paraboloid thin shell concrete roofs by the Spanish architect Felix Candela; the lacy steel tower designed and built by the French engineer Gustave Eiffel in 1889, another competition winner that produced a tower taller than any other man built structure existing at the time.

Without innovation we would live in a dull gray world with no excitement. This is apparent when travelling around the former Eastern Block countries with their ever-present and oppressive sameness. But, history has shown us that within this repressive homogeneous world can be found the seeds of a dynamic explosion of innovation. This was true in the Renaissance, the Industrial Revolution and more recently during the Great Depression. Social forces act to break us out of the mold of conformism. I find this to be perhaps the single most important purpose of innovation and I predict that out of the fragmentation that has taken place today in the East, a renaissance of creativity will emerge.

Innovation involves taking risks but in the building arts, risk does not mean danger or irresponsibility and is in fact legislated and limited by regulation. That does not mean that the creative impulse has to be strangled or handcuffed. When I approach the design of a structure, for instance, I immerse myself in the problem and seek to enjoy the process. I start with the constraints, whether programmatic, technical or architecturally defined and explore all the solutions that fit within these limits and even those which exist somewhat outside those borders. I then adjust the solutions looking for the one that both satisfies the constraints and gives me pleasure and in the process, fulfill my aesthetic vision.

Of course, I always remain aware of the lessons I have absorbed from the creative designers I've talked about today. I think of Mr Fuller and his geodesics and start with a geometric concept. For the Javits Center design, that meant starting with a tetrahedral element for the space frame derived from the 1.5m module used in planning the facility. The tetraheron allowed turning horizontal and vertical corners to create the architect's vision of stacked cubes. To satisfy the differing structural requirements and spans, the space frame consisting of the tetrahedral elements was used in a single, double or triple layers: in the center of a bay, along the column lines and above the columns respectively. For the Georgia Dome, the roof had to fit into an oval plan that I rationalized to two circular arcs describing a compression ring supported by columns about 15m on center. The resulting plan can be considered to consist of two circular segments on the ends and two fan shaped (or one butterfly shaped) segments in the middle. A triangular grid was then imposed on the plan. Finally, in section, the dome shape was modified to create the hyperbolic paraboloid fabric panels. For the La Plata Dome, two intersecting circles produced a Mastercard shaped plan.

Remembering Messrs. Nervi and Eiffel and I respond to the importance of the details. Joints become the most important design element for all these structures. The spherical node of the Javits Center provides the perfect intersection and meeting point for the pipe elements arriving from as many as twelve directions. The column holding up the spac frame roof above the floor was elegantly shaped by the architect Jim Freed to provide the perfect transition between roof and floor. The nodes of the Georgia Dome and La Plata Dome are somewhat more complicated since they provide a transition between diagonal and circumferential tension cables. Furthermore, some cables pass through the joint and others terminate at the joint and the top chord cables don't even lie in the same plane.

Then, of course, I am reminded of Mr. Geiger and his way of using new materials. The Javits Center required high strength steels for both tension rods and the cast steel nodes. In the domes, fabric panels of teflon coated fiberglass were proportioned keeping in mind the limitations on strength of the fabric.

I cannot forget Mr. Maillart and the importance of proportions. All the structures I described are carefully detailed to satisfy a sense of proportion which is rooted in artistic consciousness rather than absolute technical necessity. I have always tried to avoid situations in which what appears to look like structural innovation sometimes slides toward purely artistic expression.

In the end I think of Mr. Bunelleschi, a really practical guy who thought about how he would build, and I especially took his counsel in designing all these structures. Because the space frame of the Javits Center is a prefabricated product, it lends itself to shop sub-assemblies. I was able to work with the fabricator to design the largest possible shippable and erectable prefabricated units. As compared to previous cable domes, the Georgia Dome and the La Plata Dome are designed together with the fabricator to arrive at the simplest assembly. Every detail, every element was studied to simplify the shop assembly and to facilitate field erection. Since these designs do not allow adjustments to be made during erection it was critical to work out the whole procedure on paper before starting work in the field. It was a great relief to find the roof contours of the Georgia Dome ended within one three thousands of the expected value.

I will always be grateful for the opportunity of having been involved in such unique projects. If I've accomplished anything that deserves the term innovative, I owe a debt of gratitude to all my great predecessors for pointing the way.