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THE RELATION BETWEEN NATURAL AND MAN-MADE STRUCTURAL SYSTEMS - EXAMINATION OF 20TH CENTURY EXAMPLES IN SPECIAL CASE OF THE MODERN ARCHITECT 'SANTIAGO CALATRAVA'

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by
Ayşe Banu AYDIN

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We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

Prof. Dr. Çetin TÜRKÇÜ
(Advisor)

Assoc. Prof. Dr. Attila ORBAY
(Committee Member)

Assist. Prof. Dr. Göksel SEZER
(Committee Member)

Approved by the
Graduate School of Natural and Applied Sciences

Prof. Dr. Macit Toksoy
Director

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A. Banu AYDIN

ABSTRACT

Since the ancient times, in order to provide a place for living, for accomodating and for other vital activities, man has developed the 'architecture' which is the art of building. Nature has structures of its own. Man has always been in close observation of nature and he imitated nature's structures while he was erecting his buildings. In other words, throughout history, man referred nature as source of inspiration and made use of his derivations in architecture. Investigation of this relation between natural and man-made structures in contemporary examples and in special case of Santiago Calatrava constitutes the subject of this study.

Structures found in nature can be grouped as: the structures of non-living nature, the structures of living nature and the structures produced by living organisms. They have similarities with man-made structures and they serve as models for contemporary constructions. Researches about nature-architecture relation and close observations of natural structures provide help for the development of architectural and technical studies.

The examples that have relation with nature are chosen from different periods and trends of architecture of the 20th century. Derivation from nature has a variety of ways as conveyed by these examples. The Spanish architect Santiago Calatrava is the special example to examine the subject in detail. He is preferred as his work is specific and distinctive: he is famous for his constructions which recall structures of animals and plants.

This thesis is comprised of five chapters.

First chapter is an introductory, presenting the purpose and the method of the study.

In the second chapter, a general knowledge about the structures of nature is presented. Natural structures are examined in three groups and are given examples; the relation between them and man-made structures is sought.

In the third chapter, the examples from 20th century architecture are introduced. They begin with Antoni Gaudí, continue with the Expressionists, Organic Movement, structural engineers, contemporary architects and examples from recent issues of architectural magazines showing the current situation of this relation.

In the fourth chapter, firstly Santiago Calatrava's profession and architectural features are discussed. Second, some of his remarkable buildings and projects are introduced. Thirdly, the relation between his structures and nature is examined. Finally, the evaluation of his buildings is presented with comparisons, from the aspect of their relation with natural structures.

The fifth chapter is the conclusion part where the previous three chapters are evaluated. The 'nature' of architecture-nature relation is portrayed before the opinions about the analysis of Calatrava's work is presented.

ÖZET

İnsanoğlu eski çağlardan itibaren yaşamını kolaylaştırmak, korunma, barınma, çalışma gibi eylemlerini gerçekleştirebilmek için yapı yapma sanatı olan mimarlığı geliştirmiştir. Doğanın da kendine ait yapıları (strüktürleri) vardır. İlk insanlar, yapılarını doğayı gözlemleyerek ve doğadaki formları taklit ederek oluşturmuşlardır. Tarih boyunca, doğa insan için bir ilham kaynağı olmuş, çeşitli doğal formların mimarlığa yansıdığı gözlenmiştir. Doğal ve insan yapısı strüktürler arasındaki bu ilişkinin günümüzdeki örneklerde ve Santiago Calatrava özelinde irdelenmesi bu çalışmanın amacını oluşturmaktadır.

Doğadaki strüktürler şu şekilde gruplandırılabilirler: cansız doğanın strüktürleri, canlı strüktürler ve canlılar tarafından oluşturulan strüktürler. Doğal strüktürler insan yapısı strüktürlere benzerlik gösterirler ve çağdaş konstrüksiyonlar için model oluştururlar. Doğa-mimarlık ilişkisi hakkındaki araştırmalar ve doğal strüktürlerin incelenmesi, mimari ve teknik gelişmeler için yardımcı rol oynamaktadır.

Bu çalışmada, mimarlık-doğa ilişkisi 20. yüzyıl mimarlığının çeşitli dönem ve akımlarından seçilen örneklerde ortaya konmuştur. Bu ilişki İspanyol mimar Santiago Calatrava örneğinde detaylı olarak incelenmektedir. Calatrava'nın seçiliş nedeni, onun kendine özgü strüktürel mimari tarzı ile tasarladığı kostrüksiyonların bitki ve hayvan strüktürlerini çağrıştırmasıdır.

Bu çalışma beş ana bölümden oluşmaktadır.

Birinci bölüm amaç ve çalışma yönteminin ortaya konduğu giriş bölümüdür.

İkinci bölümde, doğal strüktürlerle ilgili genel bilgi sunulmuştur. Doğal strüktürler üç ana bölümde örneklerle birlikte incelenmiştir; bu strüktürlerle insan yapısı strüktürler arasındaki ilişki irdelenmiştir.

Üçüncü bölümde, 20. yüzyıl mimarlığından örnekler tanıtılmıştır. Bu örnekler Antoni Gaudí ile başlayıp, Ekspresyonistler, Organik Mimari Akımı, strüktür tasarımcısı mühendisler, çağdaş mimarlar, özel tekil örnekler ile devam edip, son zamanlarda mimarlık dergilerinde yeralan ve bu ilişkinin günümüzdeki durumunu ortaya koyan projelerle son bulmaktadır.

Dördüncü bölümde, öncelikle Santiago Calatrava'nın mesleki kariyeri ve mimari özellikleri tartışılmaktadır. Sonra onun bazı önemli proje ve yapılarının tanıtıldığı bölüm bulunmakta ve daha sonra da yapıları ile doğa arasındaki ilişki incelenmektedir. Son olarak, Calatrava'nın yapılarının bu ilişki açısından değerlendirmesi, karşılaştırmalar ile birlikte yapılmaktadır.

Beşinci bölüm, önceki üç bölümün değerlendirildiği sonuç bölümüdür. Günümüzde mimarlık-doğa ilişkisinin durumu ve Calatrava'nın mimari kişiliğinin analizine yönelik düşünceler ortaya konulmaktadır.

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CHAPTER ONE
INTRODUCTION

1. Introduction

Nature possesses a variety of formations depending on its basic laws. Man, in accordance with nature, has a tendency to discover and learn from his environment. Thus, man-made structures are sometimes direct results of these observations of natural structures, frequently the synthesis of them.

The architects and engineers of the 20th century have derived various concepts from nature, thus their work, the buildings reveal connections with nature. Santiago Calatrava, the famous contemporary architect, achieves an individual style of architectural work inspired by the form world of nature.

1.1 Purpose of the Study

The study has three interrelated purposes:

1. The introduction of nature's structures; examination of their features and search for their connection with architecture.
2. The analysis of the relation between nature's structures and the examples of 20th century architecture by examining selected works of architects representing different approaches.

   In this study it was not the aim to scan and list all the works related with nature and it could not be possible either. Instead, the purpose is to convey how wide the relation of nature-architecture is, by examining the examples from various periods and trends of 20th century architecture.
3. The investigation of this relation thoroughly in the approach and work of Calatrava.

1.2 Method of the Study

The relation between nature's structures and Calatrava's structures will be determined by examining the architect's projects. Most of his structures are considered as similar to skeletons, animal and plant forms, etc. Those projects which seem to have organic character will be examined and the features of nature's structures will be sought in them. Briefly the investigation method will depend on a comparative analysis between these two sides and the comparison will be made due to their structural character, load-bearing behavior and form.

1.3 Context of the Thesis

The subject is examined in three main chapters which are the second, third and the fourth chapters of the study.

In the second chapter, structures that are found in nature are presented. They are examined in three groups with discussion of their properties. The knowledge given is based on the studies of IL.

In the third chapter selected architects are examined with examples of their works. Their ideas and design concepts are reviewed and their buildings are discussed in order to convey the nature-architecture relation.

In the fourth chapter the work of Santiago Calatrava is introduced by explaining his ideas and describing his leading projects and buildings. His connection with nature is evaluated by discussing the organic integrity in his projects. Ultimately, the assumptions derived are presented.

CHAPTER TWO
STRUCTURES FOUND IN NATURE

2. Structures found in nature

Every object on the Earth has a form; it is capable of transmitting forces. This ability to transmit forces means that each object is a load-bearing structure irrespective of whether the object is formed on account of its inherent properties or whether it is assembled by external forces - like man.

"The term 'construction' is rooted in Latin (constructio) and means literally 'that which has been assembled'." (IL 23, 1992:14). 'Structure' therefore defines a system composed of individual elements.

Structure in architecture is a system of elements, which transmits forces and bears loads in order to keep a static balance.

Besides the construction activity of man since the ancient ages, nature has structures of its own: All living organisms are structures as they all react to forces as explained above. Some of these organisms produce their own structures; nests, bee hives, spider nets ... etc. In addition to these two groups, there are the structures of non-living nature; like, crystals, atoms, droplets ... etc. So the structures found in nature can briefly be grouped as follows:

1. The structures of non-living nature
2. The structures of living nature
3. Structures produced by living organisms

The structures in Nature arise by virtue of the laws of Nature. They have been developed during thousands of years of evolution, thus their forms are 'optimized'. Optimum form is the form of a structure in which the structure can, with the least possible use of mass, offer resistance to the forces acting on it at any time. The less mass an object needs to transmit forces, the more optimized is its form. (IL 27, 1980). To achieve more using less, to be stronger and at the same time lighter characterizes the general "Principle of Lightweight Construction".

Since the ancient times, consciously or not, man is imitating structures of nature. Obviously, only those biological forms which are known at any one time could bear any relationship to human building. In the past, all the large and immediately visible biological forms: plant forms, animal forms served as models for building activity - taken as wholes or in detail.

The expansion of optical horizons by the microscope, the electron microscope and photography, photogrammetry and stereoscopy have led to the development of new biological form areas in recent decades. For example the forms of amoebas, radiolaria, diatoms, microbes, bacteria, sperm, viruses, etc. are known thoroughly today. The 'interiors' of biological objects have been made visible by new photographic processes, so unexplored biological forms and aspects of nature -such as the growing processes- can be observed.

Figure 2.1 A crystal.

2.1 The structures of non-living nature:

The structures in non-living nature develop as a result of only a few processes of formation. These are the accumulation of masses, the movement of large masses, the flow of liquids and gases, the solidification of matter into solid bodies.

Figure 2.2 The structures of non-living nature: Mountains and crystals.

The objects in non-living nature -from the atom through to molecules, crystals, rocks, mountains and waters, to stars and galaxies- constitute a constructional family with characteristic forms and structural properties. The processes of formation determine the forms. The structural form adjusts itself due to the material properties and the composition of the material. All material objects are subject to the laws of Nature.

In the minimum dimension, there are atoms and molecules as examples of structures of non-living nature. Forces of attraction and repulsion determine the form and stability of them. The stars and galaxies constitute the upper limit. Large masses, stars cluster together into spheres and rotate. The accumulation of loose rock on the surface of celestial bodies -because of the frictional resistance of the flowing material- takes on the stable form of the debris cone, as known from volcanoes and mountains. Fluids acquire their characteristics decisively from the forces acting at the surface. By virtue of these forces, typical fluid forms are created: drops and bubbles. (IL 32, 1983).

The crystals and crystalline structures are the other members of this group which possess interesting geometrical characteristics. For example, the snow crystals are always hexagonal in shape but never have the same arrangement. Among the geological crystals, there exist regular geometrical forms - the Platonic solids and semi-regular forms.

In non-living nature the systems organize and regulate themselves according to external and internal conditions. Their structural forms are inherent in them. Yet they are in accordance with their specific properties and constantly adapt to the external environmental conditions. Apparently "dead" nature is characterized by this flowing potential, by rearrangement, construction and destruction. It lives in its own way. (IL 27, 1980).

2.2 The structures of living nature

Animals, plants and micro-organisms are the living structures found in nature. As a result of a long process of evolution, they are able to transfer forces with relatively low mass. The selection principle of lightweight construction, which takes effect in varied ways, is entirely in keeping with living nature, when referring to objects which are able to assimilate and transmit forces with little expenditure of materials and energy. (IL 32, 1983).

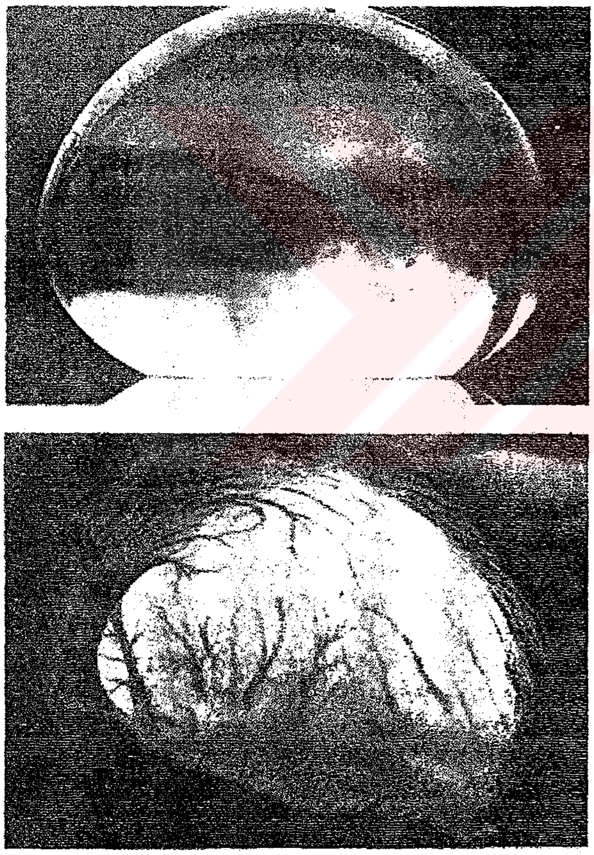


Figure 2.3 Pneus in nature: Water droplet and intestines.

The almost incalculable variety of forms of living nature, of plants, animals and human beings - their various life processes and conditions - were incredibly developed and built up through countless variations of one single construction principle, namely with the construction principle of the pneu. " 'Pneu' is a system in which a tension-resistant, flexible envelope surrounds a filling. The envelope and the filling together form a load-bearing structure." (IL 27, 1980:132).

"In biology the fundamental constructive elements are the one-dimensional tension, compression and bending-stressed constructions - e.g. filaments, bones, stalks and the two dimensional membranes and shells. The complex Gestalt forms of biology are nearly always three-dimensional assemblages of these five elements." (IL 3, 1971:17).

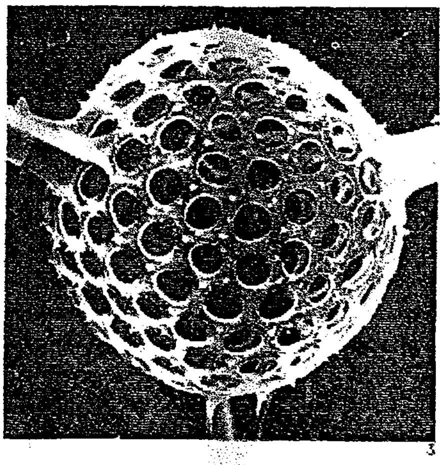


Figure 2.4 The skeleton of radiolaria.

Two-dimensional constructions, membranes and shells are of great importance in biology and technology. They transmit forces through their surfaces. Membranes are soft and pliable. They can only be tension-stressed. Membranes in biology are found in skins, intestines, eggs, larvae, worms, caterpillars, tissues...

Shells, on the other hand, are hard and stiff. They can bear any type of stress but require considerably more material. (IL 3, 1971). They are curved load-bearing surface structures and quite often used in biology. There are shells of homogeneous surfaces and those of filigreed ridge joint frames. The examples are diatoms, radiolaria, mussels, snails, crabs, skulls, turtles, insect body, legumes, eggshells and many others.

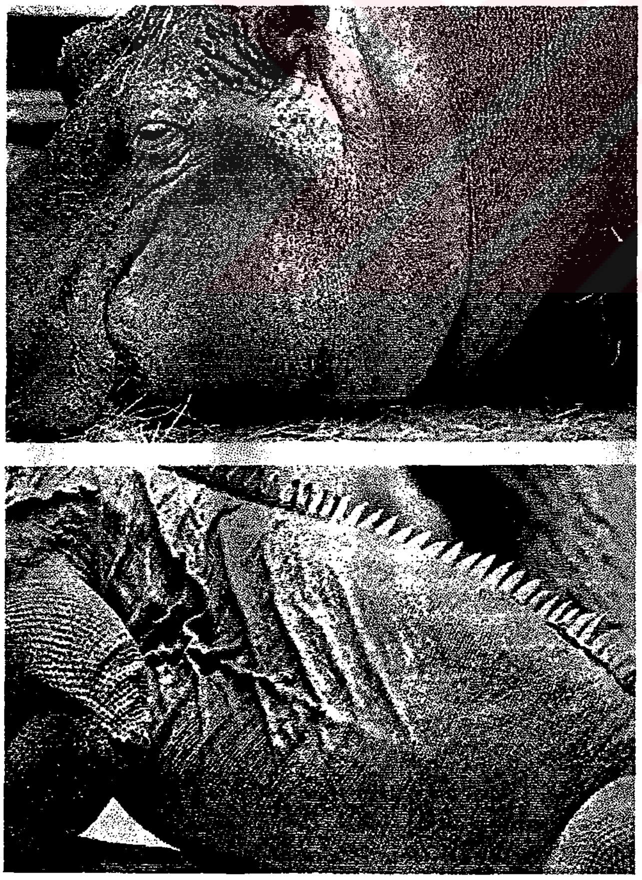


Figure 2.5 Structures of living nature: Animals.

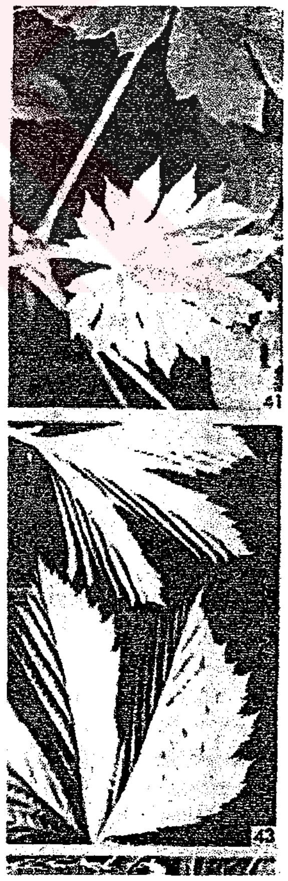


Figure 2.6 Plants.

2.2.1 Optimization in Living Structures of Nature

"Living nature is far ahead of us in the optimization of structures. It optimizes its elements by iteration over long periods of time with the aid of mutation and selection." (IL 27, 1980:140)

Birds have developed lightweight structures to a considerable extent in order to increase their ability to flight. For example, the very voluminous skull capsules of nightjars and owls were examples of extremely lightweight structures. (IL 4, 1972). In addition to birds, the principle of lightweight construction is also noticeable in the skeletons of land animals which have developed material saving structures in their bones: the larger the animal, the finer are the meshes of the bones in relation to the overall bone.

However, for some other animal species such as the corals of warm seas, which erect great stone accumulations with their skeletons, the principle of material economy appears rather unimportant.

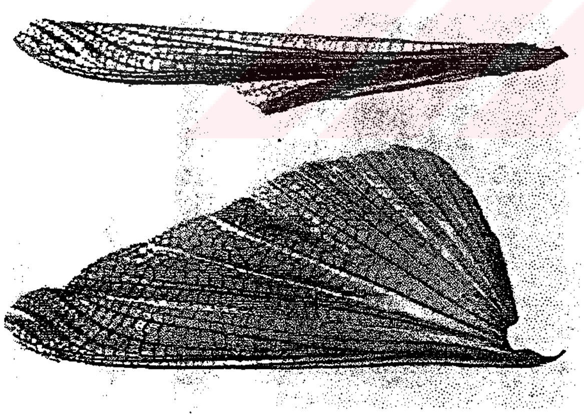


Figure 2.7 The hind wings of locust.

Biological materials and constructions are optimized structurally and arranged as ideal lightweight structures. However, they are not designed for maximum loading, they do not have structural function alone; they have to maintain some other functions as well. The main function is the formation of a strongest structure, fulfilling other vital functions. Sometimes this other functions present contradictory situations. For example; the shell of a bird's egg forms a construction which resists pressure, but it also provides the passage of gas which is absolutely vital for embryonic development: it is mechanically stable, but is porous in its microscopic dimensions.

To summarize, we can conclude that material-saving constructions occur if, for various reasons, they represent a positive selection value for a population. The effect of gravity which in many cases encourages the formation of lightweight structures is only one among ecological factors which influence material deposition in organisms. As seen by the formation of very heavy rocks of antlers in certain types of deer and the different shell thicknesses between ocean and fresh-water snails, the principle of material economy cannot be independent of environmentally-determined conditions.

2.2.2 Architecture and Living Structures of Nature

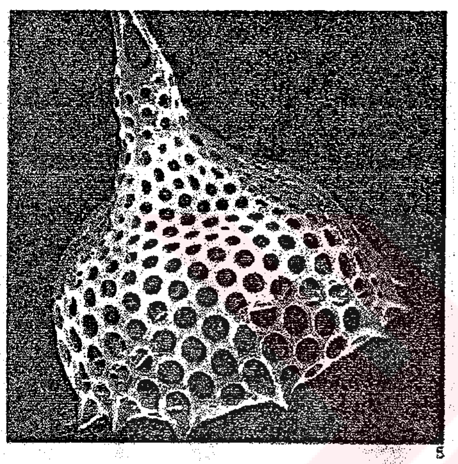


Figure 2.8 The skeleton of radiolaria.

Living structures are the architecture of nature; man-made architecture has parallel structures to those of nature. For example, "the tiny diatom shells show the same typical structures of shell canopies for large span widths in building technology." (IL 3, 1971:15). Shells have widely varying capacities for compression, tension and bending stress. The constructive form of shells is not determined by the influence of forces - as with pliable skins - but rather is determined genetically. A shell must be completed first, then it can be loaded.

"The same applies in technology. Arches of stone or concrete and lattice shells of wood and steel, boats, airplane fuselages and automobile bodies must be produced in an artificially determined form first." (IL 3,1971:15).

However, since shell forms in nature are the result of a long selection process and many shells apparently have the constructive function of a protective armor against outside forces, it may be assumed that the majority of natural shells are also optimum construction forms for technical applications. To date there are significantly more biological shell forms than technical ones. In building their magnitude is fixed. In biology there are shells which can even grow.

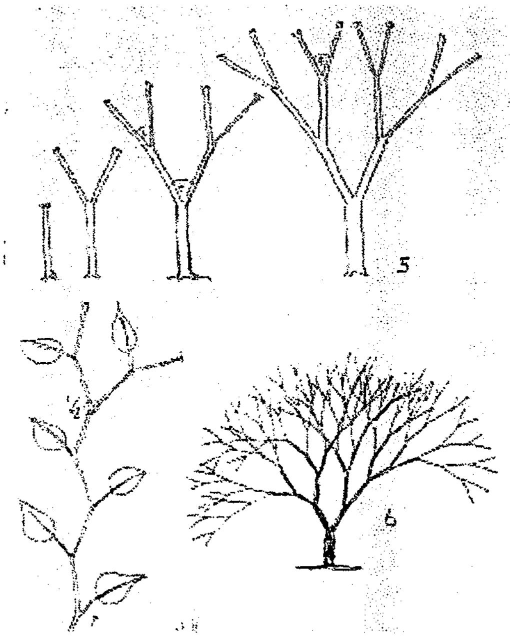


Figure 2.9 Branching system of plants.

In biology there exists another typical constructive system: the three-dimensionally branching of straight rods in practically all plants. "By this approach the problem of large chlorophyll-containing but at the same time wind-stressed surface is solved." (IL 3, 1971:15). All of these plant forms exploit this constructive system almost optimally and form complex forms in an infinite range of variations. This branching structure has a variety of examples in architecture, as examined in the next sections.

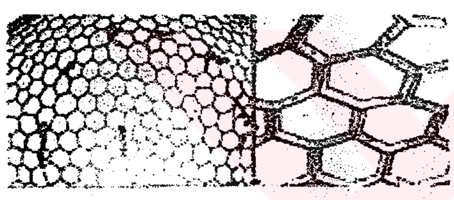


Figure 2.10 A diatom shell and the shell structure of Buckminster Fuller.

Snails, mussels, the radiolaria, diatoms and foraminifera, known and much admired since (Haeckel's monographs published in) 1878 by the help of modern researchers, such as J. G. Helmcke, who have devoted their whole life to them. They have also been greatly admired by architects such as Buckminster Fuller. He had developed the geodesic dome with the help of his observations about them. Their body shell has many other properties including adaptability and offering protection against external influences. "These shells are architecture, are construction and are very complex in their composition, load-bearing behavior and in the way they solve problems." (IL 27, 1980:136).

2.3 Structures produced by living organisms

Man and animals consist not only of inconceivably sophisticated constructions - which in their nature and manifold complexity have been technically matchless and presumably will remain so forever - but they themselves also make constructions. Structures produced by living organisms can be grouped in two as:

- the structures produced by mankind
- the structures produced by animals

The structures produced by mankind can be called artificial structures as well and they are examined in the following sections of this study.

Figure 2.11 Structures produced by animals: The nests of spiders.

The buildings of animals possess a remarkable technology, although they are much more primitive than the structures of animal and plant bodies. They can survive many generations.

Some structures made by animals possess a technology developed over millions of years. The technology of animals extends from the primitive cave to the highly specialized nest and town. It can be differentiated according to function: as habitation, weapon, trap or prey.

Animals manufacture dwellings, settlements, streets, dams and traps. "Among animal

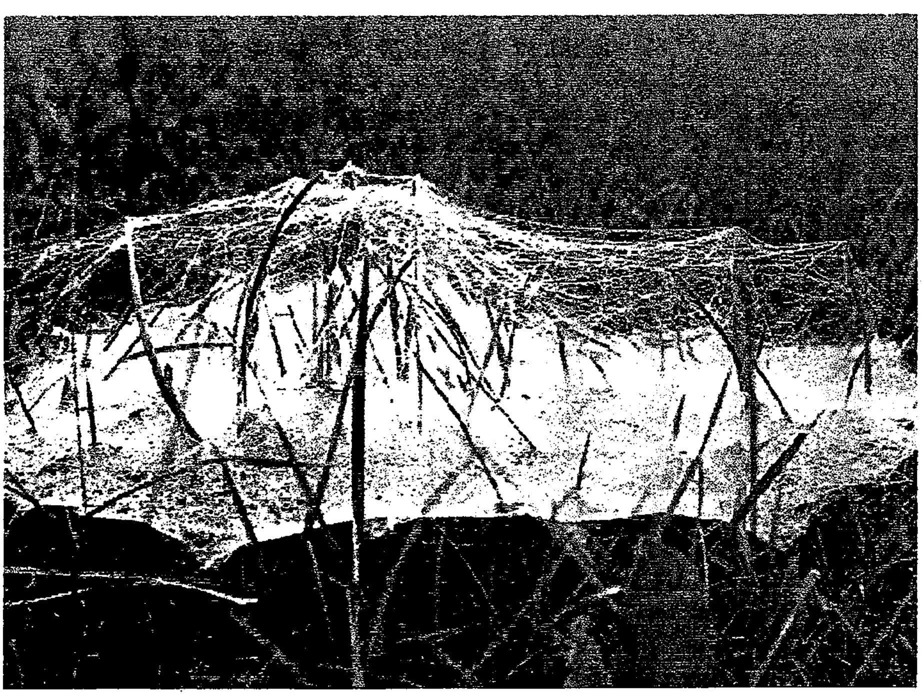


Figure 2.12 A spider net.

structures all kinds of load-bearing formations are found: cavities, frame structures (many birds' nests), membrane structures and net structures (caterpillar cocoons and spiders' webs), shells (the thin-walled nests of the salanganes), folded structures (the honeycomb structures of bees), vaults (the ant heaps above ground), solid structures (the cemented, cast, highly stable termite constructions)." (IL 27, 1980:137).

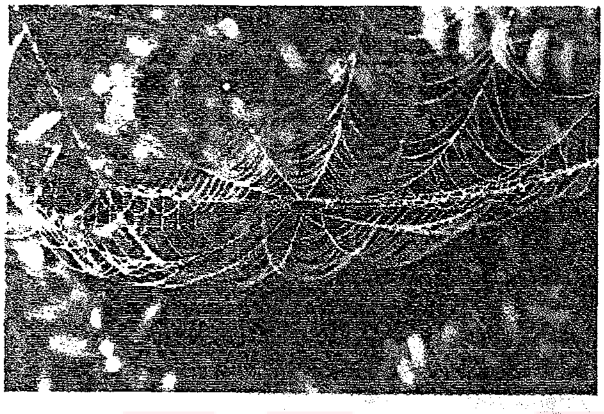


Figure 2.13 A spider net.

Animals possess numerous techniques for construction: they weave, knit, fix, glue, mold, cut, dig ... Their tools are their claws, teeth, snouts and other parts of the body. Different structural types and materials are used by them. "*Earth and foundation works include troughs, trenches, tunnels and caves. Textile structures include the nests, trapping nets and cocoons of spiders and insects. Bees cement together cities out of wax. Wasps and termites build with paper; they mince cellulose (wood and vegetable matter) and assemble it into honeycomb structures. There are many builders in timber: branches, twigs and bark from the material for the nests of birds and apes, and for the retaining dams and lodges of the beaver.*" (IL 32, 1983:23).

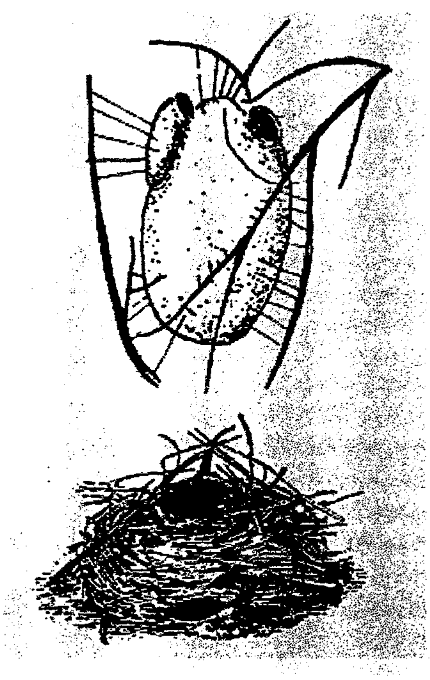


Figure 2.14 Nests of animals.

One could classify and understand animal structures by the "order of precedence" and biological system of their builders. It would then be apparent that the highly developed vertebrates - above all the mammals - erect surprisingly meagerly-developed, almost primitive structures. In contrast to this one finds that the invertebrates - the phylogenetically older animals - have highly complicated building systems. (IL 27,1980). For example the technical skills of spiders and many insects are very developed. Their structures are distinguished by high strength with low mass.

It is interesting that we can learn a great deal from bird's constructions, or termite, ant and bee cities. Even in early times, humans have seen a great deal in animal structures. In addition to the primitive forms of animal buildings, there are certain forms which match the present-day achievements of lightweight building technology. Spider webs belong to these. (IL 3,1971).

Architecture and nature have many similarities.

Nature creates structures

- *with cells and tissues,*
- *out of supporting and connecting substances,*
- *in integrated and single-piece construction,*
- *with genetically-determined and programmed gestalt but with functional, environment-oriented flexibility,*
- *without preconceived planning and without goal-directed expediency,*
- *but, technically speaking, always with exemplary efficiency, minimum material expenditure and with remarkable aesthetic perfection.*

Architecture erects constructions

- *with every means which modern technology offers in such rich variety,*
- *according to pre-determined conditions for the fulfillment of similarly pre-determined purposes,*
- *always considering safety and economy factors,*
- *and in accordance with the stylistic notions of the given era.* (IL 4, 1972:5).

Generally, the functions that natural structures fulfill does not match the functions of the buildings. Also we cannot expect nature to offer many examples directly applicable to the building. But there are some clues in the world of nature. Analyzing the forms found in nature very accurately and understanding them will certainly utilize our knowledge of lightweight building construction. For a living organism the saving of energy in the construction of an organ is the same as the saving of money for the technologist in the construction of a technical system. The concept of energy saving is valid for both disciplines.

CHAPTER THREE

20TH CENTURY ARCHITECTURE

3. 20th Century Architecture

3.1 Observation of Prior Periods

Man has always been a part of nature. He had to deal with the laws of it in order to survive. During this struggle of man, nature was also a path-finder for him. By looking at the formations in his environment, he learned adaptation and development. He learned to supply his needs by imitating, interpreting and using the opportunities of nature. Thus, we can easily see the similarities between man-made structures and the structures of nature (particularly the structures made by animals), if we have a close look at ancient times.

Obviously, only the biological forms which are known at any one time could bear any relationship to human building. In the past this meant all the large and immediately visible biological forms: plant forms, animal forms - taken as wholes or in detail. Man used to decorate buildings with flowers, leaves and figures of animals due to his aesthetic considerations or his religious beliefs. On the other hand, he made use of the constructions in nature as he had acquired an intuitive knowledge of construction by observing.

Like the evolution of natural structures towards optimum forms and lightweight constructions; man has tried to cover the maximum area with minimum material. Similarly, man-made architecture has developed form the massive masonry constructions to the lattice lightweight structures.

Everything in nature is part of a systematic order. Nature has rules due to which its structures are formed. Leonardo da Vinci had defined nature as 'an open book ... written in a mathematical language.' Like him, the artists of the Middle Ages knew to observe nature.

