LIGHTWEIGHT STRUCTURES IN URBAN DESIGN

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ABSTRACT

Lightweight architecture questions how we architects think about the environment. It has qualities which complement "mainstream" buildings. This thesis will explore these qualities and will propose that this architecture is rooted in the modern sensibility and suggests an attitude towards the environment that is needed in our cities. Lightweight architecture is concerned with optimal and, particularly, parsimonious use of materials and effort. Much lightweight architecture is tensile as structures loaded in tension use the least amount of material. Now that modern technology and materials have opened up possibilities in research and application, much of the research has been done and is no longer the exclusive realm of trained engineers. The question of application of this technology remains -- this is up to the architects.

The style of lightweight architecture can be looked at in terms of aesthetic, the process by which one develops its forms and the way of thinking from which it arises. The aesthetic of lightweight architecture enriches the traditional aesthetic notion familiar to us (symmetry, proportion and balance) with the more elusive notions of dynamic symmetry, relative harmony and equilibrium.

Form-finding is an experimental process of trial and error. It stems not only from the scientific discipline of static, but from other disciplines, explored from without. In this way, unexpected combinations appear. Complementing static research into the minimal use of materials, vernacular constructions and biology have been used for a greater understanding of parsimony in building.

The "logic of reasoning" refers to a creator's conception of the world in which one creates. The designers of lightweight architecture believe in a world not of specialization and analysis, but of creation and adaption, an ecological view of the world. Because the process of creation is more important that the resultant form, the syntactics of structural and formal assembly takes precedence on an analogical basis for form-finding.
The second section of this thesis explores lightweight architecture in the city. The current trend of placing lightweight buildings in parks rejects the possibilities of lightweight architecture can offer the city. Many architects see a conflict in the juxtaposition of lightweight buildings against traditional load-bearing urban "fabric". Lightweight architecture implies notions of boundary and mutability that are contrary to these same notions as represented in industrial cities. Being ephemeral, mobile and adaptable, this architecture, by its unboundedness, forces us to re-assess our notion of boundary. Lightweight architecture, allows for a rapid adaption of buildings in the city to climatic change and for the periodic gathering of festivals and markets.

The adaptive, mutable qualities lightweight architecture can bring to the city are particularly valuable for urban public spaces. This architecture allows for human engagement with the environment and with each other. The load-bearing wall and its function in the city -- the separation of one activity from another and the definition of privacy -- has been radically redefined by the advent of the glass curtain wall and the telephone. This process has left us with ambiguous urban "public" spaces -- spaces not much used by the public yet not truly private.

Re-introducing a mobile, lightweight ephemeral architecture into post-industrial cities is a desire to implement certain socio-political ideas about city culture and simultaneously make places where those policies are lived.

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INTRODUCTION

Architecture which uses lightweight principles fundamentally questions our ways of thinking about the built environment. Theoretically, tensile buildings are collapsible, transportable to other locations and able to be rebuilt immediately. Tensile architecture expresses, solely through its construction technology, the possibility for rapid change of form and location. The recent reappearance (since the 1950's) of tents and other lightweight construction in our post-industrial cities suggests a possibility for the resurgence of an urban architecture soft, light and responsive to change. This is in my opinion urgently needed. Such an architecture is the perfect complement to the existing stock of buildings and these lightweight structures allow for translucency, lightness, convertibility without costs, collapsibility and mobility and therefore are inherently adaptable to social and climatic changes.

Modern designers of lightweight structures are pursuing an age-old question of building: how can one achieve more using less -- less materials and less effort. Nowadays, contemporary technology has allowed those pursuing this question to elevate traditional lightweight construction to a modern building type capable of remarkably light, convertible large spans. The basis of the structural logic of lightweight structures aims for the optimal use of materials. This usually implies a prevalence of tension forces in the structure and a limitation of compressive elements. Tensile
(fig.1) Multipurpose Hall and Restaurant, Federal Garden Exhibition, Mannheim, Frei Otto, BRD, 1975.
structures (i.e. tents and other stretched membranes), characterized by having only a few compressive masts, with cables and membranes under tension, are tending towards a perfect balance between compressive and tension members. Even though lightweight structures generally use tension as a primary mode of support, they are essentially defined by their parsimonious use of materials to complete a task. For this reason, one of Frei Otto's major projects, the Multihalle in Mannheim is in fact a grid shell working exclusively in compression. (fig 1)

(fig.2) Munich Olympic Complex, Munich, 1972
The advent of high strength steel and membranes of synthetic fabric was a catalyst for experimentation in light and wide-span structures and stimulated a great deal of research in new types of envelopes and coverings. Projects and realizations range from large-scale meso-environments for extreme climates (polar and desert agriculture) to convertible translucent roofs, to small-span stretched membranes for temporary use (community meetings, performances, markets or fairs), to simple tensile street coverings as shading devices.

Large span projects such as the Olympic complex in Munich (fig.2) showed the actual advantages of tensile structures in terms of their structural potential. This is so because the length of tensile members can be increased considerably without increasing their volume proportionally. The experience of building the Munich Stadia -- because of their size and optimal use of materials -- brought lightweight technology to a workable level, accessible to any architect. Among other difficulties, static calculations of the double curved nets necessitated new computer software which are now commonly used in offices specializing in lightweight design (1).

As I attended the Third International Symposium on light and wide-span structures in March 1985 it became clear that the field of lightweight structures has reached a point where new ideas are drastically needed. As described above with the case
of the Munich stadia, the technology of lightweight structures has grown out of its purely experimental stage into being recognized as a legitimate way of building. Still, the question remains what is lightweight architecture is, what and whom is it? In other words, if this new technology can be considered a legitimate hardware for building, the time has come when new ideas must be developed -- and only architects can do it.

This Symposium in Stuttgart (for a complete report, see appendix A) was organized to evaluate a fifteen year period of research done at the Institute of Lightweight Structures. The symposium dealt with light and wide span structures, the main subjects being nets, membranes and shells. Contributions to the Symposium ranged from purely technical papers to more general environmental issues. The strength of the technical papers demonstrated the maturity of this new technology.

Two philosophies seemed to merge from these technical contributions: one, that loading forces are gathered to a few points of anchorage, massive in size and therefore a major part of architecture; two, the opposing proposition that forces should be dispersed into smaller and smaller points of attachment points. Natural laws show that more weight can be supported by the use of numerous elements than by fewer larger elements. For this reason, Frei Otto tends to subscribe to
the philosophy of dispersing structural forces.

The presentations by architects made the central problem of the field of lightweight structures come clearly to the surface: there is a need to develop an architectural language for these modern structures. The most exciting projects were often the small-scale structures, perhaps because they come closer to the essence of tensile architecture: an architecture designed for potential rapid displacement -- revealed by its lightness of construction. The diplomatic club in Riyadh (jointly designed by Buro Happold and Otto) exemplified a use of lightweight technology for creating innovative and exiting contrasts between the softness of the membranes and the hardness of a three storey high snaking wall (fig.3)

(fig.3)
Diplomatic Club in Riyadh,
Buro Happold, 1985

Contributions by members of the Institute for lightweight Structures (called I.L. for short), provided a reminder of the reasons that motivated designers to become involved in lightweight architecture. Hennicke's contribution emphasized that building lightly does not automatically mean building beautifully, so it seems unavoidable, if one is interested in
the aesthetic of such constructions, to analyse and understand how nature provides examples of light structures. For this reason, teams of biologists, architects and engineers had been involved from very early on in the research and design accomplished at the I.L. For example, in the case of research into net structures, the I.L. first looked at man-made nets and their historical development and only afterwards, pushed by a desire to understand how to design large span nets, they started to analyse nature's net constructions, i.e. various types of spider webs (2).

As mentioned earlier, the question on everyone's mind was: what kind of ideas can we bring to this new technology? Only a few contributions such as Rob Krier's historical lecture and Alexandra Kasuba's artwork, cast some light on the question. Rob Krier's contribution emphasized the "joie de vivre" of the European eighteenth and nineteenth century festive tents. Rob Krier noted that it appeared that this lightness of spirit seems to have been forgotten as the modern tent technology developed and technological difficulties were overcome. A.Kasuba was the only contributor who was not "in" the field of lightweight structures per se. Yet, her work was received as a great source of inspiration by those in search of new ideas. Her work consists of entire environments made of stretched thermal underwear nylon fabric. The forms are always taut and smooth, resembling the interiors of vegetables. The environments are colored solely by hidden lights which when
moved, changed the entire sense of place. Her enjoyment of playing with nature is revealed in her wind sculptures and rain canopies -- no flow is ever blocked by an intellectual, preconceived idea -- shapes seem to burst out from an unrestrained desire to see light.

