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Structural Aesthetics in Architecture and its Social and Technological Relevance

Esthétique structurale en architecture et ses implications sociales et techniques

Aesthetik der Architektur und ihre soziale und technische Bedeutung

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SUMMARY
Structural engineering is primarily based on logic, reason, mathematics and the understanding of the properties of building materials and finally the forces of nature. There is very little room for a structural engineer to indulge in romantic aesthetic forms. But reason in nature has its own inherent aesthetics. Each building material when used in an efficient, simple and sensitive way leads to structural solutions which have its visual strength and presence.

RESUME
L'activité de l'ingénieur civil est basée essentiellement sur la logique, la raison, les mathématiques, la compréhension des propriétés des matériaux de construction et bien sûr les forces de la nature. L'ingénieur a très peu de liberté pour se livrer à la recherche de formes esthétiques romantiques. Mais la nature a ses raisons qui sont liées intimement à l'esthétique. Tout matériau de construction utilisé de façon efficace et sensible contribue à des solutions structurales qui sont également esthétique.

ZUSAMMENFASSUNG
Das Ingenieurwesen basiert auf der Logik, dem Verstand, der Mathematik, den Materialwissenschaften und den Naturgewalten. Der heute projektierende Ingenieur hat wenig Freiheit zur Realisierung romantischer ästhetischer Formen. Aber die Natur an sich hat ihre eigene Aesthetik und jedes Baumaterial kann, wenn es praktisch, einfach und richtig verwendet wird, zu ästhetischen Lösungen führen.

INTRODUCTION

Structural engineering is primarily based on logic, reason, mathematics and the understanding of the properties of building materials and finally the forces of nature. There is very little room for a structural engineer to indulge in romantic aesthetic forms. But reason in nature has its own inherent aesthetics. Each building material when used in an efficient, simple and sensitive way leads to structural solutions which have its visual strength and presence. The aesthetics of a well designed structure is indeed inherent in its very existence and therefore, when visually expressed clearly and honestly makes its own aesthetic contribution.

The structural engineer as a specialist did not exist until very recent times. He was indeed one of many personalities of the historical masterbuilder. From the beginning of civilization when man began to establish urban settlements and up to the middle of the Nineteenth Century; buildings, edifices and monuments have reflected the work of the masterbuilders who responded to the social, political and religious needs of their time with their aesthetic creativity on one hand and the technical and management excellence on the other. The masterbuilder was a man who was taught by one or more masterbuilders of the generation before him and during his training had to demonstrate his own sensitivity in aesthetics, his thorough knowledge of various techniques and methods of construction, his deep understanding of social needs and economic limitations, and finally his capacity to direct and manage all phases of construction of a building. The one man masterbuilder with his assistants could indeed grasp all aspects of planning, design and construction of projects because the form, the method and the material for construction was very much defined by the limits of tradition of the time. Furthermore, the technology itself was relatively simple and did not require the total energy and time of a man to master it. There was indeed no distinction between structural aesthetics and architectural aesthetics. Interestingly, in many languages, the term engineer included all who were engaged in the art and science of designing anything from bridges to buildings.

The traditional role of the masterbuilder began to change with increased sophistication of technologies in the Nineteenth Century, particularly in the second half of it. From mathematics the theories of structures and applied mechanics were slowly developing to be used as specialized tools for predicting the behavior of different types of structures and thereby refining the design to its optimum and most efficient level. This required specialization and those who specialized in these areas of technology were to become the Civil Engineers, later to be even more specialized as Structural Engineers. The buildings, on the other hand, required better and more sophisticated control of internal environment, services and facilities. To design these services and facilities required thorough mastering of two other specialized engineering fields of Mechanical and Electrical Engineering. The masterbuilder, as a

single person, could no longer master all these specialized fields of technology. So he was gradually forced to take a new role and a new name - the contemporary "architect" who takes the leadership in coordinating all aspects of planning and technology while being primarily responsible for the aesthetic quality of a building project.

The aesthetic aspect of a building was inherently tied with the technology and material of construction in the earlier times. Unfortunately the evolution of the architect in the modern sense of the word split that overall creative responsibility to different specialists, namely, the architect, to see to the planning and aesthetics and the engineers to see to the strength, stiffness and functioning of the building. This unnatural separation of roles has been responsible for many incongruities between the form and aesthetics on one hand and the function and technology on the other. Aesthetics often became more a question of an arbitrary concept of beauty rather than the inherent beauty that exists in the total concept of a project.