Figure 3.1 A Gothic column.

When Gothic architecture is examined, a very deep and developed intuitive knowledge of construction becomes visible. The branched support - tree structure can be first observed in the ribs of Gothic style. The structures stiffened by ribs remind plant structures, branches, especially leaves supported by linear rib-like tissues. Gothic structures can be considered as the lightweight structures of masonry architecture. There is accumulation of material where the load is concentrated, while the other parts are lightened.

The analogy between nature and architecture was given expression in the mid-18th century by the American sculptor Horatio Greenough. He rejected the aesthetic conceptions of his time as they honored eclecticism. In his search to overcome these conceptions, he turned to nature as a source, for it offered the most diverse forms without reliance on pre-existing models. (Lampugnani, 1989).

It is interesting that the London Crystal Palace, considered as 'the turning point which gave the entire development of architecture a new direction', was inspired by nature. The roof structure of Joseph Paxton's gigantic steel and glass exhibition hall, bears an amazing similarity to the lattice-work and articulation of the dragonfly's wing. Paxton said he conceived this extremely fine-membered structure in his youth, as a gardener, by studying the leaf skeleton of the tropical water lily, Victoria regia. (Hertel, 1966).

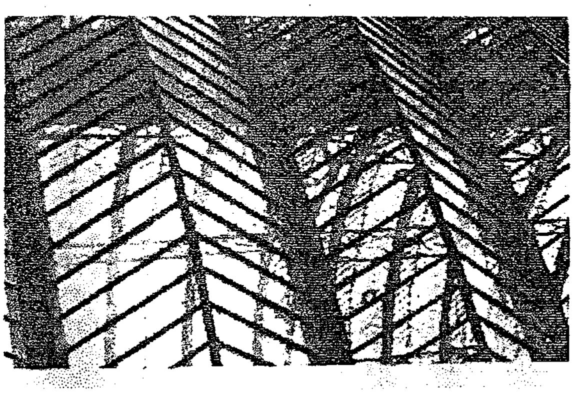


Figure 3.2 Detail of Crystal Palace.

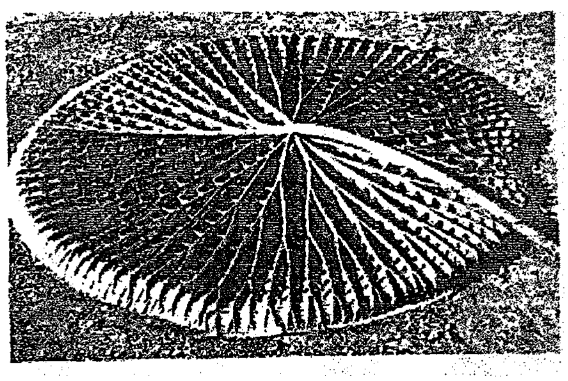


Figure 3.3 Leaf structure of Victoria regia.

Nature's effect on architects branches through many trends and spreads over periods of architecture. The examples chosen from 20th century show the breadth and variety of points of view, expressed by the architectural movement connected to the notion of organicism.

3.2 End of 19th Century-Early 20th Century

"In architecture there are two necessary ways of being true. It must be true according to the program and true according to the methods of construction. To be true according to the program is to fulfill exactly and simply the conditions imposed by need; to be true according to the methods of construction, is to employ the materials according to their qualities and properties . . ." Entretiens sur l'architecture, 1863-72. (Frampton, 1996:64).

In these writings, the French architect Eugène Emmanuel Viollet-le-Duc (1814-1879) had not referred nature and its structures but what he had deduced, matches with the construction principle of nature. (In the previous chapter the relation between the function and the load-bearing structure has been examined with examples).

In his theoretical writings, Viollet-le-Duc championed the Gothic style because he felt that its form was determined by structural necessity and its decoration both revealed and was derived from construction and materials. Thus he proposed the use of 19th-century techniques and materials, especially cast iron, according to the same rationalist principles employed by the Gothic masons. (Neuman, 1996).

Outside France his ideas had their most pronounced impact on the work of the Catalan Antoni Gaudí besides other architects.

Antoni Gaudí (1852-1926) has a special place in the history of architecture. He not only had developed an original style of his own but also brought form and construction together in a successful way. Gaudí's designs reveal the idea of an autonomous system in which the coherence between the form of the supporting structure and the final form of the building seems to be the most important subject.

Because of being influenced by the two cultures which had ruled in Catalonia; "Gaudí's work is formed by two components: the Gothic "structural and constructional" element of Roman origin and the Arab "antistructural" factor (for in Arab architecture light is the chief molder of space, the buildings and their parts apparently tend to lose substance)". (Casiraghi, 1995). His work is an impressive synthesis of these factors.

The architect (who practically never journeyed anywhere) drew his inspiration from his ability to observe and reuse the countless details offered by nature. He was quite different from the other artists of Art Nouveau as natural forms were taken realistically in his designs.

Figure 3.4 Casa Batllo (1905-7), Antoni Gaudí.

In Casa Batllo (Barcelona 1905-7), a transitional effect between the sculptural plasticity of Gaudí's earlier years (1878-91), and the structural type characteristic of his later period is observed. Natural and organic forms are no longer ornaments superimposed on the building, but constitute essential structural elements, as in the case of bone-shaped columns.

"Towards the end of his career, Gaudí asserted that the straight line belonged to men, the curved one to God ... His designs always preserved a close tie with familiar living shapes: bones, muscles, wings and petals, and at other times with caves and even stars and clouds." (Lampugnani, 1989:119). The structures of nature as being the creatures of God, are made up of curved lines and surfaces; so are Gaudí's designs. He is close to nature's structures by curves.

Gaudí took the forces into consideration during the design process. He searched for efficient and innovative structures by his experimental methods. His studies show that he had examined the flow of forces in detail, thus his buildings were shaped due to them. Thus this is a common point with natural structures as they are also formed due to the forces.

3.3 Expressionism

The famous English painter John Constable defines two ways for an artist to create his work: "... The first one is to imitate the other artists' works or make a new combination by choosing some original parts of them; in the second way, he searches for the perfection in the main source of art - nature." Designing with the first way which can be called Eclecticism results with a traditional work, while in the second and more difficult way, the artist comes up with a new, original work of art with a brand-new form. Works of expressionism belong to this second group.

Expressionism is a phenomenon which principally began in Germany. It was Peter Behrens who achieved the transition to Expressionism with his buildings for the AEG in Berlin. Hans Poelzig, Max Berg, Otto Bartning, Hugo Häring, Erich Mendelsohn, Rudolf Steiner were other architects clearly distinguishable as Expressionists.

Being examined in this study, what is remarkable of some of the Expressionists are the crystalline forms and organ-like forms recognizable in their buildings, besides their organicist ideas.

Figure 3.5 Wylerberg House (1921-4), Otto Bartning.

The dominant forms in Otto Bartning's architecture are crystalline fractures and angular folds, in plans and the general forms of buildings. The rooms of Wylerberg House near Kleve (1921-1924) are angled and folded like the roof and the façade. The bedrooms are pentagonal, the library is heptagonal and the dining room is octagonal. The most complex room is the polygonal music room with its multiple fractures. It shows the complicated figurations which he was capable of creating. Even the windows in the pointed bay turn away from the wall plane and stand angled in their soffits. The construction is irregularly polygonal and at the same time stabilized by a strong axial symmetry towards the extreme tip of the bay. (Gössel & Leuthäser, 1991).

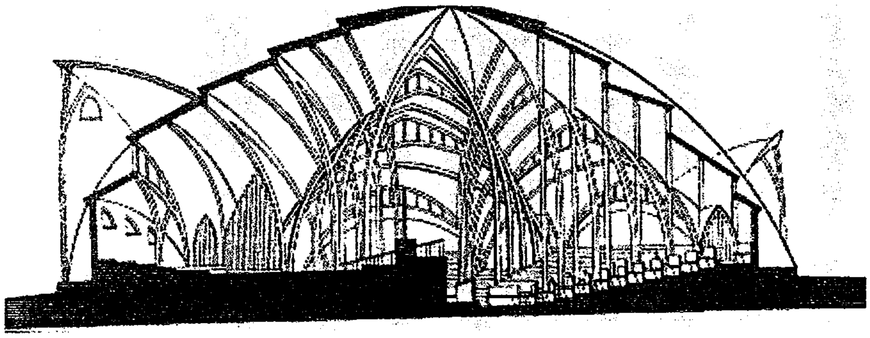


Figure 3.6 Star Church (1921-2), Otto Bartning.

"For Bartning (1883-1959), architecture was growth and activity, the force of nature itself." (Lampugnani, 1989:94). In his Star Church project (Sternkirche, 1921-2), "the structural idea of Gothic was to be realized with modern building methods." (Lampugnani, 1989:34). As seen in the section, a structure consisting of ribs is governing the project.

Figure 3.7 Second Goetheanum (1924-8), Rudolf Steiner.

Rudolf Steiner (1861-1925) demanded for the anthroposophical movement which he called into being a building which is adapted to what takes place in it, as the nutshell is adapted to the nut. He claimed that "architecture should develop from the 'geometric - dynamic' into the 'organic - living' ". (IL 27, 1980:189). His second Goetheanum at Dornach (1924-8) is linked to Expressionism by its approach, but occupies a place apart, as it was designed in accordance with the principles of Anthroposophy. It relies on the principle of growth of plants, it conveys Goethe's principle of plant metamorphosis. With folds all over, it has a crystal like appearance at first sight. But the edges are not as sharp as they are in crystals and it does not have a regular geometry. It displays a solid character instead of a ribbed, skeletal one.

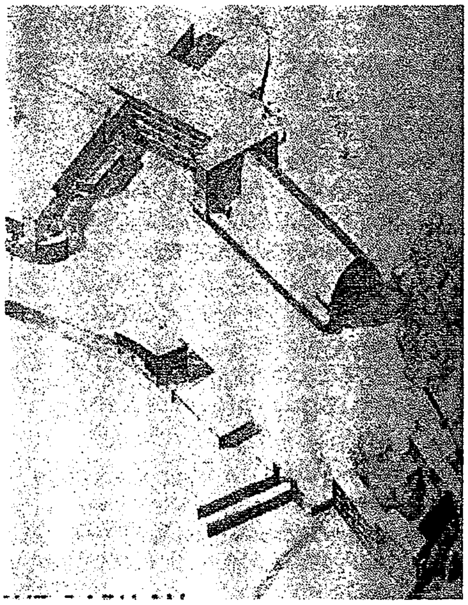


Figure 3.8 Gerkau farm buildings (1924-5), Hugo Häring.

Hugo Häring (1882-1958) was responsible for a number of important works, of which the Gerkau farm buildings (1924-5) and the housing project in Berlin-Siemensstadt (1929-31) became widely known; his real importance, however, lies in the theoretical field. He had expounded his views on organic building in numerous articles and lectures. Despite an overtly Expressionistic tendency, Häring remained preoccupied with the inner source of form. He aimed an architecture being a development process leading to the goal of efficient form.

He claimed that in order to discover the 'true' organic form, rather than to impose an extraneous form, man should act in accord with nature, (Frampton, 1996) but not imitate it. He refused the grid of geometric formation, emphasizing instead an image related to "organic order". His words below convey his beliefs about tomorrow's architecture.

"It still seems to many people inconceivable that a house too may be evolved entirely as an 'organic structure', that it may be 'bred' out of the 'form arising out of work performance', in other words that the house may be looked upon as 'man's second skin' and hence as a bodily organ. And yet this development seems inescapable. A new technology, working with light constructions, elastic and malleable building materials, will no longer demand a rectangular house, but permit or put into effect all shapes that make the house into a 'housing organ'. . ." (Conrads, 1970:126).

3.3.1 Glass Chain

During the First World War, Bruno Taut (1880-1938) started to work on a series of thirty lithographs for his book, Alpine Architecture. In these designs he proposed crystal-like structures for the peaks of Alps. These imaginary designs were evidences of a change in architecture. Taut had offered an example of such crystalline form in the Glass Pavilion which he built for the 1914 Werkbund Exhibition in Cologne.

Figure 3.10 Alpine Architectur, Bruno Taut.

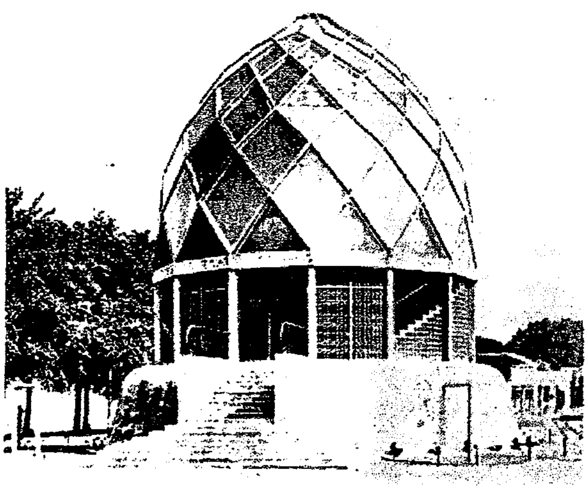


Figure 3.9 Glass Pavilion (1914), Bruno Taut.

In 1919, together with like-minded artists and architects, Taut organized the Glass Chain (Gläserne Kette). The group, including Hermann Finsterlin, the brothers Hans and Wassili Luckhardt, Walter Gropius, Hans Scharoun and Max Taut would band themselves into a private forum for the exchange of architectural ideas, drawings and fantasies. Their common aim was to overcome ossified academic architecture with fundamentally new constructional forms taken from animate and inanimate nature. (Gössel & Leuthäser, 1991). Crystals, shells, amoebae and plant forms were favored as models for future architecture, and for structural purposes, glass, steel and concrete were the favored materials, reflecting the influence of Bruno Taut and his mentor, the glass fantasist Paul Scheerbart. The correspondence ran until December 1920. (Lampugnani, 1989).

Crystals, crystal formations are the examples of structures of non-living nature and they are solid load-bearing structures. However, the glass pavilion of Taut has a lattice structure made up of linear elements.

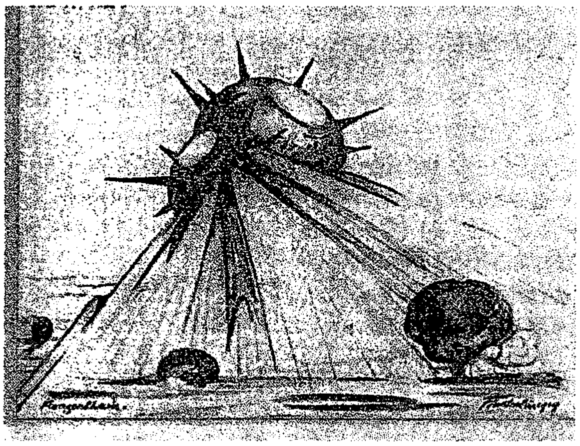


Figure 3.11 Concert House (1919), Hermann Finsterlin.

Hermann Finsterlin (1887-1973) is an interesting personality with his designs constituting an original approach to nature-architecture relation.

"A design such as the concert house (1919), with its prickly biomorphic spheres, is reminiscent of Haeckel's drawings of radiolaria and diatoms. Finsterlin, who knew Haeckel, was inspired by a wide range of natural forms, from snail shells and muscles to 'animal limbs and icy glaciers'." (Klotz, 1989:44).

Finsterlin designed unreal sculptural architecture, biomorphic form fantasies and he illustrated his concepts of organic housing in sensual, colorful sketches, solutions which were naturally never built.

3.4 Organic Architecture

"As with most concepts used in architecture, the concept of an 'organic' style is borrowed from other fields and remains difficult to delimit once applied to architecture and building." (Lampugnani, 1989:254). The term organicism as a concept of architecture has in the course of its history acquired a number of different meanings. In one of them; it subsumes a method capable of interrelating the invention of forms and spaces according to an order established by the harmonic relationship between the whole and the parts. It is also tied to natural processes such as birth, growth, and death. Another approach of organicism suggests a creation developing according to a process of configuration linked to nature, with intent to render in its own likeness the image of the object which it configures. (editorial, Domus 780, 1996). The first definition is much parallel to the subject of this study than the latter but it does not match completely; nature is present as an abstract concept in organicism.

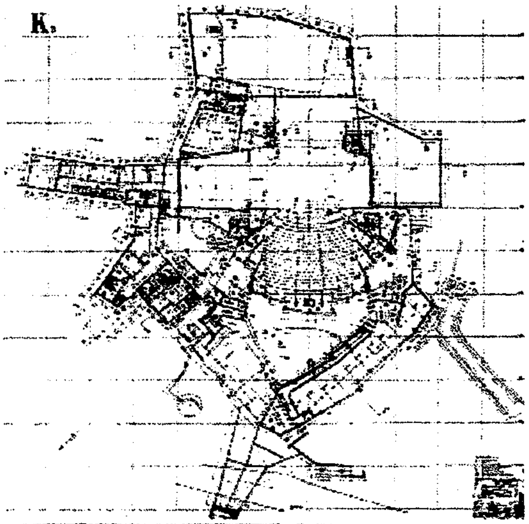
Frank Lloyd Wright, Hugo Häring, Hans Scharoun, Alvar Aalto are some of the remarkable personalities of this movement of architecture.

Frank Lloyd Wright (1867-1959) was one of the most innovative and influential figures in Modern Architecture. In his radically original designs as well as in his writings he championed the virtues of what he termed organic architecture, a building style based on harmony with nature.

"For Wright, the word 'organic' (which he first applied to architecture in 1908) came to mean the use of the concrete cantilever as though it were natural, tree-like form. He seems to have conceived of such a form as a direct extension of Sullivan's vitalist metaphor of the 'seed germ', extended now to include the whole structure rather than the ornament alone." (Frampton, 1996:188).


Figure 3.12 Johnson Wax Administration Building (1936-59), F. L. Wright.

In the Johnson Wax Administration Building (1936-50) this organic metaphor revealed itself in tall, slender mushroom columns becoming thinner towards their bases. They form the main support within a 9-meter high open-planned office space. At roof level they become broad circular lily pads of concrete.



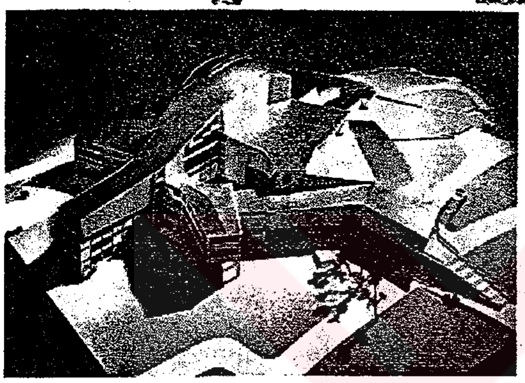


Figure 3.13 Kassel City Theater (1953-4), Hans Scharoun.

Like Hugo Häring, Hans Scharoun (1893-1972) advocated in both his architecture and his writings the idea of an 'organ-like building'. At the level of principles, Häring and Scharoun had much in common. Their attitude to massing was often naively imitative of biological form. (Frampton, 1996). Scharoun had the chance to have more buildings constructed when compared to Häring.

Alvar Aalto (1898-1976) is claimed to have an organic approach conceptually close to the ethos of Bruno Taut's Glass Chain, above all to the works of Hans Scharoun and to Hugo Häring. (Frampton, 1996). He tried to integrate nature to his buildings. Geomorphic structures are a frequent theme in his work, for example the entire display area of his pavilion for the 1939 New York World's Fair presented the contours of Finnish lakes.

3.5 Structural Engineering

Recently, nature has also served as a model and an inspiration in other regards: in the area of wide-span constructions, i.e. in the field of advanced technology. Here, the principle discovered in and borrowed from nature is achieving the maximum rigidity and endurance with the least amount of material.

Already in the 1920s, with the reinforced-concrete shell structures of Franz Dischinger and Walter Bauersfeld, the comparison to an egg shell was evoked. Although being only compatible for single arched structures, the necessary technology developed by Dischinger, Finsterwalder and Bauersfeld in the thirties. Statics were further improved by more complex forms, such as the double-arched saddle. (Gössel & Leuthäuser, 1991). By means of a double curvature in form and the use of a material of greater tensile and compressive strength, it is possible to achieve great spans combined with an exceptional thinness of construction.

"There is an undoubted expressiveness about such structures, and it is surely no coincidence that the achievements of civil engineering in this field were taken up in the fifties." (Gössel & Leuthäuser, 1991:249).

Among the engineers who began to apply technically appropriate and elegant solutions to reinforced concrete construction, there were Robert Maillart, Edouardo Torroja, Eugéne Freyssinet, Pier Luigi Nervi, Felix Candela; and it is possible to say that especially the latter two of them have relation with natural structures. For them, a structural work of art derived equally from aesthetic choices, the creative imagination and science.

Nervi (1891-1979) had a prodigious ability to derive beauty from the results of precise calculations, and form from the nature of his materials and techniques, which he made the instruments of his vision. According to him, "the process of creating form is identical, whether it is the work of technicians or of artists: the principle that is, whereby the beauty of a structure, for example, is not just the outcome of calculations, but of an intuition as to what calculations to use, or with which it is to be identified." (Lampugnani, 1989:237).

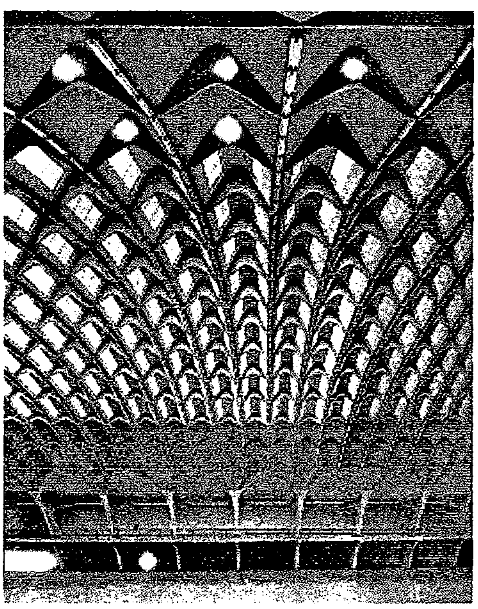


Figure 3.14 Exhibition Building (1948-9), P. L. Nervi.

His Exhibition Building in Turin (1948-9) shows that he had managed to obtain 'strength through form' in buildings which was the aim of his studies and experiments. The enormous building consists in effect of a single roof structure, made up of undulating prefabricated units, thus the space below is left completely free.

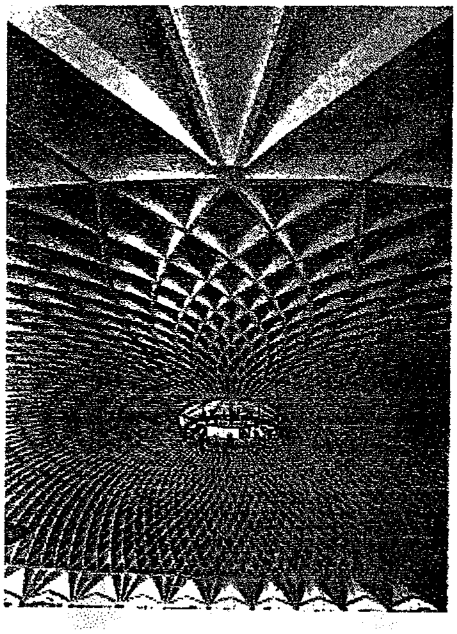


Figure 3.15 Palazzetto dello Sport (1957), P. L. Nervi.

Nervi, like Maillart, designed his works to be aesthetic but also financially economical and efficient in construction. The modern design principles of efficiency, economy and beauty became interdependent in his technical process, producing results such as the elegant roof pattern in the Palazzetto dello Sport (1957) in Rome. (McQuaid, 1993). The pattern of the roof recalls the rigid arrangement of the central part of flower (calyx).

"Like the Paris building's conference hall, the swelled surfaces of which are derived from mussels, insects or flower calyxes, the structure of the Pirelli skyscraper in Milan (1955-8) is also derived from nature. This is the prototype of the building's sectional development, with its four main stanchions growing ever more slender towards the top (in a manner reminiscent of a tree), as might have been seen more clearly if a lighter cladding had been used." (Lampugnani, 1989:239).

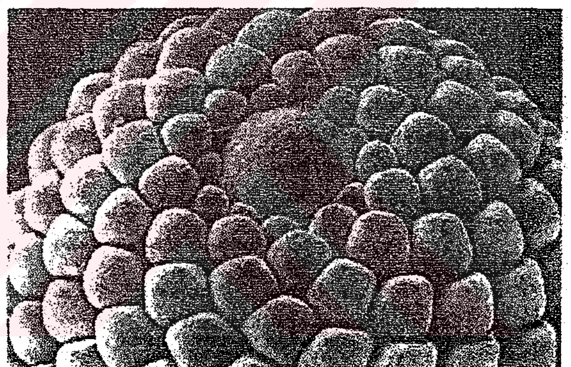


Figure 3.17 A flower calyx.

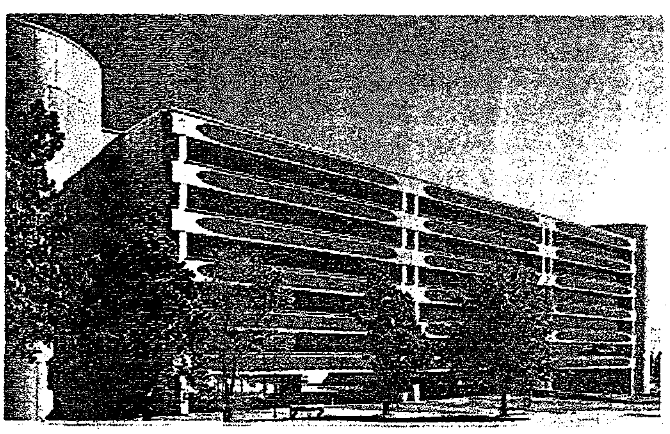


Figure 3.16 Trade Group Center (1975), P. L. Nervi.

Nervi's design for Trade Group Center building with Harry Siedler & Associates in Canberra (1975), presents another ingenious solution of him. In the design, he had used the girders and transverse girders with some of their unused mass moved out elegantly. (Bauen+Wohnen, 1976).

It cannot be denied that light vaults and domes were the most important architectural events of 1950s. Not surprisingly, most of them were the contributions of engineers like the Mexican shell builder, Spanish architect Felix Candela (b. 1910).

He draws on his experience as a builder to construct the thinnest conceivable shell by the design of a roof in hyperbolic paraboloids only 15 mm thick (Cosmic Ray Building 1951, Mexico City). His method of shell construction is notable for its extreme economy of material.

Candela created a variety of structures that used the hyperbolic paraboloid, or saddle-shaped shell, which was stiffer and easier to build than other shell constructions. The advantage of hyperbolic paraboloids (as compared with the sphere or other types of vault) is that the shuttering required can be made from straight elements. (Lampugnani, 1989). Due to the relative simplicity of this process, and the great saving in material, Candela's constructions are more economical than other rigid roofs.

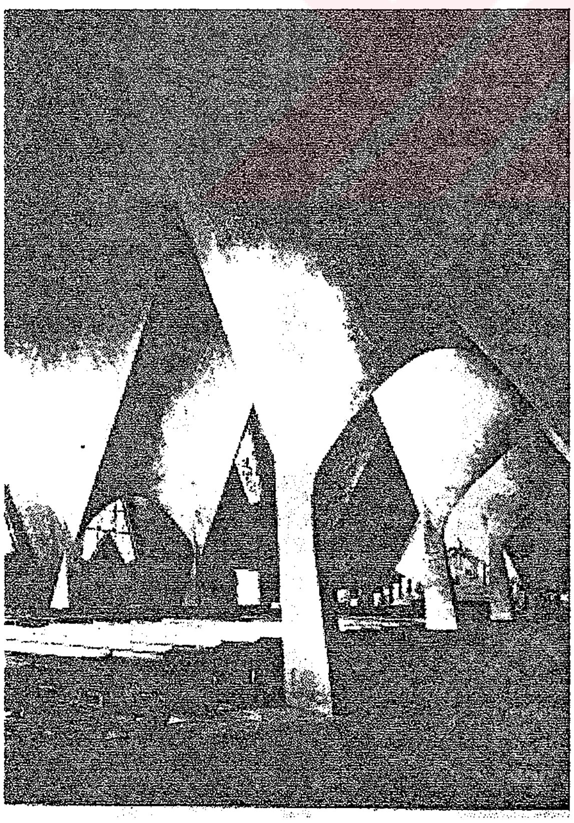


Figure 3.18 The Iglesia de la Virgen Milagrosa (1955), Felix Candela.

Hyperbolic paraboloids constitute the entire structure (including the walls and roof) of The Iglesia de la Virgen Milagrosa, in Navarte, Mexico, which was completed in 1955. The building represents the incredible virtuosity with which he was able to manipulate this form into thin concrete shell roofs and walls. (McQuaid, 1993).

Like Nervi, Candela claims that he has been guided less by exact calculation than by an intuitive feeling 'in the manner of the old master-builders of cathedrals'. This intuition is based on the knowledge of materials and stresses increasing with every project of him.

Most recently, Frei Otto (b. 1925) had been developing new constructions by analogy with nature models in Germany.

As a fighter pilot in World War II, Otto was impressed by lightweight aircraft technology; and, though in a different way, the Expressionist fantasies of Bruno Taut; his crystalline temples and Alpine Architektur sketches had effects on him. He had admired greatly the work of Felix Candela, R. Buckminster Fuller and Walter Bird.

In 1957 he established the Entwicklungsstätte für den Leichtbau (EL) in Berlin, which was the fore-runner of the Institut für leichte Flächentragwerke (IL), which he founded in 1964 at the Technische Hochschule in Stuttgart. "In 1961 he met the biologist and anthropologist J. G. Helmcke. Together they founded the research group Biology and Nature, to examine the many and varied biomorphous constructions of algae, which became an important inspiration for Otto's own structures and constructions." (Gössel & Leuthäser, 1991:412). He concentrated his attention on the analysis of biological phenomena, developing his exploration and analysis of lightweight structures in nature.

Figure 3.19 Munich Olympic Stadium (1972), Frei Otto.

He improved his new concepts by focusing his investigations on one of the principal forces extant in all structural systems - tensile stress. The modern tent is largely Otto's creation. Traditional tents were revived by him as a leading prototype for lightweight adaptable buildings.

He concentrated on how to achieve more with less, that is, less material and effort. He developed innovative structures of extreme lightness as well as extreme strength, which were to make optimum use of new materials such as thin cables of high-strength steel or thin membranes of synthetic fabric. "He also saw the potential of pneumatically distended membranes, the only building type considered suitable for extraterrestrial conditions." (IL 17, 1977:5).

During these investigations, he observed the forms found in nature and sought their relevancy to his studies by manifold experiments. IL seminars were hold as part of this studies at which biologists discuss their research on plant and animal structures. “Besides such obvious adaptations as the “vertebrae column”, his methods themselves have a tendency to produce forms which, for instance in the “tree” structures or space frames, are of outstandingly organic character.” (IL 17, 1977:6-7).

3.6 Contemporary Architecture

In his book ‘Architecture 2000 / Predictions and Methods’, in 1969, Charles Jencks had predicted that the influence of major biological inventions in 1980s and ’90s would result in the most significant architectural movement of this century - the Biomorphic School. (Jencks, 1971). He wrote that the Biomorphic School had already had a long, but fitful history reaching a high point in the beginning of this century with the work of Antoni Gaudí and Frank Lloyd Wright and later oscillating in strength with the work of Soleri, Goff, Kiesler, Scharoun, the Metabolists, Johansen, Rodilla, O’Gorman, Couëlle, Hausermann, Bloc, Katavolos, Guedes, Doernach and at times Le Corbusier. According to him, the Biomorphic School was already a strong movement - as seen from the list above - although its members ordinarily worked alone and were unaware of being part of a tradition.

Today there exists no such school but the inclination to nature continues increasingly. The architects and engineers have more chance i.e. technological facilities to have a closer observation of natural structures.

“Nature in its varied network of vital processes is a teacher not only in the optimization of construction and form, but also for total processes, which are called “buildings” and for methods which seek “total” results which transcend everything which is measurable and objective.

Nature in architecture is a spiritual principle, like a whirlpool in the dynamic river which becomes visible from the subjectively experienced inter-relations of design and construction and of theory and practice.” (IL 27, 1980:193).

Figure 3.20 Multipurpose Hall (1973-6), Günther Domenig.

These are the words of the Austrian architect Günther Domenig (b. 1934) that are extracted from his report in an IL symposium 'Natural Building'. In this report he explains how nature can be a model for building.

Domenig's projects which recall living organisms have an expressionistic character. His multipurpose hall in Graz (1973-6) resembles the folded skin of a caterpillar, both from outside and inside view. The 'Zentralsparkasse' building (1975-9) in Vienna has a similar character in the stainless steel elevation, which seems as if "it has somehow started to slide downwards, slipping off its concrete structure at the top and bulging out in a buckled compressed snout at first and second floor levels." (Architectural Review, Nov. 1980:263)

Figure 3.21 Zentralsparkasse Building (1975-9), Günther Domenig.

A specific and regional approach is developed by Imre Makovecz (b. 1935) in Hungaria. In first the work of Frank Lloyd Wright and then Rudolf Steiner, he had found something he called living, organic architecture with which he combined Hungarian folk heritage. He had explored the spirituality of natural world while seeking 'emotional and intellectual structure' from nature.