The discussion closing the symposium made the lack of ideas the most urgent problem to be looked at. The technology of lightweight structures has now reached the stage at which designers can practically do anything. Computers calculate all stresses, draw patterns for membranes and evaluate prices for all possible shapes. And still the question remains, what can lightweight architecture do, what is it for?

This thesis looks at a few aspects of this software. The first of two sections is an attempt to define what is the style of lightweight architecture is in terms of its aesthetics structural logic and philosophical background. Assuming that such a style exists, the second section briefly investigates the potential of such an architecture for the design of public urban spaces in post-industrial cities.
1.0 THE STYLE OF LIGHTWEIGHT STRUCTURES ARCHITECTURE

The style of contemporary lightweight architecture is in the process of defining itself; this makes its description both difficult and challenging. Difficult, because so few modern lightweight buildings have been built, and challenging, because to define a lightweight architectural style is fundamentally to question our common notion of a building as a solid, long-lasting, unchangeable and most importantly, immobile shelter.

This first section looks at three aspects of lightweight architecture: the aesthetic (called the logic of the eye); the form-finding process (called the logic of structure) and lastly, the inherent structure of reasoning.

These three aspects were briefly mentioned by Henri Focillon as he discussed differences between Gothic and Baroque styles in his book The Life of Forms. Focillon is especially interested in the relationship of a culture to its artifacts over time and, as one of the most interesting aspects of lightweight architecture is its cultural roots in traditional craftsmanship, Focillon is an appropriate guide for the study and the understanding of lightweight architecture.

The notion of logic in architecture is applicable to several different functions, which sometimes coincide sometimes not. The logic of the eye, with its need for balance and symmetry, is not necessarily in agreement
with the logic of structure, which in turn is not the logic of the reasoning process. (3)

1.1 THE LOGIC OF THE EYE

The concept of logic of the eye was put forth by Focillon to show that logical undercurrent to forms exists, which can be extracted and discussed in order to analyse a style of architecture. Among numerous aspects, Focillon mentions balance and symmetry as contributors to the logic of the eye. In this section an attempt is made to determine how lightweight architecture, tensile buildings in particular, have taken the notions of the logic of the eye and proposed an alternative aesthetic, where static symmetry has been replaced by dynamic symmetry, the notion of harmony has enriched the notion of proportion and the idea of balance has shifted to a notion of dynamic equilibrium.

1.11 SYMMETRY.

Visual symmetry of masonry buildings -- or other buildings working mainly in compression -- is achieved by creating a correspondance of opposite parts in size and form on each side of a median line or plane. Lightweight tensile architecture is visually dominated by the flow of tensile forces in the structure. This flow of forces is revealed by the seams of the
As an illustration, a comparison of the antique carrousel with the tensile roof protecting it, brings out the contrast between their respective symmetries (fig.4). At first glance, both symmetries seem to follow the same logic, and yet their visual qualities differ. The carrousel -- standing only through compressive forces -- visually implodes on itself, while the tensile covering -- being stretched in all directions -- radiates out like a spider web I will call this radiating quality of the tensile roof "directional symmetry". The eye follows the flow of forces along each panel in the direction of the stretch. Such a directional symmetry implies virtual lines of force which extend beyond the physical boundaries of the object. For example, the tensile forces pulling one panel are collected by a cable which guides them
along a straight line past the anchorage point, where the eye extends the vector on into the ground. If the ground is seen as a mirror plane, then the real cable is on one side, the virtual cable on the other side, thereby increasing the sense of directionality.

Thus we could say that the eye sees the tensile object larger than its actual physical size, by prolonging the directional symmetry into a virtual symmetry. In fact, the directional symmetry of tensile architecture implies its virtual symmetry just as a shadow implies light.

The symmetrical organization of the building is revealed by the seams of the membrane or cable net, as well as by the angles of the compressive members relative to their tension cables. It would seem an absurd idea to hide the existing symmetry (although it has been done) by covering the masts with wooden encasements, simply because one would have to use compressive elements and negate the essence of the building by rooting it to the ground. Decoration, on the other hand, brings other layers of symmetrical organization without destroying the original symmetry. The tapestry of the Lady and the Unicorn shows this multilayering of symmetries on an embellished tent. (fig.5)
1.12 PROPORTION.

The notion of proportion refers to a satisfying relationship between parts and the whole. Since the nature of tensile architecture is that tension members and surfaces prevail visually, proportion takes on another meaning, a meaning we associate with music made visible, its waves varying in intensity and rhythm. Anticlastic curvatures of tensile buildings are pleasing to the eye when their rhythm is right and when there is a sense of harmony between the various elements (masts, cables, clamps, eyepieces, seams, etc).
It is interesting to note that anticlastic curvatures are more satisfying to the eye than the exclusively convex curvatures seen in pneumatic structures. The anticlastic curves are visually welcoming. The pneumatic membrane, self-contained, seems to reject the people approaching it. Since pneumatics are stretched from the inside out, they do not have the virtual symmetry of doubled-curved tensile buildings -- could this mean that there exist certain qualities inherent in virtual symmetry which would fundamentally be part of the logic of the eye of tensile architecture? This virtual symmetry is perhaps a necessary ingredient to feeling comfortable in a building, as opposed to a geometry which, by being a container, focuses back into its hidden interior space, may bring to one a fear of the unknown. (4)

The harmony of tensile architecture seems to have its own set of variables imbedded in the logic of the eye of the tensile aesthetic, because even if the size of an element is statically correct, it might not appear harmonious to the eye. This is often seen in structures which were not designed with the actual size of the clamps in mind; as the size of the structure increases, the size of the clamps become visually bulky compared with the translucent membrane. One could then say that harmony in tensile architecture depends on the correct rhythm of its curvatures and a proportional relationship between the various elements of its construction.
The principles for harmony and proportion found in lightweight architecture are also found in natural landscapes such as mountains or ocean waves. Both types of shapes are commonly called free-form. Why would lightweight structures appear to be more natural than other buildings? Are the Munich Olympic stadia designed by Behnisch and Otto any closer to natural shapes than a glass skyscraper by Mies van der Rohe in New York City? Why are free-forms associated with natural shapes? One could then propose that "naturaleness" of lightweight structures is not so much a consequence of the types of forms used -- free-forms or other forms of form -- but rather a question of the use of scale. As explained below, natural looking objects seem to function within an other set of scales, an other vocabulary of forms, then artificial objects.
The contemporary mathematician Benoit Mandelbrot, in a paper discussing the logic of aesthetics of "scale", brings a useful distinction between objects which we see as natural and those that look artificial, respectively identified by him as scaling objects and scalebound objects. For example, a Mies van der Rohe building is classified as scalebound and the Paris Opera house as a scaling object. Such a distinction helps to clarify the logic of the eye of lightweight architecture: we can see how, in its use of scale and proportion, it reminds one of the harmonies that we find in nature. Mandelbrot proposes the term scalebound to denote any object, whether in nature or made by an engineer or artist, for which characteristic elements of scale, such as length and width, are few in number and each with a clearly distinct size...if a scale bound object is on the human scale it will not, in general be on the scale of a fly.(5)

This definition implies that a scalebound building has such a spare basic structure that the slightest variation in the facade is extremely noticeable. Note that this is not the spareness that derives from the parsimonious use of materials by designers of lightweight architecture; a lightweight building can be a complex layering of many different scales. One of my conclusions -- which will become clear later -- is that lightweight structures are scaling objects; a scaling object does not have a scale that characterizes it. Mandelbrot defines a scaling object as including "so many different scales, and their harmonics are so interlaced and interact so confusingly that they are not really distinct from
one another, but merge into a continuum" (6). Such multiple layers of scales of lightweight buildings are successively unveiled as the viewer approaches the building. In other words, the scale revealed to the eye varies according to the position of the viewer in relation to the building. The closer one gets, the more scales can be discovered within the detailing. A scaling lightweight building can be considered as being of human’s dimension or of bird’s dimension. The many different elements of various scales vary between the maximal scale -- the foot-print of the building or rather, the volume it occupies -- and the minimal scale or inner cutoff imposed by the size of the smallest bolt or cable.

