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By

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ABSTRACT

The integration of creative, imaginative and economically feasible structures into the design process of buildings has always been an essential issue in the history of architecture. The aim of this study is; to explore the relationship between the design of structural systems and the formation of architectural space, to display the changes in structure/space relationship in respect to scientific progress from the beginning of the age of positivism until today.

This study is structured in two parts. At first, a morphological classification is made within a retrospective overview to explore the relationship of structure and space. Secondly, the age of positivism and the effects of positivism on architectural theories are explored to determine the changes in structure/space relationship.

Today, the new developments in architectural space concept, such as "dynamic stability" affects the design of structures. Still, it is clear that the structure is an indispensable necessity during the process of shaping the space and architectural end product "building", whether the space is static or dynamic.

ÖZ

Mimarlık tarihi boyunca yaratıcı, iyi planlanmış, ekonomik açıdan makul taşıyıcı sistemlerin yapının tasarımı süreciyle bütünleşmesi her zaman önemli bir sorun olmuştur. Bu tezin amacı; taşıyıcı sistem tasarımı ve mekan organizasyonu arasındaki ilişkiyi incelemek, pozitivist çağdan başlayarak günümüze kadar, bilimsel gelişmelere bağlı olarak taşıyıcı sistemler ve mekan organizasyonu arasındaki ilişkelerin değişimini göstermektir.

Bu çalışma iki kısımda kurgulanmıştır. İlk olarak, taşıyıcı sistem ve mekan ilişkisini incelemek için morfolojik bir sınıflama tarihsel süreç içinde yapılmıstır. İkinci olarak, pozitivist çağ ve bu çağın mimarlık teorileri üzerindeki etkileri mekan/taşıyıcı sistem ilişkisindeki değişiklerin belirlenmesi için incelenmiştir.

Günümüzde dinamik denge gibi mimari mekan kavramındaki gelişmeler taşıyıcı sistemlerin tasarımını etkilemektedir. Yinede, mekan statik yada dinamik olsa dahi, taşıyıcı sistemin mimarinin sonuç ürününün "yapı" tasarımı süresince vazgeçilmez bir gereklilik olduğu açıktır.

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CHAPTER 1

INTRODUCTION

1.1. Definition Of The Study

Structure is an indispensable necessity during the process of shaping of the architectural end product "the building" and also the creation of the architectural space. Without structure there will be no built form and consequently no spatial order at all. The integration of creative, imaginative and economically feasible structures into the design process of buildings has always been an essential issue in the history of architecture.

The main purpose of this study is to explore the relationships between the formation of architectural space and the design of an appropriate structural system. Structures can be integrated into the body of buildings in various ways: it is sometimes hidden, sometimes ignored and at some other instances displayed. The relationship between structure and space has an evolutionary pattern and closely connected with each other. While the evolution of structural systems can be traced as a transition from load-bearing to skeletal systems the concept of space has evolved towards more openness and transparency. In other words, a relationship of solids and voids.

This study is clearly focused on the factors that develop the structural design. During the process of classification of these factors scientific developments have played an essential role. For this reason, the evolution of structural systems have been analyzed in two periods, namely the age of empiricism and the age of positivism.

In the age of empiricism, accumulation of knowledge is empirical and based on the observation of nature. Space concept is related to the conception of the universe as an ideal static form. Structural design develops with the experience, imagination and the creativeness of the designer. During this period, the integration of the structural system and the space organization is based on Euclidian geometry.

Positivism constructs a new way of the conception of nature with scientific methods. With the ideas of Copernicus, the concept of space has evolved into openness and become independent from the structure. New building types are demanded for the new social and cultural activities prompted by the Industrial Revolution. The Revolution creates a break with the past. The break allows the basic principles of architecture to be reconsidered in new ways. Developments in the technological and social realities are formed by the designer with new building forms. These new forms are provided with the help of analytic geometry.

The scientific revolution expands the knowledge of building technology. The radical increase in the accessibility of technology fosters the structural systems and the forms of social norms. The introduction of new materials and calculation methods made the design of advanced structural systems possible.

Extraordinarily imaginative structures were produced with the deeper meanings of their times. The deeper meanings have been searched with the questions "what, why and how" that one may ask for any period.

After giving the definition of the study, the methodology used are presented in Chapter 1.2.

In Chapter Two, a definition of what structural design means for space organization is presented in addition to the lexical meaning of the word "structure".

In Chapter Three, a morphological classification is provided for the period in which structural design was dependent upon empiricism. The relationship between space formations demanded during this period and the structural systems has been studied in its historical perspective.

In Chapter Four, scientific and theoretical developments which established the foundations of the age of positivism have been studied in depth.

Upon entering the age of positivism, theoretical and scientific developments caused the structural systems to be transformed from load-bearing to skeletal systems. In this period, the properties of the materials were effective in the formation of the structural form. For this reason, skeletal systems have been classified in Chapter Five according to the construction material used.

In Chapter Six, the advanced structural systems of the twentieth century have been studied. In the designing of these structural systems, the rapid change in construction technology and the large variety of materials have been effective besides the creativity of the architect. Each new construction material has brought a new interpretation to the concept of modern space.

In the last chapter the relationship between structural systems and the space organization has been summarized in three stages throughout the history of architecture. Furthermore, the new space concept has been emerging towards the end of the twentieth century has also been briefly explained.

1.2. The Method of the Study

In this study, the structural systems and spatial relations will be analyzed in the following order.

1.) Analysis and delineation of the conceptual background of the spatial and structural organization.

2.) A morphological classification is made according to the materials used, structural form, load carrying and transferring capacities in relation to spatial organizations.

3.) The effects of scientific methods on space perception and on the developments of structural systems will be explored. The role of technology in our life and in building design will be put forth.

4.) The interrelation between the choice or the development of the appropriate structural system and the formation of spatial organization will be illustrated by means of sample solutions in a historical perspective.

CHAPTER 2

DEFINITIONS

2.1. Structures

The word structure comes from Latin "structura, structus, struere" origins. In Oxford dictionary it is defined as; "the way in which something is organized, built or put together", "the state of being well planned or organized", "a thing made of several parts put together in a particular way". If the definitions are compared, "parts" and '"particular way" will be found as common words

Every plant and animal has a structural system. Their structures have balance and internal stiffness to obey all the fundamental natural laws such as strength and stability. The roots of tree prevent the tree from falling over. Its internal stiffness prevent the trunk and branches to be broken by the wind (Figure: 2.1).