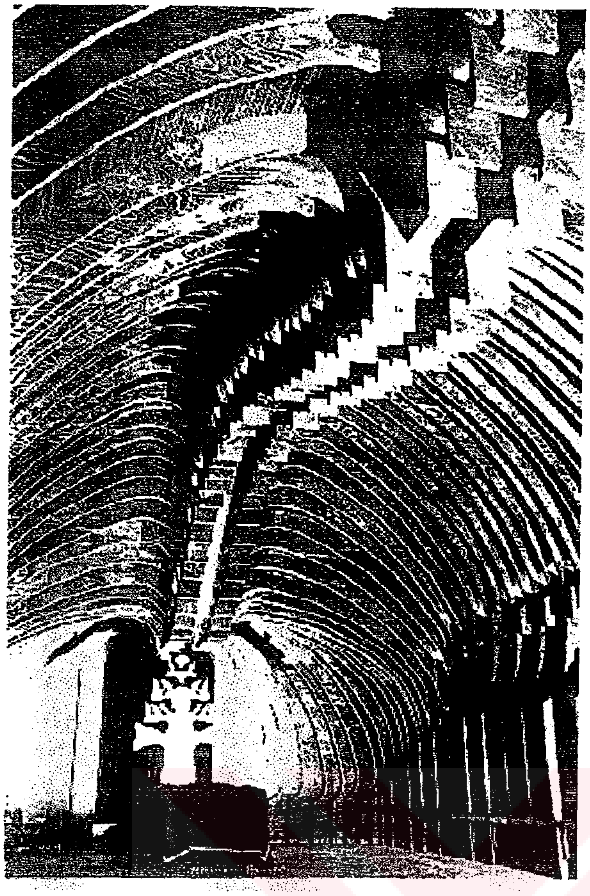


Figure 3.23 Farkasrét Mortuary Chapel, Imre Makovecz.

In his work, the synthesis of regional cultural values and natural concepts can be perceived. He has a talented use of natural materials in forming the structures. His buildings seem as if they are part of landscape, nature.

Figure 3.22 Interior view of a dog skeleton.

The interior space of Makovecz's Chapel in Budapest is very much like the rib-cage of a vertebrate. A central spine and the wooden ribs create this impression and give the space a mystic atmosphere.

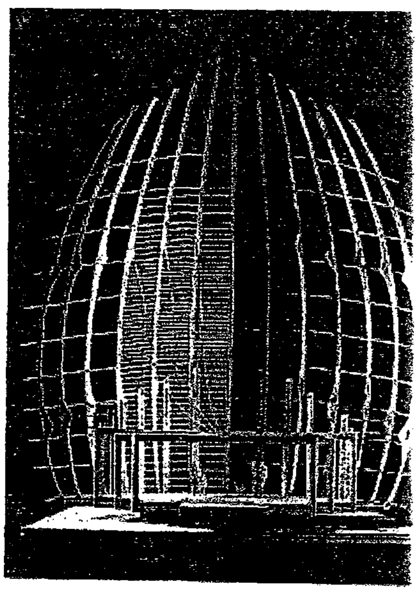


Figure 3.24 Tjibau Cultural Center, Renzo Piano.

Renzo Piano's (b. 1937) competition-winning design combines nature, local materials and tradition with technology. The Jean-Marie Tjibaou cultural center has external forms resembling vegetables growing on the ground. They are framed with curving laminated pine ribs which are secured together by stainless-steel rods and have bamboo and bark slats outside. (Buchanan, 1992:61). The structures shade the volumes below and guide wind and convection. They have a lattice-like appearance which recall plant tissues.

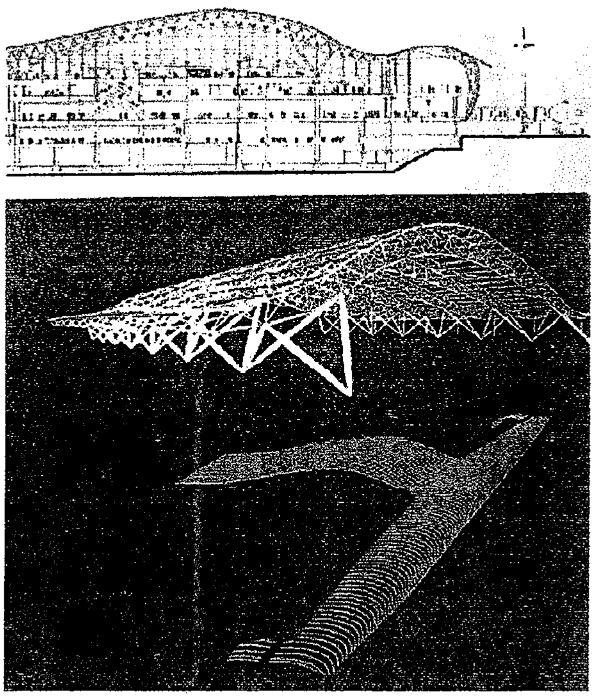


Figure 3.25 Kansai Airport, Renzo Piano.

The Japanese capacity for combining high technology with nature and tradition will be seen at perhaps its most extreme in the Kansai International Airport and Passenger Terminal Building at Osaka, Japan. "In this project, won in December 1988 in an international competition and designed with Noriaki Okabe, Renzo Piano seems to have found the perfect outlet (and receptive client) for his noted ability to apply the laws and forms of nature to sophisticated high-tech systems." (Architectural Review, 1991:86).

The lightweight structure of the terminal roof, designed with Ove Arup & Partners (Peter Rice), derives its form from aerodynamic and seismic considerations. The structure which is made up of tubular steel space trusses, spanning 82 m on bipod legs seems like a rolled wave of the surrounding sea.

Nicholas Grimshaw's concept of design does not have a direct and strong relationship with the structures of nature. However he explains his concept 'Structure, Space and Skin' (also the name of the book about his work) which he tries to achieve, by giving examples from the world of nature.

According to him, among many features - good workmanship, appropriate materials economy, etc.-, 'Structure, Space and Skin' are the ones without which a good building cannot be consummated. To illustrate what he means by these three elements: "a horse skeleton is all structure, while the Omnimax theater at La Vilette in Paris is all skin; a bat's wing is definitely structure and skin. A shell combines all three in rather a beautiful unity: it has marvelous spatial qualities, its structure is extremely strong and it is a skin." (Moore, 1993:236). He thinks in Joseph Paxton's Crystal Palace and Norman Foster's Stansted Terminal these three are provided.

Figure 3.26 Stock Exchange and Communications Center (1991-5), Nicholas Grimshaw.

His design for Berlin Stock Exchange and Communications Center (1991-1995) is one of his recent buildings which have an organic aspect. The spaces are gathered along a central spine which runs down the middle of the site. The office floors are suspended from nine steel arches, which rise the full height of the building and span from the structural spine to the back of the site. These arches together have the appearance of ribs of an unnamed vertebrate.

"Grimshaw attributes this organic approach to circumstance, such as irregular sites." (Moore, 1993:224). One factor for this attitude is his familiarity with technology which gives chance to realize complex forms. Another one is that organic patterns give buildings unity and strength especially in the common environment of a city.

Recently the Finnish architects have approaches influenced by the Finnish organic tradition and the work of Alvar Aalto.

Designed by a young group of architects MONARK, the recent Finnish world-exhibition pavilion (Seville, 1992) synthesizes aspects of Finnish architecture, which are bound to national culture and a desire for universality.

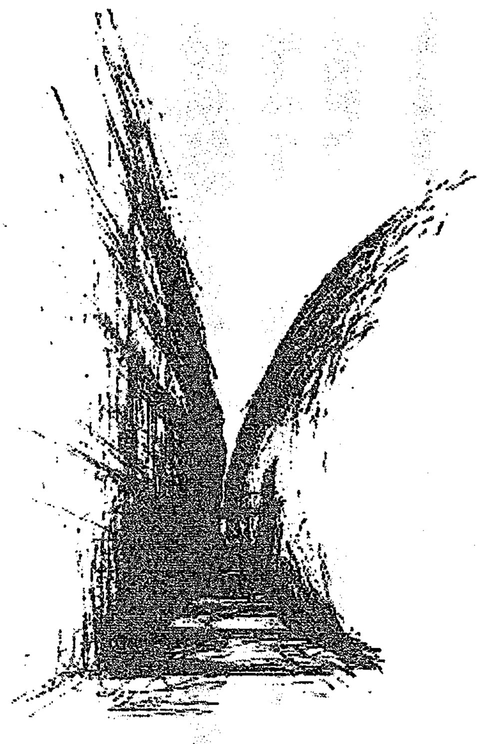


Figure 3.27 Finnish Pavilion (1992), MONARK.

The pavilion comprises two buildings that have different material and shape. The main thing is not the buildings themselves but the space between them. Keel and Machine (the names of the buildings) create between them a long, narrow shaft - fifteen meters high and thirty-five meters long but only two meters in width. A special atmosphere and tension are assembled by this space.

"This primary idea of the pavilion comes from central Finland, near Ruovesi. In the middle of that wilderness can be found a place where rock has split into two parts through natural forces. In old Finnish superstition people feared and worshipped this place. They named it the Shaft of Hell." (Poole, 1992:219). The design has a different approach from the other examples: it is very interesting that not only a structure of nature but a space in nature is the source of inspiration.

3.7 Single Examples

There are many other architects who are inspired by nature in their approach of architectural work. Among them, The group Haus-Rucker-Co., Paolo Soleri and Jacques Couëlle are chosen as specific examples.

Haus-Rucker-Co. is an architectural group founded by Laurids Ortner, Günther Zamp Kelp and Manfred Ortner in Vienna in 1967, and also active in Düsseldorf since 1970, as well as in New York since 1971. "They seek to propagate a temporary, disposable architecture, a concept which anticipates changes in the environment." (Lampugnani, 1989:144).

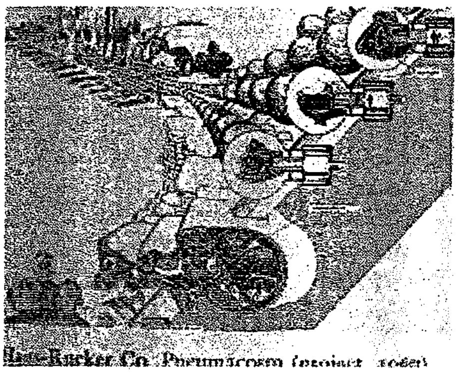


Figure 3.28 Pneumacosm (1967), Haus-Rucker-Co.

Among the group's best-known achievements are: Balloon for Two, Vienna (1967); the shell around the Haus Lange museum, Krefeld (1971). In addition, a considerable number of 'paper projects' have been undertaken. These include Pneumacosm (1967), an expansion proposal for New York using pneumatic cells. Their projects which are related with future architecture make use of natural forms such as pneumatic structures and shells. This is common with other architects and engineers. Frei Otto, Buckminster Fuller, Yona Friedman, Paul Maymont are some of them who had imagined futuristic city or habitation projects that involve natural forms.

Similar to this attitude, Paolo Soleri (b. 1919) have designed thirty 'Arcologies' (a term coined from architecture and ecology) - a series of high-density, fantastically unreal megastructures for up to six million inhabitants. The thirteenth of these Arcologies, Arcosani, originally projected for 1,500 inhabitants, has been under construction since 1970 in the desert near Scottsdale. (Lampugnani, 1989).

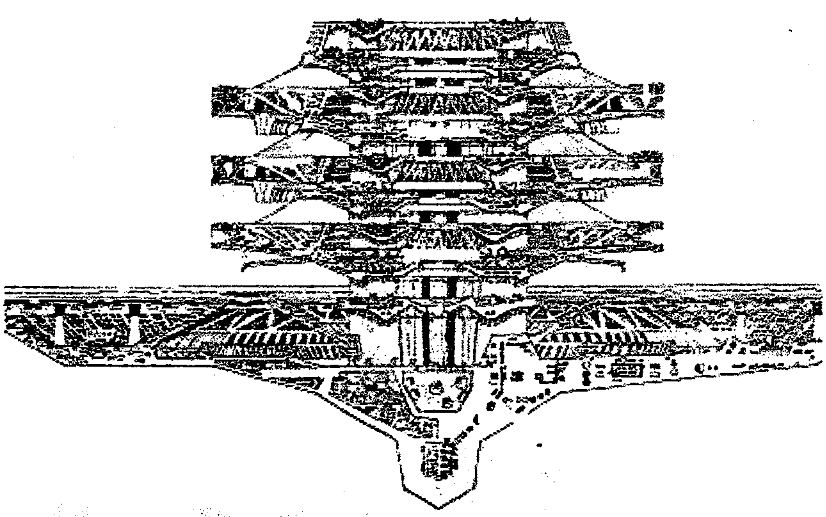


Figure 3.29 Babel (1968), Paolo Soleri.

Soleri emphasizes ecological balance and the emergence of the psycho-social order made up of the totality of ideas and social organizations which are superimposed on the vegetal and animal orders. (Jencks, 1971). His visionary tree-like megastructured city Babel (1968), which has levels suspended around a central core and climatic controlled spaces, recalls the cities of ants or termites.

Jacques Couëlle is a unique personality with his designs developed due to his organicist ideas. He had founded a center for the explorations about Natural Buildings and he invited the architects to think of micro-climate, the caves of the animals, cities of ants, etc. in order to search for the discipline of a new geobiologic architecture.

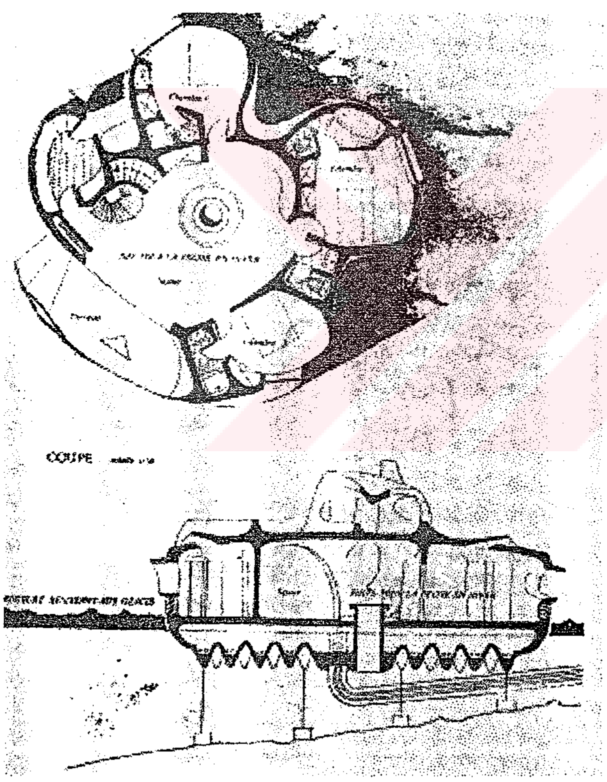


Figure 3.30 Plan and section of one of the typical buildings of Jacques Couëlle.

"I was seeking for the mysterious architecture of the shaped patterns. Industry required a kind of tire which would not burst; we directed our researches to the feet of elephants. We could improve the bodies of the ships by examining the shells of turtles. The structure of the body of the whales gave knowledge about separation walls." says Jacques Couëlle. (Erginöz, 1988:10).

By examining the caves, cavities, he has deduced a concept of house which should be in adaptation with the landscape.

"There is no right angle in nature and in the motion of man."

3.8 Examples of Today

"The closeness of architecture to the forms and laws of nature was for centuries a salient aspect of the theoretic apparatus used by the architects to legitimize their choices." says Paolo Porthogesi in his article named 'Towards a new organic architecture'. (Porthogesi, 1996:4). After having been a source of theoretic and foundational developments of the discipline, the nature-architecture relationship became a "tendency", or rather a "creative strategy". As a creative strategy, organicism spread in American culture, - through the thoughts of Louis Sullivan and Frank Lloyd Wright. By the time it reached Europe, it had lost its original characteristics; it became a tautological and interchangeable category which sought for man's psychological and spiritual happiness.

Then, after a inactive period, architecture inspired by nature and its laws, seeking to attain a "unity in multiplicity" comparable to that of living organisms became a worldwide wave. One of the reasons was the attention to natural morphologies because of the developments in biology and other sciences. Also the development in bionics made a contribution to engineering.

Another aspect of architecture inspired by nature led to the idea of 'natural building' which proposed a house designed according to the energy saving factors, climate etc.

Paolo Porthogesi conveys his idea that perhaps a new organicism, expanding in the directions most congenial to the earth's different places, might be the architectural outcome of the lesson at this moment received from nature and history. He sees the symptoms in the works of the architects like Piano, Foster, Calatrava on one side, and Hollein, Kroll, Albers and Van Uut on another. "In these architects attunement to nature appears in the development of polished or ribbed detail, in structural conception or in the relation between space and light, as in the search for assonances with landscape." (Porthogesi, 1996:4).

The growing idea for protection and improvement of environmental quality of our planet in recent years (environmentalist movement) has made designers and architects, at any rate in the most industrialized nations, more sensitive to new organicism.

These examples from of the recent architectural magazines give a brief knowledge about the behavior of the architects today.

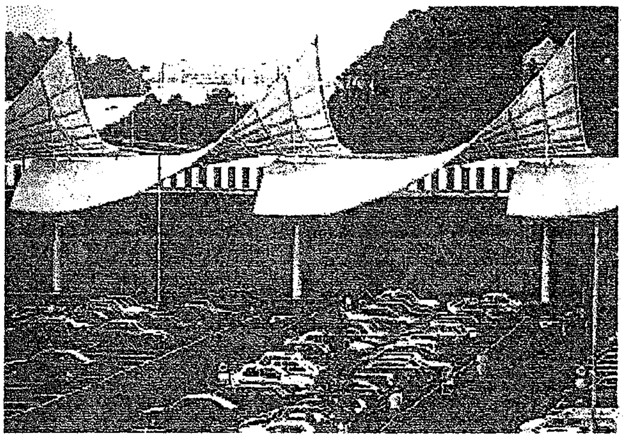


Figure 3.31 Canopy (1994), J. Dixon and E. Jones.

Parallel to the development in technology, roof systems become more stimulating as seen in the canopy design of Jeremy Dixon and Edward Jones in Plymouth, England (1994). The canopy is the largest and most conspicuously visible object in a complex including a superstore. The canopy structure being supported by 11 separate free-standing trees, is 16 meters tall and spans 16 meters. It is constructed of semi-translucent pvc stretched over an armature of fine steel members following the soap bubble principle. The doubly-curved steel lattice was so defined as a soap film so that a pre-stressed fabric would accurately follow its surface without requiring additional restraint. As a result of its parabolic shape the canopy has different appearances from the various viewpoints. (A & U 301 October 1995).

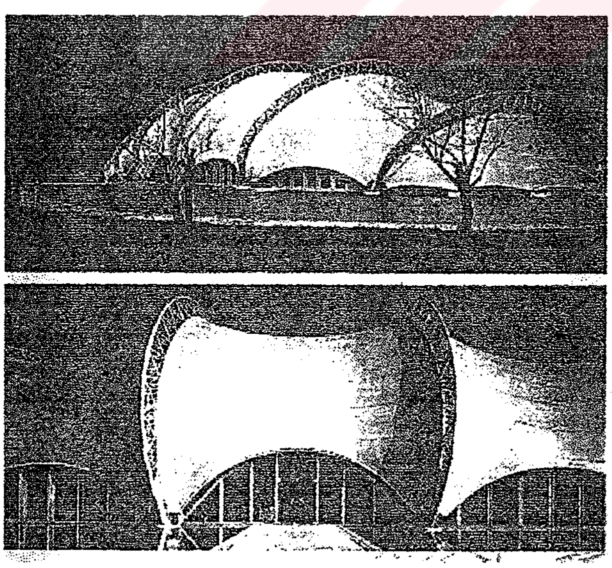


Figure 3.32 Chemical Research Center (1992), Samyn et Assoc.

In Venafro, Italy, a gestural structure recalling natural structures has been constructed. The demand was to build a chemical research center with controlled environment laboratories, supporting offices, and the possibility of erecting test rigs. Belgian architect Philippe Samyn decided to bring all the functions into one volume by creating a tent structure. The basic functional requirements suggested an area of about 35 m x 85 m. The maximum height needed for the test rigs was 15 m. A basically oval plan was evolved, from which six triangulated arcs of tubular steel rise to support the fabric roof. The arches grow in size from the two ends to give the building maximum height in the middle. They are inclined symmetrically to give curves for the tensioning cables which run on the long dimension of the oval plan. The cables are contained within the fabric - a semi-transparent PVC -, and are connected to the structure by pyramids of steel tube that point downwards from the latticed arches. (The Architectural Review 1143, May 1992).

Another tent structure is Ron Herron's roofing of a courtyard between two blocks. It was the notion of translucency, combined with the need for a more flexible and tailored solution which led to the use of fabric. Furthermore it was calculated that, the fabric enclosure would be approximately one third of the cost of a glazed alternative and weigh only one sixth as much. (It is interesting that Ron Herron was one of the founders of the group Archigram which designed high-tech and light-weight structures like, geodesic domes, tension nets, space frames, etc. for future architecture.)

Figure 3.33 Fabric roof for headquarters building (1983), Ron Herron.

The area of the roof is approximately 590 square meters and it was fabricated and installed in two sections separated by a central gutter. The fabric panels are supported on a lightweight steel-framed grid. Each panel is perimeter-clamped to the frame, supported and stressed at points in mid-span by machined aluminum push-ups on stainless steel tie rods. The fabric which would require replacement about fifteen years later, is of PVC-coated polyester scrim with a total weight of about 820 g/m2. (Herron, l'Arca 39).

A challenging exploration is held by FTL Happold about the use of tensioned fabric membranes as cladding for skyscrapers. Besides the aesthetic benefits, there are economic reasons to use fabrics. These conceptual explorations reveal that single layers of fabric can provide structural spans and environmental barriers over large vertical surfaces. In addition, double or triple wall fabric constructions of approximately 5 x 30 meters can be pre-stressed, using heated airflow at very low pressures, to provide the acceptable levels of thermal insulation at a fraction of the weight and cost of more conventional materials. They also have the ability to deflect solar gains which is a major problem with skyscrapers. Moreover many of them are only in need of replacement every 30 years. (AD, Vol: 65, 1995).

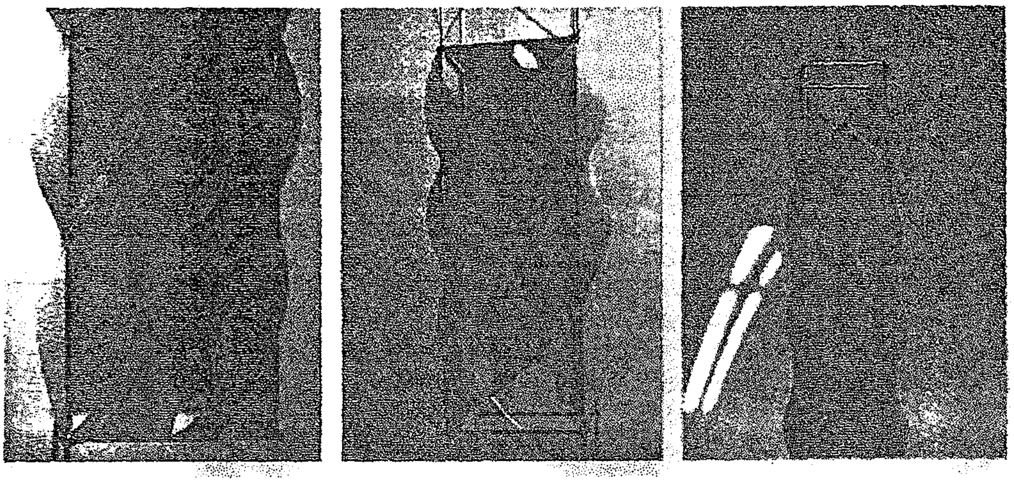


Figure 3.34 Fabric cladding for skyscrapers (1995), FTL Happold.

Although the project is in its preliminary stages, this is an interesting area to explore because, despite the vast technical improvements, the materials utilized in high-rise construction have remained basically constant. Considering the trend in architecture throughout the twentieth century, from the monolithic to the ethereal, this challenging use of fabric may have a very current situation in near future.

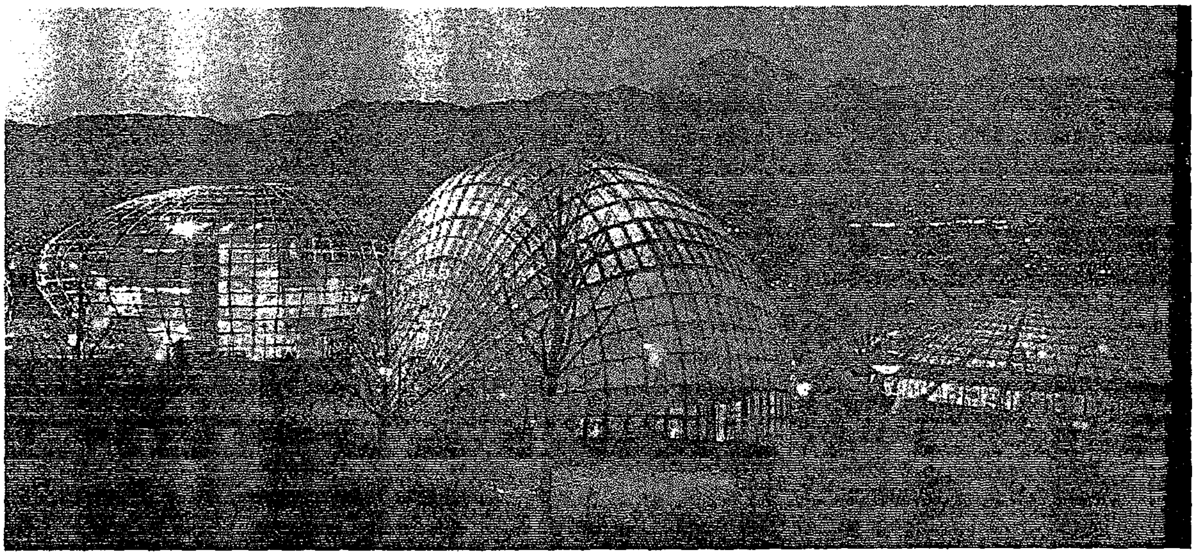


Figure 3.35 Three shell structures of the Museum of Fruit, Itsuko Hasegawa.

Shell-like structures are also quite common in architecture. Museum of Fruit in Yamanashi, Japan has three main steel shell dome structures representing the organic shapes of different kinds of seeds dropped on the ground. The geometry of the three structures was developed through the manipulation of computerized three-dimensional data. Each shape was created through the rotation of simple bodies into complex volumes. The architect Itsuko Hasegawa's approach is an expressive synthesis of technology and nature. "From a distance, the museum resembles three drops of water, resting lightly on the sloping hillside. Yet the shapes of the three buildings are not perfectly Euclidean, their sensuous deformities reflecting the influence of such natural forces as gravity and wind." (Chow, 1996:47). The architect sees technology and nature as reciprocals instead of antagonists. At Yamanashi, this reciprocity is the starting point for extraordinary architecture.

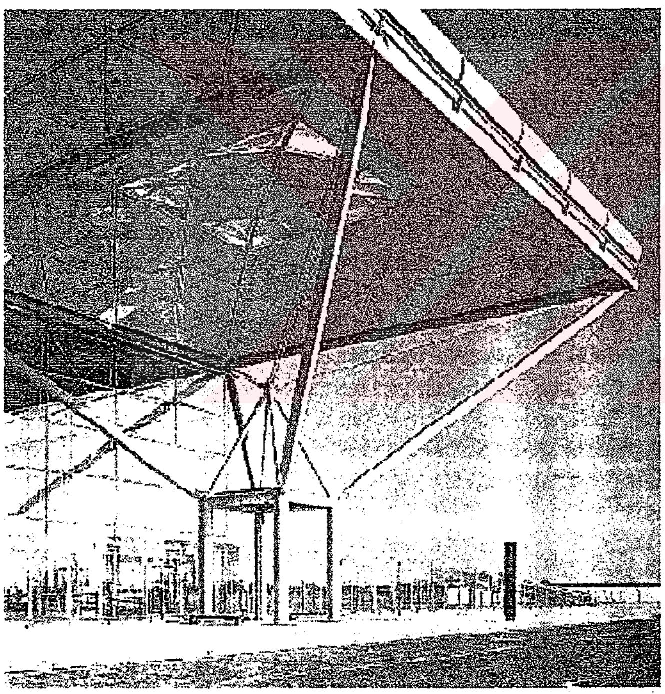


Figure 3.36 Stansted Airport Terminal, Norman Foster.

Another widely used structure of nature is the 'tree'. It has its roots in earlier periods of architecture as well.

Norman Foster's terminal building at Stansted Airport is a steel structured building, with its roof consisting of a series of shallow, partly-glazed domes supported by a forest of tree-like structures. The columns are set on a 36 m2 grid, generated by the functional requirements of the terminal and the need to provide maximum layout flexibility on its passenger floor level. The tree-like structures are comprised of clusters of four interconnected tubular steel columns. These are angled at 4 meters above concourse level, to reduce the structural spacing at roof level to an 18 m2 grid. The tree-like structure is a very far relative of the natural tree when compared to the examples below.

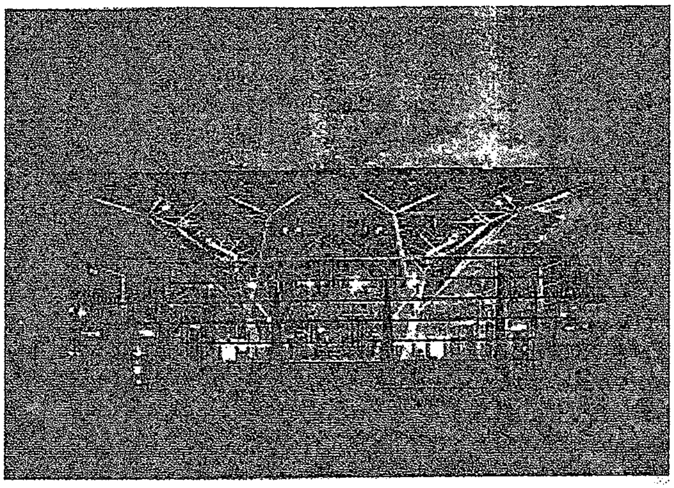


Figure 3.37 Roof for metro station, Jourda & Perraudin.

The recently completed metro station at Parilly in Lyons was planned by architects Jourda & Perraudin. In place of an unbuilt office tower which was included in the original design, the architects had designed a temporary canopy. The canopy is made up of four slender columns which rise from the basement level. The tree-like columns branch out in a series of decreasing sections of circular steel tubes supporting a light transparent curving roof high over the station. (A. Review 1157, 1993).

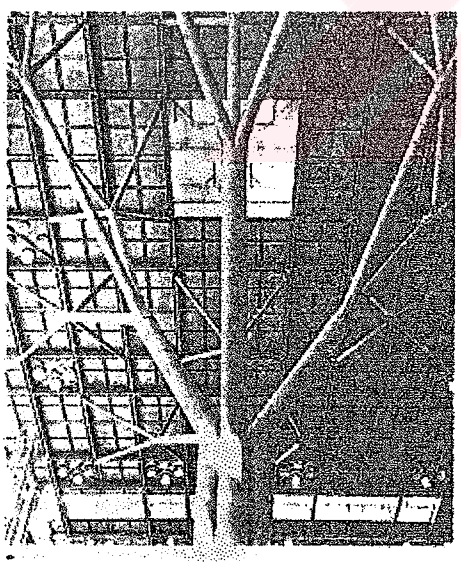


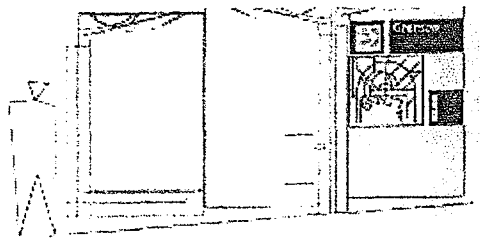
Figure 3.38 Stuttgart Terminal Building, Gerkan & Marg.

Stuttgart Airport, designed by von Gerkan & Marg was completed within weeks of Stansted Airport. The huge sloping roof is supported on 12 very tree-like steel structures, in which the loads can be seen to be descending through an elaborate hierarchy from twigs to branches to trunks, all fundamentally in compression. (The Architectural Review 1131, 1991).

An interesting example is the bus shelter design for the city of Oslo. The architects, Jensen & Skodvin and Carl-Viggo Holmebakk have come up with a small basic unit that can be combined with others to form larger ones. The unit is composed of a 1.24 m2 glass roof carried by an elegant spreading branched cast aluminum bracket carried on one adjustable corner column.

The effects of the improvement of the technical knowledge, high-tech materials and construction facilities are observed in these designs.

In addition, the help of computers in the visualizing, calculating and drawing processes of these designs cannot be denied. The designers of today have a perfect tool to realize what they can imagine. Computers save time and mental energy and furthermore they offer drawings almost without fault.



Elevation of Oslo's new bus shelters

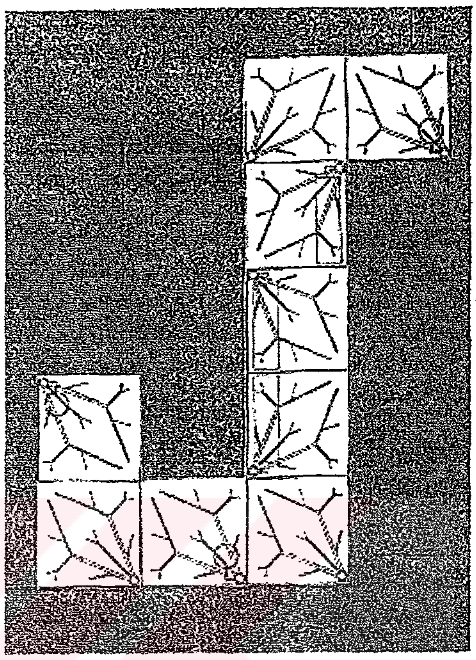


Figure 3.39 Bus shelter design for Oslo, Jensen & Skodvin and Carl-Viggo Holmebakk. Above; the elevation and below; the plan.