The multiple scales are so interconnected that they are not easily distinguishable from one another; these interconnections merge the scales into one continuous flow which we associate with natural objects. One can conclude that lightweight structures generally have the characteristics of scaling objects and since most natural objects are scaling, we tend to visually associate lightweight structures with natural forms. Note that there are natural objects that are scalebound, crystals being a good example, but somehow, Mandelbrot says, they do seem less "natural" than the complex shape of a coastline.
1.13 EQUILIBRIUM

The energetic shadow of symmetry is also found in what Focillon calls "balance". But visual balance in tensile architecture is experienced as being somehow out of balance, at a transitory point of equilibrium. Cables and masts stretch the membrane just before the point of seams bursting. It is an equilibrium at the edge of a rupture, at maximum effort. Since these structures are held under tension it is clear that if a cable breaks -- sometimes an attractive thought for vandalism -- the structure will immediately collapse. This sense of risk, embodied in the design concept, introduces an aesthetic of being on the edge, one that requires muscular effort yet has the lightness of a kite in the wind. The notion of equilibrium in compressive buildings is purely visual, in other words, the visual masses balance each other without a direct correspondance to the structural masses of the structure -- they are independent. Conversely, because of the structural principles of tensile architecture, there exist a one-to-one correspondance between structural masses and the visual equilibrium of masses.

The parsimonious quality of space in tensile buildings seems to be achieved by bringing into play the principle of harmony and the dynamic symmetry together with the minimal use of the materials for structural requirements.
1.2 THE LOGIC OF STRUCTURE

"To accomplish a task with a minimum use of materials is finally the only interesting problem." Bernard Lafaille.

The success of engineering constructions in the late nineteenth early twentieth centuries nourished an enthusiasm for modern technology in the field of architecture. The constructivists and futurists such as J.J.Leonidov and A.Sant'Elia saw in technology a vehicle for expressing their contemporary culture. The development of theoretical knowledge and the appearance of steel gave rise to numerous exciting engineering constructions among which was the long span suspension bridge. (For example, the computations for the Manhattan bridge could not have done without Melan's work on deflection theory and elastic theory in 1913.) A suspended structure, such as a long span bridge, adjusts itself to approach optimum performance; architects saw in it a culmination of method and structure (7).

The first attempts at designing tensile buildings were greatly inspired by the triumph of suspension bridges of the 1920's and 1930's. But the avant-garde's enthusiasm for tensile architecture was not matched by technological knowledge and they associated efficient living (the machine for living) with highly technological structures. According to P.Drew, Le Corbusier tried to fit modern cubic forms into partly suspended structures but did not recognize the need for
anticlastic curvatures of the surfaces working in tension.

In a world largely structured by scientific thinking, the
difficulty lies in finding a common ground, a meeting point,
where modern technology is in accordance with and does not
overwhelm its logic of the eye. Otto's German pavilion
embodies this meeting point because its aesthetic is totally
supported by its technology. And yet, the intelligence of the
engineering clearly comes through in the design of the
details.

Drew comments:

The adoption of the suspension bridge and the
neglect of the tent as a prototype of the new
tensile architecture was neither inevitable
nor, as it turned out, the most fortunate of
choices. The confusion between form and
technology which underlies much early modern
tensile architecture was not fully resolved
until the emergence of a modern tent
technology at Montreal in 1967 (8).

The Montreal tent represents a landmark in the development of
a style for the lightweight structure technology. One of the
strengths of the aesthetic of tensile architecture lies in the
sophistication of tent design and the cultures which have
created it. Tensile architecture, and nomadic tents in
particular are often assumed to be primitive dwellings.

P. Drew clears up such a misconception as he explains,

Tents are usually considered to be primitive
shelters. The evolution of vernacular dwelling
form shows that the black tent is comparati-
vely a recent development. Far from being
primitive shelters as is sometimes thought,
tents are actually advanced and extremely
refined structures. The value of traditional
Mongol encampment from a fourteenth century Chinese handscroll

tents lies in their demonstration of intrinsic character of tensile architecture. Such outstanding qualities as light weight, economy, portability and flexibility account for the extensive employment of tents by nomadic hunters and pastoralists (9).

Nomadic tents, tensile coverings of streets or amphitheatres, lightweight suspension bridges and tensile buildings for entertainment have not been regarded as architecture, they therefore take a special position in the field (fig. 6, 7, 9.).

(fig. 7)
Black Tent of Southern Tunisia
In the 1950's, these types of structures started to be seriously documented by architects -- in particular the research group directed by Frei Otto (called I.L. for short) -- with the intention of integrating some of their design principles into contemporary tensile architecture. Most of the information on tent life and tent design could only be found in missionary journals, and those of other travellers who described, sometimes in minute details, nomadic tents they would encounter in their travels. Scholarly information was mostly done by geographers (ie. Pierre Defontaines), not architectural historians.

(fig.8)

Etching of a catenary bridge over Rio Chambo River, Peru 1800

The I.L.'s research on vernacular constructions has not been to look for an aesthetic -- even though it has certainly contributed to the logic of the eye -- it has rather been a search for more effective ways to build lighter and convertible structures. Tent builders have been searching for more effective and more beautiful designs for centuries and
the richness of these traditions is one of their major resources of information.

The I.L. research group collected, classified and analysed construction details of tensile architecture and other traditional lightweight structures such as umbrellas, kites, windmills, sails, etc... Craftsman have been perfecting these construction details for centuries in order to approach a perfect fit to the taste. Even though modern tensile architecture uses contemporary technology, the principles of design remain the same. Thus the design of modern clamps was greatly inspired by the multitude of various attachments found in nomadic tent design.

The strong and sudden winds of the desert have traditionally made the craftsmanship of tensile roof attachments one of the most difficult design problem nomads had to face. (fig. 9) As

A variety of stay fastener designs for the Black Tent
explained by Faegre:

... the development of the Persian black tent which was first made of goat's hair cloth breadths sewn side by side, made of two parts, and joined down the middle with toggles and loops. However, the Semitic people who developed this tent weren't content with this simple rectangular cloth. Probably because of the high winds they encountered in the desert, they developed the tension band as additional reinforcement of the tent cloth and turned the whole tent into a more sophisticated structure (10).

One could say that modern designers of tensile architecture are translating ancient knowledge of craftsmanship into contemporary technology of tensile architecture. (Compare fig. 9 and 10.) But this contemporary technology functions according to different physical laws and has another range of structural potential; the analysis of natural objects gives the designer the necessary tools to develop structural principles for building modern lightweight structures. Organic
structures such as spider webs were investigated in detail as preparatory work for developing the cable net technology. Inorganic structures such as soap-film models give information about the minimal surface required to enclose a volume with a stretched membrane. (fig.13)

1.22 BIOLOGY IN LIGHTWEIGHT STRUCTURAL DESIGN

Biological influences do not appear in the logic of the eye because they are part of the form-finding process (the logic of structure) and not the aesthetic. The goal of lightweight design is not to make buildings which resemble natural objects but to incorporate their growth patterns in the form-finding process. (Compare figs. 11 and 12.) This would ultimately mean a way of building which would come so close to natural principles that the structures could be organic and grow.

The fascination for natural shapes is expressed by Focillon as he comments:

... nature as well as life creates forms. So beautifully does she impress shape and symmetry upon
the very elements of which she herself is made and upon the forces with which she animates them that men have been pleased to regard her from time to time as the work of some God-artist, some unknown and guideful Hermes, the inventor and contriver (11). Otto is impressed by the beauty of nature too, but he does not feel he has time to contemplate it and simply paint its beauty, he is on the path of inquiry where Hermes now inhabits the graph machine for recording static lines of stress in loaded structures. The God-artist is in the computer, remembering all necessary information and cutting the most efficient patterns.
The logic of structure, described in this section, shows the attitude of the designer, in this case Otto, towards research and modern technology. The question is how can a designer, who is looking at scientific data such as biological objects and maximum economy of materials, reconcile this sort of form-finding process with the logic of the eye (as described in the previous section) in a society bathed in scientific thought? One could think that such a prominent scientific culture would overwhelm the search for an aesthetic. But the search for a logic of structure is in itself a creative process simply because most lightweight architecture still is experimental.

The logic of structure uses biology as a tool to translate traditional knowledge of craftsmanship into modern technology and it is the meeting of these completely different source of information which allows for a creative experimental process.

1.23 THE FORM-FINDING PROCESS

From the documentation, it appears that a large part of lightweight design is based on experimentation and guesswork. Otto's experimentation is based on certain hypotheses derived from observations of lightweight structures. Even though the research is conducted with rigorous reasoning and inner logic, the main creative stage is based on trial-and-error model making. The novelty of the aesthetic also necessitates an enormous quantity of experimentation, little of which is seen in the final products. It is this emphasis on process rather
than product which characterizes the work done at the I.L.