Stability of animals is provided by their legs. Their skeleton is placed in particular way as to provide balance during running, walking or standing.

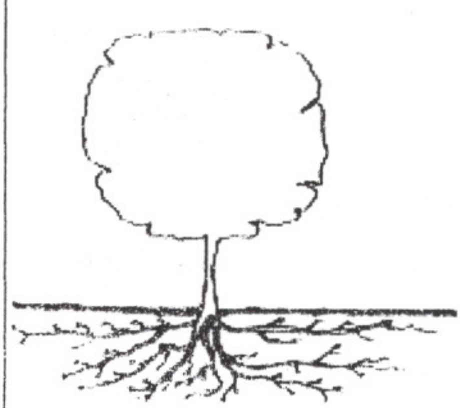

Figure 2 1. Stability of a tree.

The structural requirements for each plant or animal are different. Structures differs according to these requirements but obey all the fundamental laws of stability. At this point it is better to compare the skeletons of a rabbit and tortoise. Rabbit has a internal framed support system. Its structure changes in shape and size so as to provide the possibility to escape from the enemies (Figure: 2.2). The tortoise doesn't have a great deal of movement. It has a fabric supporting system. Its shell protects it from the enemies (Figure 2.3).

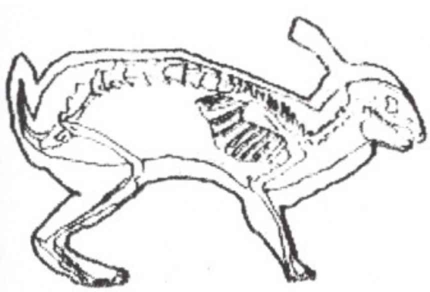

Figure 2.2. Cross-section through the body of a rabbit.

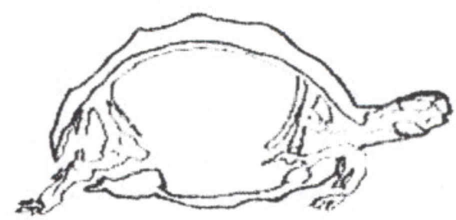

Figure 2.3. Cross-section through the body of a tortoise.

If the structure has to be defined with an architectural knowledge that it's putting of several parts together in a particular way so as to resist to the impact of loads imposed on it. It supplies the strength and rigidity which are required to prevent a building from collapsing.

However, the structure in architecture is more than a means to resist the loads imposed by external forces. It has a close relationship with the organization of space. It may even emphasize the definition of the space. Space order is related with the requirements of the society. These requirements are complex and not easily definable. They change according to the developments in social life, building technology and economy.

In the past, the static space of early primitive buildings were almost totally enclosed by the load bearing structure systems (Figure:2.4). In the present, structure systems are singled out from the main body of the building and erected with methods based on scientific methods. Space concept has evolved towards fluidity and provided with skeletal structures. (Figure: 2.5).

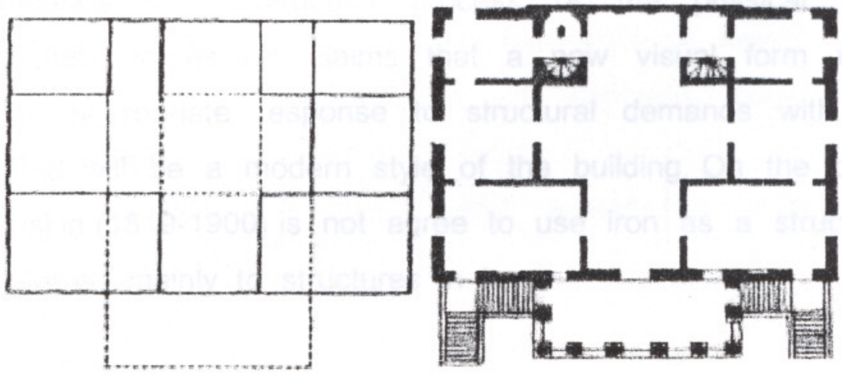

Figure 2.4. Villa Malcontenta, Palladio, 1560.

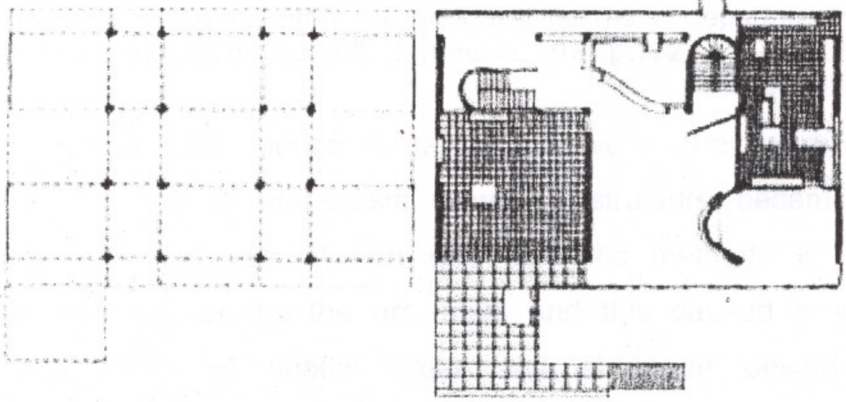

Figure 2.5. Villa de Monzie, Le Corbusier, 1927.

2.2. Interrelation between the Structural Systems and Spatial Organization

The integration of structural system and architectural space is possible in various ways. The relationship between structure and space is first explored by Viollet-Le-Duc (1814, 1879). He observes that stylistic elements of Gothic architecture are parts of the structure. These elements determine the spatial order but they are originally derived from the demands of construction process or the physical laws governing structural forces. He claims that a new visual form must derive from an appropriate response to structural demands with the use of iron. This will be a modern style of the building. On the other hand John Ruskin (1819-1900) is not agree to use iron as a structural element. He referred mainly to structures in iron:

> "(...),that art having been, up to the beginning of the present century, practiced for the most part in clay, stone or wood, it has resulted that the sense of proportion and the laws of structure have been based, the one altogether, the other in great part, on the necessities consequent on the employment of these materials; and that the entire or principle employment of metallic framework would, therefore, be generally felt as a departure from the first principle of the art" (Benevolo, 1971,p:172).