CHAPTER FOUR
SANTIAGO CALATRAVA

4. Santiago Calatrava

4.1 Santiago Calatrava in General

"If there was any need to prove that we had entered a new architectural age then the work of Calatrava would definitely be used to support the case." says Dennis Sharp in his article about the architect. (Sharp, 1994:8). This expression might seem challenging before discovering the work of Santiago Calatrava.

He was born in Valencia, Spain, on July 28th 1951. During the years 1968-1969, he attended to the Art School there. He studied architecture at the Escuela Téchnica Superior de Arquitectura de Valencia. He graduated in 1973 and in 1975 he attended to the Eidgenössische Technische Hochshule (ETH) in Zurich to study civil engineering. After finishing his graduate course he went on to complete a post-graduate Ph.D. thesis in the ETH's Architecture Department on 'Zur Faltbarkeit von Fachwerken' (the foldability of space frames). In 1981 he set up an independent architecture and civil engineering office in Zurich. Today he has offices in Paris and Valencia as well. He is also a sculptor.

Santiago Calatrava has an international character: he speaks English, German, French, Italian, Swedish apart from his mother tongue, Spanish. He has been working all across Europe. He first became known with his innovative designs of bridges but he has a remarkable number of buildings completed in many countries of Europe and even in Canada.

He is famous for his designs for competitions. Ernsting Warehouse (1983-85) in Coesfeld, Caballeros Footbridge (1984) in Lerida, BCE Place: Galleria & Heritage Square (1987-92) in Toronto, TGV Airport Railway Station (1989-94) in Satolas-Lyon, Science

Center: Communications Tower (1991) in Valencia, Cathedral of St. John the Divine (1991) in New York, Médoc Swingbridge (1991) in Bourdeaux, Spandau Railway Station (1991), Jahn Olympic Sports Complex (1992) and Reichstag conversion (1992) in Berlin, Platform Roofs of Main Station (1995) and Airport 2000 in Zurich are some of the them.

He has been awarded by various foundations of architecture and engineering. Also he has some of his remarkable buildings specially awarded, such as Stadelhofen Railway Station (1983-90) in Zurich, Bach de Roda bridge (1984-87) in Barcelona.

Since 1985, his works of architecture and sculpture are exhibited in the leading museums and galleries of the world. Two of the exhibitions were arranged as traveling exhibitions, the first one was for New York, St. Louis, Chicago, Los Angeles and the second was for Toronto, Montreal and Helsinki.

4.2 Architectural Features of Calatrava

Being neither solely an engineer nor an architect, but qualified as both at once, Calatrava's designs are contributions to both professions. According to his designs, "structure alone is the expressive agent and needs no concealment. His early examples of architecture, such as the Stadelhofen station in Zurich, also follow the same principle of leaving the structure exposed, bare, unclad like his bridges. It is not necessary to add 'architecture' to a building; that is, to dress it up in the latest fashion. Structure is architecture." (Candela, 1994:10).

Calatrava's triple professional situation is reflected through his works which are then the combination of architecture, engineering and sculpture (art). He has explained some of his fundamental approaches applied for the various products of his practice parallel to this situation. First of all, there is the approach of the engineer that comprehends the concept of forces, the understanding of forces at play, the use of forces with which one can work, transform and compose. Secondly, there is the concept of kinematics and movement. Thirdly, there is a very abstract and formal approach to architecture, applied and expressed through construction and the use of materials. It is that of pure sculptural understanding: the sculptural element is one of the huge variables of architecture. (Calatrava, RSA Journal, 1994).

He sees sculpture as central to his work. "It is there that Calatrava first explores the ideas and themes later elaborated in buildings and other structures." (Buchanan, 1987:51). His sculptures - some of which are compositions of granite cubes, silver threads and spindles - explore interesting shapes, equilibrium, the structural principles of statics and mechanics. This experiments with sculptures help the observer be more aware of the differences in character and function of each component and the material it is made of, and they are related to the "investigation into a structure's lightness and movement" (Tischhauser, 1996:2) which leads to the application in projects.

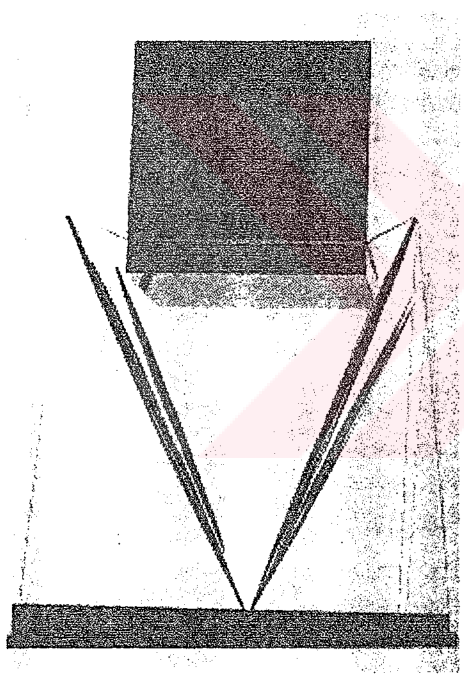


Figure 4.1 Sculpture.

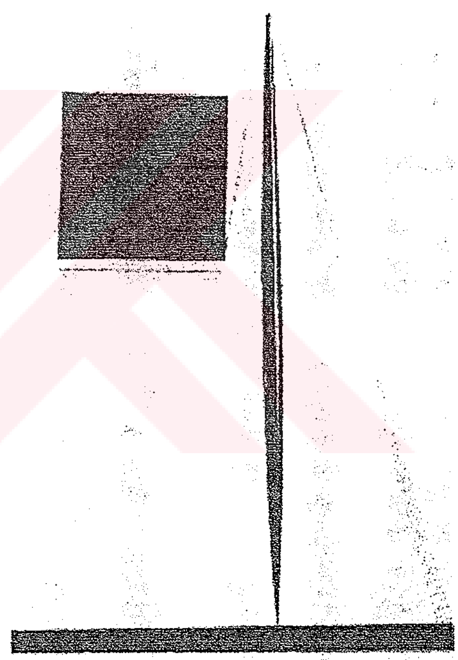


Figure 4.2 Sculpture.

'Four or five years before I started on this design I had made a sculpture of black granite and brass, about three feet high, with a great triangular, leaping shape. I discovered that I still had this shape in the back of my mind. But then I have always regarded my sculptural work as mental preparation for my architecture.' (Metz, 1994: 94).

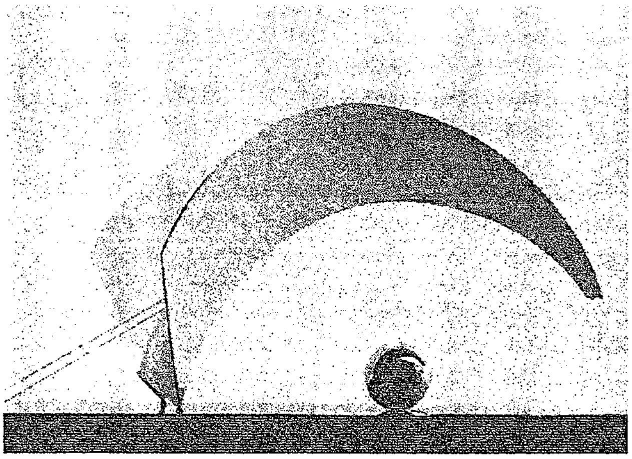


Figure 4.3 'The Bird', side view.

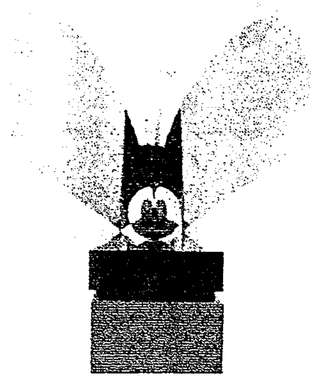


Figure 4.4 'The Bird', front view.

His design for TGV Railway Station resembles his sculpture, named 'The Bird'. (Figure 4.6).

"Calatrava uses self-finished and self-colored materials." (Tischhauser, 1994:28). He frequently makes use of some structural and aesthetic dialectic between a pair of materials - like concrete and steel, steel and aluminum. This characteristic is also present in his sculptures. "... Most of the buildings and projects I have worked on are designed of steel and concrete, the two materials being put together in a relation, similar to the sculptures, complementing and contrasting each other, creating a kind of tension." (Calatrava, RSA Journal:43). He also uses other dual situations in his projects: simplicity versus complexity; heavy versus light; transparent versus opaque; compression versus tension; visual weight versus physical weight. For him duality is a simple principle of beauty, like symmetry.

Except the calculation work done by computers; it has not been a long time since Calatrava's offices moved to computer aided design. For Calatrava, sketching has always been unavoidable. It is his way of seeing. He sketches endless variations of an idea as well as making models at various scales. During the development of a design through an applicable project, this process needs to be accelerated and checked by the aid of computers. Calatrava thinks that computers provide more freedom to give more care to the construction or to the other problems, as placing something new in a city or a landscape is a big responsibility.

Site characteristics affect Calatrava's work. This is easily observed by the three station projects he had designed for three different cities of Europe: Stadelhofen Railway Station is located at the foot of a park-like hill which was once the limit of the old city's fortifications. In order to uphold the green appearance of Zurich, the green space lost - due to the excavation to make way for a third track - was replaced by the promenade, overlooking the tracks, and covered with a natural green roof. This natural garden which quickly includes this intervention to the city was realized by the vines pouring over wires strung between steel pergolas along the hill. (Figure 4.11) The design attempts to give an answer to the problem of the peculiar topography of the site. The urbanistic concept is the station's importance, the building gives such a characteristic location a new identity by integration, not by opposition.

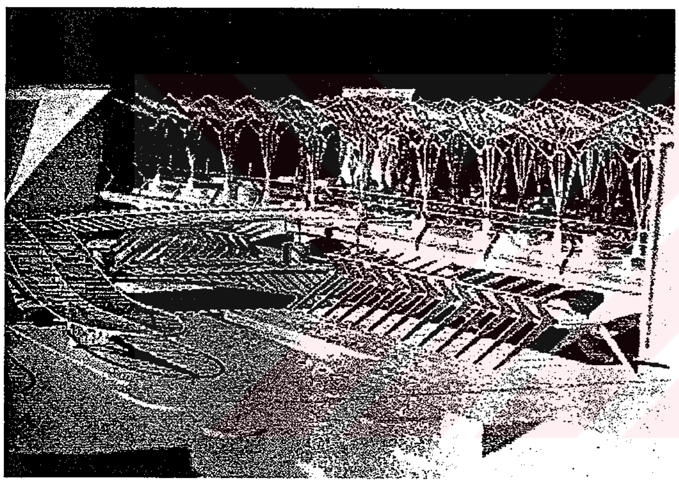


Figure 4.5 Oriente Station (1993), model view.

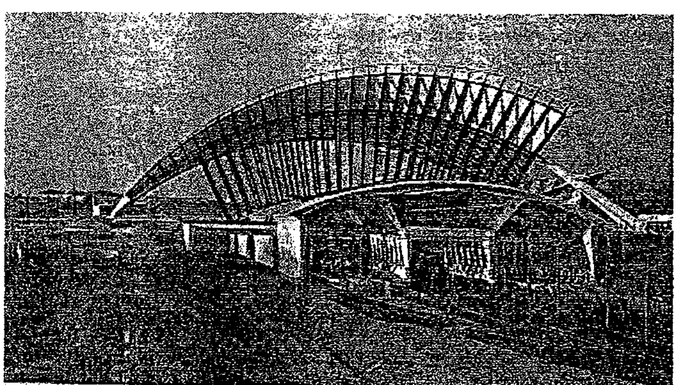


Figure 4.6 TGV Railway Station (1989-94).

Oriente Station is designed for Lisbon, an old city whose strong urban character dates back to the Baroque era. The design is again an intervention in the existing structure of the city; it is embedded in a strong context. (Metz, 1994). The design is respectful to this fact, bringing a similar approach of Stadelhofen. Thus it is quite a different design from the station in Lyon which achieves an identity of its own. Being far from the city, in an unbuilt locality, TGV Railway Station building has an expressive autonomy.

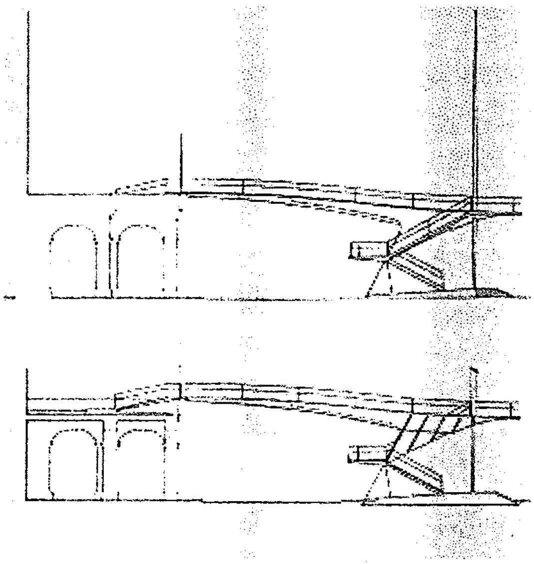


Figure 4.7 Salzburg Footbridge (1986).

Calatrava has also the same attitude towards the bridges. His bridges are designed asymmetrically due to the different characters of the two banks of a river. His designs for a pedestrian bridge (1986) for Salzburg, Austria and Trinity bridge (1993-95) across Inwell river for Salford, England are examples revealing this attitude.

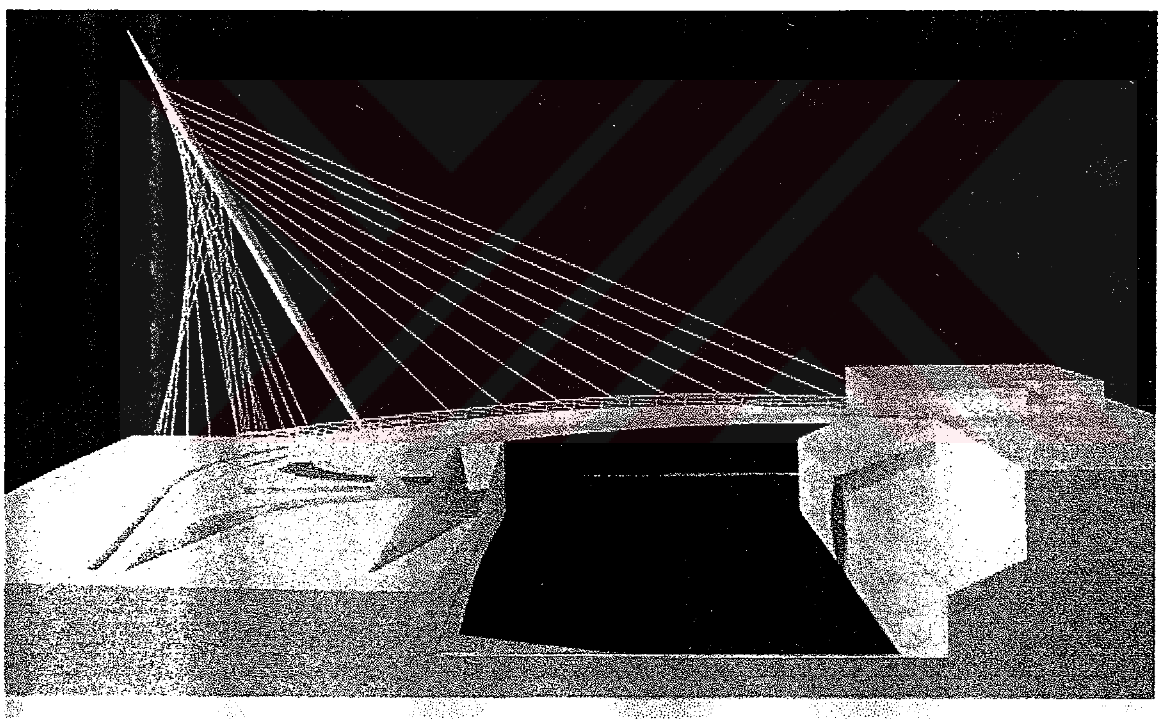


Figure 4.8 Trinity Footbridge (1993-95), model view.

Although the projects are sensitive to the specifics of their settings, they are not contextual. They do not seek relations with their architectural environment and they do not have references to local cultural heritage. Instead, they all reveal the definite and independent identity established by Calatrava.

"The bringing up of a sense of beauty through the section seems very appropriate to me" says Calatrava after mentioning Danielle Barbara's idea that 'the plan is order and the section is beauty'. (Calatrava, 1994:16-17). In Calatrava's designs it is easily observed that plans are not complicated as sections. The dynamism of his projects is created with elaborating sections and shaping the components. It is in the third dimension: the section that structural forces are played with and resolved ...

4.2.1 Intuitive Sureness

Calatrava's ideal is 'to make works of pure engineering that are inspired by the soul of the artist'. He has the soul of the artist: intuition is the keyword for the work of Calatrava. He thinks 'art' is not just in museums but also on the streets: the buildings that serve us everyday. Like the other works of art: the paintings, sculptures or musical compositions, a station or a bridge can be the bearer and the transmitter of a cultural message over time.

"Transformation of something that looks banal on the surface into a work of art is a matter of attitude and talent. A piece of canvas and a tube of paint are poor things in and of themselves, but together they can become a great painting that far transcends the simple materials it is made of." (Metz, 1994:88). This is what he conveys in his projects.

There is a special relationship between Calatrava's designs and nature. Nature provides stimulus for his work. Additionally, movement is a principal notion in Calatrava's work. He has various projects which have mobile structures. These projects and their theme are going to be discussed comprehensively (together with their natural aspect) in the next sections.

It is very interesting that, in various articles and books, he is compared to many architects, engineers and artists like; Leonardo da Vinci, Michelangelo, Eugéne Viollet-Le-Duc, Antoni Gaudí, Robert Maillart, Christian Menn, Felix Candela, Jean Prouvé, Alvar Aalto, Constantin Brancusi, Henry Van de Velde, Louis Kahn, combination of Gaudí and Philippe Starck, Eero Saarinen, Renzo Piano, Jujol, Eduardo Torroja, Emilio Perez Pinero, Pier Luigi Nervi, Frank Lloyd Wright and Erich Mendelsohn.

Moreover, Calatrava's precise structural expressionism is claimed to have, as critic Kenneth Frampton suggests, its origins in the perpetual Germanic fascination with technology. (Sharp, 1994).

It is true that he has those variety of features of others. He seems to be not one or the other alone, but a combination of them all.

4.3 Selected Projects of Santiago Calatrava

Below, the brief descriptions of the projects that are revealing the features of Calatrava successfully are listed. The section contains both the leading projects, and the ones that are examined in the other parts of this study from the aspects of organic integrity, structural character and movement.

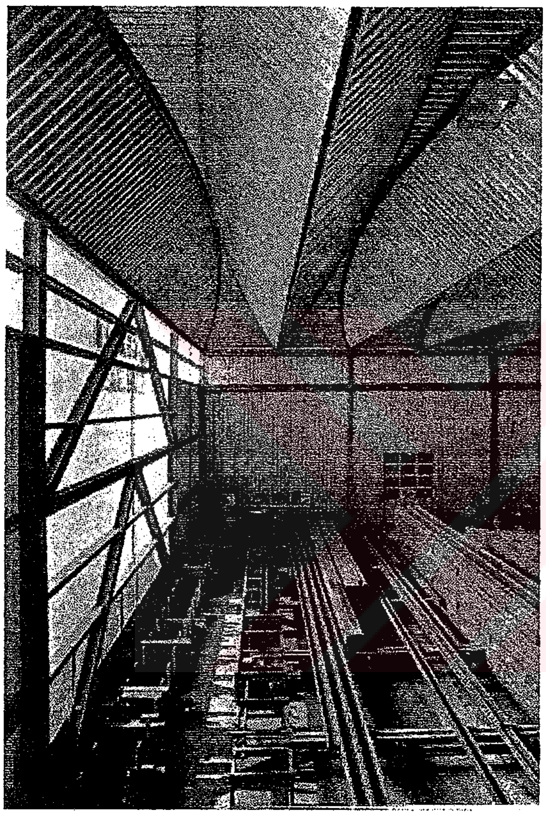


Figure 4.9 Interior view of Jakem Steel Warehouse.

4.3.1 Jakem Steel Warehouse, Münchwilen, Switzerland (1983-84)

Calatrava has designed a different type of roof structure for the warehouse in Münchwilen. The girders are made up of undulated sheet metal plates two of which are fixed at right angle at the bottom of the girder. They are put side by side and linked all together by the roof material covering them. So the cross section of a girder is a triangle and the longitudinal section has a parabolic shape. The girders individually are not very strong but they gain efficiency and strength when they act as a system. Here Calatrava has used minimum amount of material and gained maximum strength.

4.3.2 Ernsting Warehouse, Coesfeld, Germany (1983-85)

The façades of the factory building were designed by Calatrava. The closed east side is covered with large waves of aluminum sheets. There are three doors in the west façade which are designed ingeniously. They are folded upwards when opened and they form canopies in this upright position. The analogical approach of this structure of doors will be discussed in the following section.

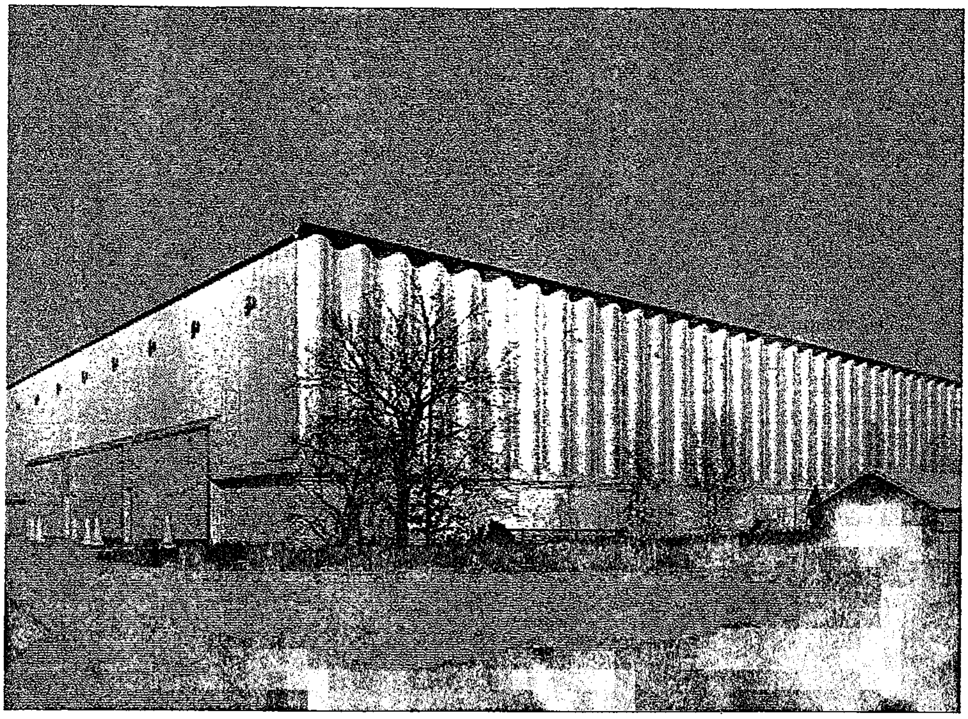


Figure 4.10 Ernsting Warehouse, general view, the folding doors and the undulated façade.

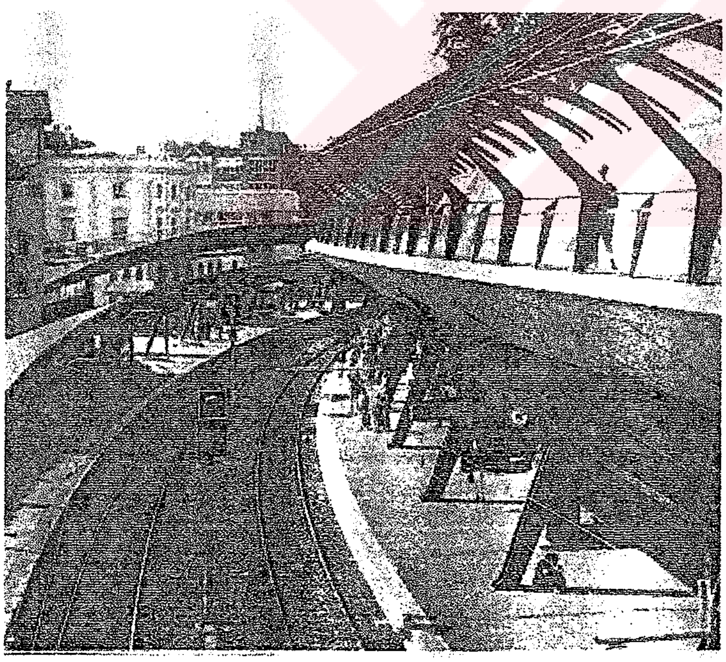


Figure 4.11 Stadelhofen Railway Station.

4.3.3 Stadelhofen Railway Station, Zurich, Switzerland (1983-90)

Stadelhofen Railway Station is a competition winning project which has integrated well to its setting. It has three major parts which have interesting and different structures of their own: The covered promenade, the cantilever platform roof and an underground shopping center.

4.3.4 Wohlen High School, Wohlen, Switzerland (1983-88)

Four different roof structures were designed by Calatrava for four different spaces of Wohlen High School.

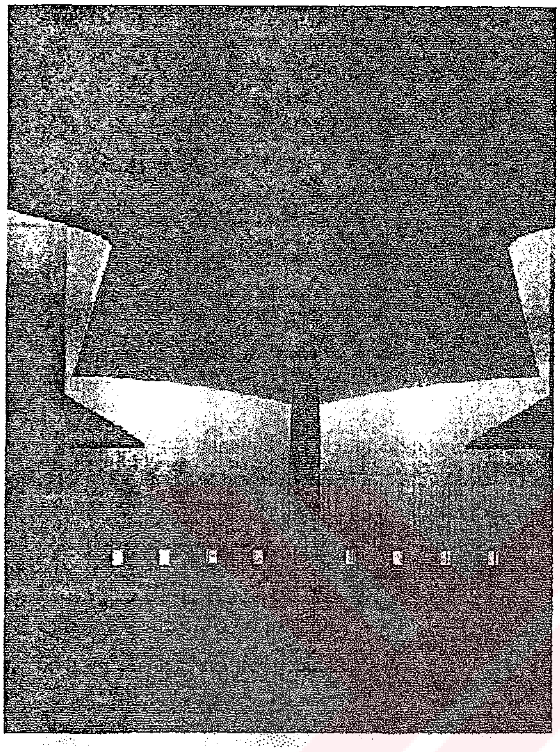


Figure 4.12 Wohlen High School, roof for library.

The entrance canopy (Figure 4.44) has a rectangular plan and its form is generated by two conical surfaces whose intersection forms an arch. The arched steel spine is a triangular girder to which the cantilevered steel ribs supporting the glass panels are affixed. (Levene & Cecilia, 1994).

The roofing of the library (Figure 4.12) consists of four curved surfaces which come together at a single point where they are supported by only a central column. This thin concrete shell remains almost completely detached from the side walls, allowing natural light illuminate the interior.

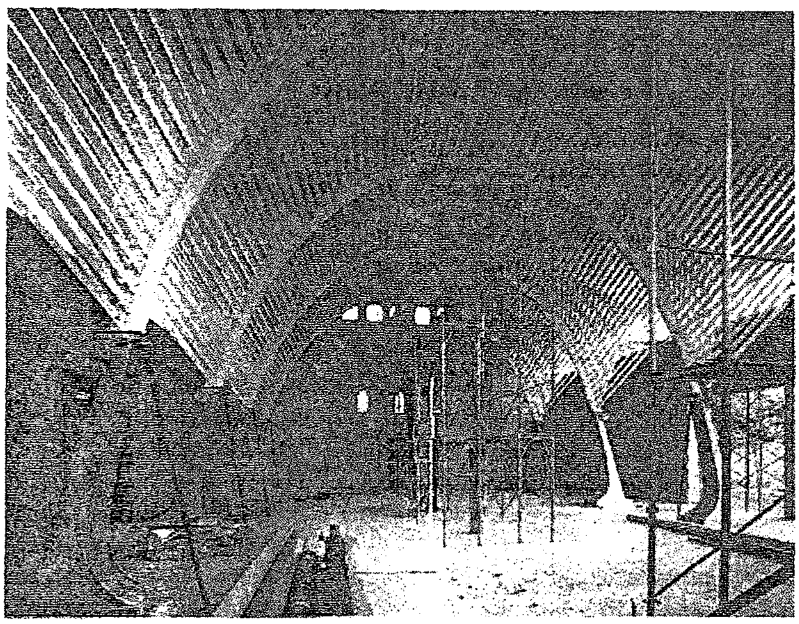


Figure 4.13 Wohlen High School, roof for the great hall.

The roof of the great hall is an innovative timber construction consisting of V-shaped structural elements. This individual beams form part of an intricate system in which the outer roof is separate from the load-bearing structure so as to allow natural light filter into the hall below. The beams are in the form of parabolic arches and they are supported by elegant inclined columns recalling ionic style.

The roofing of the entrance hall is an extremely light construction presenting the image of a great tent. It is constructed from laminated-wood girders, cables and steel spindles, and sheathed with opaque glass.

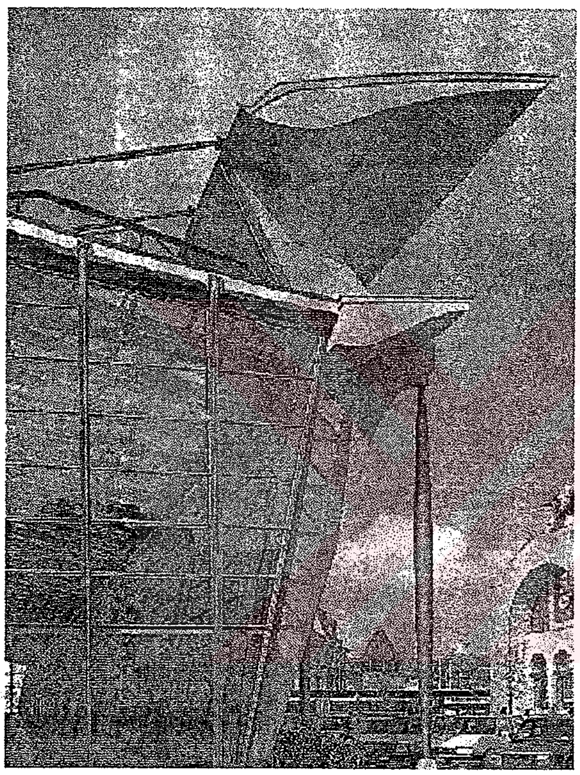


Figure 4.14 Lucerne Station Hall.

4.3.5 Lucerne Station Hall, Lucerne, Switzerland (1983-89)

The structure which is constructed to serve as the hall for the existing station is comprised of two main elements: the reinforced concrete entrance portico and the glass and steel roof suspended from it. The entrance portico contains pre-fabricated concrete columns connected to the main building at the back and stabilized at the front by smaller columns. The wide V-shaped beams connecting the portico and the station building support the light glass and steel roof. (Blaser, 1990).

4.3.6 Bach de Roda Bridge, Barcelona, Spain (1984-87)

The structure is 129 m long with a span of 46 m. The twin leaning steel arches widen slightly at both ends to increase structural rigidity of the major inner arches and, in their closeness to the ground, branch out so as to allow pedestrian traffic through the structure. The construction of the arches is steel and concrete; the lower parts of the arches and the abutments are of concrete and the middle section of the bridge and footpath are of steel.

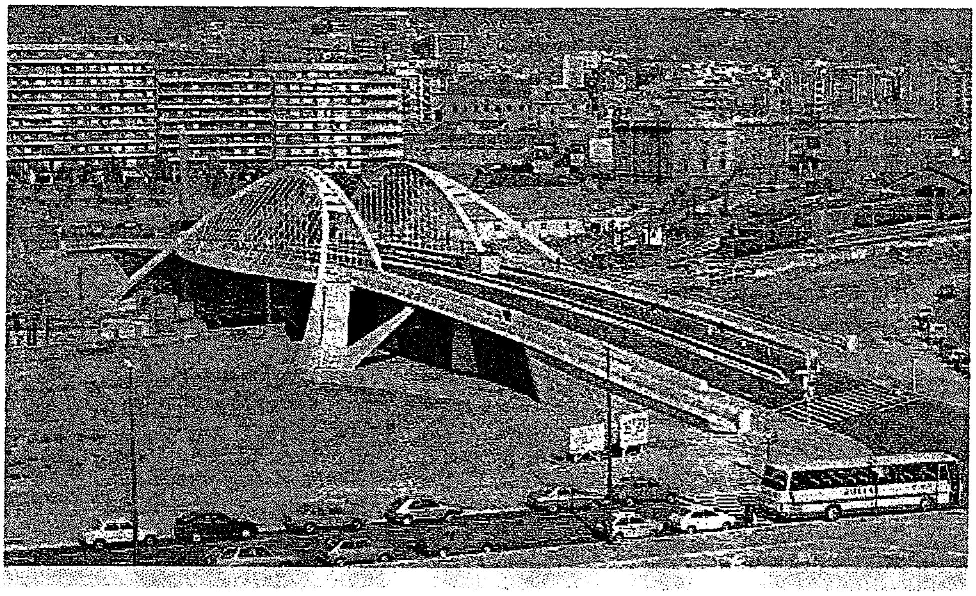


Figure 4.15 Bach de Roda Bridge.