P. Drew describes the I.L.'s experience during the design of the German Pavilion:

The design evolution was a trial-and-error process of developing a form that defined the desired architectural spaces and corresponded as closely as possible to a minimal surface. ... The initial shape of the roof could only be determined by means of model iterations. For this reason the model test was a crucial factor in the form-finding process (12).

This type of trial-and-error search for form is characteristic of an architectural style in the process of defining itself. Gothic art, according to Focillon, is such an example where the form-finding process was the process of experimentation -- much of it misdirected as experiments followed their own blind alleys. F. Otto was trained as an engineer, not a biologist. He looks into the world of natural sciences only to acquire information. He is a man looking from the outside in.

Santillana demonstrates in Reflections on Men and Ideas that the inventors of new modes of thinking and aesthetics (during the Renaissance) were never products of the established culture. Often they could not even read Latin and for information would rely on discussions with literate friends. Leonardo da Vinci, for example, whom Santillana calls the man without letters, needed a sort of naivete in order to ask questions -- the modern questions. He says, "This man without letters is not illiterate, but as a mistrustful suspicious, and captious artist-peasant he examines letters from without." (13) Even though their
situations are, doubtlessly, dramatically different, I will draw a comparison between Leonardo and Otto because of the similarity in their attitudes to research. Both believe in an aesthetically justified science. Leonardo affirmed "Painting is a philosophy and a legitimate science of nature" and Santillana comments, "for from it, that which in the universe is unconcious of itself emerges. That is where truth breaks the knowledge of all nature's effects that contribute to the creation of the image."(14) Leonardo does not dissociate aesthetics from science because he, like Otto, is a creator and not simply a researcher. They use the logic of structure -- the scientific aspects of their research -- as tools in the expression of a larger vision in which aesthetics is the goal.

Leonardo is a man without letters and Otto is a man without the natural sciences. Both ask the question: HOW does a natural object work, not WHY does it work this way. In other words, scientists usually want to understand why "a" causes "b". Otto and Leonardo are looking for structuring patterns of natural phenomena: Leonardo classifying various types of cracks in walls or eddies in rivers, Otto classifying spiders' webs according to their system of attachments. They both ask HOW does this natural object take this form? They humbly draw to understand a little more.

This section has attempted to show that the logic of structure in lightweight design is based on a rigorous and extensive
1.3 THE INHERENT STRUCTURE OF REASONING (third logic)

According to Focillon, an artist or craftsman creates objects within an encompassing view of the world and his place in it. Focillon calls this artist's concept of the world in which he creates "the inherent structure of reasoning" (pure raisonnement). There are times when the process of reasoning has dominated the aesthetic of a style to the point of its aesthetic becoming distorted. Such distortion is evident in the Baroque architecture.

1.31 TOWARD AN AESTHETIC OF SELF-EFFACEMENT

The inherent structure of reasoning in lightweight design is based on a holistic view of the world. This is a consciousness of the importance of an ecological view of the world as opposed to a view which would plead for the specialization of activities. Such a holistic view would imply man-made objects fundamentally adaptable to the ever-changing flows of creation and re-creation. Note that the analysis of
biological objects is used only as a tool to an end and should not be seen as a substitute for an "ecological way of building".

The researchers at the I.L. are not looking at all types of vernacular architecture, but only at lightweight buildings designed to be collapsible, portable and convertible, designed for a nomadic life. Researchers were looking for these qualities as they documented ancient coverings of roman theatres, nomadic and festive tents and buildings made of fibers. Tents are designed with mobility and transportability in mind. Such buildings, designed to disappear at any moment, offer a different aesthetic, an aesthetic of self-effacement in relation to the land and to the history of the land. Such structures will contribute to the memory, the sense of place of an area, only by returning to the same place cyclically. When we see the piazza of Verona we immediately imagine the umbrellas of its farmer's market, and this, because they reappear daily. The aesthetic of tensile architecture rejects the idea of being bound to the land but accepts the idea of recurrant existence. This is cyclical memory.

Tents suggest mobility, uprootedness, and the potential to disappear. A shack is also an ephemeral building, but a tent can be reduced to a bundle, transported, and in no time be redeployed elsewhere without a trace of a memory left lingering. It is an architecture, of action, of forwardness,
it can move anytime, and be carried by hand. Solid, long lasting buildings stay on and accumulate memories, stories; non-ephemeral buildings, made of compressive elements, enter all sorts of stories and histories -- the history of a region, a place, the history of architecture, of battles for territories and ideas. Tensile architecture bypasses all this. Nomads create a sense of place wherever they decide to camp. The sense of place exists within them and they reproduce it wherever they settle. The qualities of tensile buildings are therefore more diffused, more difficult to grasp than the qualities of "solid" architecture.

Small scale tensile buildings show in their form the potential for easy rearrangement of pieces and thus the whole (I am referring to small scale modern tents such as Otto's tent building system to house the pilgrims at Mecca during Ramadan). Unlike solid buildings -- even ones made of ephemeral materials -- tensile architecture allows for change of configuration at each erection. It adapts to different terrains; weather, social organizations and even other buildings in a city. This is an aesthetic of negotiation, of compromise, of adaptability.
1.32 AGAINST METAPHORS

The second aspect of the this third logic is the non-analogical aspect of the form-finding process as shown by the I.L. Otto, as well as Leonardo, had to find a level where objectivity, analysis and aesthetics could come together into one. In order to find a meeting point between objective analysis and the aesthetic, Otto emphasizes the importance of avoiding direct analogies with nature. He explains in I.L.6:

> We are seeking the forms of lightweight structures, i.e. objects which can convey forces with a minimum mass. We have no intention of finding new lightweight structures by imitating nature. We have seen that the structural principles in organic nature can only be comprehended when the technical development allows it, i.e. when our knowledge permits comprehension. Thus the biologists show us not so much construction of organic objects, but rather expect an analysis from us based on our research. (15)

Otto has brought the intellectual search for the essential, the abstraction, into the world of D'Arcy Thompson where an understanding of nature is the source for the development of a form language. In fact, there is a long tradition of designers who have been searching for a parsimonious method of building in both vernacular buildings and architecture. But one could say that the parsimonious aspect of lightweight structures is relevant to us today because it corresponds to a deep change in our way of thinking. Many current trends show that our way of thinking is tending towards a reduction of essential elements, overall, towards a greater abstraction.
Lightweight architecture is perhaps the purest style of contemporary architecture tending toward such an abstraction, both in terms of structure and aesthetics.
The aesthetic of abstraction is perhaps best exemplified in modern literature. Gertrude Stein, who brought the English language to perhaps its purest level of abstraction, removed all analogical forms from her work; in it, there are no more metaphors. The great variety of her sentences are built out of simple set of components, as the simple components of DNA (cytosine, adenine, guanine and thymine) which then build the whole range of life. Her sentences are reduced to the DNA of language. Each paragraph is seen as a picture frame of a film and in each frame, there is a small change. When projected, the film made of all these frames tells a story. Each successive frame, or paragraph, is seen as always being the same and yet different.

The Olympic stadia in Munich are made of repeated elements which are always the same and yet always different. The elements are not mass produced and assembled in various ways; each one is a little different according to its particular requirements. As the book has one storyline, the entire complex has one overall image. In fact, it is quite easy to sketch the buildings from memory. The design of these details reveal the logic of structure, by showing how much force is taken up and in which direction.
The third and last aspect of "the inherent structure of reasoning" in lightweight architecture is the importance given to the design process as opposed to the final object -- the building. Putting of emphasis on the process as opposed to the finished object (with a conciously designed image) liberates the designer from having to create a symbology other than the one inherently present in the building. A lightweight structure is only more or less pleasing to the eye, it does not attempt to be a metaphor of natural forms or any other forms. A lightweight structure gives sense of being in a constant evolutionary process and not in a final, closed significant object. It used not to be so. The Great Dome of Brunelleschi represents a case in which the building itself was the embodiment of philosophical solutions. According to Santillana,

...this metaphysical aspect had been fully grasped by Brunelleschi himself, as is shown by his main line of research, the inflexible endavor pursued through his life to achieve a synthesis between the longitudinal perspective, implying transcendence, and the central perspective, which implied to him an intrinsic organization of space,or, in philosophical terms, immanence... For the Dome is not only his most outstanding solution in static engineering, it is also, in its "rib-and-sail"structure as it was called, the conclusive formal solution of [the above] philosophical issue. The slowly convergent triangles are pure geometric forms leading up to infinity, as no hemispherical dome ever could. (16)
Architecture that is built as a formal proof of philosophical investigations belongs to the Renaissance era. Today, Otto does not solve philosophical debates through building but rather in the form-finding process itself.