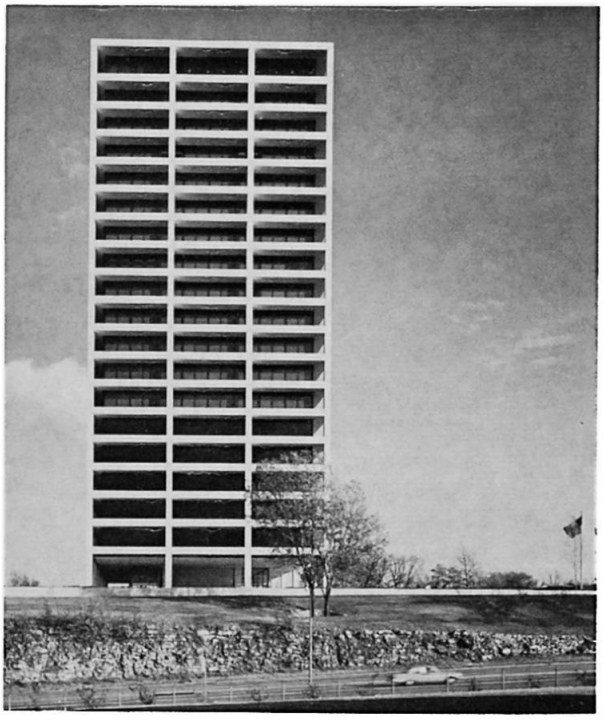
The building profession as a group is beginning to recognize the need to correct this unnatural architect - engineer dichotomy through a fresh reevaluation of the essence of design itself. Aesthetics and technology need to be reunited again by replacing the single person masterbuilder with the team of specialists working together in a complementary spirit to create the right solution, sociologically, aesthetically and technologically.

The author has had a fortunate role in designing a number of significant building structures in the last twenty-five years. Only by working closely with his architectural counterpart could he successfully express these structures and integrate them with the overall architecture. In some of these buildings, the structure, expressed clearly and honestly without any conscious effort to mold it into "art," contributed to the overall architectural strength and beauty at the same time. The author feels that only when architecture and structure become one and the same, the structure can achieve its aesthetic objective. The following examples are presented to support this point of view.

AESTHETICS OF STEEL STRUCTURES

Clear and honest expression of a structure designed to carry the loads without any redundancy can have a visual and architectural impact by itself. Many of the early highrise buildings were designed by architects with preconceived ideas of the exterior of the building based on the Greek, Roman, Gothic and other medieval heavy stone and masonry expression. Because of this a-priori concept of the facade, most of the early steel and concrete frame buildings were not only clad with masonry or stone but also were given visual expressions unrelated to the structure within. The Chicago school of architecture under the leadership of such men as LeBaron Jenney was the first to question these classical exterior expressions. It was indeed the first serious effort to explore more consistent

expression of the exterior facade relating to the form and proportions of the structure of the building. The buildings such as the Leiter Building and the Carson Pirie Scott Building in Chicago built around the turn of the century, are indeed excellent examples of the aesthetics of reason achieved by integrating the proportions of the structural frame with the architectural elevation. This bold step set the stage for further purification of the facade's expression in the last few years. The strength, proportion and elegance of the frame construction showing the beams and the columns interacting and providing the basic framework for the building reached a high point in excellence of expression in the BMA Insurance Building in Kansas City completed in 1962 (Fig. 1). In this 20-story all welded rigid frame building, the columns and the exterior beams were clearly, honestly and articulately expressed by moving the glass line six feet (1.8 m.) behind the face of the building. The inherent aesthetics of a well designed rigid frame was emanated from the most optimum design of the steel columns and beams. Their dimentional slenderness and their proportions achieved through high level of structural efficiency were the two essential ingredients for making a convincing and yet pristine aesthetic statement. The structural steel frame itself if left totally exposed could of course make the clearest aesthetic expression. However since it is not possible to do so because of the requirements of fire protection, white marble was chosen for encasing the exposed frame thereby expressing the natural aesthetic of a slender and efficient structural frame. After almost twenty years this building still remains one of the most elegant expressions of structural frame in contemporary architecture.