4.3.7 Tabourettli Theater, Basle, Switzerland (1986-87)

Figure 4.16 Tabourettli Theater, model view of the staircase.

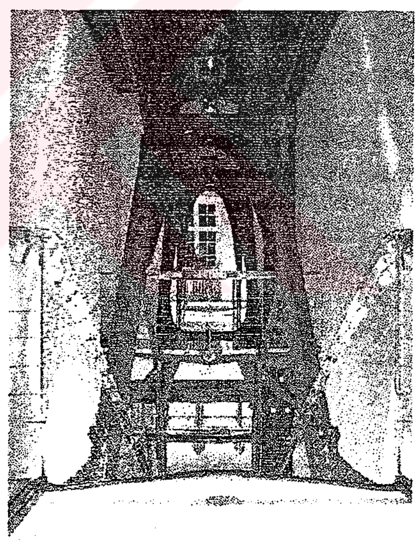


Figure 4.17 Tabourettli Theater, view downwards from the staircase.

The design is part of the restoration of an old building in the heart of Basle. Calatrava was to deal with the static problems involved in the operation, concerning the structure of the building which had almost no foundations. Some parts were rebuilt in such a way that three existing columns were removed. "This necessitated the suspension of the roofing structure, the loads of which were transferred to the steel staircase. The steel structure therefore transfers the load of approximately 211 tons into the foundations, while at the same time creating a staircase for the cabaret-theater Tabourettli and a cross-walk between the foyer and the theater itself." (Blaser, 1990:105).

4.3.8 BCE Place: Galleria & Heritage Square, Toronto, Canada (1987-92)

Calatrava has designed a roof combining a street gallery and a square. The scheme has two main elements. The first is a 350 ft (106 m) long arcade that forms the spine of the complex, linking the two towers to the low-rise part of the scheme and leaning out over the Bay street to create an entrance canopy. The dimensions of the five-storied arcade are monumental - 90 ft (27 m) high and 42 ft (14 m) wide (Figure 4.59). The arcade is defined on each side by a line of eight free-standing inclined steel supports that branch out into a single plane. They support the parabolic arches of the glazed canopy.

Figure 4.18 BCE Place: view from Heritage Square.

"The quadrangle, a perfect Euclidean square is enclosed by muscular brick walls, infilled with narrow rectangular slivers of curtain walling. The rustic solidity of the prefabricated brick panels is offset by the sinuous steel arches that extend upwards to support the nine intersecting barrel vaults of the delicate glazed roof. The wide, upturned parabolas of the support structure follow the basic rhythm established by the arcade." (Slessor, 1994:30).

4.3.9 Alamillo Bridge, Seville, Spain (1987-92)

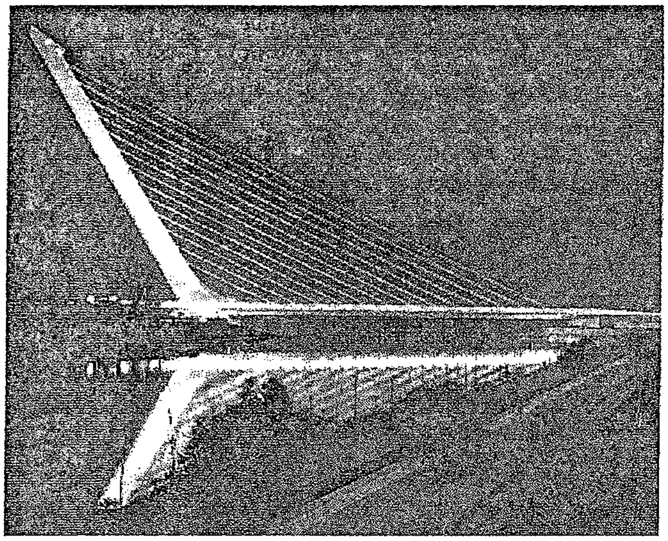


Figure 4.19 Alamillo Bridge, at night.

The impressive bridge consisting of an inclined pylon and cable-stays supporting the deck is stated to have a similar construction principle of Gothic. Using the weight of the pylon to counter the pull of the cable-stays is compared with using of vertically projecting pinnacles to counter the outward thrust of flying buttresses. (Webster, 1992).

4.3.10 Bauschänzli Restaurant, Zurich, Switzerland (1988)

The glass canopy of the Bauschänzli Restaurant is supported by nine steel columns which resemble trees with their branched forms. The vaulted steel and glass canopy has panels which can fold up in order to open the restaurant to the sky (Figures 4.39 and 4.40). The design demonstrates Calatrava's interest in movement and in kinetic structures, particularly folding ones.

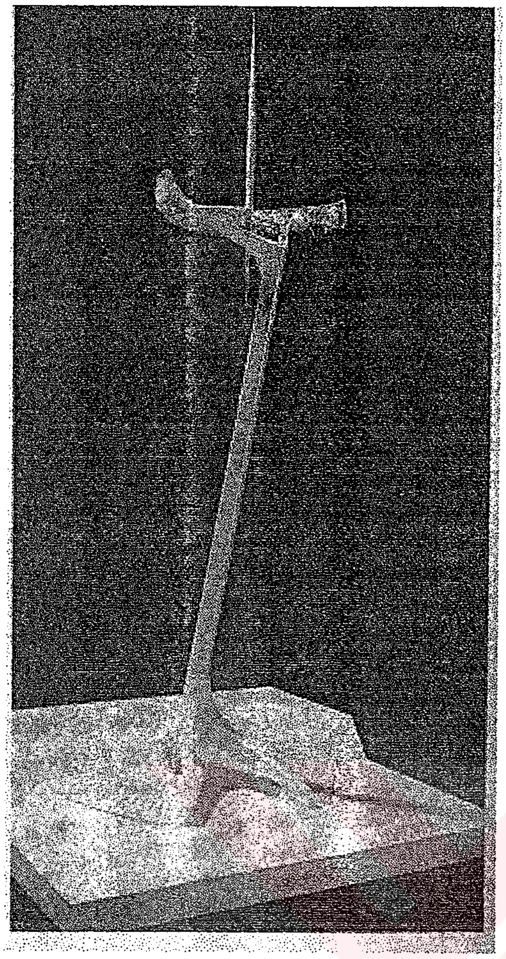


Figure 4.20 Montjuic Tower, model view.

4.3.11 Montjuic Communication Tower, Barcelona, Spain (1989-92)

The tower was constructed as part of Barcelona's preparations to stage the 1992 Olympic Games. A gently inclined concrete shaft rises up from a circular base, forks into two and is crowned by a semi-circular element housing the devices for telecommunication. At the top, a vertical device is suspended upright in mid air. Unfortunately, the construction is different in proportion from the original design: the main shaft is shorter in application. (Sharp, 1994). "Its singular form does not contradict the laws of statics, because the center of gravity of the base coincides in the same way with the vertical resultant of its weight." (Levene & Cecilia, 1994:104).

4.3.12 TGV Railway Station, Satolas-Lyon, France (1989-94)

This competition winning project of Calatrava is examined in detail in the following section.

Figure 4.21 TGV Railway Station, interior view.

4.3.13 CH-91 Floating Concrete Pavilion, Lake Lucerne, Switzerland (1989)

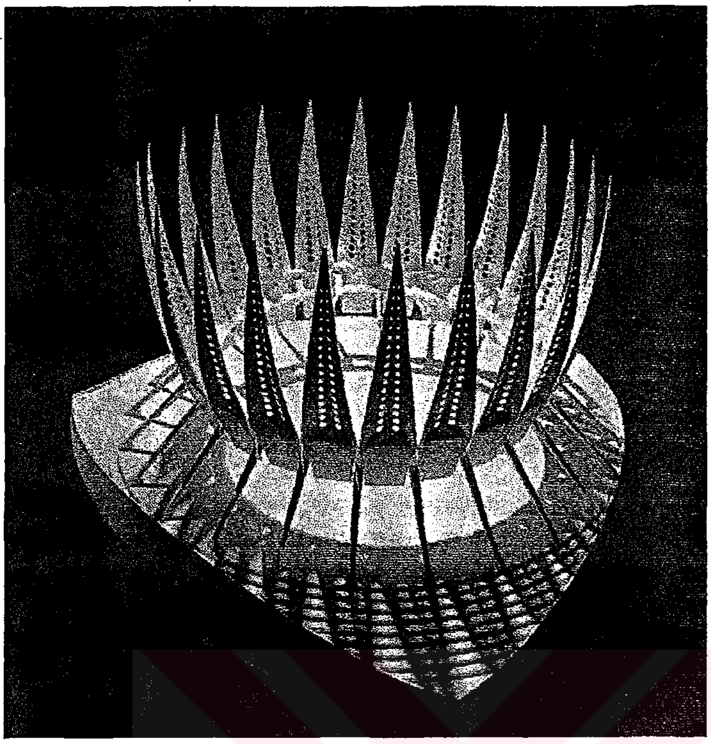


Figure 4.22 CH-91 Floating Concrete Pavilion, model view.

The pavilion is designed as capable to float on the lake. It has a roof consisting of 24 leaf-like concrete elements which can move to open the space up to the sky and, with these features, "it recalls the shapes of nature and the animal kingdom..." especially a flower. (Blaser, 1990:124).

4.3.14 Sondica Airport, Bilbao, Spain (1990)

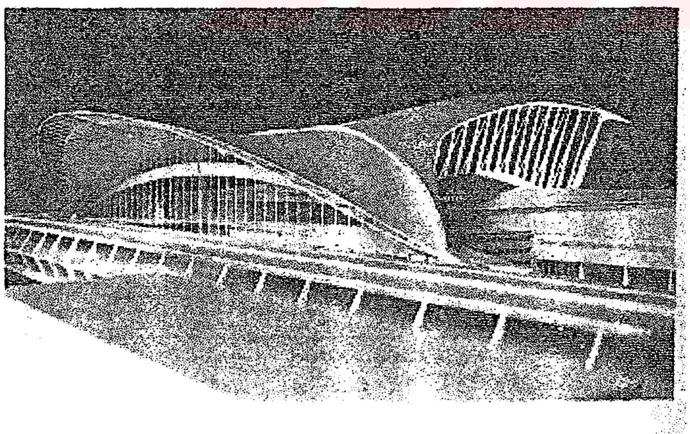


Figure 4.23 Sondica Airport, model view.

The airport building design for Bilbao has a theme of bird in flight, like some other projects of Calatrava. The structure of the main building is a conventional post and beam system, to give the necessary stability to the free-form roof. The steel-framed roof which is formed by a series of steel ribs, is based on an approximately triangular plan, supported by the inclined wall structure. The inclined façade is framed by a series of steel members supported by two concrete bearing arcs that transmit the system's forces to the ground. (Sharp, 1994).

4.3.15 Concert Hall, Tenerife, Spain (1991)

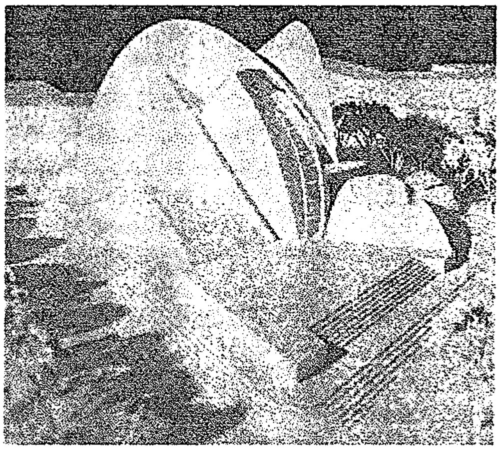


Figure 4.24 Tenerife Concert Hall, model of the first scheme.

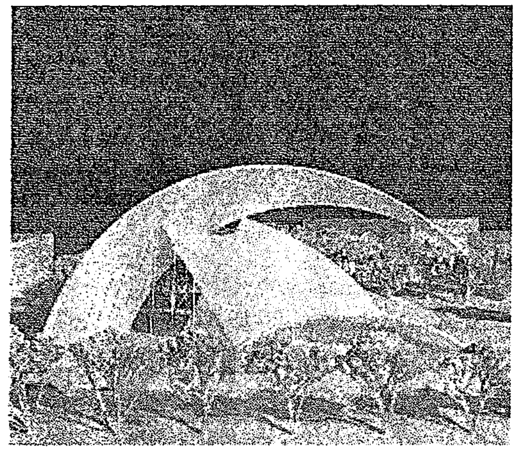


Figure 4.25 Tenerife Concert Hall, model of the first scheme

The concert hall project for Tenerife has two auditoria with capacity of 2000 and 400 people. The stage belonging to the main hall is designed to be rotated 360° and enlarged if required. It has a dynamic form which is made up of conical surfaces. There is again the theme of bird in this project and the roof strongly recalls one sculpture of Calatrava: 'The Bird (Figure 4.3 and 4.4).

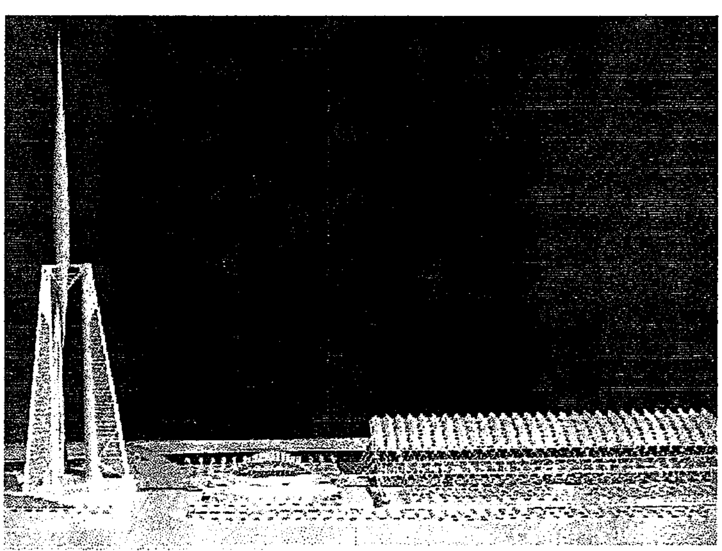


Figure 4.26 Science Center, model view.

4.3.16 Science Center, Valencia, Spain (1991)

The complex is comprised of three main buildings: the communications tower, the science museum and the planetarium. The tower which has three legs supporting a slender structure rises up to 327 m. The science center has complicated structural elements: V-shaped, triangular supports and even tree-like columns, elements that create a lattice-like filigree façade are all typical of Calatrava. The planetarium has an additional feature: the roof can be opened making the building very impressive.

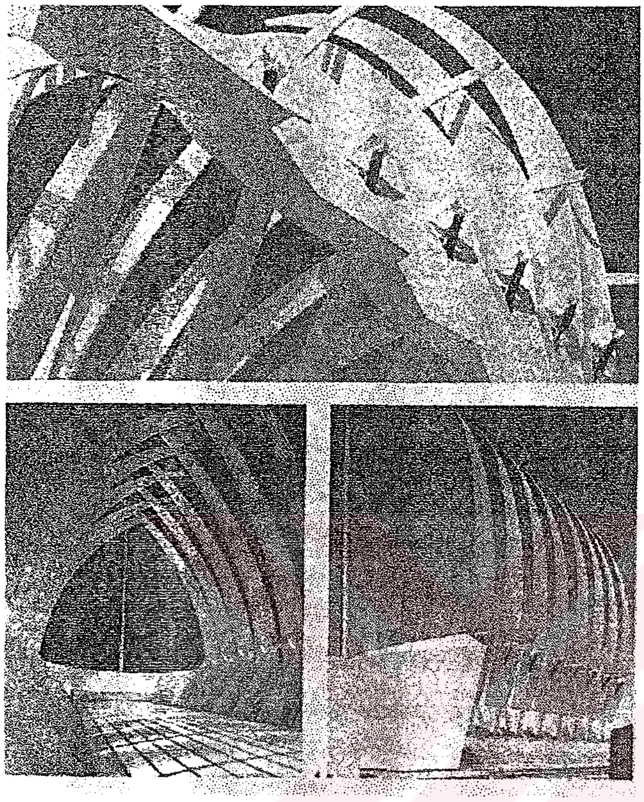


Figure 4.27 Kuwaiti Pavilion, mobile ribs of the roof.

4.3.17 Kuwaiti Pavilion, Seville, Spain (1991-92)

The national pavilion of Kuwait for Expo '92 was designed by Calatrava. The building has a very simple rectangular plan but it has a changing roof which is formed by 17 mobile timber ribs similar to the ones in CH-91 Floating Pavilion. They are individually controlled by a hydraulic system and are able to rise from 45° position up to 90°. The movement of the roof creates games of light and shadow as well as bringing the building a different appearance.

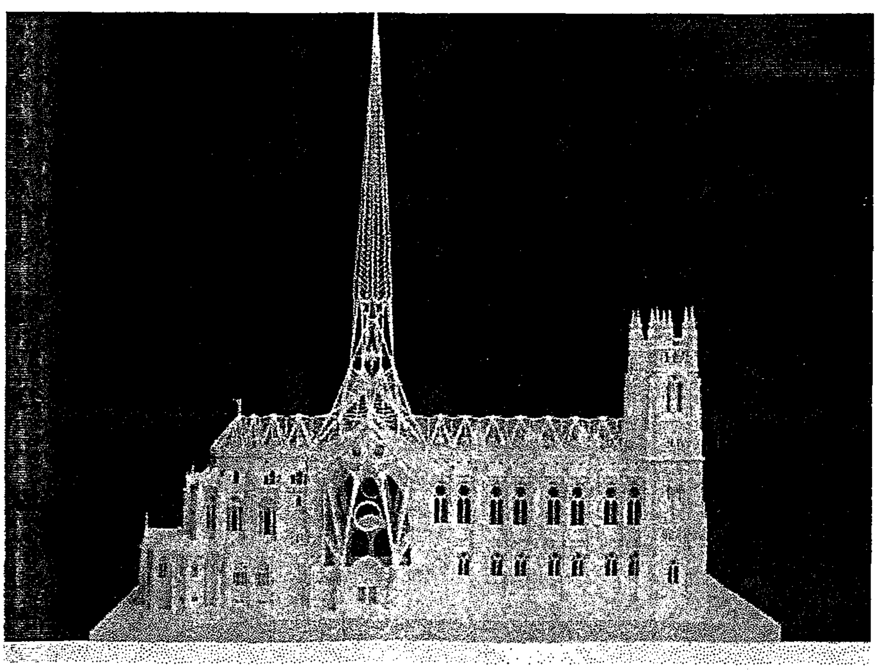


Figure 4.28 The Cathedral of St. John the Divine, view of the model.

4.3.18 Cathedral of St. John the Divine, New York, USA (1991)

The proposal of Calatrava for the unfinished cathedral of St. John the Divine was awarded the first prize in an invited competition in 1991. He was found successful as he had managed to design a structure matching with the Gothic idiom. There is the image of a tree in the section and the structural features of the project will be discussed together with this tree image in the next section.

4.3.19 Reichstag Conversion, Berlin, Germany (1992)

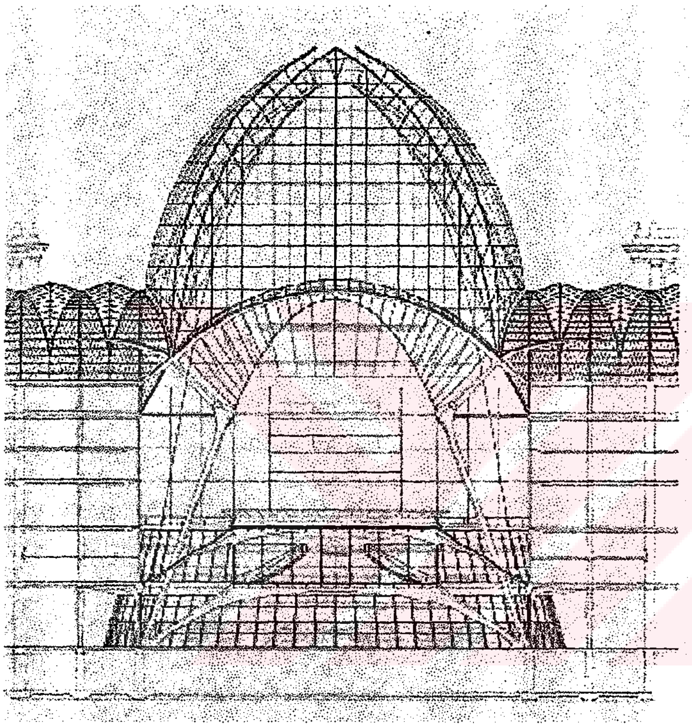


Figure 4.29 Reichstag Conversion, section.

The conversion of Reichstag as the new Bundestag in Berlin was opened up to international competition in 1993 and Santiago Calatrava was awarded one of the three prizes. With his proposal, "the architect bears witness to the eclectic and historical methods of the original master builder of the Reichstag, while assuming for himself the required degree of freedom due to him as a structural artist of reputation." (Kieren, Berlin Five Projects, 1994:19).

"We proposed the Reichstag as a solitary, freestanding building as it originally was, with its cupola fitted into the landscape of Berlin with its many cupolas. We wanted to give back the building some of its symbolic value. The dome (that could be opened) would be made of glass and a light metal construction to ensure maximum transparency seen from afar but also light into the interior of the Reichstag." (Calatrava, RSA Journal, 1994:45).

The project represents Calatrava's concept of movement as applied to building as a whole.

4.4 Santiago Calatrava And Nature

"The use of only one material is a very elementary expression of architecture", Calatrava says. "Minimalism in material is a good thing: it cleanses you and ensures that everything you do has an intention."

Although Santiago Calatrava uses simple and limited kind of materials, the forms of his structures are plentiful, they have no limit in being shaped. He conveys an integration of technology and aesthetics in his structural inventions. He has artistic behavior in design, he draws inspiration from various sources.

In Calatrava's work, it is stated that, among this variety of inspirational sources and impulses, the most dominant is the growth and form of the world of nature. (Sharp, 1994). However, unlike the Art Nouveauistes of the turn of the century period, with whom his work is often compared, he does not draw upon nature as a source of forms nor as a resource for decorative ideas. Nature provides a stimulus for the creative process. He can therefore be seen to be more in line with the interpretative approach of Antoni Gaudí.

'*... At a point in time I devoted myself to the study of organic forms, with which my work has some similarities. This is the result of option. And which has not so much to do with the fact of how to solve a given structural problem. I am increasingly tempted by the simple forms, by* ***minimizing...*** *My work is figurative rather than organizational, in the sense that I am interested in certain sculptural-anatomical relationships. It is like placing a fringe on a tremendously purist static model. Working with isostatic structures almost inevitably leads one to nature sketches. When a dog stands on his four legs, it constitutes an isostatic body. The load is divided by the number of legs, there are no embedments other than those supplied by the muscles...*' (Calatrava, 1994:20).

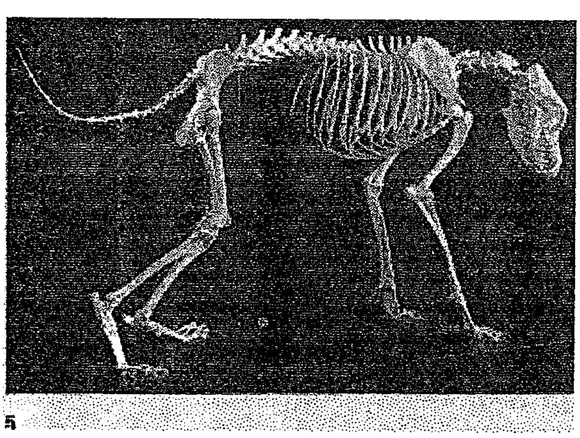


Figure 4.30 Dog skeleton that is displayed in Calatrava exhibitions.

"For me, looking at the natural construction of animals and birds has always been a fountain of inspiration. In my office I have a skeleton of a dog: I find

the study of its bones, the way they are joined and move is important in relation to my on-going study and appreciation of architecture and engineering.

I am fascinated by the idea of the eye and after much contemplation I developed a mechanical eye and built a model which will open and close in the same way as an eyelid. An interpretation of this idea has been applied to the doors of a warehouse we built for Ernsting's Warehouse as a part of their distribution network in Coesfeld, Germany."(BCA, 1992:10).

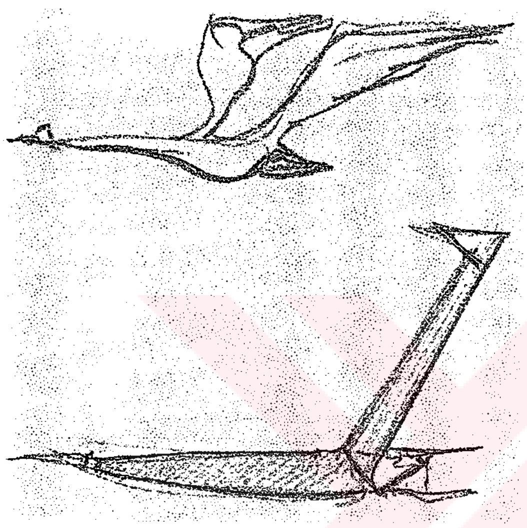


Figure 4.31 Sketchs of Gentil Bridge, Paris.

References to nature can be observed in the numerous sketches of him. The many drawings found in his sketchbooks search for the expressive potentiality and nature of things. These sketches - of a flying bird or the skeleton of a dog (a model which is shown in Calatrava exhibitions) might turn to structural inventions realized in his buildings.

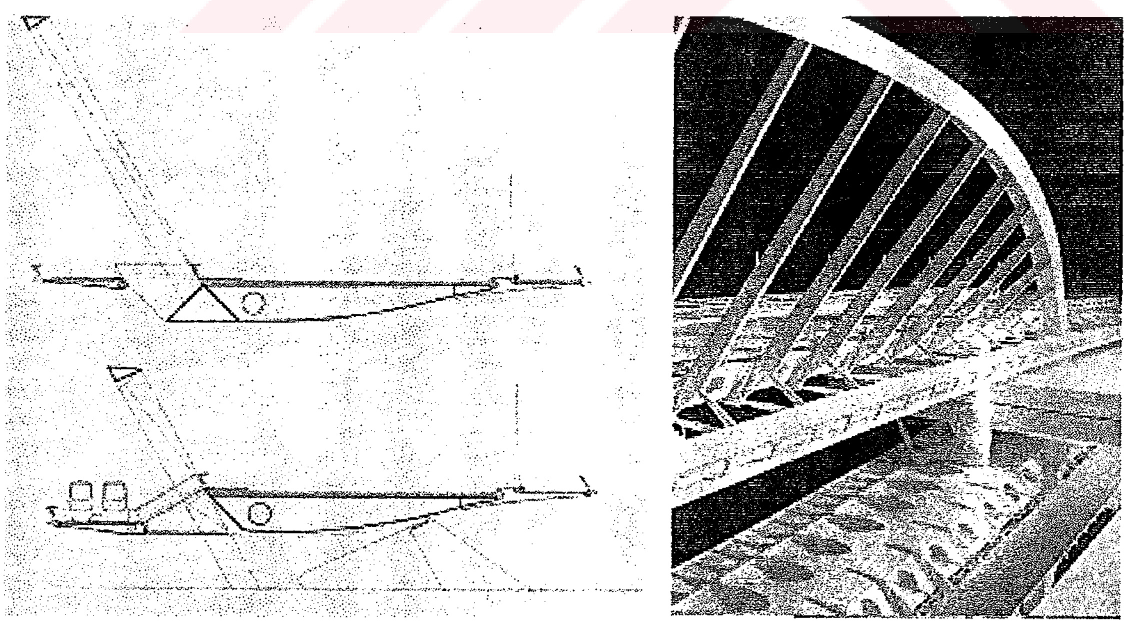


Figure 4.32 Sections and model view of Gentil Bridge.

Natural images - the profile of a bull or a horse, the various contortions of the human body, studies of trees; diffuse with the sketches of his projects: bridges, stations, pavilions and others. They can certainly be considered as 'thought-provoking metaphors that can be seen to be translated into structural terms' in his designs. In other words, they are not solidified into built forms directly but they lead up to the projects by the help of their impelling force.

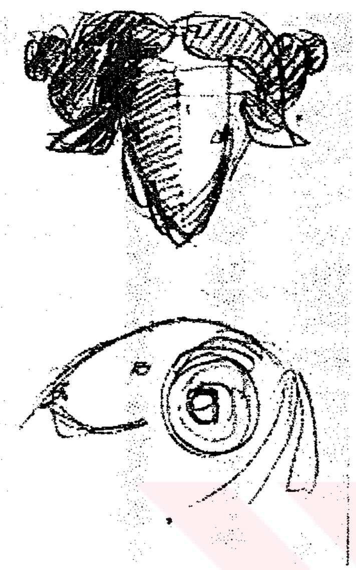


Figure 4.33 Calatrava's sketches of animals.

"A lot of inventions can be derived from observation of nature. Nature teaches us and we can learn from nature. Flowers, plants, trees, grass can serve as a measure for architecture. Nature can be approached in two different ways: we can learn from nature, from natural movement and we can imitate and interpret nature. The concept of metaphor is of interest here. Nature is so inherent and immediate to us and to all existence that when there is a reference to nature, whether for justifying or interpreting a situation, it can serve as a point of orientation for our thoughts." (Calatrava, RSA Journal, 1994:39).

The project Calatrava designed for the completion of the Cathedral of St. John the Divine in New York holds the image of a tree as the basis for the proposed structure. Conceptually, the crypt is the roots, the trunk is the transept and the branches are the pillars. It is used as a metaphor. (Figure 4.61)

The roof of the actual station hall Lyon Airport Railway Station at Lyon-Satolas has two wings resembling a bird in flight. Above ground and as if hovering over the tracks, it reflects the profile and appearance of a bird and marks the passage of the trains to be seen from afar. (Figure 4.55)

The theme of the bird in flight has been carried through and applied to a project for the new concert hall in Santa Cruz, Tenerife. The building is a composition of conical and cylindrical shapes. The base and core of the building are constructed in concrete and the curved roofs of wood and steel. The two wings are dominant in the project. (Figure 4.24)

Another project having the same spirit is the airport for Bilbao. It has a double curved steel roof which has a triangular plan similar to the TGV Railway Station. It is supported by inclined façade elements, thus it presents a dynamic appearance. (Figure 4.23)

Calatrava has a careful eye for the organic forms. The interpretations of these forms are observed in his designs as mentioned before. How this is conveyed in his designs is going to be examined in detail in the next section.

Calatrava's artistic character is introduced by his approach examined up to this line. We can conclude that he behaves like an artist who derives inspiration from nature and interprets what he sees into his masterpiece. His approach is accomplished by another career of him: engineering. He comes closer to natural structures as an engineer.

As an engineer, Calatrava goes beyond an approach that merely solves technical problems. Structure, for him, like the other appreciated engineers of the century, is a balance between the scientific criterion on efficiency and the innovation of new forms. (McQuaid, 1993). Moreover, in his work a remarkable expression is given to the action of forces.

The 'natural' aspect of Calatrava's work is partly related with the inherent laws of nature. Instead of imitating organic forms, he analyzes the internal forces within nature, observes the movement in natural objects; which leads to the shapes that correspond to the same constructional rules. The shape's plasticity reflects the fluidity of the internal forces. When the flow of forces plays a role in the shaping of the designed project, that means the project is subject to the laws of nature like natural structures.

"Besides, in the expressive play with equilibrium, there is in many instances an anatomical aspect ... Anatomical structure is determined in part by the demands of movement. While I think of structure in organic terms, the iconography I employ is not solely skeletal ..." (Tischhauser, 1996:2).

Understanding structures as living organisms is demonstrated very clearly through the introduction of movement as a conceptual support of Calatrava's projects; movement has always fascinated him. For him, mechanics has been a major theme, a source of inspiration and innovation. "It is movement that leads us to associate an apparent lightness with Calatrava's architecture." (Tischhauser, 1996:1).

His structures are capable of moving and adapting themselves to the changing conditions of their environment. Such similarity of his structures to a "mobile" proves his interest in the dynamic conception of the structure. Even in his engineering thesis on foldable space frames, he investigated movement as an inherent part of architecture, concluding that a building is not just a visual image made up of different volumes and textured surfaces but a dynamic object.

Apparently, Calatrava not only seeks for assembling the static equilibrium but also the dynamic equilibrium as well. Then he deals with the problem of movement, that is maintaining a continuously changing equilibrium.

Even in his static structures he seeks a sense of movement. Some of his structures literally move, while others, such as Lyons Airport Railroad Station or the Cathedral of St. John the Divine in New York and Stadelhofen, represent "crystallized movement." (McQuaid, 1993:12). His attitude results from an understanding of the laws of static as a different case than the laws of dynamics. In the delicate balance installed into Calatrava's structures, the line of force becomes a diagram of the currents that flow through the organism, expressing its vital energy. They seem to be mobile.

"You could say that forces are like crystallized movement. This is of course a very poetic and idiosyncratic interpretation of these matters. You could say that forces are things that could happen. But they do not happen because, like ice, they are crystallized. When you let them go, they immediately produce movement." (Calatrava, RSA Journal, 1994:41).