1.4 THE THREE LOGICS MEET

Like three colored gels over a spotlight, the three logics overlap perfectly. The logic of the eye is the aesthetic of a parsimonious and scaling structure. The logic of structure is the physical realization of this aesthetic, always tending towards the use of minimal material. The logic of the inherent structure of reasoning gives us a philosophical basis to the search for lightweight structures in relation to the everchanging flows of creation and re-creation. The union of the three logics lies in the search for parsimony. This union of the three is best exemplified in the Montreal pavilion of Expo '67 (fig.13).

The aesthetic of the pavilion is in accordance with the logic of the eye; we find in this pavilion the harmony of anti-clastic curvatures, the multiplicity of scales (scaling object) and the formal organization of the masts relative to the translucent surfaces which creates the energetic shadow discussed earlier.

Of all of Frei Otto's works, the logic of structure is perhaps best expressed in this particular project because soap-film models were used to find the minimal surfaces for the tensile
membranes (fig.14). The parsimonious use of a stretched membrane is, according to Otto, best evaluated through these soap-film models because they will take the most effective shape possible -- offer the best surface-thickness ratio. The clarity and effectiveness of this form-finding method was kept throughout the design process and still appears clearly in the final building.

A soap-film model for the Pavilion of the Federal Republic of Germany at the World Fair in Montreal, 1967

The temporary quality of the structure and its reason for being built -- to demonstrate an alternative way of thinking about shelter -- brought the third logic in accordance with the other two. Such an alternative way of thinking about shelter refers to an inclusive vision of the world where shelter is only part of an evolutionary process and is not seen as an end product of a design.
In contrast to other architectural styles which suppress one of the logics to fit a meaning or idea, the style of lightweight structures appears as a rare case of a dynamic balance between the three logics. Just like a kite, a lightweight structure is not only physically light, it is a symbol of lightness and mobility. Built of distinct, light elements, lightweight structures also symbolize that which they are made of/for: lightness, and mobility.

The first section has attempted to understand what is the architectural language of lightweight structures and the following section investigates how such a language can be integrated in the urban architecture of post-industrial cities.
Organic containing membranes are often filled with liquids or gasses which makes it look like they could burst at any moment.


Drew, Philip, Tensile Architecture, Western View Press Inc., Boulder Colorado, 1979,


SECTION 2  LIGHTWEIGHT STRUCTURES IN URBAN DESIGN

In order to further investigate the potential of lightweight architecture in post-industrial cities, I will assume that a style of lightweight architecture already exists. Its intrinsic nature is generating its own development much as the technological potential of steel and glass became significant and transformed our cityscapes.

The lightweight technology is at a crucial period because its experimental phase is now over and the technology is accessible to any designer. The 1985 symposium of the I.L. in Stuttgart made clear that the next step has to be taken by architects. Is lightweight technology going to be considered architecture? If the answer is yes, what is this architecture's relationship to the existing built environment? This brings us to the subject of this second section which attempts to understand the potential of lightweight architecture in post-industrial cities.

One could say that lightweight architectural enclosures fundamentally question our concept of enclosure -- of boundary -- between one type of space and another. The boundary of a mobile lightweight building is not clearly defined; it is in constant mutation. This constant mutation takes its fullest meaning in small, collapsable lightweight individual structures which are transportable to various sites. The automatic umbrella roofs designed by Otto in 1971 (fig.15) are especially interesting because their design has translated the traditional common umbrella into a much larger, highly sophisticated structure
without loosing its beautiful simplicity. Like the discontinuous

( fig. 15 ) Automatic Umbrella Roofs for the Federal Exhibition,
Cologne, Frei Otto, BRD, 1971

presence of the edge of the flame, it is there at one instant
and not there at the next. Since the structures are
ephemeral, mobile or convertible, their lifespan on a location
is quite uncertain. The mobility and ephemerality of these
structures forces us to reassess the notion of boundary we
recognize in real estate and land ownership.
SECTION 2.1 TWO LAYERS / TWO RYTHMS

It is surprising to see how pre-industrial cities can achieve a balance between solid construction and the soft ephemeral structures such as awnings, umbrellas and free-standing tensile buildings. Solid compressive walls clearly distinguish between inside and the outside, between private and the public spaces. But in the public realm, yet another duality appears, the duality of hard and soft textures: hard textures of surrounding solid walls are interlaced with the soft textures of lightweight structures.

These two layers of hard and soft are not purely aesthetic devices -- they correspond to two basic rythms of change in the city. The hard layer -- the basic stock of housing making up most of the city -- is in constant but gradual mutation. The soft layer -- awnings and tensile buildings -- satisfy the needs for constant change.

Such lightweight structures are designed to be mobile or merely convertible when put up in spaces usually used otherwise. Umbrellas of the farmers market in Verona are closed and packed away at night, other tensile buildings are erected for yearly celebrations and then put away. The soft layer of the city stretches in between the solid buildings and creates a hierarchy both in space and time: in space, by making some open areas more habitable than others (in Taxco, Mexico the covered streets are the busy ones.), and in time,
simply by the fact that these ephemeral structures symbolise the idea of a special event -- a building which will soon vanish.

The notion of dynamic symmetry or directional symmetry, can be extended to groupings of lightweight structures in between solid buildings. This directional symmetry comes forth in Mexican covered street (fig.16) where the cables radiate outwards like a spider web to attachment points on buildings on either side of the street.

The distinction, expressed in the "Logic of the Eye", between natural and artificial looking objects, respectively called "scaling" and "scalebound" shapes can also be extended to the large scale of the city. The solid layer, which changes slowly, can be said to be scalebound and the soft layer, which changes quickly, can be described as being scaling. The solid scalebound layer is based on a limited and distinct number sizes and scales. The soft layer made of lightweight scaling tensile elements is characterized by having many different scales and these scales are so interlaced that they seem to merge into a continuous ever-growing network interspersed within the solid layer. But this network is not always present, it changes according to the seasons and the periods of celebrations and other cyclical events. So various parts of this scaling network will appear at certain times and fill up spaces in between scalebound buildings and when the event
is over, they will vanish until their next reappearance.

Like clouds, the volumes defined by lightweight structures are in constant evolution. Sun rays, passing through the slits between panels, flicker like a dancing flame. The clarity of the solid wall is balanced by the fuzzy boundaries of the tensile structures: the inside is so interlaced with outside that both spaces flow into a continuum. Like water, the crowd can flow under and around the tensile structures without interruption: the solid wall has exploded into soft translucent vibrant screens. There need be no windows. The sunlight comes through the translucent membrane in such a way that the space below is bathed in a diffused shadowless light. There need be no door and no doorstep, only slits up the sides or across the roof.

In hot countries, the soft textures act as one of the climate controllers, defining and organizing the space in between the solid buildings. The street coverings regulate the sun and cool the walls and streets below allowing for many more activities to develop there; lightweight buildings bring activities to the city that the solid wall would not. The heavy and the light complement each other to make both the private and public spaces more habitable, encouraging a denser mix of people and activities -- a mix more city-like. As the Chinese concept of yin-yang, the solid and the soft layers of urban tissue are interdependent.
Awnings not only cover streets to create shade, they link buildings together into networks of trafficked streets. Covered

(fig.16) Awnings and umbrellas covering a shopping street in Taxco, Mexico
streets are for commerce, and commerce is not only the exchange of goods for money, it is the conversation, the communication between a mix of citizens. The awnings create a hierarchy of streets which provides a support structure for a vitally dense and mixed public life. Such dense urban public spaces increase the rhythm of communication and recharge human life. This "recharging" of public life in the city has been described by Fernand Braudel as the "city as an electric transformer". (1)

This "recharging" of urban culture happens in a place where the architecture symbolizes change. What was called dynamic equilibrium in terms of the aesthetic of these structures now takes a political dimension in the city. The lightweight structures symbolize change -- by the way they are designed and their cultural heritage -- and they can physically be altered and moved about by the citizens.

SECTION 2.2 THE SOLID WALL DEFINES PUBLIC AND PRIVATE

Our desire for balance between hard and soft, enduring and ephemeral, protection and communication is supported by the combination of lightweight elements and solid boundaries. Looking more closely to the solid boundary, one can see that the solid wall is punctured by doors and windows which choreograph what Goffman calls the rituals of everyday life. Windows and doors serve as a frame for the choreographed activities in the same way a painting bounds an image. This accentuates the difference between inside and outside, between the private and the public realms. Note that the window --
which can be seen as the picture plane -- reverses the spectator-actor relationship every time the light brightens one side of the wall more than the other. This is how, during the day, the spectators are inside looking out and night reverses the roles. The window frame functions in the same manner as the frame of a painting in perspective: the bi-dimensionality of the frame gives the third dimension of the painted scene within it.