Structure design and space organization were the work of master builder in the age of empiricism. However, structure became a work of engineer with the use of iron and scientific methods in the construction. Iron was refused by the architects and this caused a split between the relationship of spatial order and structural design. In nineteenth century large scale buildings were designed by the engineers without a fundamental spatial concept. Later the split ended with the conceptual understanding of the structure. Space order was again connected with structure by the architects.

In the architectural history, from time to time structure becomes more important than the space it carries. When the structure is accepted as a visual component that allow the spatial idea to become reality, it becomes a work of art in itself rather than remain a technical exploit. To be successful in relationship between theory and reality, structure has to be designed with the creative path of any architect to play a subservient role to form, space, scale and function. This is successfully managed in the beginning of twentieth century by some great architects. One of them is Frank Lloyd Wright.

The remarkable expression of Falling Water House of Frank Lloyd Wright is achieved with the successful integrity of the structure with the open plan theory. It can be seen that while he proposes an open space, he uses the advantages of concrete construction successfully to integrate indoors and outdoors. Concrete cantilevered terraces give the sense of integrity and express a remarkable perspective (Figure: 2.6).

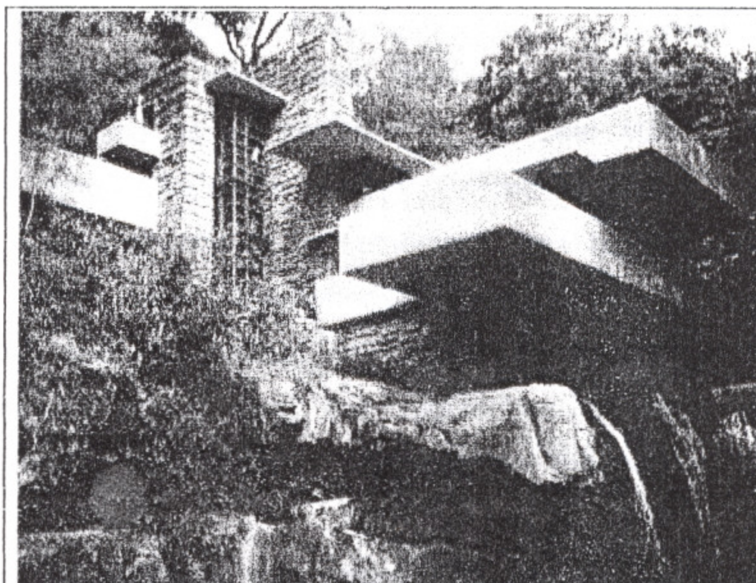

Figure 2.6. Falling Water House, Frank Lloyd Wright.

CHAPTER 3

MORPHOLOGICAL CHANGES OF THE STRUCTURE IN THE AGE OF EMPIRICISM

3.1. Characteristics Of The Age Of Empiricism

In the age of empiricism, knowledge of construction technique was entirely empirical and the method of learning was by analogy from the nature. Analogy is perceiving the similarities from the dissimilarities . By understanding the similarities, a new set of relationship can be constructed.

Developments in social life change human activities and demand various kinds of building tasks with greater spans. The reason of the construction of new structure systems is related to the space organization progress. Long span areas for the new human activities are enclosed with vaulted and domed structures.

In that period Batlamyus's ideas were dominant. It was believed that universe was a contained space, enclosed in an ideal static form and earth was in the center. Designers were interested in objects and to find a link to reach at a divinity of the objects. It was believed that the link was order which was determined by mathematics. It was achieved by numerical and geometrical principles. The former assert that order in architecture arises from the regularities of numerical ratios. The latter assert that architecture must emulate the geometrical order of the nature.

The integrity of the structure with space was entirely based on Euclidian geometry, proportion and harmony. Analysis of the geometry of architectural forms has long used. Euclidean geometry was formulated by a Greek mathematician named Euclid in third century B.C. He concerned himself with the fundamental properties of the sizes and shapes of objects. This method restricted him to lines, circles and figures derivable from them. These figures can be drawn by a straight-edge and a compass and nothing else. Primary geometric forms were used extensively and also appropriate with the Platon aesthetic. Plato defined universe as a compound of four fundamental substances "earth, water, air, fire" [1]. He associated four solids with these substances. He assigned the earth to cube, the icosahedron to water, the tetrahedron to fire, the octahedron to air (Figure: 3.1). Geometry was the only "architectural science" that existed until the time of Galileo.

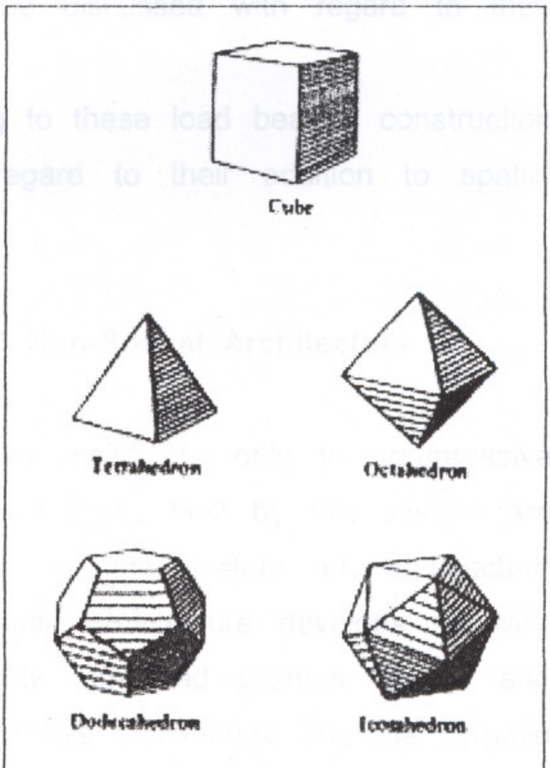

Figure 3.1. The Platonic Solids.

In this period, the method of construction is empirical and the construction technique discussed in this chapter is the product of craft tradition. It has an evolutionary pattern with the appropriate use of materials. All the materials used are natural. The structural systems below will be discussed according to the use of geometry, craft tradition and introduction of new materials. Space organizations enclosed with

[1] Stevens, Garry. The Reasoning Architect, McGraw-Hill,1990, p:75.

these structures are represented by seeking order, axiality, symmetry in this period.