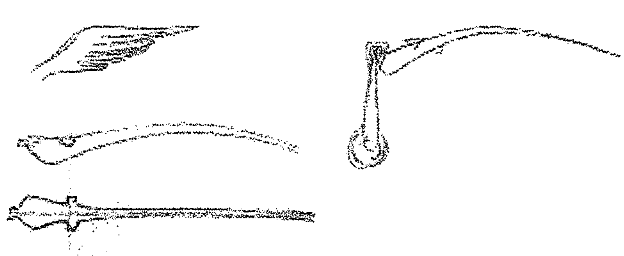


Figure 4.34 Sketches about Swissbau Pavilion.

"Movement, mutation and time constitute the fundamental ideas of Calatrava's projectual thought ... From his studies on foldable space-structures to his most recent projects, ... determined parts of the organism

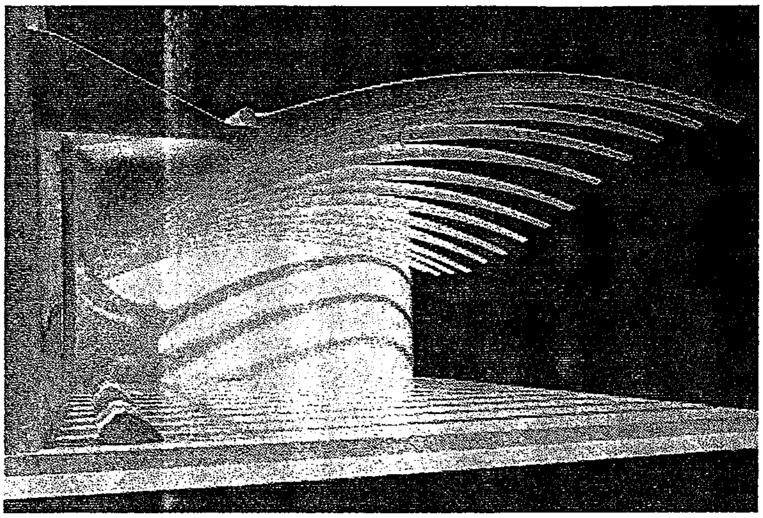


Figure 4.35 Model of Swissbau Pavilion.

are capable of moving and adapting themselves to the changing conditions of their environment" (Zaera, El Croquis, 1994:25): In case of the Swissbau Pavilion at the Basle Building Fair, in 1989, 14 fine velvet textured concrete fingers were designed to move gently up and down in a wave motion, simulating the sweep of a bird's wing. Calatrava's explains his aim in designing the pavilion as; to show that, as a building material, concrete can forge a link between building engineering technology and the perfect forms of nature. (Blaser, 1990). Prefabricated elements are the optimal answer to the demand for freedom of design. This pavilion represents the first in a series of projects exploring the idea of kinetic architectural components.

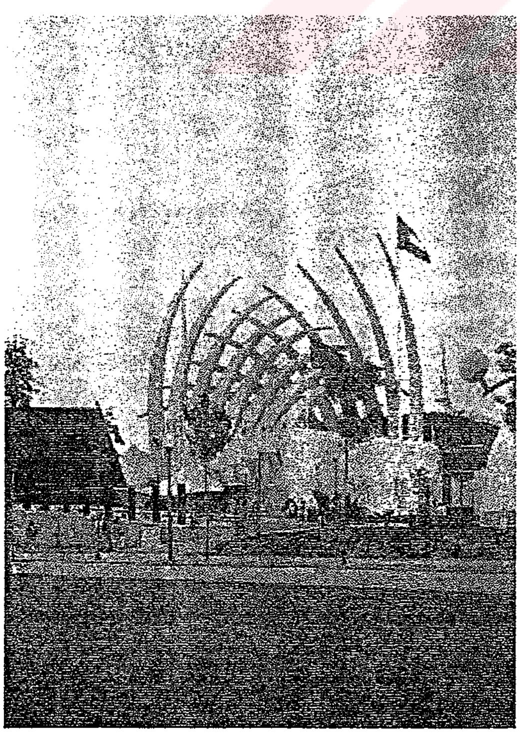


Figure 4.36 Kuwaiti Pavilion, the mobile roof.

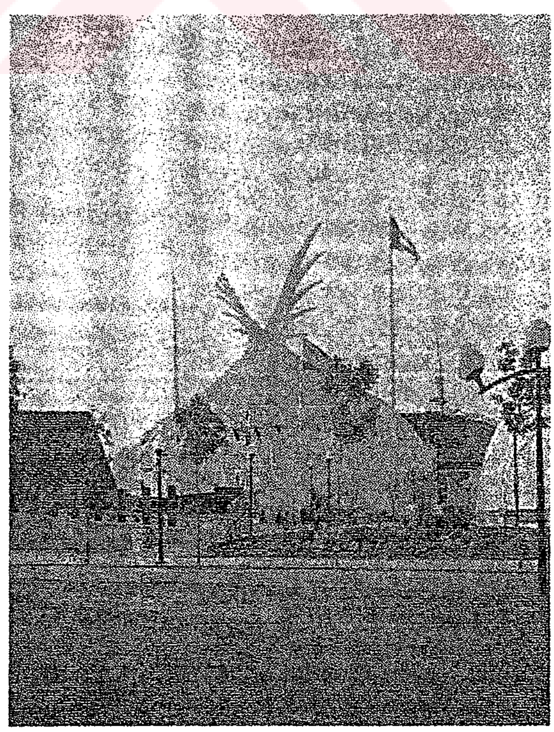


Figure 4.37 Kuwaiti Pavilion, a different position of the ribs.

For the national pavilion of Kuwaiti in Expo '92, independently moving wooden fingers constituted a mobile roof which altered during day and night, creating the impression of a moving sculpture. The building has a very simple rectangular plan but the section possesses an ability: the roof is formed by 17 mobile timber ribs. They are controlled by a hydraulic system and are able to rise from 45° position up to 90°. They resemble the fingers' movement with the joint similar to that of a hand. The movement of the roof creates interesting appearances as seen in figures 4.36 and 4.37.

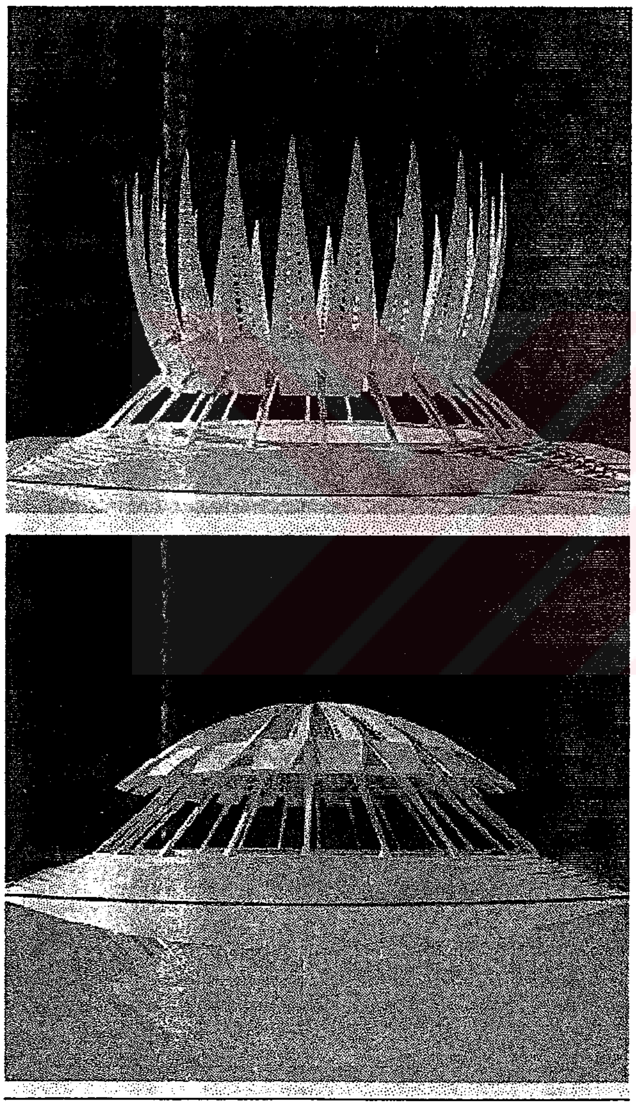


Figure 4.38 Mobile model of CH-91 Floating Concrete Pavilion.

The project of the CH-91 Floating Concrete Pavilion (1989) at the lake of Lucerne has an opening roof which was formed by concrete pre-cast elements. "Under the motto 'Concrete in Harmony with Nature', the structure is intended to blend in naturally in with the environments of the Lake of Lucerne..." (Blaser, 1990:124). Thus the pavilion is designed as capable to float on the lake. The circular building has a roof consisting of 24 leaf-like concrete elements which can move upwards to open the space to the sky and, with these features, it recalls the shapes of nature especially a flower.

The glass panels on the steel trees of Bauschänzli Restaurant extend and fold to make the canopy cover or open. The building is designed to be set amongst trees on an island fortress in Zurich. Among these trees, another nine branching steel trunks support the vaulted steel

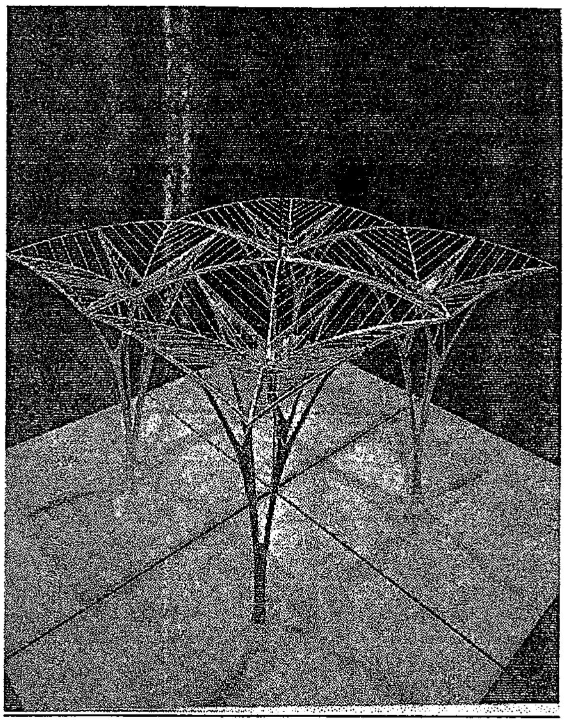


Figure 4.40 Bauschänzli Restaurant, model view of the roof.

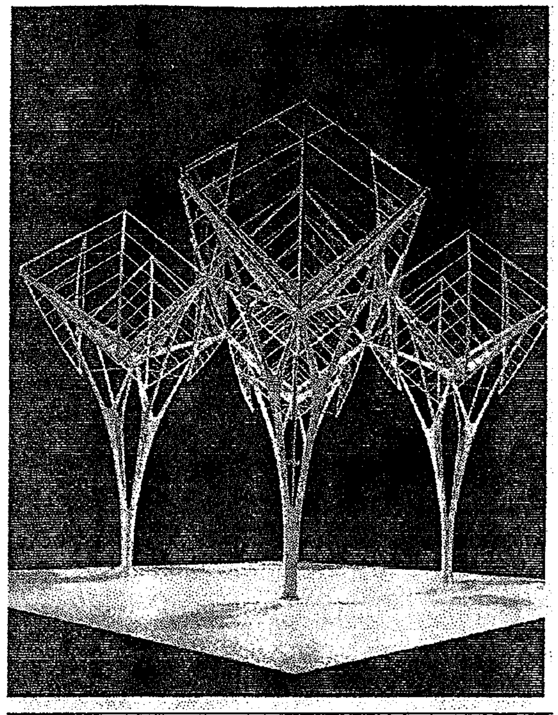


Figure 4.39 Bauschänzli Restaurant, folded position of the roof.

and glass canopy of the restaurant which is 12 m high. In fine weather, the vaults will fold up like flower petals to open the restaurant to the sky.

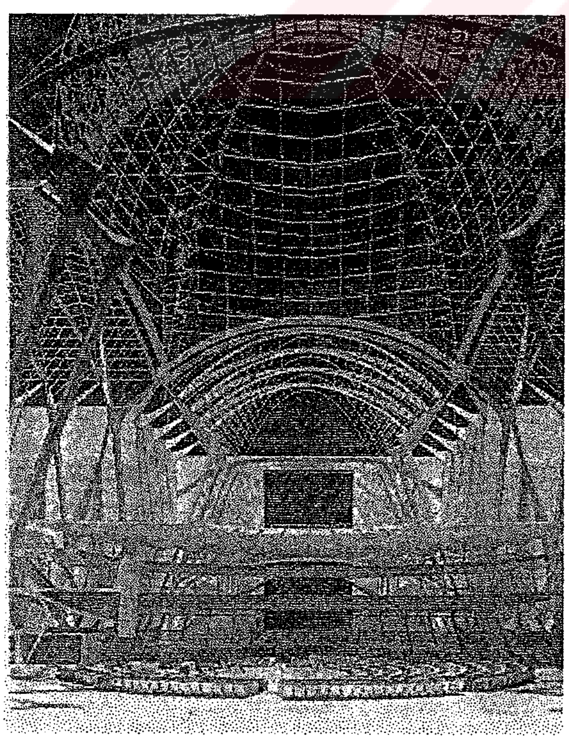


Figure 4.41 Reichstag Building, interior view of the model towards the dome.

Similarly the proposed huge domes of the Reichstag building are designed to be opened by the rotating glass panels.

The project which has two large mobile roofs is another example that represents Calatrava's concept of movement as applied to building as a whole. The glass dome has the profile of the original one, but pivotal joints allow it to open like a flower. The second glass roof which covers the central assembly hall below is also able to open, so when both of the roofs are opened, the interior of the building meets with the sky.

Movement is not something accustomed in architecture. What Calatrava does a new thing. This new means of aesthetic expression is not just the motion of the parts, but the change of the whole building: its overall appearance and the quality of the internal space.

"Engineers usually understand dynamics as a question of frequency and vibration. Dynamics can also be part of form, and a component of 20th century art, as in mobiles ... I tried to introduce collapsible or dynamic elements in order to give another order of architectural expression to the subject." (Tischhauser, 1996:3), Calatrava says.

"There is a huge source of innovation when moving from the static understanding of forces into the dynamic understanding of forces with the same degree of safety. In my opinion it opens up a wide horizon." (Calatrava, RSA Journal, 1994:42).

It really does.

4.5 Evaluation of the Work of Santiago Calatrava

It will be necessary to examine some structures of Calatrava in more detail in order to understand the relations that were sought in the previous chapter. In nearly all the articles about Calatrava or the ones introducing his buildings, the organic aspect of his designs is touched.

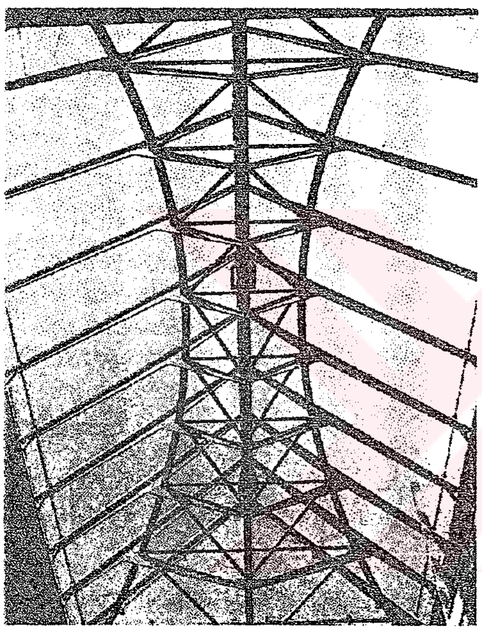
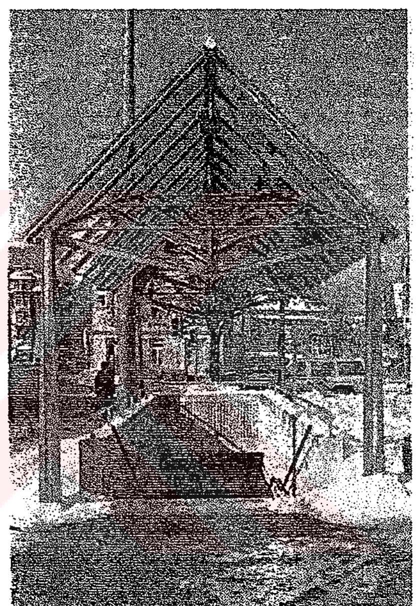


Figure 4.42 View up into the roof of entrance canopy in St. Gallen.



.Figure 4.43 General view of the canopy in St. Gallen.

Some of his structures are claimed to be inspired directly from nature, especially from animal skeletons. For example the roof of the entrance to an underpass in St. Gallen, Switzerland, has ‘a structure of rib-like glazing bars supported on a bowed vertebral truss on four corner columns’, according to Peter Buchanan. (Buchanan, 1987). This structure is an intermix of a pitched roof and a spine-like truss. The roof structure gains stability by this truss, which is something beyond an ordinary support. The appearance actually recalls the skeleton (backbone) of an animal.

There is a similar and perhaps a much more vertebral structure of Calatrava which is the entrance canopy of Wohlen High School. It is a bowed structure fixed to the ground at two ends and supported laterally with the attachment to the building. Although it is not possible to define the structure as one thing, it is plainly a spine with the cantilevering ribs supporting the glass panels.

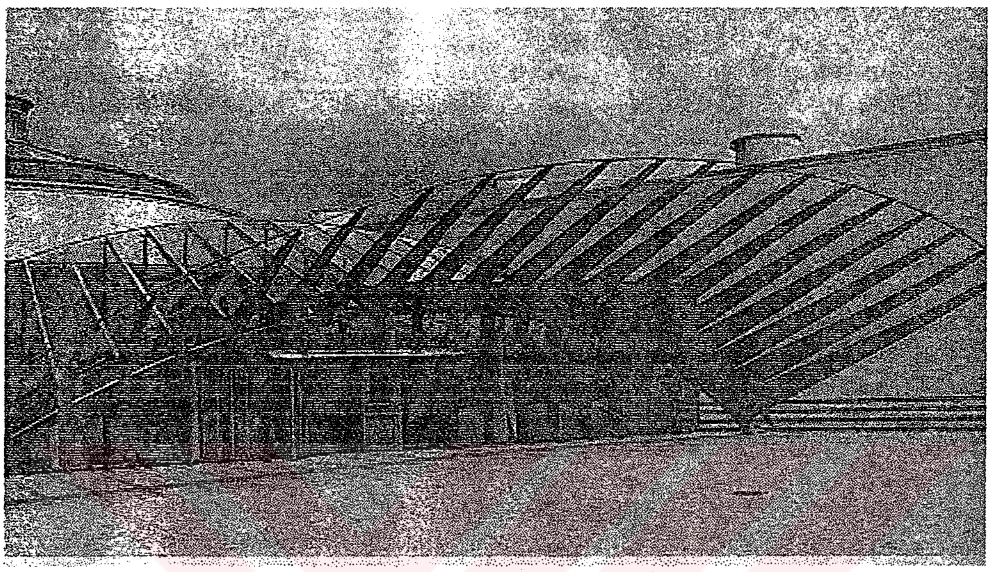


Figure 4.44 The entrance canopy of Wohlen High School.

Figure 4.45 The canopy structure of Stadelhofen Railway Station.

Then Buchanan finds other organic aspects in Stadelhofen Railway Station: "Here again canopy and pergola use skeletal cantilevers, but now held aloft on supports derived from the hindleg of a quadruped." (Buchanan, 1987:54). Also, "the repeated structural elements over the promenade canopy look like the ribcage of a stegosaurus." (McQuaid, 1993:11). According to Dennis Sharp, biomorphism is dominant in Stadelhofen throughout where Calatrava's notion of structure as a form of petrified movement is evident. (Sharp, 1994).

Stadelhofen Railway Station is among the first projects that introduced Calatrava to the world by representing his significant approach of architecture. Here the architect had designed the project employing both steel and reinforced-concrete structures in harmony. Concrete parts have biomorphic plasticity while steel parts which constitute the canopies along the tracks have organic skeletal construction. The cantilevered beams of the canopy (seen in Figure 4.45) are welded to a steel pipe that spans horizontally between the pairs of columns. The beam has a parabola shape agreeing the moment diagram. The column do not have the same function although it recalls the back leg of a deer-like animal. In the situation of an animal, legs function together in order to provide the stability. It has joints and its skeleton is supported by muscles. Here, the structure reaches the same shape because of the flow of forces.

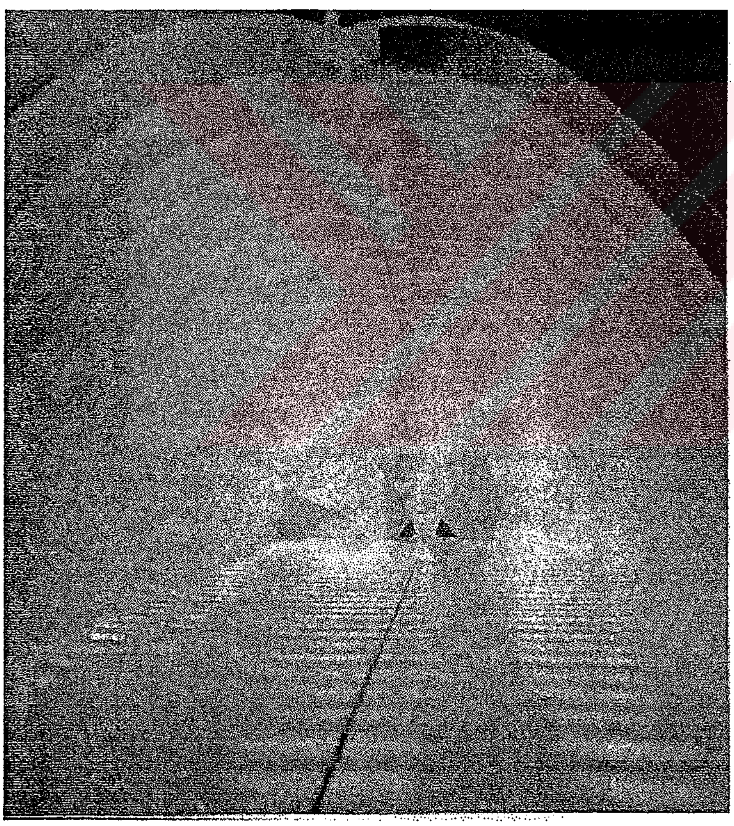


Figure 4.46 Inside view of a dog skeleton.

Figure 4.47 Interior view of Alcoy Commune Hall.

Alcoy Commune Hall is designed underground and it is illuminated by natural light as the rib-like structures constitute a separate system from the outer one. The interior view of the hall very much resembles the inside view of the dog skeleton. There is a bowed spine in the central part of the structure and the atmosphere created is like the rib-case in the figure.

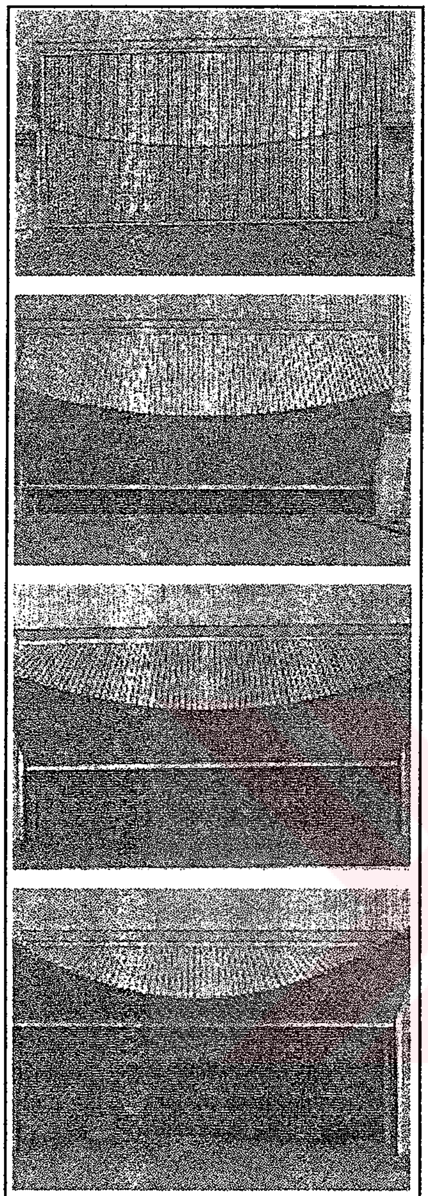


Figure 4.48 The door of the Ernsting Warehouse, Coesfeld.

The extraordinary and ingenious loading doors of the Ernsting Warehouse are derived from part of a kinetic sculpture that is inspired by the way eyelids open and close. The doors are made up of linear elements put side by side forming the surface. Each of them has a joint where it is folded when the door is to open. Each joint has a varying place with respect to the one beside it, and they form the arc of an eye.

Calatrava says that the movement of doors resembled the knees and that they had studied bone structures of animals while developing kinetic forms. (Calatrava, 1994:40).

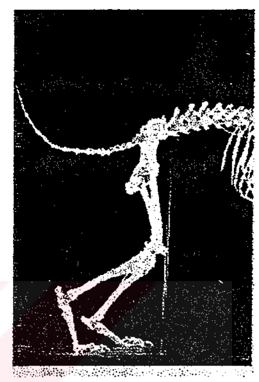


Figure 4.49 Legs of a dog skeleton.

Here the eye is rather an abstract theme, it is used as a metaphor. But the folding of the elements individually have an organic aspect as mentioned by Calatrava. Each element has a joint at the top, at the middle and at the bottom like a leg. Movement at the joints is provided by pinned hinges on each aluminum rib.

The roof covering the pool in the Alcoy complex has a similar opening system. Here, again linear elements are at work to create the interesting opening phases of the roof. The pictures show these phases prepared on a model.

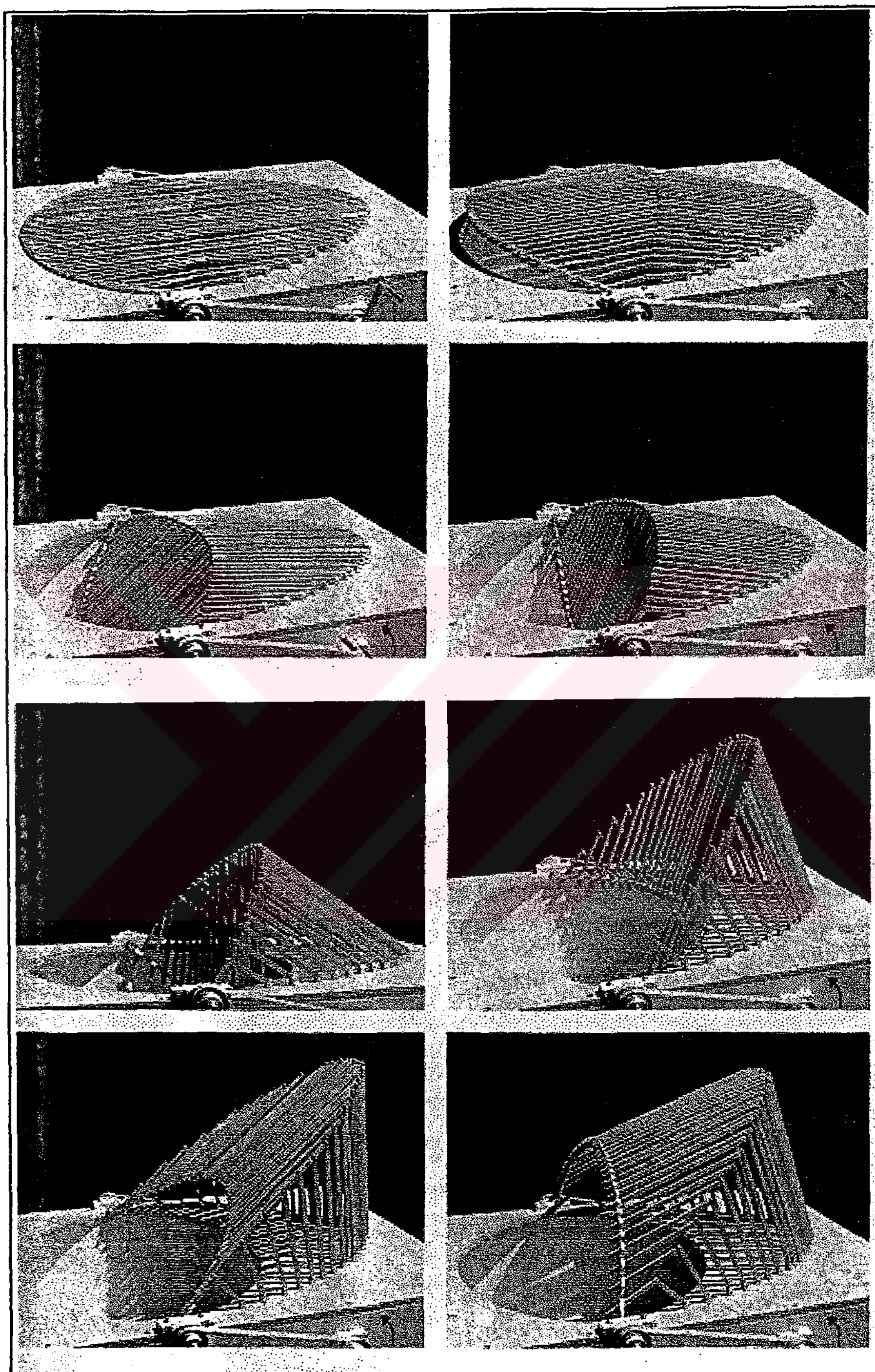


Figure 4.50 Phases of the opening of the roof covering the pool in Alcoy (1991-5).

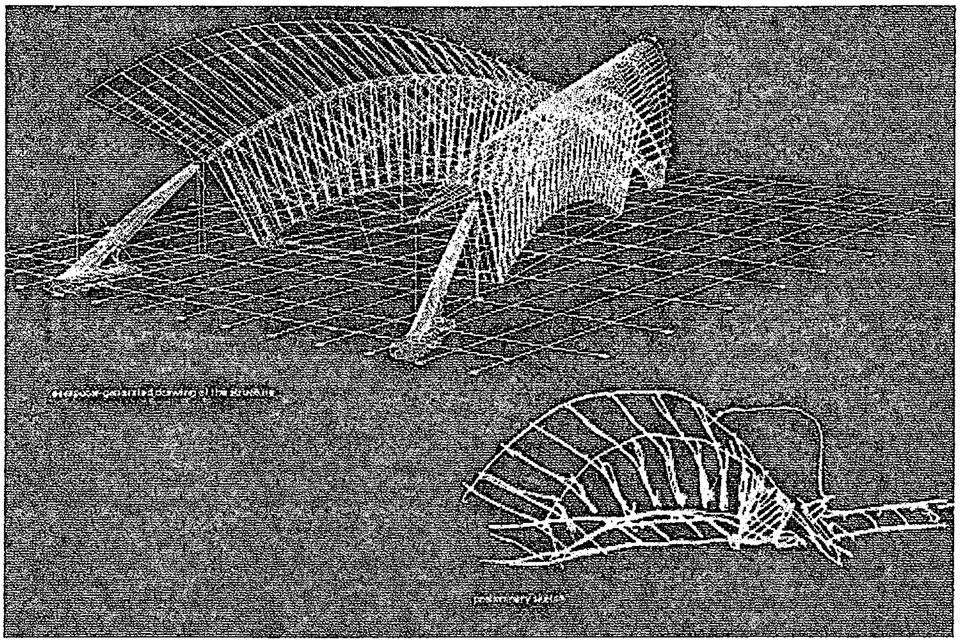


Figure 4.51 TGV Railway Station, computer drawing and Calatrava's preliminary sketch of the main hall.

The examples below are the projects of Calatrava which are claimed to have natural images as their themes.

A recently constructed project of him, TGV Railway Station building is a significant example that has been being discussed in articles. The complex is made up of three parts: the technical infrastructures, the vault of the roof over the platforms and the passenger hall.

Theme of bird in flight dominates the design. The lightweight, aluminum roof of the passenger hall is wide, having two parts resembling the spread out wings of a bird. "The central spine of the hall ... is supported by a big concrete element at one end which not only takes all the forces but the rainwater as well. Opposite this focal element there are concrete buttresses supporting the steel roof arches. Between the arches is a distance of 140 meters." (Calatrava, RSA Journal, 1994:42). The branched posts support the rest of the roof, whose overhanging end is perforated, (like the tips of the wings of a bird). The posts stand on a hollow arch of concrete that takes the exact shape of the vault covering the platforms and are supported, at the top, by arches set at right angles to the tracks.

In this powerfully expressionistic structure, Calatrava's characteristic touch of making use of dual situations, - as with the contrasts between concrete and steel, horizontal and vertical, black and white, high and low - can be observed. (Lotus 86, 1995).

The building is connected to the airport buildings by a gallery and the platforms and the ambulatory below are covered by a lattice-like structure. It can also be defined as a perforated vault. This long vault of white concrete is slightly curved and has a span of 50 m. It is ribbed with a series of arches set at an angle that make the whole roof look as if it is skewed and form diamond shaped openings some of which are covered by pyramidal glass canopies. The ribs rest on inclined supports and upturned V-like structures at the sides of the vault.