Even though the solid wall clearly excludes the space around it, making it a different space, the window experienced as a framed view of the world links both sides together into one continuous space -- the perspective space. A duality appears: the wall both excludes and includes at the same time. It clearly separates the private space from the public one, and at the same time, the window frame unifies the public and private spaces into one continuous perspective space. I see this duality of enclosure and unified space as one of the basic elements of physical communication in pre-industrial cities and it is characterized by solid walls.

SECTION 2.21 GLASS AND TELEPHONE

The pre-industrial city is a world in which the concept of boundary is clear and distinct; the duality of inside/outside, hard/soft textures is immediately and physically expressed. The industrial city shows an intermediate stage where this
duality, facilitated by the new iron and glass technology, became less distinct and more complex. Certain spaces were neither inside nor outside such as the shopping arcades of Paris or the department stores of London. The density of the industrial city created an active street life where shops extended onto the sidewalk and cafe terraces took over the street. These in between spaces, packed with activities, gave meaning to the public realm.

This section describes the disappearance of the soft layer from the industrial city; a move that has had greater consequences on our urban culture than we might at first be aware of. The invention of air-conditioning and other mechanical climate controls have precipitated the enclosure of vast inhabited volumes of controlled temperature and humidity behind sealed glass space. Downtowns became two high glass walls facing each other across a street wide open to the sky. The simple climate controls hung between buildings have disappeared; only a few umbrellas are left on some chic cafe terraces.

The spread of climate-controlled lobbies and other indoor public spaces have drawn crowds away from the street activities; this would not have turned out to be such a problem if concurrently, people did not start to think of the public domain as meaningless. These enclosed public spaces have become only a means of passage and have destroyed one of
the most important functions of outdoor space: the intermixing of people and diverse activities.

One can say that the balance between solid walls and soft textures has been fundamentally altered by the advent of the glass curtain wall and that the very concept of boundary has been transformed from the solid to the liquid state. The glass wall can be seen as a liquid barrier because it allows for a total transmission of the visual -- an ultimate transparency. But this liquified wall is even more of a barrier than the solid masonry wall; it permanently isolates activities on both sides, making everything across the boundary visible, but letting nothing within touch. The glass wall makes the building mute, like a film without its proper sound track; the glass wall rejects the street and the street culture.

A person walking in a modern street bordered by these two glass walls experiences the paradox of that which Sennett calls "isolation in the midst of visibility". This isolation in public is twisted by the telephone. As explained by Pool, the invention of the telephone was as important as that of the elevator in the development of vertical densification (office towers). The paradox of visibility in public is strangely altered when someone calls home from a public phone because he is instantaneously projected through the receiver into privacy, and yet is still in a public street. Formerly,
people gossiped on their doorsteps -- now they call. One could say that the door of the solid wall has been liquified by the telephone.

As awnings stretched between buildings to cover busy streets, the telephone networks stretch throughout the city for rapid communication. As networks connect homes and offices and reach out to foreign countries, the concept of boundary as a separation between public and private is being radically redefined. A private call, just like a business call, can enter the privacy of the home at any point in time, from any point in space. One has to be alert, available and especially, able to switch from private to public as soon as the phone conversation begins.

SECTION 2.3 CONTEMPORARY LIGHTWEIGHT ARCHITECTURE IN THE GREEN

Most projects executed up to now in cities using lightweight technology are found in parks, rarely in the city itself. From small projects such as the high-point tent in Cologne in a public park (fig.10), to the very large Multihalle in Mannheim surrounded by landscaped area, the buildings are isolated from the city by a belt of greenery (fig.1).

This suggests that either the city is rejecting free-form architecture or that designers have no desire to work with the city fabric. Both seem to be true for different reasons.
Cities are consumed by a collective fear of violence where soft light buildings appear too vulnerable; many architects believe that "free" form lightweight structures belong in natural environments. They think that these buildings need open green space around them to look attractive. (This reminds us of the modernists' concept of a plaza in front of a building placed solely for a better view.) It is often said that a buffer of greenery is important to prevent a visual clash between free-forms and the edge of conventional urban buildings. As a result, lightweight buildings stand out, more often then not, as strange objects. Lightweight architecture is been displayed on a podium of grass as a curiosity a wealthy country can afford. This shows that the third logic (as described in section one) has generally not found an expression in the design of lightweight structures for the urban context, particularly regarding the ecological philosophy of building lightweight structures.

SECTION 2.4 TOWARDS A NEW CITYSCAPE

This section has described the two ends of a spectrum: at one end is the balanced cityscape where solid and soft layers are interdependent and at the other end, only the solid layer of buildings remains. J.B.Jackson, in his book Vernacular Landscape, distinguishes in this spectrum three types of landscapes: he calls them Landscape One, Two and Three.
Landscape One is derived from the "early colonial vernacular culture which preferred the mobility, adaptability and transitory qualities of short-lived log cabin even while waiting for Jefferson's Classical farm villages to appear."

(3) This mobile, ephemeral landscape was then replaced by Landscape Two which "impressed upon us the notion that there can be only ONE kind of landscape: a landscape identified with a very static, very conservative social order" which -- as described earlier -- is found in most of our contemporary cityscapes. The people of Landscape Two feel isolated from one another even though they work and live in the midst of transparent facades.

Rediscovering the value of mobile and ephemeral structures and re-introducing these structures into stable and permanent Landscape Two would contribute certain qualities J.B. Jackson is looking for in Landscape Three. Perhaps such settlements will in time serve as nuclei for small-scale landscapes. "I would like to think that in the future the profession of landscape architecture will expand beyond its present confines (established by Landscape Two) and involve itself in making mobility orderly and beautiful."(4) To design lightweight structures for the city would help to materialize the new integration of mobile, soft elements with solid non-ephemeral ones and thus build towards a Landscape Three.

But in the same manner designers have studied vernacular
lightweight structural details of construction (see the "Logic of Structure" of section one), it is necessary -- in order to design lightweight structures in cities -- to study organized groups of vernacular tensile buildings in and around cities. Such a study would investigate the socio-economical impact organized events and temporary settlements have on the city and particularly on the city culture. It would be interesting to study some of the summer theatre and dance festivals now becoming popular in Europe, or the transformation of cities during some celebrations: Halloween, Olympics or, at a small scale, the mobile units designed by Renzo Piano for the rehabilitation of housing in Italy.

SECTION 2.41 SOME CONTEMPORARY EXAMPLES FOR LANDSCAPE THREE

Events and celebrations, fairs and festivals are not only important because they bring back soft ephemeral elements into the city fabric but also because they are cyclical and, at each appearance, bring out the special qualities of this particular

(fig.17) Neighborhood Workshop with a tensile structure covering the gathering space.
city. For a short time the city is transformed: people come from everywhere to enjoy the event or participate in a celebration and this re-energizes the city. Karin Bacon, a modern designer of outdoor festivals and celebrations explains the reasons why she believes her work to be vital:

In cities where constant change is a fact of life, annual parades and celebrations lend a sense of durability and continuity with the past. The ephemeral magic of spontaneous happenings is buoyed by repetition of annual community traditions. Incongruity and friction between people is balanced by the affirmation of recognizing shared human activities. Vital energy is generated by street rituals when strangers interact with each other and their environment brings them together as spectators and participants. (5)

At a small scale, the modern mobile unit for neighborhood workshops designed by Renzo Piano (fig. 16) should be mentioned here. Renzo Piano’s lightweight structure is perhaps one of the most interesting projects of this sort because it contributes to the making of J.B. Jackson’s Landscape Three through the introduction of mobile units in the Landscape.

Piano is interested in stimulating people to rediscover what he calls the "culture of making". His method is research into everyday problems but nonetheless on a high level of competence: a process of continuous re-invention of instruments, techniques and methods, "so as not to submit to any kind of blackmail, technological or otherwise", as he explains in his book, Pezzo per pezzo.

Piano and his group decided to set up a mobile workshop near the housing units [he was hired to rehabilitate] because it makes it possible to carry out experiments at three levels -- on the immediate, surrounding and future environment -- the mobile workshop covers an area of about 3700 square meters and is composed of modular pre-fabricated steel elements, thus being easily removable. (6)
This type of utilization of lightweight structures exemplifies one of the many roles such an architecture can play in our cities. Rehabilitation, and especially participatory rehabilitation, has been going on in Italy for a number of years, and it is not surprising that Piano's experiment of mobile workshops have been successful. These workshops provide an example of modern software for lightweight technology; a mobile, lightweight core, which brings information, serves as a laboratory for experimentation with specialists, and acts as a magnet for people to gather, exchange ideas for renovations and discuss their problems with the housing they live in.