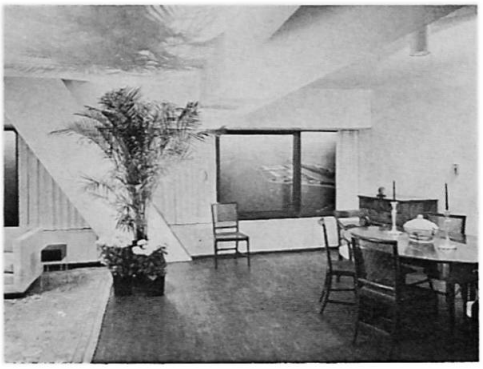
1. BMA Insurance Building in Kansas City, Kansas

2. John Hancock Center in Chicago, Illinois

The 100-story John Hancock Center in Chicago (Fig. 2) on the other hand achieves its structural aesthetics through a visual recognition of its strength and stability through the interplay of horizontal, vertical and the diagonal members. For the design of the 100-story John Hancock Center, the truss-tube concept is based on the interaction of the exterior columns, spandrels and the diagonal members which simulates a hollow tube consisting of the entire exterior perimeter of the building. The diagonals in this building were not designed as wind bracing in the classical sense, but as inclined columns which also distributes the gravity loads uniformly to all vertical columns. This integral structural composition of the exterior of the building which was responsible for its unusual economy had an inherent aesthetic quality. The visual quality of the structure was the reason why it was decided to express the structure without any arbitrary superimposition of any preconceived architectural facade. The decision to express the structure by cladding the main structural members with black anodyzed aluminum and slightly receeding the remaining surface to be filled in with a glass curtain wall was a deliberate act to highlight its visual strength. The clear expression of the structure indeed helped to give the building a character and an architectural quality that an a-priori facade would have never achieved. But to achieve structural aesthetics the design of the structure itself had to recognize at every step its potential visual statement. Such an awareness makes the engineers more conscious of the need to design the structure as efficiently, elegantly and articulately as possible. The John Hancock Center in Chicago is a structural expression of strength and vitality that gives it a distinct architectural presence in its urban setting.

Structural aesthetics goes beyond the visual expression of the structure from outside the building. The visual and physical environment it creates within the building for the occupants is of great importance. The John Hancock Center diagonal truss tube while producing a sense of strength and physical elegance of the building from outside also contributes to the sculptural elegance of the spaces within. The juxtaposition of the diagonal members in its fenestration gives it an unusual sculptural effect. The two intersecting diagonals looked at from inside the second floor lobby as well as the lobby of the apartment on the forty-sixth floor (Fig. 3) are particular examples of the structural aesthetics of this frame as perceived from within. In the apartments located above the forty-sixth floor which had diagonals going through their exterior fenestration were of high demand because of an additional sculptural impact (Fig. 4) Structural aesthetics in its more comprehensive aspect therefore, must consider the external view and perception of the structure and its proportions as well as the internal perception of the structure by the occupant creating a sense of elegance, sculpture and comfort. The triangular window spaces in the John Hancock Center, particularly in the apartments are indeed perceived as extremely desirable, comfortable and sculptural in character.

3. John Hancock Center, lobby on forty-sixth floor



4. John Hancock Center, model apartment

Steel trusses have their own natural proportions and when set at intermediate levels on the exterior of the building create an aesthetic form worthy of full expression. The belt truss concept in steel construction for intermediate height buildings, within 40 and 60 stories, has the inherent structural aesthetic quality which deserves full architectural expression. The First Wisconsin Bank Building in Milwaukee (Fig. 5) is an excellent example of the structural aesthetics of trusses in a building.

AESTHETICS OF CONCRETE STRUCTURES

The aesthetic of concrete structures in bridges by engineers like Maillart and in shell structures by engineers like Nervi is well established. But in buildings until the early 1960's, the exterior of concrete buildings were mostly given the curtain wall or masonry bearing wall expression. In as much as the concrete beam-column frame for earlier tall buildings was considered inadequate for more than ten stories, the frame expression of concrete buildings could seldom be justified. But their expression even in low rise buildings, except in shell structures, was not exploited by the architects, perhaps because of a lack of understanding and appreciation of their structural forms. In the early sixties the use of prestressed concrete made it possible to create long span floor systems and with it great opportunities to express the elegance of such structures became available. An excellent example of such a building was the United Air Lines Headquarters Building near Chicago (Fig. 6) which was designed as a two-way post tensioned grid with column spacing at 66 feet (20 m.) in one direction and 60 feet (18 m.) in the other direction. A clear expression of that structure and its elegance was architecturally highlighted by moving the window glass line about six feet (1.8 m.) behind the exterior so that the structure and its proportions could be clearly expressed. Structural aesthetics is once again enhanced by the slender elegance of the thin slab spanning 66 feet (20 m.) integrated in scale with the slender columns in the same plane. The particular case of the United Air Lines Building brings out an interesting aspect of