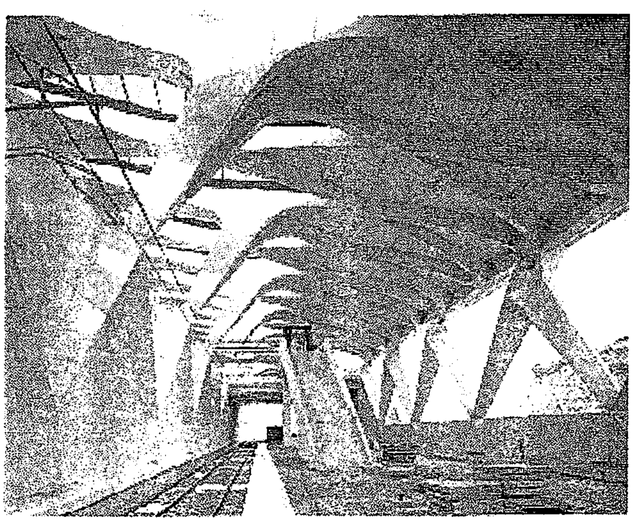


Figure 4.52 TGV Railway Station, supports at the sides of the vaulted roof of the platforms.

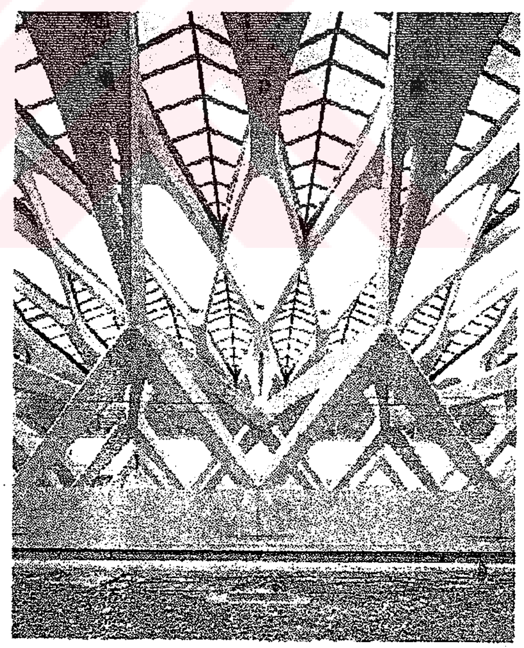


Figure 4.53 TGV Railway Station, detail of the glazed vault.

In nearly almost every article about this project; TGV Railway Station building is compared to Eero Saarinen's TWA terminal in New York because of the bird or flight metaphor. It might be more useful if we begin to discuss the characteristics of the project through this argument.

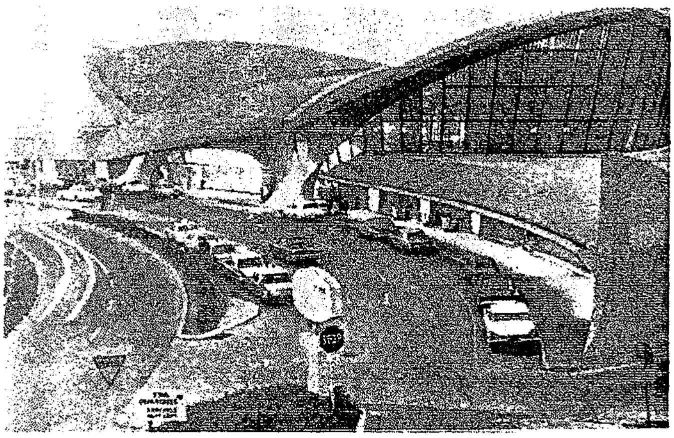


Figure 4.54 TWA Terminal Building of Eero Saarinen, general view.

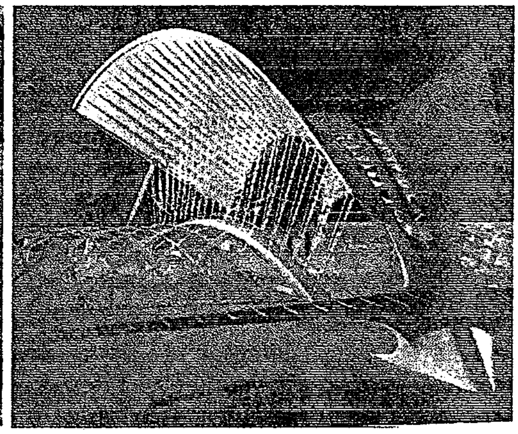


Figure 4.55 TGV Railway Station, model view.

TWA terminal which is considered to be 'the outstanding fusion of function and experimental form', has an innovative approach. The roof of the passenger hall is formed by meeting of four shells each of which stand on two feet. One of them extends over the entrance confirming the image of the bird with its beak.

According to one of the authors, both buildings are deliberately expressionistic works of architecture in which the anthropomorphic forms help to impart, through the use of concrete, a very strong sense of dynamism. "This is due to, in particular, to the recourse to metaphors that are founded as much on the program as on the structural design ..." (Lotus 86, 1995:37).

Another author considers that; because of the analogy to the act of flying, Calatrava's main hall recalls Saarinen's iconic terminal at JFK Airport. Perhaps as a result of using more inherently rigid steel structure the design seems less exuberantly plastic when compared with Saarinen's seductive biomorphic geometry. But the station vaults below, with their effortless, organic fluidity can claim a more close similarity with Saarinen. (Slessor, 1993).

Peter Buchanan from The Architectural Review, finds Calatrava's main hall more dramatically expressive of flight than Saarinen's building. (Buchanan, 1989). Dennis Sharp also agrees that the analogy recalls Saarinen's terminal, although at Lyon, Calatrava uses steel clad in aluminum as opposed to TWA's biomorphic concrete. (Sharp, 1994).

Santiago Calatrava thinks that the difference is obviously seen when each of the buildings is just slightly examined. According to him, one can easily see that they are completely different. (Calatrava, 1996, personal interview).

It is quite natural that, TGV Railway Station building recalls TWA terminal, because they have the same metaphor: a bird with its wings widespread. They also meet at another common point: strong expressionistic gesture. The architects both have certain success in expressing their personal artistic character. But the buildings belong to different periods of time and architectural medium, so they do have distinctions, such as materials and type of constructions. TWA terminal has a massive volume while TGV station is lightweight, ethereal and transparent. TWA terminal has a plastic figure on the other hand TGV station is a more dynamic construction. Another thing is that; Calatrava's design is more distant to the figure of a bird, what he has achieved is just a reminiscence, reminiscence of flight. So Saarinen's building has a more organic character than the other.

Figure 4.56 Sea eagle, height, 0,7 m; wing span, 2,4 m.

The structure of a bird's wing consists of a skeletal arm and of the feathers hung to this skeleton. The skeletal arm is attached to the body at one point. The wings of the TGV Railway Station have two big arches supporting them. The steel members radiating from the arches recall the feathers. The arches rise from the same support, diverge and touch the ground at two separate points. Although they function as the main supports of the roof, like the wing skeleton of the bird; they are not cantilevering as the latter does. This means the structure do not imitate the structural principle of the wings of a bird, it has a different organization. Perhaps TWA terminal has a further resemblance to the bird at this point although its wing structure bears loads not with a skeletal structure but with a shell.

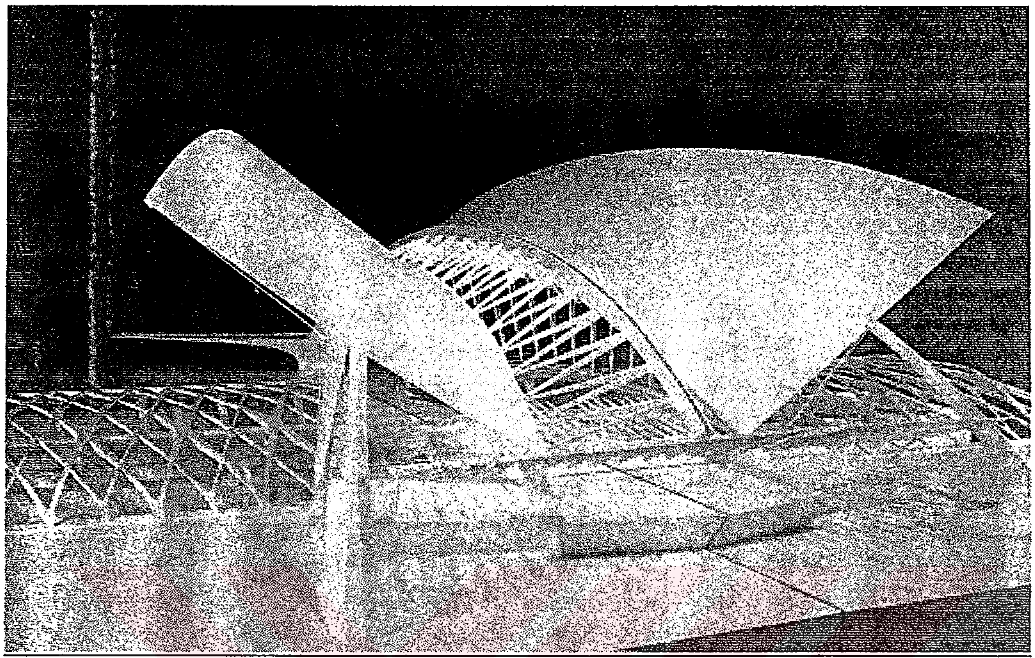


Figure 4.57 TGV Railway Station, back view of the model showing the structure of wings supported by the arches.

According to Matilda McQuaid, Calatrava's closest link to nature is possibly his interpretation and use of the tree form. (McQuaid, 1993:13). "It is a historical motif that has also inspired some of the major architects and engineers of the twentieth century - Wright, Nervi, Maillart, Frei Otto. They have chosen this form not only because, as a column, it counteracts the thrusts of arches and domes and supports the weight of massive stone construction, but also because it conveys structural clarity and rhythmic qualities." (McQuaid, 1993:13-14).

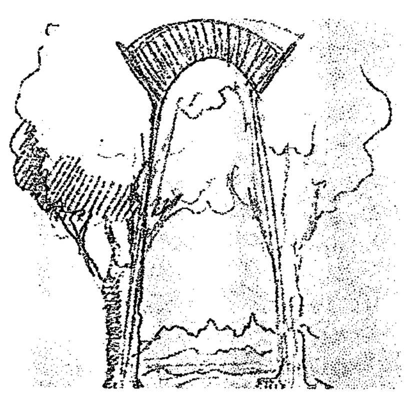


Figure 4.58 Calatrava's sketch of 'tree' and the section of the gallery.

Calatrava has used tree-like forms in some of his projects examined below.

In Gallery & Heritage Square, branching steel columns support the canopy of the gallery and the square. They are placed along the gallery giving the impression of a tree-lined street.

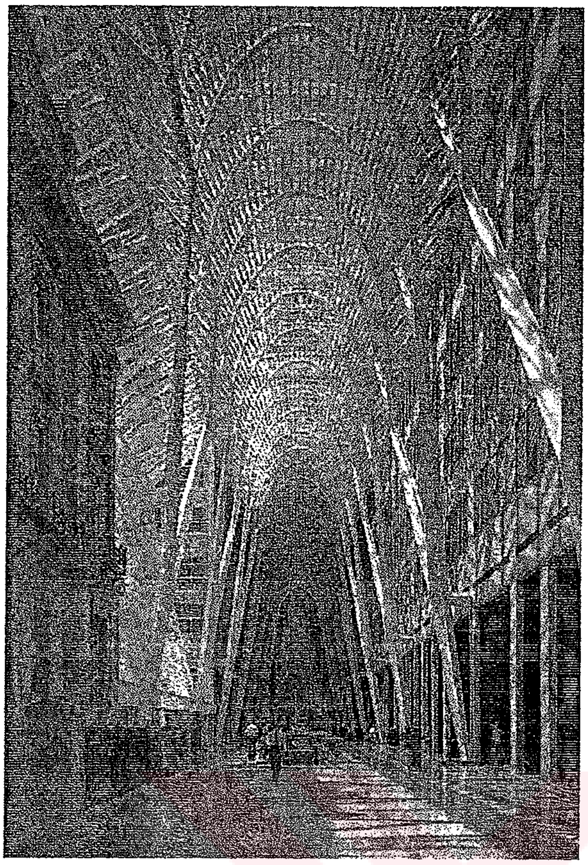


Figure 4.59 BCE Place: view of the gallery recalling a tree-lined street.

The gallery's roof system, a space frame that is also attached to the buildings behind it, contains parabolic arches at a low level, circular arches (with 40-foot radius) at an upper level. Both groups are placed at 12-foot intervals but shift 6 feet in plan. When the arches are joined by a lattice of individually angled steel bars, space-frame structures are formed. The steel columns which are supporting these space-frames on their top are placed every 45 feet. They branch into two, first at 22 feet, then at 48 feet above grade, (in the same plane).

In this situation, although the steel columns resemble the form of trees, the load-bearing system is different -except the branching that support the space-frames. A tree is poised still because of its being fixed to the ground by its roots. The branches stretching every direction balances its position. The cross section becomes larger at the bottom parts of the branches and the trunk; fitting the principle of cantilever.

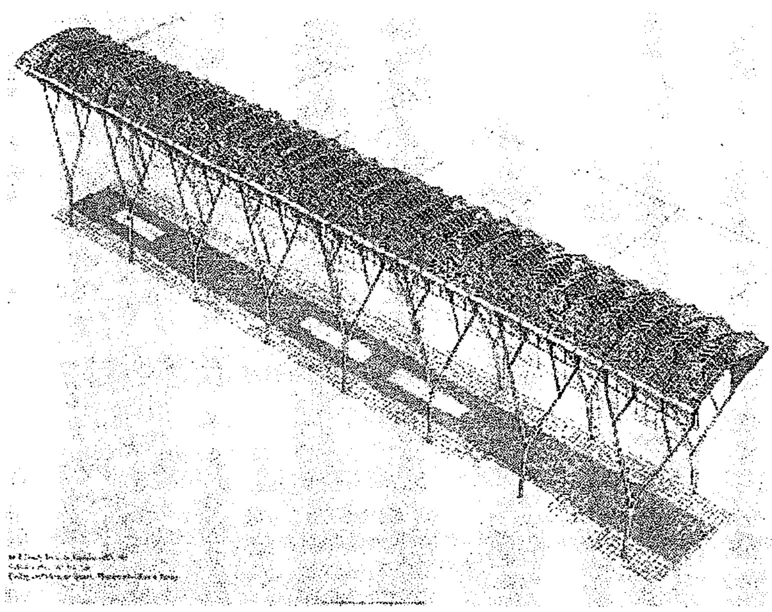


Figure 4.60 BCE Place, structure of the canopy.

On the other hand, branching of the steel columns of the gallery is planar. The columns placed correspondingly are in balance as they are tied with the arches in one direction and with the tips of the branches in the other -making the whole system a vault. (They are also fixed to the buildings behind). Their connection to the ground need not to be rigid in order to provide balance.

The structures supporting the mobile roof of the Bauschänzli Restaurant are more similar to the tree structures with their trunks that seem rooted in the ground rather than pivoted (Figure 4.39 and 4.40); but there is another interesting thing about them: foldability. The folding panels recall some kinds of leaves. Similar structures are designed for Berlin Spandau Railroad Station. They function as the structural supports for the glazed roof over the train platform and have a visual link with the trees of the city around.

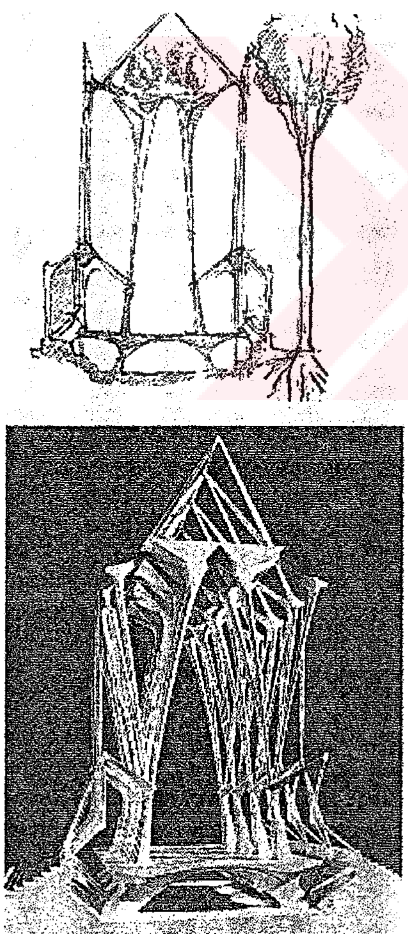


Figure 4.61 Above, Calatrava's sketch belonging to the section of the Cathedral St. John The Divine and below, model of the structure.

The 'tree' of the Cathedral of St. John the Divine is a sectional metaphor.

The cathedral has a complex structure. The tree which served as inspiration here, is a deliberately deformed, distorted structure, thus does not have a relation with the structure of the biological tree. The design consists of Calatravian steel modules which can partly be described as composition of 'X'-like (cross-shaped) elements folded in space and strengthened by linear supports. These modules are placed side by side creating the lattice-like structure of the transept. The joining of modules as rib-like structures, the modulation and the assembled curved section have created a contemporary expression for Gothic.

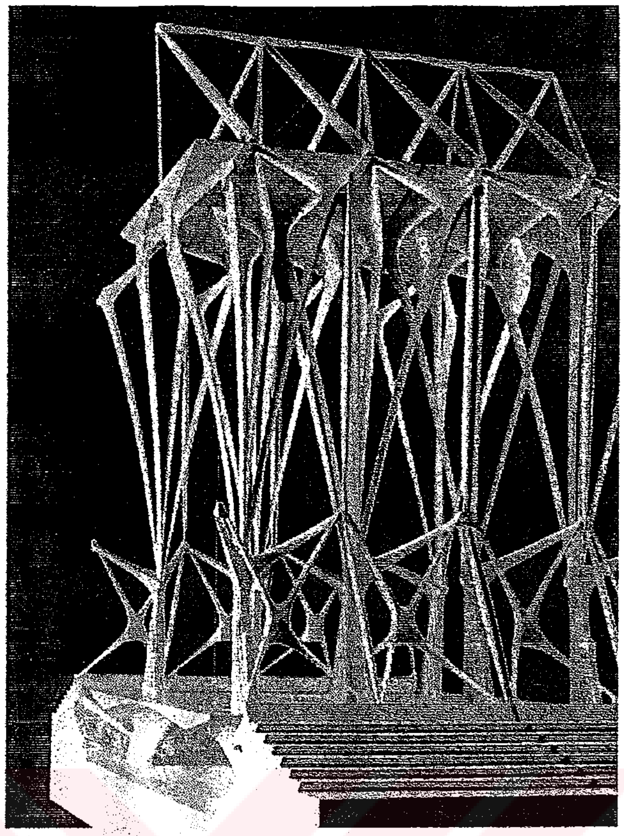


Figure 4.62 Structural model of the Cathedral of St. John the Divine.

As mentioned before, Calatrava sketches some animal figures together with his sketches of bridges or buildings. Generally the images of animals are superimposed on the sectional arrangement of projects, i.e. relations are sought in the cross sections of the projects.

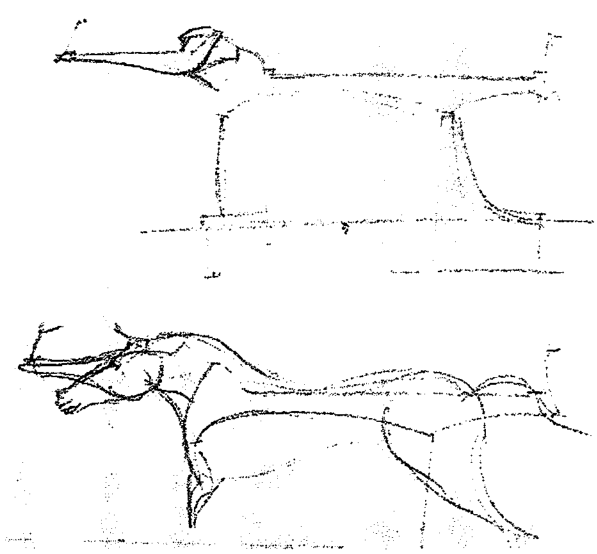


Figure 4.63 Sketch of a horse and the section of 9 d'Octubre bridge.

Side view of a horse standing still and the sectional idea of 9 d'Octubre Bridge over Turia (Valencia, Spain) are considered together in one of Calatrava's drawings. It is a complex, made up of two identical bridges with a gap between them. Each one of the bridges has a pedestrian sidewalk and three highway tracks. The cross section presents two support points (resembling the front and back legs of the horse) with a distance of 8 m between them. The pedestrian sidewalk is cantilevered like the head of the horse with its stretched neck.

Actually, the support points are not placed correspondingly on the same line in plan (they are skewed). In the section, while one of them is crossed, the other one is seen as elevation. However, there might have been a structural connection between the two structures but they look rather distant except the resemblance of the shape.

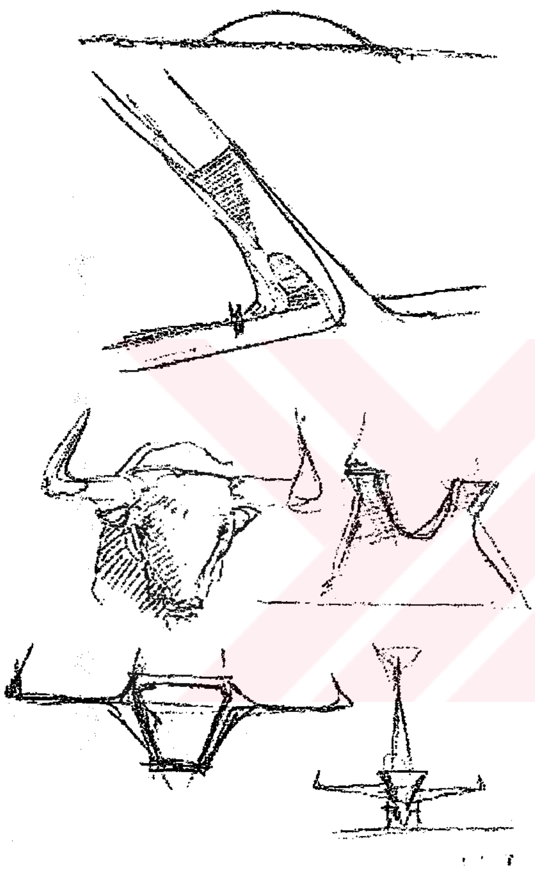


Figure 4.64 Sketches of Merida Bridge.

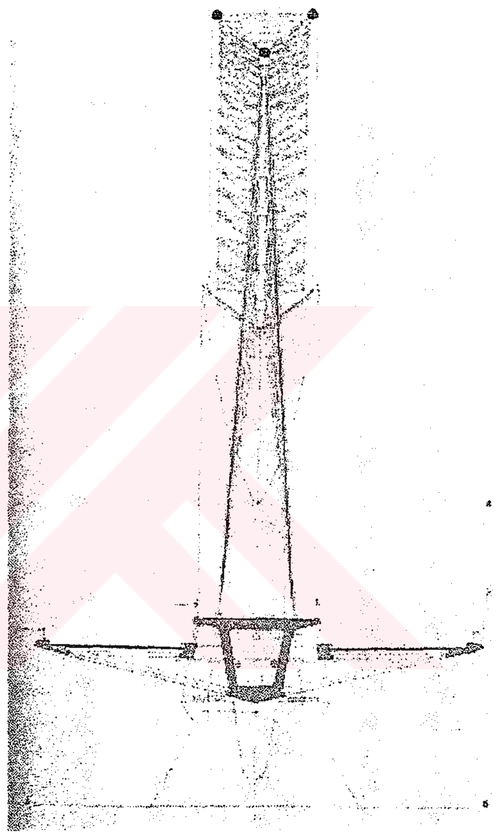


Figure 4.65 Section of Merida Bridge.

Similarly, Merida bridge in Spain has a cross section related by the bull's head. The highway tracks are placed on the two sides of the main load-bearing arch, so they look like the horns cantilevering from the head of a bull in the cross section. There is an equilibrium like the bull's head balanced by the horns, but the bridge is a continuous structure. It has a more rigid character unlike the head of the bull cantilevering from its body. Here, again there is an interrelation between the natural images and the design.

The images are metaphors whose function in design cannot easily be analyzed as they are part of a mental process of imagination.

There are other comments on Calatrava's projects such as: An organic integrity is seen in the skeletal nature of Calatrava's structures. They resemble the skeletons of dinosaurs or the petrified remains of primeval plants. (In other words) they reveal zoomorphic or vegetal character. (Buchanan, 1989). The structures have "a heavily underlined constructive organicism. They look like ancient relics, prehistoric skeletons that challenge us or even swallow us up ..." (Castellano, 1995:18).

On the other hand; it is claimed that in actual fact the structures are not, as has been asserted direct references to animal or vegetable worlds, as Calatrava has studied nature by breaking down the composition of its forces, so as to assimilate its inherent laws. (Gazzaniga, 1994). Another similar comment is of McQuaid's: She thinks although nature is Calatrava's structural inspiration, he does not imitate any particular organic form. Instead, he observes the strong visual movement in natural objects that derives from the fact that their shapes are the traces of the physical forces that created them. (McQuaid, 1993).

4.5.1 Comments on Aspects Related with the Properties of the Natural Structures

Apparently, Calatrava places his approach on abstract references. His tendency is to use natural images only as thought-provoking metaphors. However, in spite of these, we can find some aspects close to natural structures depending on the assumption that he has intuitive knowledge of natural structures acquired by observing skeletons, joints, etc.

- In nature, the formations of the structures are due to the forces. Natural structures are capable of adapting themselves by evolution and they obey the flow of forces acting on them, for example, there is accumulation of material where the load is concentrated. As an engineer, Calatrava is also familiar with the play of forces and he shapes the materials considering statics.

- The shapes in nature generally possess curved lines and surfaces, in other words, they are organic. Calatrava, with 'an eye for the curve', expresses each object in the rhythmic flow of moving, changing curves.

- In nature, a structure does not accommodate many kinds of materials. Calatrava's limiting his palette of materials, even leaving his structures unclad is a similar attitude. In nature, structure is clearly expressed, so in Calatrava's work. The load-bearing structure is the building itself.

- Natural structures have complex forms that cannot be imitated easily or constructed economically. Calatrava designs complex structures, most of them cannot be visualized without seeing the models; thus construction costs of such forms are higher.

"The shapes and forms applied and evolved by Calatrava always appear molded and crafted. Considering the size of space often created and nature of the elements employed, this is unusual." (Tischhauser, 1996:5). Calatrava goes beyond the common load-bearing, structural elements. He designs and shapes his own structural components according to the theme in each project. These crafted constructions 'challenge the industrial process'.

On the other hand, he uses prefabricated elements which are, optimal answer to the demand for freedom of design. "Top material quality, small tolerances, and the repeated use of molds ensure economy of production even with difficult shapes." (Blaser, 1990).

Cost is one of the subjects Calatrava is sometimes questioned. TGV terminal, Cathedral of St. John the Divine, etc. are some of his projects which have high costs. Many of his designs are accomplished with sinuous elements, foldable structures. Thus the additional qualities bring additional costs. However, Calatrava says, his elements are elaborated but the molds are used many times for realizing a project (his projects are modular), thus this means saving labor and time which are also very expensive. (Calatrava, 1996, personal interview). By shaping the elements due to forces i.e. giving the form resistance, he also mentions that steel can be saved. These prove that he makes efficient use of material and forms.

- One significant thing in natural structures is that living structures are capable of moving. Their structural elements are appropriately shaped for movement. Movement is also a central item in Calatrava's work. (He has designed mobile structures as discussed previously). Thus he has made use of the movement capability of natural structures. From the structural point of view, this aspect perhaps is the most referring one to nature, as it proposes adaptation.

CHAPTER FIVE

CONCLUSIONS

5. Conclusions

There has been a relation between natural structures and man-made structural systems. Sometimes consciously and sometimes not, man saw a lot in nature. What he learned has been reflected in the small huts and in today's complex and contemporary architecture.

Man is able to perceive statical function and its expression by observing the shapes of structures. All shapes show that they are subject to certain forces, the shape is somehow related to statical function. According to a theory, man unconsciously compares a shape, its different postures, -how it acts in order to overcome the forces or how it rests- to the human body in order to judge its statical position (compressed, bent, twisted, etc.). (Zannos, 1987). Through experiences man has developed a feel for the effects of compression or tension on the shape of bodies. "Similarly, natural forms such as tree trunks and branches demonstrate that a correctly shaped cantilever is thicker near its fully fixed end and thinner towards its free end." (Zannos, 1987:68). Nature has an effect on mankind. The reasons, the events and the results are extant in nature, if we manage to see.

Nature has structures that have been optimized structurally through years of evolution and as a result of selection. In other words, they are developed to provide maximum efficiency with minimum possible mass. They are not only beautiful but also seem to meet the requirements of structural engineering. However, natural structures do not only mature the most optimum form for load-bearing but fulfill other vital necessities for organisms. This is a fact which should be remembered while considering them from the structural point of view. J. G. Helmcke warns against overly hasty conclusions, but he also points out that, out of many natural shapes that are meaningless from the engineering point of view there are some optimal forms, although they have come into being on the basis of different principles - and moreover, are aesthetically satisfying. (Bauen+Wohnen, 1976). There are differences between natural and man-made structural systems. The latter has technology and creativeness. Moreover mankind concerns planning for future. However, there are examples applicable to architecture; thus they can provide precise solutions to man-made structures.

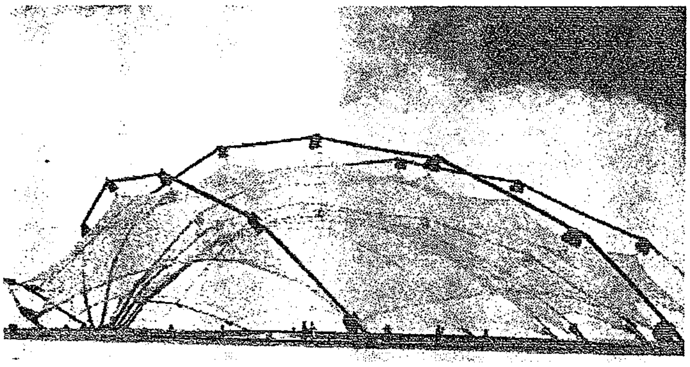


Figure 0.1 A structure developed by Frei Otto: Roof for ice-skating rink, France, 1969.

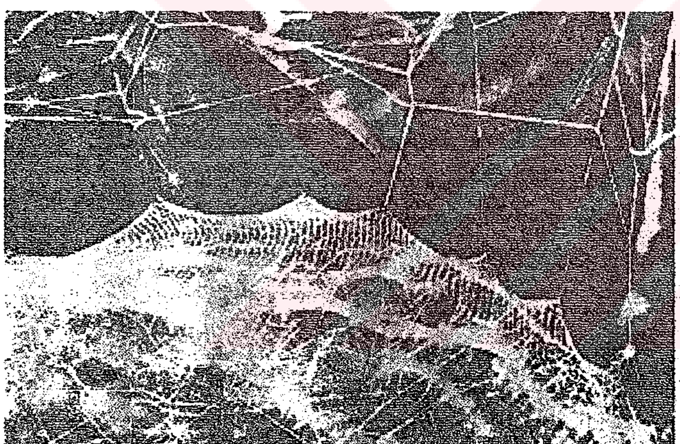


Figure 0.2 A spider net.

Spider nets are good examples of optimum systems and are very appropriate for architecture. Also pneus in nature, the soap bubble and the soap film (membrane) possess features applicable to man-made structural systems. The common feature of these structures is that, they bear loads by the tensile stress. In order to overcome tension, little amount of material is necessary when compared with the structures under the stress of compression. They are capable of allowing a minimum increase in force level, by "distributing loading by an acceptable change of shape." (Happold, 1995). As a result of this, tensile structural systems provide large spans with minimum amount of material - matching the lightweight principle of natural structures. Frei Otto had designed the most successful examples of these kind of structures; his designs are results of his explorations about nature's structures, thus they carry the principles of them.

Buckminster Fuller is another personality who also had searched for the greatest performance with the least investment of energy and material. He tried to improve structures which could cover a maximum space with the smallest surface area of material. His achievement was the geodesic dome inspired by natural shell structures. (Figure 2.10)

When we come to the observation of the 20th century, it can be seen that:

- the architects sometimes applied nature for exploring new forms in order to overcome the classical forms and concepts of architecture, as in the case of the Expressionists and the movement Glass Chain.

- They sometimes sought the connection between form and space, the relation between the whole and the parts from nature and derived the organic thought which gathered the architects around the Organic Architecture.

- More realistically, some of them took structural ideas from natural forms, analyzed their properties and interpreted them for their own structures. These were generally the engineers searching beyond the limits of engineering.

  There were even comprehensive researches about natural structures. IL, the Institute for Lightweight Structures in Germany is one of the places of these kind of studies with the efforts of Frei Otto. Since 1960, in (the old) USSR, the specialists had concentrated on architectural bionics which meant the research into the laws of growth of living nature with the object of employing these laws in architecture. They had a scientific approach to the problem of creative modification of the laws of living nature and their application in architecture. (IL 27, 1980).

- Some of them imitated the forms but not the structural concepts. Some got only inspiration for their designs and so on.

Nature always served as a source or affected the ideas of many of the architects and engineers of the 20th century. It is very interesting that there are so many derivations from nature and it is very advantageous as architecture improves because of the variety.

Today, -perhaps with a slight effect of evocation of the environmentalist thought- a tendency towards nature is observable. Recent magazines contain articles about projects showing an organic character. This breeze of nature mostly depends on the technological development: contemporary construction methods, high-tech building components and materials and efficient climate controlling systems. Moreover, computer is one of the main inventions of 20th century which provides precision to overcome the gap. Technical knowledge has expanded and improved a great deal. Man has more chance to create 'natural' buildings and catch up with the efficiency of natural structures.