There are two principle forms of construction system for architecture in the age of Emprisim. These are trabeated system (post and lintel) and arcuated system. However, megalithic mass of Egyptian architecture can be discussed in simple compression construction system. These systems arise from the natural characteristics of materials of construction, along with the processes that set those materials into place. Structures classified according to these load bearing construction systems will be discussed with regard to their addition to spatial concept.

Structures classified according to these load bearing construction systems will be discussed with regard to their addition to spatial concept.

3.2. Simple Compression System & Non-Spatial Architecture

The simplest structural system resists to only to compressive forces (Figure:3.2). Pyramids of ancient Egypt built by this system are the most impressive constructions in the history of architecture (Figure:3.3). Characteristics of Egyptian architecture develops naturally from the wish to represent a highly organized cosmos. "Order" and "constancy" indicate the basic aim of this architecture and the pyramid is generally regarded as the typical manifestation of Egyptian architecture. Its megalithic mass and precision of form appears as a synthesis of vertical and horizontal forces, and the massive and solid construction seem to embody a constant, eternal order [2].

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[2] Norberg-Schulz, Christian. Meaning in Western Architecture, Rizzoli, New York, 1980, p:7.

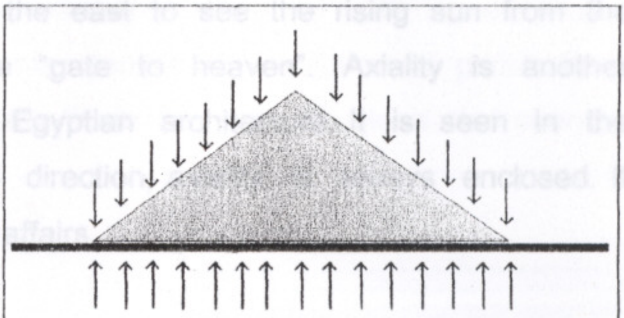


Figure 3.2. Compression Forces.

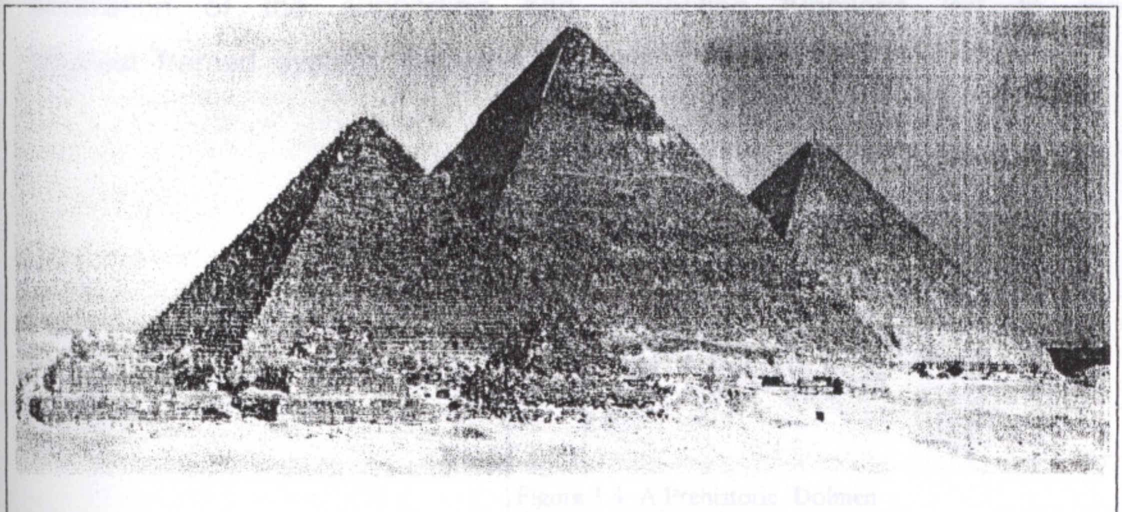


Figure 3.3. Pyramids of Mycerinus, Chefren and Cheops at Giza.

Mass and weight are abstracted as to become part of a general system of symbolic organization, in which the vertical and horizontal are unified to form an orthogonal space. This can be called "absolute space" and the pyramid acts as a materialization of it. Egyptian architecture arrives at a level of abstraction which may be considered the first integrated architectural symbol system.

Stone is selected because of its durability against external forces and its smooth surfaces and sharp edges. Cosmic order is seen in the organization of the temples. They wish to represent eternal order and concretized the idea according to the Egyptian nature and landscape.

Temples are oriented towards the east to see the rising sun from the inside and door becomes the "gate to heaven". Axiality is another distinguishing phenomenon in Egyptian architecture. It is seen in the temples. Although it implies a direction, axiality is always enclosed. It represents an eternal state of affairs.

3.3. Trabeated Structural System

In prehistoric times walls and roofs were made of the same material for a supporting "structure" and protecting "skin" (Figure: 3.4). A separation of the supporting and protecting functions led to the simplest framed system: trabeated system.

Figure 3.4. A Prehistoric Dolmen

The trabeated system is born of wood. This is the simplest method for creating the openings in walls and essentially a post and lintel frame. In this system sides of the openings act as supporting posts, the lintel on the top acts as a beam in bending (Figure: 3.5). Wood was the efficient lintel from the very beginning of the primitive hut because of its good tensile strength and light weight. The strength of wood beams allowed the supporting columns to be spaced far away. Wood was selected for the roof construction not to erect column in the temple. Because of the greater relative durability of stone, wooden lintels were rarely used in monumental buildings in Greek architecture. On the other hand, stone being weak in tension is the most inefficient bending element. Columns must be both more massive and spaced closer to support the stone lintel. Evolution of primitive hut of wood into a form of the Doric temple of stone is seen in (Figure:3.6).

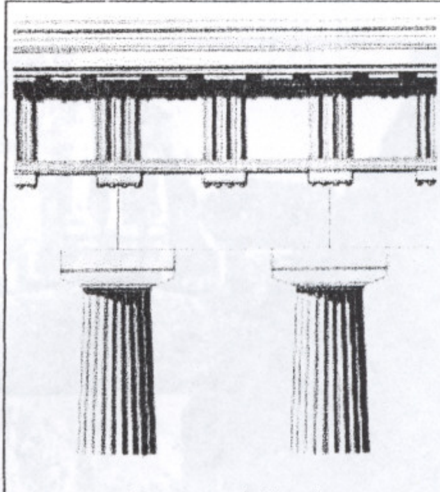


Figure 3.5. Post and lintel.