structural aesthetics; that is, the structural aesthetic appreciation of any period in history is intimately related to its contemporary technology of structural materials and methods of construction. For example, if a masterbuilder in the Nineteenth Century had proposed and drawn up an elevation of the building showing 30 inch (75 cm.) deep edge beams spanning 66 feet (20 m.) without any intermediate support, he would certainly have been seriously questioned, not only for his lack of knowledge of construction but even more for his lack of structural aesthetics. With today's technology of prestressed concrete, these slender proportions are feasible and buildable and therefore can be visually accepted and enjoyed as an expression of the beauty of structure.

In taller reinforced concrete buildings, the visual expression of structures has been integrated in the overall architectural facade only very recently. If we look at the flat plate construction in tall buildings we find that it is used mostly in conjunction with a shear wall. Even in such a structure an effective expression of the structure can be made by moving the glass line inside from the perimeter thereby exposing the slab and exterior columns in their true proportions. An excellent example of such an aesthetic expression of structure is the Hartford Insurance Building in Chicago (Fig. 7). The visual effect of the structure is heightened by the gentle tapering of the slab at the columns. The occupants of this building enjoy the aesthetic value of the structure further because of the added comfort created by the shading effect of the overhang.

5. First Wisconsin Bank Building in Milwaukee, Wisconsin

6. United Air Lines Headquarters Building in Elk Grove Village, Il

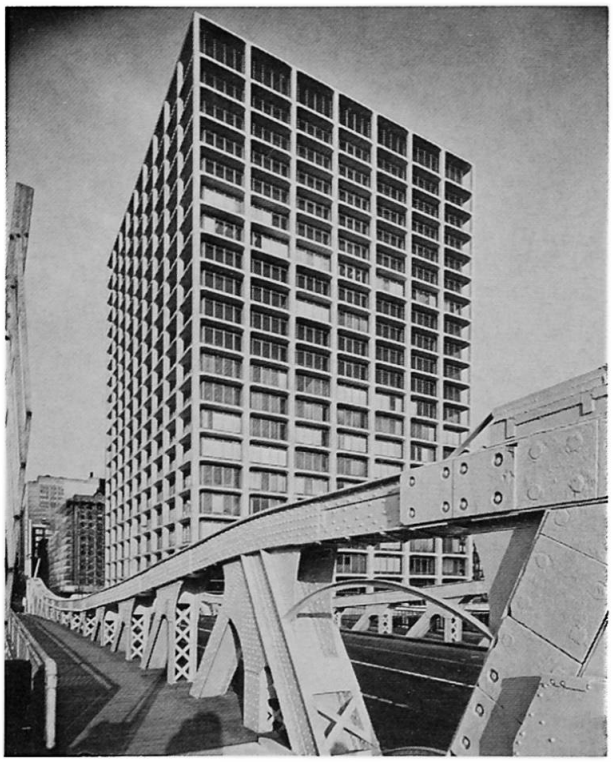
AESTHETIC EXPRESSION OF LOAD PATHS

In the framed tube concept the exterior elevations of the building are indeed bearing walls in contemporary materials which have been punched through at intervals to create windows. Once this is understood it is easy to look at the larger openings which may be necessary at the ground floor more in the concept of the bearing walls rather than the concept of a very rigid transfer girder. In the 38-story Brunswick Building in Chicago the large opening at the ground floor was created by a 24 foot (7.5 m.) deep reinforced concrete girder, 8 feet wide all around the perimeter to support the framed bearing wall above that level. This was a monumental solution and its clear expression of structure had indeed a strong structural architectural impact. But in a later building a more transitional transfer was achieved in a classical bearing wall approach. In the Marine-Midland Bank Building in Rochester, New York (Fig. 8) the large opening on the ground floor was achieved through a gradual transition of load paths from the upper floors to the far spaced ground floor columns. The structural shapes and sizes of intermediate floor columns and spandrel beams were proportioned according to the actual load flow. The result was indeed a visual impression of the classical arch in a traditional stone-masonry bearing wall construction. The structural aesthetics here was the result of the honest expression of the load flow pattern.