Nature is vital for our existence and also for the development of architecture. It will keep on opening up new horizons ahead of mankind, parallel to its being discovered, but as long as it challenged man.

Kenneth Frampton tells about a battle, between functionalism and the organic thought, which ended in CIAM in 1928. "While Le Corbusier here proclaimed an architecture of functionalism and pure geometrical form, Hugo Häring tried in vain to win the Congress over to his own conception of 'organic' building. His failure to do so not only emphasized the non-normative, 'place'-orientated nature of his approach but also denoted the final eclipse of the Sheerbartian dream." Despite the work of Hans Scharoun, "the idiosyncratic nature of the 'organic' approach has since been given little chance to prevail." (Frampton, 1996:122).

It is hard to predict what would have been the trend of architecture today, if Häring had won the battle . . .

5.1 Santiago Calatrava

The special example of this study Santiago Calatrava has an original situation which creates an original accomplishment. Being a sculptor, an engineer and architect provides him enough potential and confidence to investigate beyond customary.

Sculpture is an important thing as a mental preparation in Calatrava's architecture. He experiments and exercises structural solutions with his sculptures. He investigates the forces and the relations between the elements with engineering in one hand, art in the other. Some of his sculptures have very close relations with his buildings; especially his mobile structures are first experimented and improved as small models. He has statical intuition. An intuitive knowledge of statics provides him to perceive the statical functions of structures and to develop solutions to structural problems.

As an architect, he works intuitively, concerning the site characteristics but not traditional forms and historical references. His approach is not only artistic or pragmatic, but the synthesis of them. In every project of him there exists an invention, either the quality of space or the load-bearing structure.

Calatrava's buildings have extraordinary, striking and complex structures. They have a common language which determines the style of him. However, they are thought to have an exaggerated sculptural character challenging the concepts 'necessity' and 'efficiency'. Some of them are considered as too much elaborated, over-designed and even ugly. According to Peter Buchanan, such claims "result from considering Calatrava from the wrong perspective - that of the conventional engineer ... he is no plain problem solver and rational organizer". (Buchanan, 1989:87). Calatrava does not only seek the most efficient and economical forms, but he also behaves artistically searching for a memorable and qualified form. He seeks the synthesis, he neither goes towards the extremes of these two sides, nor omits them.

The architect certainly has a careful eye for observing nature. He is inspired by nature, there are considerable amount of animal and human postures among his countless sketches. His buildings give the impressions of reminiscences of skeletons, parts of animals and plants. Especially these projects which are considered to have relations with nature were discussed in the previous chapter. The author's comments can briefly be arranged as follows:

The roof of the entrance canopy in St. Gallen is considered as vertebral by some authors but it resembles the spine of an animal in appearance only as seen from the figures 4.42 and 4.43. It is a qualified structure but not related with nature.

The entrance canopy of Wohlen High School is a closer structure to the spine. It is supported by being fixed to the ground at two ends (although it is stabilized by lateral attachment) (Figure 4.44). The ribs are cantilevering like the natural ribs in a skeleton. The structure's being bowed recalls the flexibility of the spine, although it is not flexible in fact.

Parts of the Stadelhofen Railway Station complex have similarity in shape with natural forms (Figures 4.11, 4.45) but they are not very similar in structural terms. However, the load-bearing elements are successfully shaped according to the flow of forces and this is a feature of nature's structures.

Alcoy Commune Hall's inner structure wholly resembles the ribcage of the dog skeleton in Figure 4.46, but it is not likely to bear load as the skeleton does (Figure 4.47). Part of the natural ribcage is used as a vaulted structure so it functions in a different structural way.

The doors of the Ernsting Warehouse possess a more organic character. The individual elements forming the door are developed by the study of bones of the animals (Figures 4.48, 4.49). Here the articulation idea is taken from the skeleton, the elements and the articulations are not necessarily shaped due to this movement capability.

TGV Station main hall building like Tenerife Concert Hall and Sondica Airport Building has the bird image as metaphor which gives them dynamism. The latticed structure of the vaults recall some regular patterns of structures in nature (Figures 4.52, 4.53). In addition, the inclined columns and their connection to the ribs of the vault are shaped due to the forces so the structure fulfills some principles of nature's structures.

In case of the Cathedral of St. John the Divine, the tree image is very abstract, it is a metaphor. Its form is adapted neither structurally nor in appearance (Figures 4.61, 4.62) but only the parts of it are related with the levels of the section. However, the structure is an ingenious solution matching with the cathedral's character.

In BCE Place, the roof structure of the gallery and the square is supported by tree-like columns. The form of tree is observable but the load-bearing principle is different from the biological tree (Figures 4.59, 4.60). The structure gives the impression of a tree-lined street.

Although Calatrava has sketched the figure of a horse, the section of the 9 d'Octubre Bridge does not build up the same balance as a quadruped does (Figure 4.63). Here, a complete natural structure is used in design but it is not successful from the natural aspect.

The section of the Merida Bridge is sketched with a bull's head. The cantilevering platforms of the tracks resemble the horns but again the total structure is apart from the bull itself (Figures 4.64, 4.65). There is an interrelation between the natural image and the concept of the section.

We can say that, in general, the forms are not taken realistically. His structures have some similarities with natural structures but only at some parts of them. The whole system of a natural structure is hardly seen to be used by Calatrava. They are similar to nature's structures in form but apart in structural terms. Briefly, they do not have the concern of realizing ideals and principles of nature -like the ideology of minimum material. Calatrava thinks, nature solves many parameters in one structure while the architects can solve two or three simultaneously; man cannot reach its complexity and perfection. (Calatrava, 1996, personal interview). Thus, natural structures are not his principal notion in the creation of a design. Instead, his structures possess artistic intention and they are evidences of Calatrava's unique architectural character. Natural images are 'thought-provoking metaphors' that lead him to synthesis in the design process. ('Intuition' and 'synthesis' are the keywords for the description of Calatrava's work.) He works rather intuitively, trying to reach a coherent form concentrating on the material's capacity and forces.

On the other hand, one of his main contributions to architecture is movement. Despite the necessity of comprehensive elaboration, he has designed mobile structures most of which propose great alterations in the appearance of the buildings and the quality of spaces. Movement is the dominant aspect that brings him close to nature. His structures have joints, they are capable of moving, thus adapting themselves due to several demands like the structures of nature.

Calatrava is neither very close to natural structures nor apart from them. "It comes as no surprise to see in the basement of Calatrava's Zurich office racks of slides of shells and animals' skeletons." says Tracy Metz (Metz, 1990). He presents a dog skeleton in his exhibitions. Also Calatrava himself tells that he has examined bone structures of animals while developing kinetic forms. (Levene & Cecilia, 1994:40). These prove that the images of nature are preserved in his subconscious together with many other things. Thus they are interpreted appearing as abstract ideas in his designs.

REFERENCES

Arnaboldi, M. A. (September 1995). "Do Oriente" Station in Lisbon. l'Arca, 96, pp. 22-25.

BCA-British Cement Association. (1992). New Horizons. Santiago Calatrava.

Blaser, W. (1990). Santiago Calatrava - Engineering Architecture. Basel: Birkhäuser.

Blaser, W. (1990). Santiago Calatrava - Engineering Architecture. W. Blaser (Ed.), Who is Santiago Calatrava?

Buchanan, P. (September 1987). Expressive Engineering - Calatrava. The Architectural Review, 1087, pp. 50-61.

Buchanan, P. (October 1989). Artful Engineering - Santiago Calatrava's City Structures. The Architectural Review, 1112, pp. 87-95.

Buchanan, P. (December 1989). Planes, Trains and Automobiles. The Architectural Review, 1114, pp. 50-53.

Buchanan, P. (January 1991). Artist & Baumeister - Santiago Calatrava. The Architectural Review, 1127, pp. 45-48.

Buchanan, P. (March 1992). Pacific Piano. The Architectural Review, 1141, pp. 61-63.

Calatrava, S. (1994). Santiago Calatrava. R. C. Levene & F. M. Cecilia (Eds.), Dissertations.

Calatrava, S. (Aug-Sept 1994). Inner-city regeneration: works and projects. RSA Journal, No: 5452, pp. 37-47.

Calatrava, S. (1996, June 14). (Personal Interview).

Candela, F. (1994). Santiago Calatrava. R. C. Levene & F. M. Cecilia (Eds.), The inevitability of Santiago Calatrava.

Casiraghi, A. (May 1995) Gaudí e Barcellona. Domus, No: 771.

Castellano, A. (June 1995). High-Speed Station in Lyon. l'Arca, 94, pp. 16-23.

Chow, P. (March 1996). Fruitful Synthesis. The Architectural Review, No: 1189, pp. 43-47.

Conrads, U. (1970). Programmes and manifestoes on 20th-century architecture. (M. Bullock, Trans.). London: Lund Humphries Publishers Ltd. & MIT Press.

Cook, J. (1996). Seeking Structure From Nature - The Organic Architecture of Hungary. Basel: Birkhäuser.

Çağlayan, G. (1994). Maceraperest bir virtüöz: Mimar-mühendis-heykeltraş Calatrava. Arredamento Dekorasyon, No: 59, pp. 72-73.

Delight. (July 1993). The Architectural Review, No: 1157, p. 98.

Domenig in Favoriten. (November 1980). The Architectural Review, 1005, pp. 263-264.

Eastern Promise. (F. J. A.) (May 1991). The Architectural Review, 1131, pp. 83-90.

Editorial. (May 1995). Domus, No: 780, p. 3.

Erginöz, M. A. (1988). Mutluluk Evlerinin Mimarı Jacques Couëlle ve Ekolojik Mimari. Ankara: Kültür ve Turizm Bakanlığı Yayınları.

Fabric Skyscrapers. (1995). AD, Vol: 65, p. 49.

Frampton, K. (1990). Santiago Calatrava - Engineering Architecture. W. Blaser (Ed.), Look No Hands: Santiago Calatrava and the Well-Tempered Reconstruction.

Frampton, K. (1996). Modern Architecture - A Critical History. (3rd ed.-reprint). London: Thames and Hudson Ltd.

Gazzaniga, L. (September 1994). The Lyon-Satolas TGV Station. Domus, No: 763, pp. 38-47.

Gössel, P. & Leuthäuser, G. (1991). Architecture In The Twentieth Century. Köln: Benedikt Taschen.

Günther Domenig: The other face of Austrian architecture. (May 1981). The Architectural Review, 1001, pp. 291-296.

Hans Scharoun 1893-1972. 11-22 Kasım 1975 tarihleri arasında Ege Üniversitesi Güzel Sanatlar Fakültesi Sergi Salonu'nda düzenlenen sergiye ait yayın.

Happold, T. (1995). Chariots of Fire. AD, Vol: 65, p. 31.

Herron, R. (1990). The Great Web of Herron Associates. L'Arca, No:39, pp. 12-18.

Hertel, H. (1966). Structure-Form-Movement. New York: Reinhold Publishing Corporation.

IL 3 Biology And Building I. (1971). Stuttgart: Institut für Leichte Flächentragwerke.

IL 4 Biology And Building II. (1972). Stuttgart: Institut für Leichte Flächentragwerke.

IL 6 Biology And Building III. (1973). Stuttgart: Institut für Leichte Flächentragwerke.

IL 17 The work of Frei Otto and His Teams 1955-1976. (1977). Stuttgart: Institut für Leichte Flächentragwerke.

IL 23 Structures - Form, Force, Mass 3. (1992). Stuttgart: Institut für Leichte Flächentragwerke.

IL 27 Natural Building. (1980). Stuttgart: Institut für Leichte Flächentragwerke.

IL 32 Lightweight Structures In Architecture And Nature. (1983). Stuttgart: Institut für Leichte Flächentragwerke.

IL 33 Radiolaria - Shells In Nature And Technics II. (1990). Stuttgart: Institut für Leichte Flächentragwerke.

Jencks, C. (1971). Architecture 2000 - Predictions and Methods. London: Studio Vista Ltd.

Jeremy Dixon and Edward Jones. (October 1995). A & U, No: 301, pp. 94-105.

Kieren, M. (1994). Calatrava Berlin - Five Projects. Basel: Birkhäuser.

Lampugnani, V. M. (1986). Encyclopaedia Of 20th-Century Architecture. London: Thames and Hudson Ltd.

Levene, R. C. & Cecilia, F. M. (1994). Santiago Calatrava. Madrid: El Croquis Editorial. (38+57 Omnibus Volume).

McQuaid, M. (1993). Santiago Calatrava - Structure and Expression. New York: The Museum of Modern Art.

Metz, T. (October 1990). Structural Dynamics. Architectural Record, pp. 54-61.

Metz, T. (August 1991). Express Track. Architectural Record, pp. 84-89.

Metz, T. (October 1994). Retun to the Heroic. Architectural Record, pp. 88-95.

Moore, R. (1993). Structure, Space And Skin - The Work of Nicholas Grimshaw & Partners. London: Phaidon Press Limited.

Neuman, R. (1996). Grolier Multimedia Encyclopedia. Grolier Electronic Publishing, Inc.

Nicolin, P. (1990). Santiago Calatrava - Engineering Architecture. W. Blaser (Ed.), Questions on Santiago Calatrava.

Norri, M. R. (April 1190). Six journeys into architectural reality. (Hildi Hawkins, trans.). The Architectural Review, 1190, pp. 68-74.

Oslo Stops. (August 1996). The Architectural Review, No: 1194, Marginalia.

Özer, B. (1975). Bruno Taut: Kişiliği ve Boğaziçi'ndeki Bir Evi Üzerine. Yapı, 13, pp. 37-43.

Pearce, P. (1978). Structure in nature is a strategy for design. USA: The MIT Press.

Polano, S. (1996). Santiago Calatrava. Milano: Electa.

Poole, S. (1992). The New Finnish Architecture. New York: Rizzoli.

Porthogesi, P. (May 1995). Towards a new organic architecture. Domus, No: 780, p. 3.

Rastorfer, D. (1994). Santiago Calatrava. R. C. Levene & F. M. Cecilia (Eds.), The structural art of Santiago Calatrava.

Reichstag Unresolved. (April 1993). The Architectural Review, 1154, pp. 8-10.

Salmon, K. (1991). Ecological Sanctuary. Architecture, 80, p. 35.

Sandaker, B. N. & Eggen, A. P. (1992). The Structural Basis of Architecture. New York: Watson-Guptill Publications.

Santiago Calatrava - Aeroporto Sondika, Bilbao. (1993). Domus Dossier No:1, pp. 24-29.

Santiago Calatrava - Lyon Airport Railway Station, Competition Project for the Orient Station. (July 1995). A & U, No:298, pp. 10-33.

Seidler und Nervi in Canberra. (1976). Bauen+Wohnen, No: 9, pp. 319-328.

Sharp, D. (1994). Santiago Calatrava. London: E & FN Spon.

Slatin, P. (February 1993). Steel Connection. Architectural Record, pp. 84-91.

Slessor, C. (June 1992). Popular Mechanics. The Architectural Review, 1144, pp. 55-56.

Slessor, C. (August 1992). Tower of Babble. The Architectural Review, 1146, p. 23.

Slessor, C. (September 1993). Big Bird on a Wire. The Architectural Review, 1159, pp. 61-66.

Slessor, C. (March 1994). Glorious Galleria. The Architectural Review, 1165, pp. 24-30.

Slessor, C. (February 1995). High Flyer. The Architectural Review, 1176, pp. 36-39.

Sola-Morales, I. de (1987). Gaudí. London, Academy Editions.

Stuttgart airport opens. (May 1991). The Architectural Review, No:1131, p. 4.

Tanyeli, U. (1994). Calatrava ve 'Bizim Neyimiz Eksik' Üzerine. Arredamento Dekorasyon, No: 59, pp. 68-71.

The Calatrava effect. (November 1992). The Architectural Review, 1149, p. 10.

The phenomenon of the TGV. (1995). Lotus, No:86, pp. 35-43.

Tischhauser, A. (April 1992). Tree of Life. The Architectural Review, 1142, pp. 34-37.

Tischhauser, A. (1994). Santiago Calatrava. D. Sharp (Ed.), Santiago Calatrava: An Eye for the Curve.

Tischhauser, A. (1996). Aspects of movement in the work of Santiago Calatrava.

Türkçü, Ç. (1990). Çağdaş Yapım ve Strüktür Sistemleri I. İzmir: Dokuz Eylül Üniversitesi Mühendislik-Mimarlık Fakültesi Yayımı.

Webster, A. C. (November 1992). Utility, Technology and Expression. The Architectural Review, 1149, pp. 68-74.

Zaera, A. (1994). Santiago Calatrava. R. C. Levene & F. M. Cecilia (Eds.), Santiago Calatrava: The living structure.

Zannos, A. (1987). Form and Structure in Architecture - The Role of Statical Function. New York: Van Nostrand Reinhold Company.

APPENDICES

APPENDIX A.

INTERVIEW WITH SANTIAGO CALATRAVA AT HIS EXHIBITION IN PADUA, ITALY

Interview With Santiago Calatrava at his Exhibition in Padua, Italy

This small interview with Santiago Calatrava was recorded by the author of this study at the opening of Calatrava exhibition in Palazzo della Ragione, in Padua (14th June 1996). The hall was very crowded and inevitably some parts were disturbed by the other visitors.

B. A.: Are we able to reach the strength of natural structures or - I mean the principle: maximum gain with minimum loss, strength, effort or is it very expensive to apply their forms, to give their shape?

S. C.: Yes, well I think you see this principle for me is just an ideal, it is just an ideal research but it is not the principle that I am using as a basic item. I am working -you know- in an intuitive way, also looking very much for a coherent form. More than looking for a form in which the relation between the material and the strength is maxi-optimalised I am deserving also very much the construction principles and material principles and what I do is a little bit like a synthesis. Do you understand the word 'synthesis'?

B. A.: Yes. And then your idea is that the stability gained can compensate the difficulty in construction.

S. C.: Yes?

B. A.: I mean it is more expensive but very stable, I mean, I think the...

S. C.: Yes, well I will say that another approach that I try to achieve in any building that I do is that the structure is a global item. It means that we are not only resolving ... for example the question of ... when you want to do something works ... the cost you see ...

So the question of the cost is the question that you can manage in other cases relatively. We develop may be a form which is a little bit elaborated but we make it many many times and with that you are saving from work, saving also steel and also you are saving hours of work which are very very expensive.

B. A.: And how did you gain - I have written here 'intuition', I know, I have read a lot about you. How did you gain your intuition? How did you gain your knowledge of natural forms? I know you are also a sculptor, perhaps you have studied anatomy?

S. C.: Yes well you see first of all ... the mother of intuition... I would like to add that you see, there is a very beautiful article written by Francesco Dal Co. He has written the introduction to the catalogue of Electa and I think he speaks very very nicely about my item of intuition. But of course being a sculptor, my relation with the form is very much related with intuitial item of ... approach of the statical and structural models.

B. A.: OK. and I think you have answered this question: The relationship between form and material; is it the same for natural structures and man-made structures?

S. C.: Yes, the relationship between form and material is very important but not necessarily the same because nature works solving may be twenty or thirty parameters and we as a structural engineer or an architect we are deserving may be two or three simultaneously. So it cannot be the same, we are deserving very much to the structural and to the functional I mean but not to the complexity as nature. For example ... in the legs, the beam of an animal ... also the items of movement and many other things that we don't know how to take care.

B. A.: And there is something different: movement in your projects. And I see a dog's skeleton. How is the movement capability of skeletons realized by your projects?

S. C.: Yes the movement capability. There is a model there behind the horse (the big wooden horse existing in Palazzo della Ragione). It moves, I don't know if you have seen but you have to go and look...

B. A.: OK.

S. C. : You see we have strive many models and structures here and there are also many other structures you see that can be folded and defolded and that we don't how here - they are exhibit now in Zurich and the idea of movement in my projects is also a very central item, a research.

B. A.: And the last question: Saarinen's airport building -

S. C.: Yes what is the difference you can see. You see Saarinen has ... his building -

B. A.: Yes I see but there are many years between -

S. C.: Yes, yes but you can look, you should go to New York and look the Saarinen's building and then go to Lyon and you can now see - you will see they are completely different. It is no way to give you an answer.

B. A.: I know both of them. OK. and can you give concrete examples of your buildings that have direct relationship with natural structures?

S. C.: No I don't have any one because -

B. A.: But I read -

S. C.: Yes I think you see the problem of your issue, you want a little bit to conduct the dialectic of my discourse to the question of natural structures in the fact you see I am quite far away.

B. A.: Of course -

S. C.: I am a little bit afraid of disappointing you because my issue is not as someone who is watching the nature and just stopping here for making any scientific research. My issue is very very intuitive. And you see the fundament of my work is much more synthetic and very much related with the knowledge of a civil engineer or an architect than of someone who studied bionic. Even if it is may be for someone like you who are looking for a sudden approach can give as a relation and I mean also from the beams and many things are very much related with nature but in the fact I am very far away from the study of nature.

B. A.: Yes but I read that for example in St. John the Divine -

S. C.: Yes here it is.

B. A.: You told about - yes I know all of them, I read that it was a tree. And the eye?

S. C.: Yes but it is only a metaphor. Do you understand the word 'metaphor'?

B. A.: Yes.

S. C.: It is just as a metaphor, it is just a metaphor.

B. A.. But intuitively I think you are doing this - you are forming this relationship.

S. C.: I think we have to stop. Thank you very much.

B. A.: Thank you!

APPENDIX B.

BIOGRAPHY OF SANTIAGO CALATRAVA

Biography of Santiago Calatrava

28 July 1951	Born in Valencia.
1959-1960	Visited evening courses at the school for Arts and Crafts in Burgasot, Spain.
1961-1968	Secondary school and graduation in Valencia.
1968-1969	Art school in Valencia.
1969-1974	Studied architecture at the 'Escuela Technica Superior de Arquitectura de Valencia' qualifying as an architect. Post graduate course in urbanism.
1975-1979	Studied civil engineering at the Swiss Federal Institute of Technology, ETH, Zurich.
1979-1981	Doctorate of Technical Science of the ETH. Phd. thesis: On the Foldability of Space Frames.
	Assistant at the Institute for Building Statics and Construction at the ETH, Dept. 1.
	Assistant at the Institute for Plane Statics and Light Constructions at the ETH, Dept. 3.
1981	Architecture and engineering practice established in Zurich.
1985	Exhibition of sculptures in Jamileh Weber Gallery, Zurich.
1985-1986	Exhibition, Fundacio Joan Miro, Barcelona.
1987	Member of the BSA (Union of Swiss Architects).
	'Auguste Perret UIA' Prize (Union Internationale d'Architectes), Paris.
	Member of the 'International Academy of Architecture'.
	Exhibition, Museum of Architecture, Basle.
	Exhibition, Triennale di Milano.
1988	Art prize of the city of Barcelona for the Bach de Roda bridge.
	'Premie de la Asociacion de la prensa', Award of the Press Association, Valencia.
	IABSE Award (International Association for Bridge and Structural Engineering).
	FAD Prize (Fomento de las Artes y el Diseno), Spain.

	Fritz Schumacher Prize for 'Urbanism, Architecture and Engineering' Hamburg, Germany.
	Fazlur Rahman Khan International Fellowship for Architecture and Engineering.
	Exhibition, Berowergut, Basle.
1989	Second architectural and engineering practice established in Paris.
	Honorary Member of BDA (Union of German Architects).
	Monograph exhibition, Columbia University, New York.
	1st Travelling Exhibition, New York, St. Louis, Chicago, Los Angeles.
1990	'Medaille d'Argent de la Recherche et de la Technique' (Academie d'Architecture Foundation 1970), Paris.
1990-1991	2nd Travelling Exhibition, Toronto, Montreal, Helsinki.
1991	European 'Glulam Award' (Glued Laminated Timber Construction), Munich.
	'Award for good buildings 1991' Zurich, for Stadelhofen Station.
	Exhibition, Suomen Rakennustaiteen Museo (Museum of Finnish Architecture), Helsinki.
	Exhibition 'Dynamische Gleichgewichte' (Dynamics and Equilibrium), Museum of Design, Zurich.
1992	Member at the 'Real Academia de Bellas Artes de San Carlos', Valencia.
	Member of 'dell'Europa Akademie di Colonia'.
	Brunel Award for Stadelhofen Railway Station.
	Gold Medal of the Institution of Structural Engineers, London.
	Retrospective Exhibition, the Dutch Institute for Architecture, Rotterdam.
	Retrospective Exhibition, RIBA (Royal Institute of British Architects), London.
	Exhibition, ArkitekturMuseet, Stockholm.
1993	Honorary Fellow, Royal Institute of British Architects, London.
	Doctor Honoris Causa, University of Valencia.

	The city of Toronto Urban Design Awards, Award of Excellence for the BCE Place Galleria.
	Exhibition of bridges, Deutsches Museum, Munich.
	Exhibition 'Structure and Expression', the Museum of Modern Art (MOMA), New York.
	Retrospective Exhibition, La Llontja Museum, Valencia.
	Retrospective Exhibition, Gammel Dok: Danish Center for Architecture, Copenhagen.
	Exhibition for Overbeck Gesellschaft, Lübeck.
	Medal of Honor of Fomento de la Invencion, Fondacion Garcia Cabrezio, Madrid.
1994	Exhibition, Bruton Street Gallery, London.
	Doctor Honoris Causa, University of Sevilla.
	Exhibition, the Museum of Applied Arts and of Popular Art, Moscow.
	Doctor Honoris Causa of the University of Edinburgh.
	Exhibition 'Dynamics of Equilibrium', MA Gallery, Tokyo.
	Exhibition, all'Arqueria de los Nuevos Ministerios, Madrid.
	Exhibition, alla Sala de Arte La Recova, Santa Cruz de Tenerife.
1995	Exhibition, cultural center of Belem, Lisbon.
	Exhibition, Masieri gallery, Venice.
1996	Exhibition, Palazzo della Ragione, Padua.

APPENDIX C.

PROJECT LIST OF SANTIAGO CALATRAVA

SANTIAGO CALATRAVA

Status; 25.3.1996

Project list

Item	Place	Country	Year	
Acleta Alpine Motor-Bridge	Disentis	CH	1979	
IBA Squash Hall	Berlin	D	1979	x
Züspa exhibition Hall	Zurich	CH	1981	x
Letten Motorway Bridge	Zurich	CH	1982	x
Schwarzhaupt Factory	Dielsdorf	CH	1982	x
Mühlenareal Library	Thun	CH	1982	x
Rhine Bridge	Diepoldsau	CH	1982	x
Thalberg House Balcony Extension	Zurich	CH	1983-83	
Jakem Steel Warehouse	Munchwilen	CH	1983-84	
Ernsting Warehouse	Coesfeld	CH	1983-85	x
Baumwollhof Balcony	Zurich	CH	1983-83	
Stadelhofen Railway Station	Zurich	CH	1983-90	x
Post Office Dispatch Roof Canopy	Lucerne	CH	1983-85	
St. Fiden Bus Stop Shelter	St.Gall	CH	1983-85	
Wohlen Highschool	Wohlen	CH	1983-88	
Lucerne Station Hall	Lucerne	CH	1983-89	
Bärenmatte Community Centre	Suhr	CH	1984-88	
Dobi Office Building	Suhr	CH	1984-85	
De Sede Mobile Exhibition Pavilion	Zurich	CH	1984-84	
Caballeros Footbridge	Lerida	E	1984	x
Bach de Roda Bridge	Barcelona	E	1984-87	
Feldenmoos Park & Ride Footbridge	Feldenmoos	CH	1985	x
Station Square Bus Stop Shelter	Lucerne	CH	1985	x
Trade School Gymnastics Hall	Bienne	CH	1985	
Avenida Diagonal Traffic Signals	Barcelona	E	1986-86	
9 d'Octubre Bridge	Valencia	E	1986-88	
Youth Music School Concert Room	St. Gall	CH	1986-86	
Blackbox Television Studio	Zurich	CH	1986-87	
Tabourettli Theatre	Basle	CH	1986-87	
Raitenau Overpass	Salzburg	A	1986	x
BCE Place:Galleria & Heritage Square	Toronto	CDN	1987-92	xx

Oudry-Mesly Footbridge	Créteil-Paris	F	1987-88	
Passarelle de Thiers	Thiers	F	1987	
Pontevedra Bridge	Pontevedra	E	1987	
Basarrate Underground Station	Bilbao	E	1987	x
Alamillo Bridge & La Cartuja Viaduct	Seville	E	1987-92	
Buchen Housing Estate	Würenlingen	CH	1987-	
Banco Exterior	Zurich	CH	1987-87	
Cascine Footbridge	Florence	I	1987	
Pré Babel Sports Centre	Geneva	CH	1988	
Leimbach Footbridge	Zurich	CH	1988	x
Lusitania Bridge	Merida	E	1988-91	
Collserolla Television Tower	Barcelona	E	1988	x
Wettstein Bridge	Basle	CH	1988	
Gentil Bridge	Paris	F	1988	x
Bauschaenzli Restaurant	Zurich	CH	1988	
Emergency Centre	St.Gall	CH	1988-	
Administration Building	Feldmeilen	CH	1988	x
Miraflores Bridge	Cordoba	E	1989	
Montjuic Communication Tower	Barcelona	E	1989-92	
Bahnhofquai Tram Stop	Zurich	CH	1989	
Reuss Footbridge	Flüelen	CH	1989	x
Swissbau Concrete Pavilion	Basle	CH	1989-89	
Bohl Bus Stop Shelter	St.Gall	CH	1989-	
Zurich Univrs.-Faculty of Law Library	Zurich	CH	1989-	
Muri Cloister Old Age Home	Muri	CH	1989	
Lyon Airport Railway Station	Satolas-Lyon	F	1989-94	x
CH-91 Floating Concrete Pavilion	Lake Lucerne	CH	1989	
Gran Via Bridge	Barcelona	E	1989	x
Puerto Bridge	Ondarroa	E	1989-95	
La Devesa Footbridge	Ripoll	E	1989-91	
Port de la Lune Swingbridge	Bordeaux	F	1989	
Campo Volantin Footbridge	Bilbao	E	1990-	
Spitalfields Gallery	London	GB	1990	
East London River Crossing	London	GB	1990	
Nouveau pont sur le Vecchio Bridge	Corsica	F	1990	x

Belluard Castle Theatre	Fribourg	CH	1990	
Sondica Airport	Bilbao	E	1990-	
Tenerife Concert Hall	Tenerife	E	1991-	
Calabria Football Stadium	Calabria	I	1991	x
Science Centre: Communications Tower	Valencia	I	1991-	
Kuwait Pavilion - Expo'92	Seville	E	1991-92	
Salou Football Stadium	Salou	E	1991	x
Science Centre (Museum & Planetarium)	Valencia	E	1991-	x
Grand Pont Motorway Bridge	Lille	F	1991	x
Alameda Bridge & Underground Station	Valencia	E	1991-95	x
Cathedral of St. John The Divine	New York	USA	1991	xx
Médoc Swingbridge	Bordeaux	F	1991	xx
Kronprinzen Bridge	Berlin	D	1991-96	x
Beton Forum Standart Bridge	Stockholm	S	1991	
Spandau Railway Station	Berlin	D	1991	xx
Klosterstrasse Railway Bridge	Berlin	D	1991	
Oberbaum Bridge Restoration	Berlin	D	1991-	
Jahn Olympic Sports Complex	Berlin	D	1992	xx
Solferino Footbridge	Paris	F	1992	x
London Underground Modular Station	London	GB	1992	
Tenerife Exhibition Hall	Tenerife	E	1992-95	
Reichstag Conversion	Berlin	D	1992	xx
Serreria Bridge	Valencia	E	1992-	
Lake Bridge	Lucerne	CH	1992	x
Shadow Machine	New York	USA	1992-93	
Alcoy Comune Hall	Alcoy	E	1992-95	
Alcoy Bridge	Alcoy	E	1992-	
Öresund Bridge	Copenhagen	DK	1993	x
Ile Falcon Motorway Bridge	Sierre	CH	1993	x
Trinity Footbridge	Salford/Manchester	GB	1993-95	
Granadilla Bridge	Tenerife	E	1993-	x
Alicante Tower	Alicante	E	1993-	x
Hospital Bridges	Murcia	E	1993-	
Sondica Airport Control Tower	Bilbao	E	1993-	x
Southpoint Pavilion	New York	USA	1993-	
Herne Hill Velodrome	London	GB	1993	

Oriente Station	Lisbon	P	1993-	x
St Pauls Bridge	London	GB	1994	
Manrique Footbridge	Murcia	E	1994-	
Quay Point Pedestrian Bridge	Bristol	GB	1994-	
Milwaukke Art Museum	Milwaukke	USA	1994-	
Fair and Convention Centre	Fiuggi	I	1994-	
Marseille Football Stadium	Marseille	F	1995	x
Platform Roofs, Zurich Main Station	Zurich	CH	1995	xx
KL Linear City	Kuala Lumpur	MAL	1995-	
Airport 200 Zurich	Zurich	CH	1995-	xx
Poole Harbour Bridge	Portsmouth	GB	1995-	x
Embankment Renaissance Footbridge	Bedford	GB	1995	x
Sundsvall Bridge	Sundsvall	S	1995	x
Casa Pavilion Semler	Sao Paul	BRA	1995-	
Bilbao Fooball Stadium	Bilbao	E	1995-	

19__-19__ : built 19__ - : not yet built / decision open 19__ : will not be built, remains project

x = competition xx = invited competition