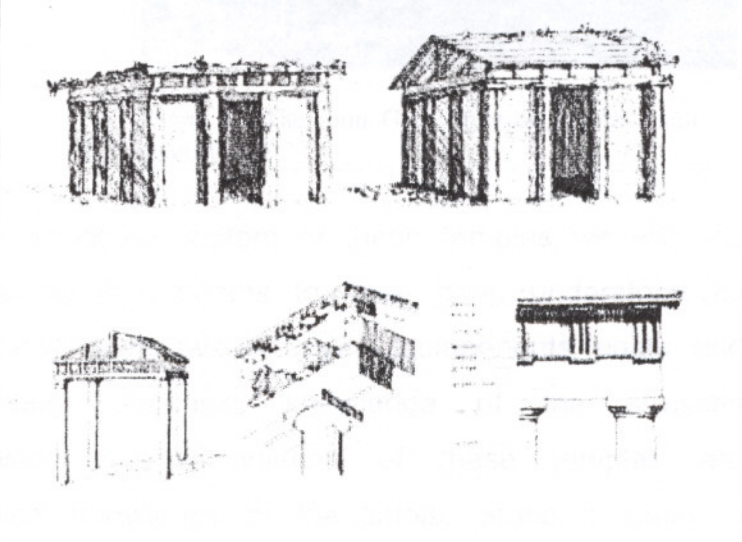


Figure 3.6. Evolution of primitive hut into Doric temple.

In mid-thirteenth century B.C. , an early example of the trabeated system is seen. Greek cultures Lion Gate at Mycenae is built with trabeated system (Figure: 3.7). The gateway incorporates a heavy lintel of which the bending moment is the greatest in the mid-section. Lintel benefits from the beam depth. The temples of ancient Greece are built with trabeated system. The plan is axial and symmetric. External colonnade is of primary importance so the appearance of these temples is as clearly defined, plastic bodies. Because of this insufficient concept of inner space Greek buildings are perceived as "large sculptures".

Figure 3.7. The Lion Gate, Mycenae, mid-thiteenth century B.C.

If we analyze the structural system of these temples, we will see that the basic structural problem seems to have been understood by the ancient designers. They have two structural components (posts and lintels) and have enough technical knowledge of the stresses (compression and tension). Intercolumniation of these temples are according to this technical knowledge of the lintels. Stone is used to build the walls and columns because of its resistance to decay. Additional columns are erected inside temple for long span wooden roofs (Figure: 3.8).

The rules used are all expressed in terms of geometry. Certain geometric symbols can be drawn to the facade or plan of temples (Figure: 3.9). Also aesthetic rules of architecture are based on various geometric ratios.

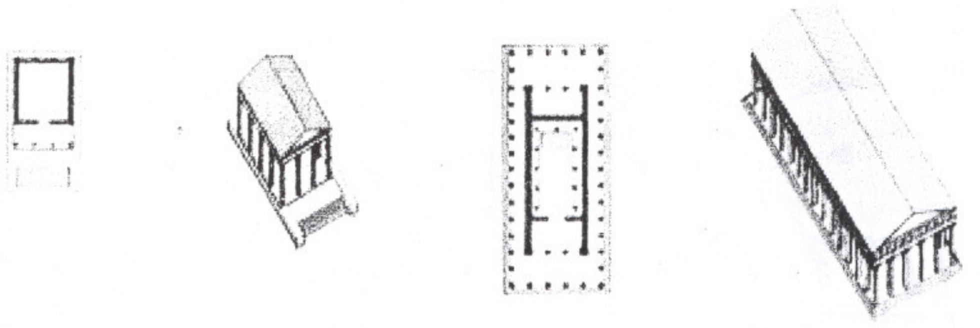


Figure 3.8. Standard Greek Temple Form.

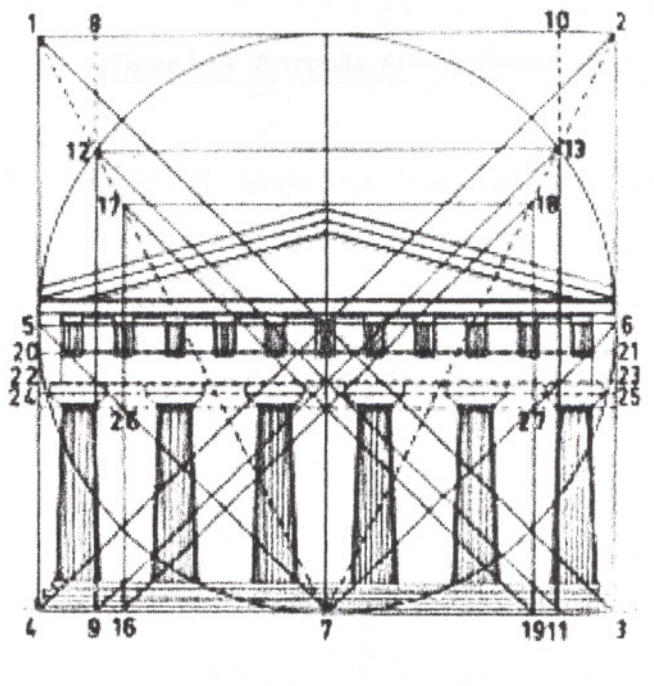


Figure 3.9. The Temple of Poseidon at Paestum

Greek temple is related to its environment. They appear clearly organized but their distribution seems irregular and haphazard. The arrangement of space outside the buildings cannot be described by means of the concepts of geometry and symmetry which determine the single building. Their seemingly haphazard distribution has a spatial function in relation to the surrounding landscape. (Figure: 3.10)

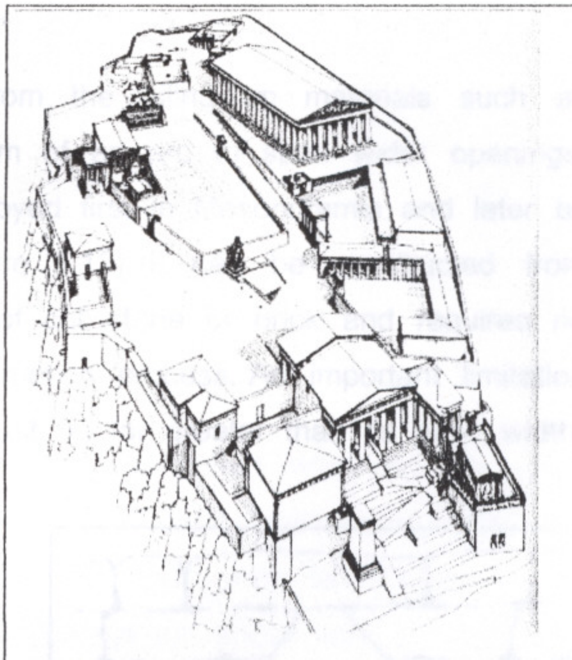


Figure 3.10. Acropolis, Athens. Reconstruction.