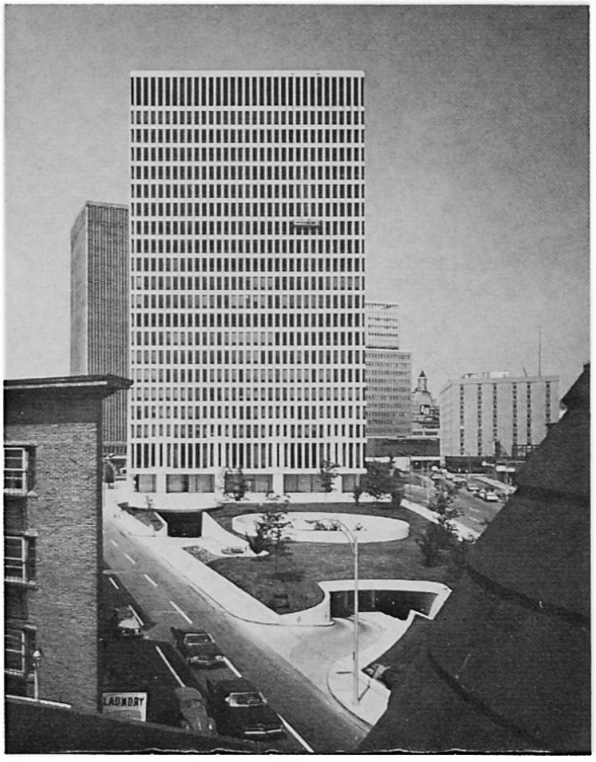
For concrete tall buildings the original concept of bundled tubes, first used in the Sears Tower, is now being explored in a more organic shape in a number of new buildings. Each of these buildings are being studied for the proportions and forms through a totally integrated structural architectural expression. The author hopes to discuss the findings of some of these studies at the time of the Congress.

AESTHETICS OF CABLE STRUCTURES

Cable suspension bridges have been in use for almost 75 years. These bridges all derived their aesthetic value from the natural form created by the structure. In buildings, the use of cables has not yet been fully explored and experimented. There does exist the possibility of creating large clear spans for special unobstructed space needs by hanging the roof structure from cables projecting out of masts. A very recent example of it is the Baxter Lab Cafeteria Building near Chicago (Fig. 9) which has a 300 foot by 150 foot (90 m. by 45 m.) roof. The need for an inside column free space was social as well as functional; social in the sense that it was desirable to create an inner environment with a spirit of celebration and relaxation which would be enhanced by a clean structural grid on the roof and a feeling of unobstructed extension of inner space into the outer landscaped area; and functional in the sense that the gathering of large numbers of people throughout the day indicated elimination of inner supporting columns, if possible. In designing this building every effort was made to express the unusual slenderness and