SECTION 2.5 FROM COLLAGE TO SIMULATION

This section briefly discusses one way to approach design of lightweight structures for public spaces while balancing the three logics (as described in section one): we could conceive of urban lightweight structures not as objects enclosed and enclosing, but as elements in a collage. The idea of architecture as collage is not new, but it is especially appropriate for lightweight structures because they are the antithesis of a solid, bounded, scalebound object. Lightweight structures are fundamentally unbounded and functioning in an open system, can associate, as a collage, with other built elements of the city.
The term "architectural collage" is certainly vague and is only useful as a jumping stone to describe a particular type of collage, which I believe to be an interesting way to think about lightweight structures in post-industrial cities.

(fig. 19) Convertible roof, Hoechst Stadium, Frei Otto, Hanover, 1970
According to Jean Baudrillard, we are shifting from a culture largely dominated by production (the scheme of the industrial era) to a culture which is under the reign of "the simulation". (7)

The convertible roof over the Hanover stadium (fig.18) exemplifies design influenced by the industrial era because its main emphasis is on functionalism; the other convertible roof over the ruins of Bad Hersfeld (fig.19), on the other hand, already exemplifies Baudrillard's "simulation" aesthetic. The Hannover project is a collage of a solid concrete seating construction and a cloud-like tensile roof. Nothing is being communicated about the particularity of this stadium, this roof could be juxtaposed to any other modern stadium, the sense of place would still be nonexistant.

(fig.18) Convertible roof, Hoechst Stadium, Frei Otto, Hanover, 1970
(fig.20) Set Design by Richard Peduzzi for La Dispute of Marivaux directed by Patrice Chereau, Paris, 1973
Conversely, the association of the romantic ruins with the high technology of lightweight retractible roof brings the original building to another level of meaning. These covered ruins give an atmosphere of being unreal, like a stage set, their representation in space is a simulation of itself.

These covered ruins become a place where people seek to implement certain socio-political ideas about their public spaces in the city and simultaneously it is a place where these policies are lived. The walls in ruins (the muratore) being a scalebound enclosure is being redefined by the intervention of the scaling convertible roof and which symbolizes change: a place in the city where certain ideas are been expressed in a group -- not alone.

The desire to make a place where people live out their political ideas was pushed very far by Richard Peduzzi, a modern stage designer, "to a level of visual hallucination, without ever deserting the realm of maniacal realism".(8) A parallel could be made between Peduzzi's stage design and the architectural collage of solid scalebound walls with convertible lightweight structures. The stage set for La Dispute shows the solid walls as tall, immaculate, strangely timeless architectural forms. We could then say that this strange atmosphere is often felt in renovated areas of old city centers, where the Goffmanian rituals of everyday acting seems to be emphasized by the timeless architecture. Such renovated areas are good examples of city simulations. The
dense forest of the set, like the modern retractible lightweight structures covering renovated streets, could be seen either as a possible escape or still an other confinement. (fig.20)

References of section 2


(4) Ibid. p.155


The closing discussion of the Third International Symposium on lightweight structures in Stuttgart was for me a catalyst to try to understand this new conception of building, this new aesthetic. After exploring the subject in the past two sections, I now see the technology of lightweight structures as an adequate tool to express a contemporary philosophy of aesthetics.

The design of lightweight architecture has a unique beauty, a beauty which seems to transcend the material and approach a universal beauty. James Joyce comments on Thomas Aquinas's definition of universal beauty in A Portrait of an Artist as a Young Man as he says:

Aquinas says: Ad pulcritudinem tria requiruntur integras, consonantia, claritas.
I translate it so: Three things are needed for beauty, wholeness, harmony and radiance. (17)

This definition reflects the style of lightweight structure and the following parallel can be drawn.

"Wholeness" is expressed through the physical integrity of the structure of the lightweight building: each piece is needed. Joyce says that "You apprehended it as ONE thing. You see it as one whole. You apprehend its wholeness. That is integritas." (18) The meeting -- as described in section one -- the fusion of the three logics into one complete, self-sufficient object: this is the wholeness of the architecture.
Joyce comments on the notion of "harmony" as he says that "You apprehend it as complex, multiple, divisible, separable, made up of its parts, the result of its parts and their sum, harmonious. That is consonantia."(19) "Harmony" is the scaling quality of lightweight architecture: scaling at the level of one building and scaling at the level of the city in which the networks of soft lightweight structures appear and disappear in the midst of the scalebound urban fabric.

About "claritas", Joyce thinks that Aquinas used the term in such a way that "it would lead you to believe that he had in mind symbolism or idealism, the supreme quality of light from some other world"(20); in terms of lightweight aesthetics, "radiance" is the translucence of tensile coverings which creates shadowless spaces and at night, the glowing architecture is transported, like a phantasm, into the realm of the simulacre.

If tensility is the beauty of architecture and also the architecture of beauty, then we could well imagine that Thomas Aquinas would have found the qualities of universal beauty in modern tensile architecture.
(17) Joyce, James  A Portrait of an Artist as a Young Man, editor: The Egoist, 1916  p. 248

(18) Ibid.  p. 249

(19) Ibid.  p. 249

(20) Ibid.  p. 249
THE THIRD INTERNATIONAL SYMPOSIUM IN STUTTGART, WEST GERMANY

The Third International Symposium in Stuttgart west Germany, was organized to evaluate a 15 year period of research done at the Institute of Lightweight Structures. In keeping with the objectives of SFB 64 the Symposium dealt with light and wide span structures, the main subjects being nets, membranes and shells. The I.L. has been one of the major contributors in this field, examples being the shell structures of the Muthalle in Mannheim and the wide span nets of the Munich Olympic Complex. The organizers of the conference asked the participants to address the question of whether such structures could be integrated within today's architecture or whether they served merely as accessories to conventional buildings?

Contributions ranged from technical papers to more general urbanistic and ecological issues involving lightweight structures. Purely technical papers that related to pattern cutting, and other papers around various form finding methods and their translation into measurements. Other contributions covered more general environmental design issues such as the use of membranes as climate changing envelopes.
The contributions can be divided into four basic categories:

-1- Analysis methods, techniques of measurements and computer software for lightweight structures, usually presented by engineers.

-2- Presentations by architects of their work ranging from quite small spans to enormous tensile buildings for sport stadiums.

-3- Reports by the I.L. staff on their work of the past 15 years.

-4- Art in Lightweight structures today, as well as historically.

-1- ANALYSIS METHODS

This category showed the extent to which engineers had conducted researched and experimented so as to develop the necessary technological background on lightweight technology. Precision and rigor of method is especially important here because, for example, an anticlastic surface will only be taut if all anchorage points pull the surface to an exact amount in specific directions; if this were not the case, surfaces would ripple immediately. On a small scale, the detailing of anchorage and cable attachment requires detailed attention since they would be totally exposed to the viewer.

Two philosophies seem to emerge from these technical contributions. One, the gathering of forces to a few anchorage
points, which are massive in size and therefore a major part of the architecture. Two, in total opposition to the above, is the belief in dispersing forces into smaller and smaller attachment points. Natural laws show that more weight can be supported by numerous elements than by fewer larger elements. For this reason, Frei Otto tends to subscribe to the second philosophy.

Another paper dealt with the form finding technique embodied in this example of the Montreal Pavilion in 1967. The Montreal tensile building designed by Frei Otto and his team was the first application of close range photogrammetry. Photogrammetry is a technique which superimposes the photograph of a model with a grid which then allows accurate measurements. Previously, photographs had been taken from only two sources. Due to the size of the project, more accuracy was needed and cameras were stationed to obtain a 360 degree picture of the model.

The Munich Olympic complex required special software to calculate the static-analytical computation of nets and cutting patterns. The software had been developed in 1968 by the I.L. staff. Ulrich Hangleiter examined the theory behind the MEMCUT software. The MEMCUT software seems to be one of the most flexible tool available at the present for pattern cutting.
According to Mr Hangleiter,

The first problem solved in MEMCUT consists of finding the points belonging to a strip and taking into account their neighbouring points onto the surface. The basic ideas for solving the problem of flattening is that the distance between neighbouring points on the surface should be the same in space as it is projected onto the plane. The solution can be divided into three steps:

- Finding planar coordinates for the points within a strip.
- Finding neighbouring points belonging to a given strip.
- The procedure for flattening the strip on the plane.

Result of flattening with strip direction B
(the distortions are represented by solid circles)
2) PRESENTATIONS BY ARCHITECTS.