At present there are lots of Turkish traditional buildings built with trabeated system (Figure: 3.11). This system gives opportunity of free facade so removing the walls create a terrace for the people. Terraces give the fresh air and the view. In the rural areas these buildings are lifted over the ground to allow a space for the animals. Traditional house in the city has oriel window that is another method of integration indoors with outdoors.

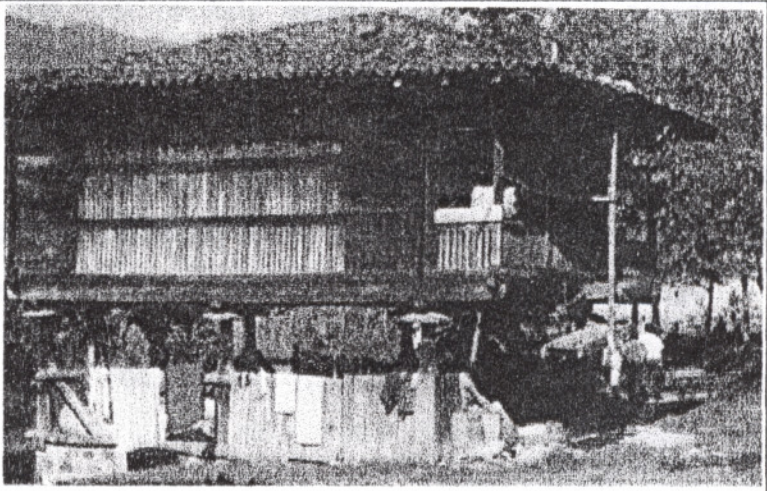


Figure 3.11. Timber System in Traditional Building.

3. 4. Arcuated Structural System

Arcuated system arises from the piling up materials such as stone, brick and earth in the form of an arc to span wider openings. The primitive arc forms are employed first in Mesopotamia and later by Greeks, namely corbel arc (Figure: 3.12). It can be constructed from relatively small elements, usually of cut stone or brick and requires no supporting centering in the construction process. An important limitation of corbel arc is that its height must be far greater than its base width.

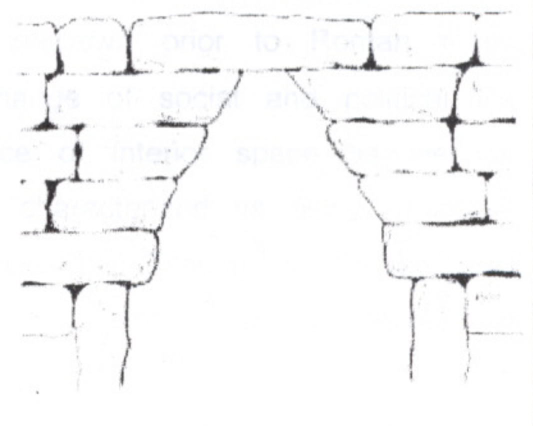


Figure 3.12. Corbel Arc Figuration.

3.4.1. Arcuated Structural System In Roman Period

Romans were the first to fully exploit arc's inherent potential. In Roman period as a consequence of development in building technique and experience, structurally a more efficient form true arc was developed (Figure: 3.13). It could resist horizontal forces as well as vertical reactions and built relatively small, easily managed elements. This system easily became a structural element of large scale buildings.

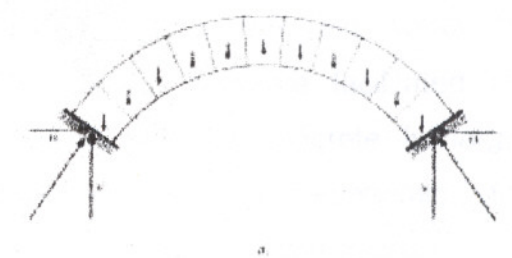


Figure 3.13. True Arc Behavior.

Roman architecture can not be associated with one particular building type, such as the temple of Greek architecture. Basilicas, amphitheaters, circuses which were unknown prior to Roman times, demanded with the increase and change of social and political life. Social activities raised the importance of interior space as well as exterior space. Roman architecture is characterized as being spatial, in contrast to the plastic architecture of classical Greece. For the first time grand interior spaces become the primary concern of architecture and are covered by a combination of vaults and domes.

To built these type of structural elements they employed a kind of concrete, which was cast to form continuous walls, vaults and domes. The developments of construction materials offered wide range of possibilities for building construction. The most common materials used in early constructions were timber, stone , fired brick. Only timber could resist the tensile strength. It's both tensile and compression stresses was changing from 150kg/m2 to 400kg/m2 , but it was vulnerable for changes in moisture, long-time loading and bedbugs. Limestone was the most commonly used stone for masonry construction. It had great compression strength but the tensile strength was depending on the mortar used as grout between the surfaces of stones. Most pre-modern mortars were basically composed of pure lime or lime and sand mixtures. They did not use the mortar under water because it was not hydraulic. It was taking mounts to dry above the ground. Unlike that, Roman pozzolana cement , consisting of dark volcanic sand and lime with water was introduced. It was hydraulic and compression strength was also far superior than lime mortars, but it was still weak for resisting the great tensile stresses. The Roman concrete facilitated the process of building. Indeed, the utilization of Roman concrete in large-scale buildings in Roman architecture was due to economic and constructional reasons rather than purely structural considerations.

Roman builders accumulated experience with construction of large scale buildings. Colosseum was the last great scale building which was erected with masonry structures of limestone (Figure: 3.14). This great amphitheater was described by the archaeologist John Ward-Perkins as "a building of not any great originality, conservative in its structural methods and choice of material as it was in design," (Mark, 1990, p:69).