7. Hartford Insurance Building in Chicago, Illinois

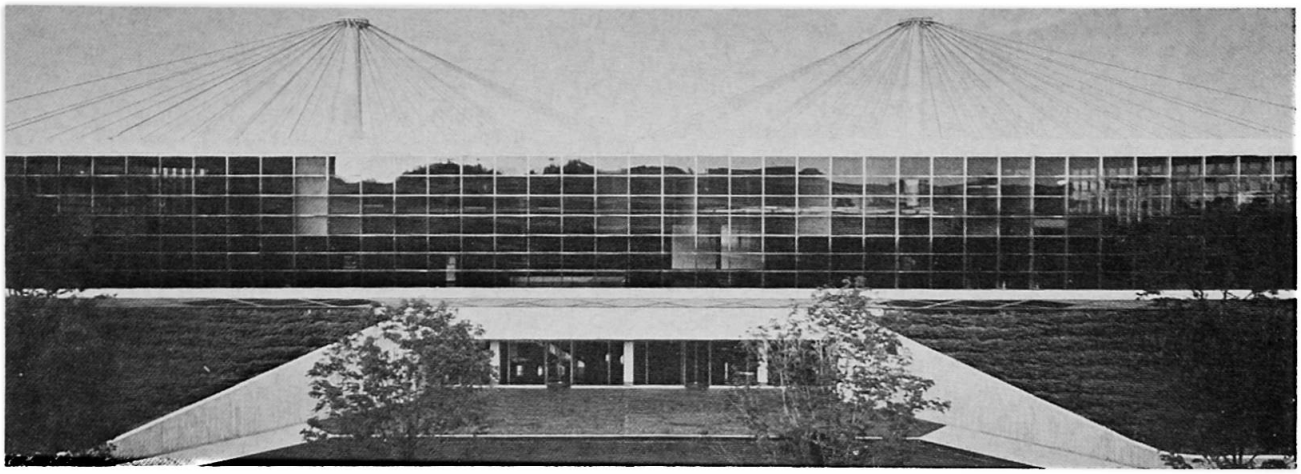


8. Marine-Midland Bank Building in Rochester, New York

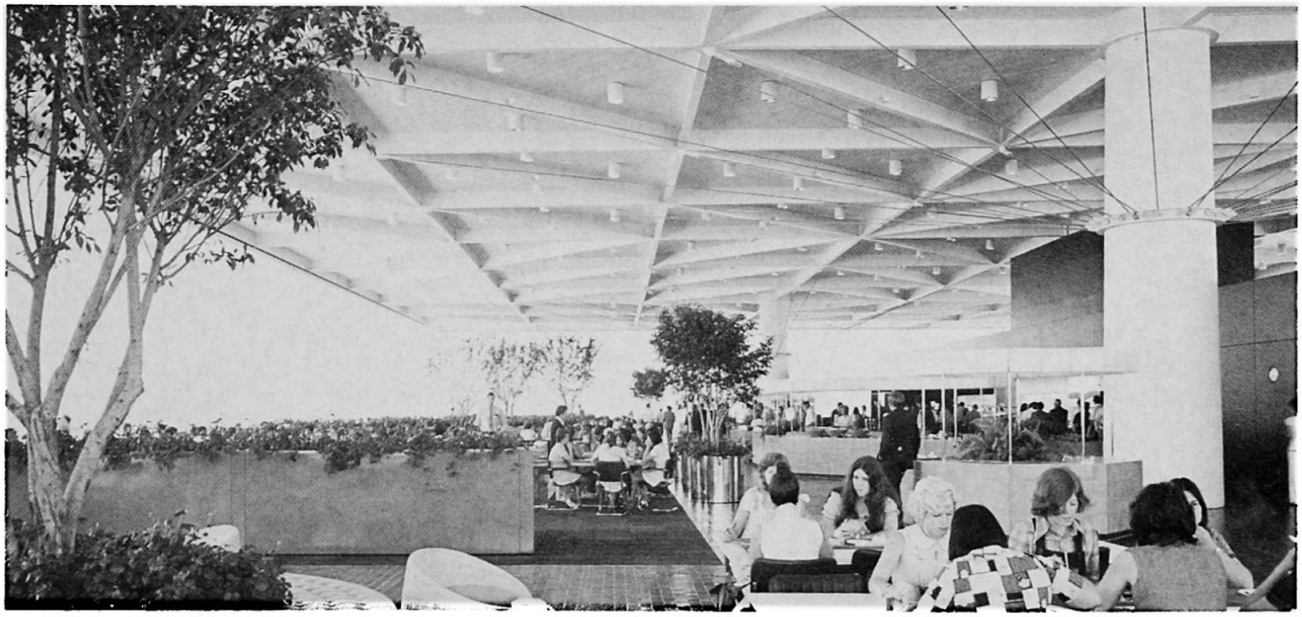
floating character of the roof line and to visually create the honest impression that the entire roof is indeed supported by the radiating cables from the two central masts. From inside, stabilizing cables radiating from the mast up to the roof beams, give the inner space a convincing and distinct structural aesthetic character generating a sense of amazement on the first visit into the space (Fig. 10). Structural aesthetics, once again, was achieved by making the structure efficient and achieving simplicity in slender proportions while satisfying the social and functional needs.