These presentations made the central problem in of the field of lightweight structures come up to the surface very clearly: the lack of an architectural language for these structures. The most exiting projects were often the small scale structures, perhaps because the lightness of the stretched fabrics communicated a sense of ephemerality. Examples of this were projects of Larry Medlin, which were all small movable structures to be put up for a limited amount of time, i.e. for an occasion, or an event. Mr Medlin believes in conserving material resources not only by building light but by planning the design for the period of time needed. In other words, a structure which will be up for three days is designed differently for a period three months then it would be for three years. The structure done for the Museum of Modern Art in New York, for example, was taken down after three months and rebuilt in Ontario an later again in Chicago. Clearly, such a structure was designed for mobility. Other projects such as covered podiums are brought in by truck and then the wooden platform of the stage is opened up to act as a foundation for the major loads -- minor loads being anchored on the ground.

Another view was provided by the work of the Buro Happold, which is based in England. Considered the most advanced in the design of lightweight structures, this approach seems to be
the most integrated. For example, the Riyadh Diplomatic Club
(undertaken jointly with Otto and Omrania Architects) consists
of a three-storey high snaking "wall" containing squash
courts, a library, hotel, music rooms and other facilities.
Within the arcs described by the wall, five large tented
structures, provided covered areas for various sporting and
leisure activities. This project along with the inflated cell
structure of Liverpool Garden Festival site, exemplify designs
which use technology for creating innovative shapes and
exciting contrasts between the softness of the membrane and
the hardness of the wall in the Riyadh project. The
illustration below is a sketch of the bird's eye view of the
model.

The largest lightweight project existing today is the
International Stadium os Riyadh designed by Bergerann and
Goodson and consists of twenty four masts of 60 m high, each
of which holds a segment of the tent which is secured by a
central ring. The sketch below gives the section through one
of the twenty four masts.

Such a project is an expression of a country which shows that
they can pay for a very expensive stadium. The result is an
overdesigned and significantly out of scale building. Frei Otto
reacted violently to this and urged the audience to
realize the danger of such projects. Not only, he added, does
the large scale make people feel small and oppressed, but such buildings ignore the fundamental reasons for the "invention" of lightweight structures: a desire to build more effectively by learning from nature's constructions. Such a way of designing, gives people a chance to explore an interest in nature and become more aware of its fragility, beauty and, of course, its unlimitedness. The desert green houses of C. Jofeh and the northern climatic envelope planned by A. Fullerton are worth mentioning here. The green houses for the desert land are based on methods which utilize climate-moderating envelopes. The climate within the enclosure is influenced by both the shape of the enclosure and the materials used. Computers are needed to predict three critical phenomena: the natural convection of the air inside the green house, the storage of heat in the ground and the levels of radiation inside the green house.

On the other side of the climatic scale, a Meso Environment on the 58th parallel in Canada will be the focus of its first National Exposition for 1955. Messrs Fullerton, and wilkinson, Frei Otto and Buro Happold designed a self-sustaining environment for 30,000 people which does not require any source of external energy other than that available on the site. Mr. Fullerton believes that,

...most recently in northern cities, outdoor corridors have become hallways, outdoor shopping
streets have become interior malls, exterior courts have become atriums and whole new city centres have been built in highly controlled mega structures. While all of these incremental steps brought protection from the harsh climate, they have internalized our environment, sacrificing all contacts with nature. With the advent of lightweight technologies combining cable nets and transparent membranes we are now able to consider a whole new paradigm of possibilities.

Two solutions are being worked on: one consists of a large moderating membrane enclosing the entire community, and the second deals with a series of connected membranes each covering a segment of the community.

3) REPORTS FROM I.L. STAFF

J. Hennicke briefly explained how the I.L. works and summarized the 15 years of research and experimentation that had gone on. The I.L. was interested in finding out more elegant solutions for structures, organic and inorganic. Teams of Biologists, Architects, and Engineers had been involved in this work from the beginning. For example, in the case of research of net structures, the I.L. first looked at man-made nets and their historical developments and only afterwards, pushed by a desire to understand how to design large span nets, the I.L. team started to analyze nature's net constructions, i.e. various types of spider webs.

This attitude toward form finding appears to be of great importance because Mr. Hennicke remarked that designers who
simply copy other lightweight buildings without an understanding of the past examples or natural behavior built structures from which very little can be learned. The I.L. contributions provided a reminder of the reasons that motivated designers to become involved in lightweight architecture. Building light does not automatically mean beautiful structures so it seems unavoidable, if one is interested in the aesthetic of such constructions, to analyse and understand how nature provides examples of light structures. At the same time it is important to examine the vernacular that has been using materials to their fullest structural potential in the past as well as in the present.

4) HISTORICAL PRESENTATIONS AND ART IN LIGHTWEIGHT STRUCTURES.

Historical presentations demonstrated the importance of the decorative arts in the embellishment of tents throughout the centuries. Rob Krier's contribution emphasized the "joie de vivre" of these festive tents of the European eighteenth and nineteenth centuries. This lightness of spirit seems to have been forgotten as the technical difficulties were overcome. Rob Krier also referred to the manner in which architects reacted to the advent of steel: i.e. the work of Horta and other designers of this period. Here heaviness of stone contrasts with the transparency of glass and the sculptural
quality of steel links these two opposites together. Rob Krier insisted on the sensuality and playfulness of the forms found in the metal work as a "positive" response to a new technology that did not obscure the integrity of the structure. Steel is steel and glass is glass and yet they respond to each other and express the excitement of their meeting.

The field of contemporary art work with stretched fabrics was illustrated by the sculptures of Alexandra Kasuba. Her earlier work consists of entire environments made of stretched thermal underwear nylon fabric. A.Kasuba explained that she would always stretch the fabric in the direction it would "want" to go and never against it. In this way, the forms are always taut and smooth, resembling the interior of vegetables. The environments are colored solely by hidden lights, which when moved change the entire sense of the space. The fabric bends the light rays in such a way that very low wattage can make an entire environment glow at night as if spots lights were on. The art work of A.Kasuba created a catalyst among the participants of the symposium because it exemplified how someone could discover the natural laws of tensile behavior on a purely intuitive basis. This type of art work points to a freer approach to form finding and expression through tensile forms. The enjoyment of playing with nature is revealed in
her wind sculptures and rain canopies - no flow is ever blocked by an intellectual, preconceived idea -shapes seem to burst out from an unrestrained desire to see light.

Consciously or unconsciously, everyone in the symposium is eager to find new software for the existing hardware of modern lightweight technology. The discussion closing the symposium made this lack of software the most urgent problem to be looked at. The technology of lightweight structures has now reached a stage at which designers can practically do anything. Computers calculate all stresses, draw patterns for membranes and evaluate prices for any possible shape. But the question is, what is the architecture, what is it for and for whom? Otto intervened in the discussion and said that engineers have been doing their job in bringing lightweight technology to a workable level and that now is the time for architects to step in and take over. The philosophical background, Frei Otto added, being the conservation of energy, and the drive of the designer to built good architecture, architects have to create an aesthetic through the understanding of natural form building.

Up to now, most tensile buildings show the excitement of this new technology but reveal little emphasis on its architectural
contribution to modern public life, especially in the urban context. The more the technology of lightweight structures develops, the more we tend to move away from the fundamental questions which originated the research in the first place. Our society has changed substantially, Frei Otto commented, and as we are more aware of the finite nature of our earthly resources, it is more important than ever not to work in isolation. The future of architecture consisting of lightweight technology should be done by interdisciplinary working groups so as to create solutions to problems that have been comprehensively studied. It is this process of working together with people from different fields that has allowed the I.L. to enrich the field in the way they have done and continue to do still.

Throughout the presentations and group discussions, little mention was made of problem of integrating lightweight structures in the urban context. By talking privately with people who seemed to have a sense of how to approach this problem, I was able to pin down a few of their design guidelines. For example, if a piazza needs to be covered by a tensile open roof, it is usually better to keep it substantially smaller then the open space. If the entire
space has to be covered, then the scale has to be brought down by designing individual repeatable elements. These elements give rhythm to the space beneath and become visual links for the pedestrians between the buildings and the coverings. In addition, the geometrical arrangements of the elements should derive from the surrounding street pattern. It is important to keep in mind the difficulties that have been encountered in past projects using free forms as opposed to regular geometrical shapes. Unless there is enough "breathing" space, one of the architects remarked, edges of free form structures often clash with the hard edges of the surrounding buildings. The idea of "breathing" space is vague and amorphous, and therefore needs to be analysed further.
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