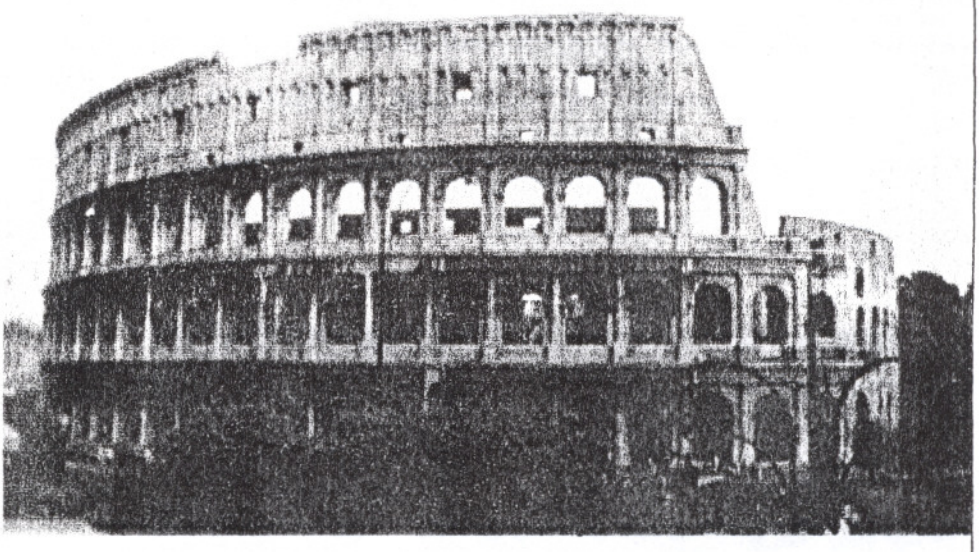


Figure 3.14. Colosseum, Rome.

Widespread use of the semicircular arc and the introduction of Roman concrete contributed to the greater buildings. An example of Roman early concrete groined vaulting was found in the main market hall of the Markets of Trajan (Figure: 3.15).

Semicircular arch allowed large openings in walls for light , access and different spatial developments of the arch form into vaulting: barrel vaulting, generated by a lateral translation of the arc ; groined vaulting , formed by two intersecting barrel vaults ; and hemispherical domes , the semi-circular arch rotated (Figure: 3.16) . The basic constructional idea that generated these domes and vaulting were still the planar arc. The success of plasticity and the three-dimensional form of these buildings depended on the successful harmony of the material , structure and form.

For a new breakout design, every factors such as activity in social life, experience of appropriate use of material, developments in construction technique were ready. As a consequence of all these developments the zenith of the reign of the Roman Empire was marked by the Pantheon constructed AD 118-128. It was a transition from conventional masonry structures of brick and stone to domed and vaulted buildings using cast 'monolithic' concrete for load-bearing structures. The dome extrados presented a much flatter, more complex profile. The progress in building technique has opened a way for a new kind of aesthetic of large-scale buildings which can be cast in curvilinear form. (Figure: 3.17)

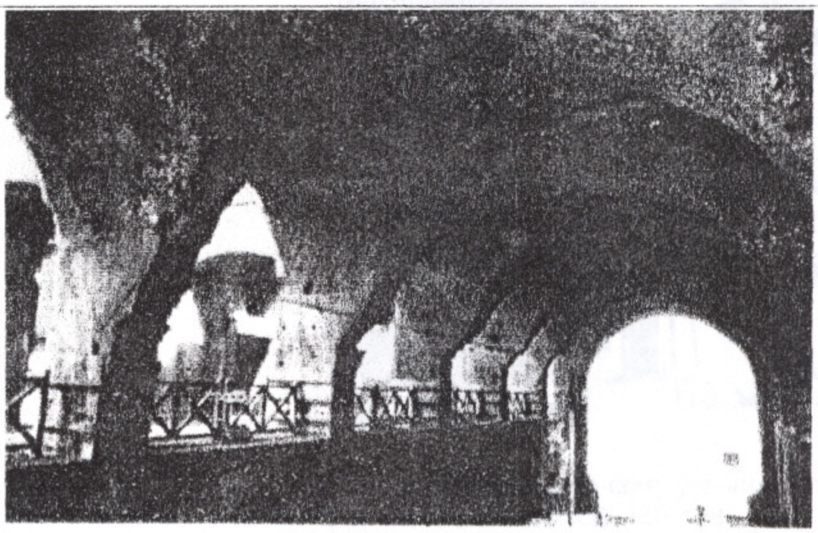


Figure 3.15. Markets of Trajan, Rome, market hall.