AESTHETICS OF FABRIC TENSION STRUCTURES

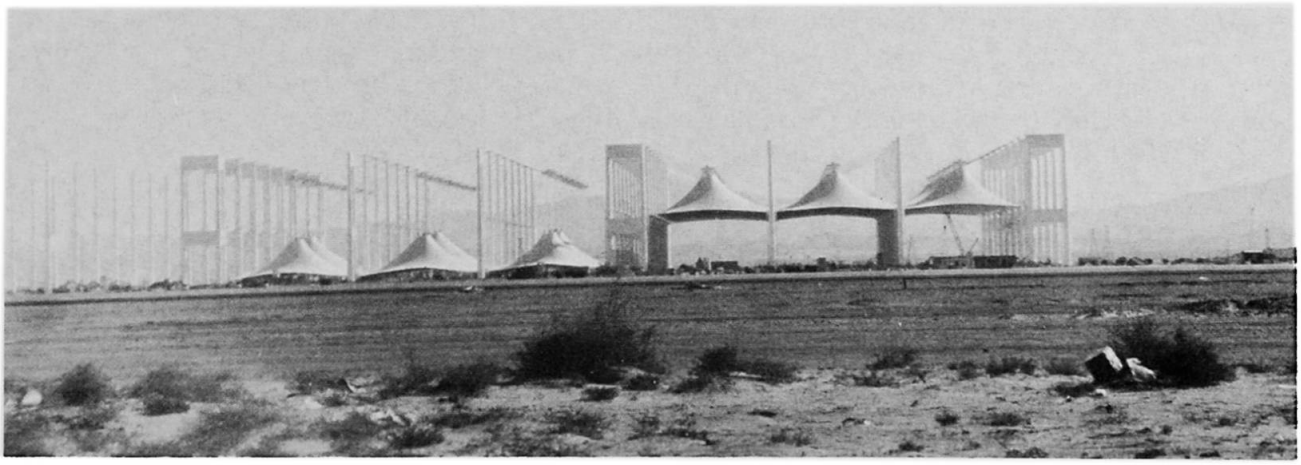
Cable network tension structures have been used successfully for a number of years and the structural simplicity and elegance have always been the essense of the overall architectural expression of these buildings. The pioneering work done for the German Pavillion in the Montreal Expo, 1967 and the Munich Stadium for the Olympics in 1976 are two excellent examples of this kind of structure. Unlike the rigid structures discussed earlier, the tent forms created by the two-way cable network had an added impact on the environment and thereby also made a cultural statement by the engineer/architect. A logical extension of such a structural system has been tried by the author in the Haj Terminal in Jeddah (Fig. 11) requiring a roof surface of almost five million square feet (470,000^{2}m.). The need for such a terminal for the pilgrims coming to Jeddah for their final destination to Mecca indicated the creation of an environment and not an enclosed building.



9. Baxter Laboratories Cafeteria Building in Deerfield, Illinois



10. Interior Baxter Laboratories Cafeteria Building



11. Haj Terminal, New Jeddah International Airport in Jeddah, Saudi Arabia

In search of the most appropriate forms of roof in the desert environment of Saudi Arabia, the fabric tent form appeared to be the most natural and attractive for the region and evoked the cultural heritage of the land. Furthermore, in the perspective of the thousands and thousands of tents which are used for the Haj in the Mecca area, it was even more relevant to devise a tent form that evokes the spirit of the Haj. In recognition of these factors, a structural tent form was developed using teflon coated fiberglass fabric 1 mm. thick which interacts with radiating cables. These tent units are hung from piers spaced at 150 feet (45 m.) on centers and soar from 65 feet (20 m.) above ground reaching to a height of 118 feet (35 m.). These tent units are arranged in modules of twenty-one such units (3 x 7 units). Ten such modules (210 units) provide the Hajiis an environment of transition from the air-conditioned spaces inside the airplanes to the generally open environment of the Haj process. The structure of the tent repeating itself 210 times, helped in making the structure more economical compared to possible alternate steel or concrete roof systems. What is more, through the expression of the simplicity and naturalness of the structure form, it provided an aesthetic ambience and a cultural identification which will undoubtedly evoke the spirit of Haj to the millions of Hajiis who pass through it.

CONCLUSIONS

In describing the examples of steel, concrete, bearing wall, cable and fabric tension structures in building, an attempt was made to underline and bring to focus the essense of structural aesthetics in buildings. Structure is based on reason which has its own inherent aesthetics. Well detailed efficient structures always possess the elegance of slenderness and reason and has the possibility of a higher transcendental value than the whims of an a-priori aesthetics imposed by some architects who do not work closely with the engineers and do not have an inner feeling of the natural forms of structures. The a-priori concept of building expressions and forms are indeed the result of the dichotomy created in the last century by the splitting of the classical masterbuilder into architects and engineers working separately from each other. The simplicity and honesty of structure with its implicit strength and stiffness, its elegance through optimum slender proportions, can indeed provide an architectural expression that has its own vitality and aesthetics. It is hoped that the clear understanding of structural behavior and the resulting forms will help the future teams of architects and engineers to design buildings in which the aesthetic quality of structure and technology can merge with the social and architectural values to create buildings that will eloquently speak of our time.

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