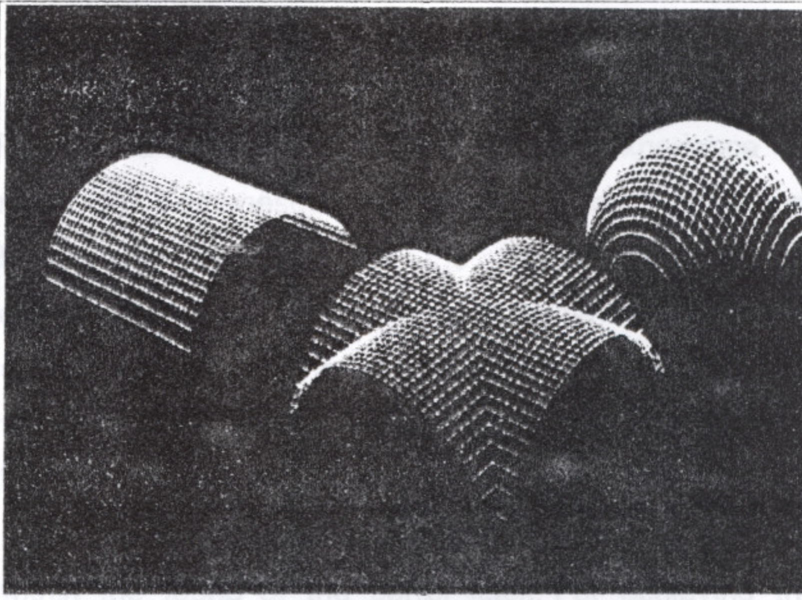


Figure 3.16. Shell forms generated from semicircular Roman arch

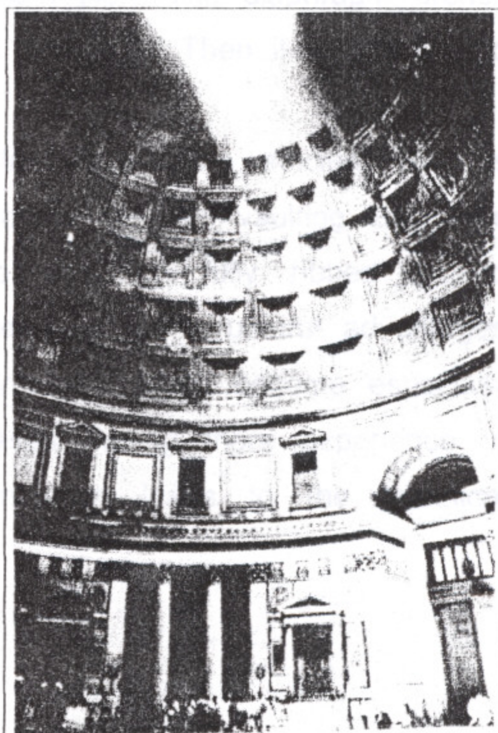


Figure 3.17. Concrete-core construction of the Pantheon, A.D. 118-128.

3.4.2. Arcuated Structural System In Romanesque Period

The need for new buildings with greater spans gave an opportunity to Roman architects to have more experience in construction technique. In Romanesque period the builders weakened the massive and enclosed character of the Christian basilica to emphasize the growing importance of the religion. When a third story was introduced to emphasize the horizontal rhythm of the building, increasing the illumination levels became an important issue to light the upper reaches of the buildings. A simple barrel vault, like an arc, requires continues rigid walls to support. As a result it can not accept window openings within the fabric of the barrel itself. For achieving this problem each nave bay of St. Philibert is covered with transverse barrel vault (Figure: 3.18). The relatively light vaults, about 6.5 meters wide by 5.5 meters in length, rests on a series of deep transverse "diaphragm" arches that connect the main piers. The diaphragm arches carry only the vertical acting weight of the vaults. Then it is possible to create openings to furnish direct light.

To reach the same solution structurally more efficient form is developed. In a manner similar to Roman groined vaulting, England's Durham Cathedral, began in 1093, is the first fully ribbed -vaulted building (Figure: 3.19). Ribbed vaults have all the structural advantages of groin vaults and also easier to construct, which become especially important as nave vault height increases. Having more experience in construction technique and light illumination leads to the technical success of the Gothic.

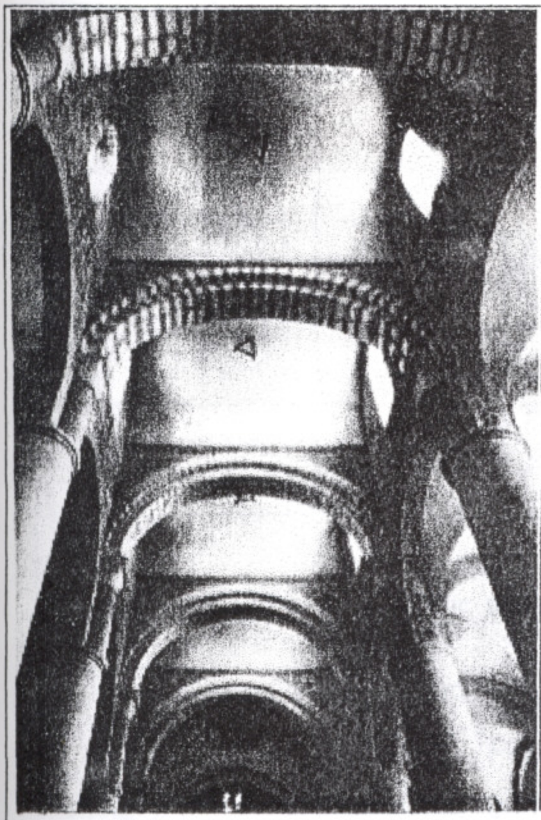


Figure 3.18.St. Philibert, transverse barrel vault, ca. 950-1120.

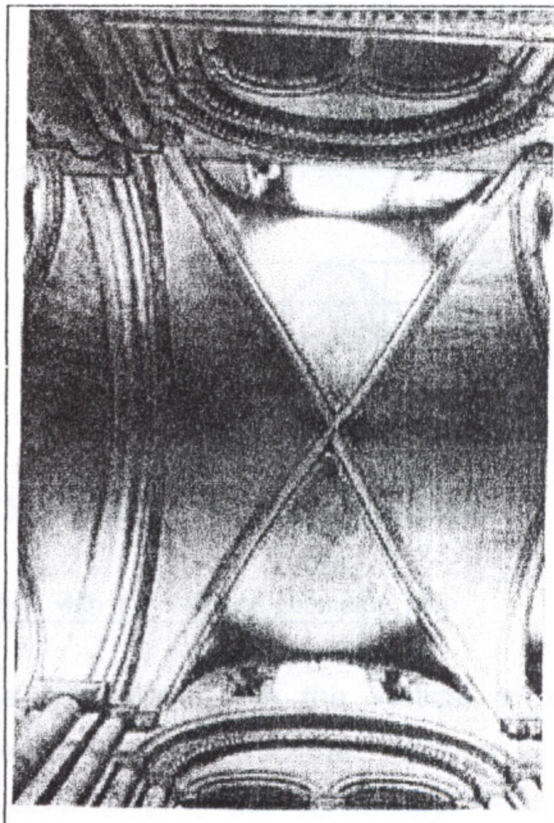


Figure 3.19.Durham Cathedral, early ribbed vaulting, ca. 1115-1133.

3.4.3. Arcuated Structural System In Gothic Period

The main features of Gothic architecture are -space, line, light, geometry- to create the transcendent atmosphere in the building. The cathedral becomes the leading building in Medieval Age, while the urbanization develops. The basic function of the cathedral is to illustrate and explain the meaningful organization of the medieval world.

According to the theory of Plato, one way to seek the God was possible with arriving at an aesthetic perfection. This perfection was achievable only through the application of mathematics and geometry to the artistic creativity. It was perceived that mathematics was a link between God and the world. in architecture a building had to be built with the correct proportioning to arrive at an aesthetic perfection. The rational aesthetic of Milan cathedral derived from a series of equilateral triangles (Figure: 3.20).

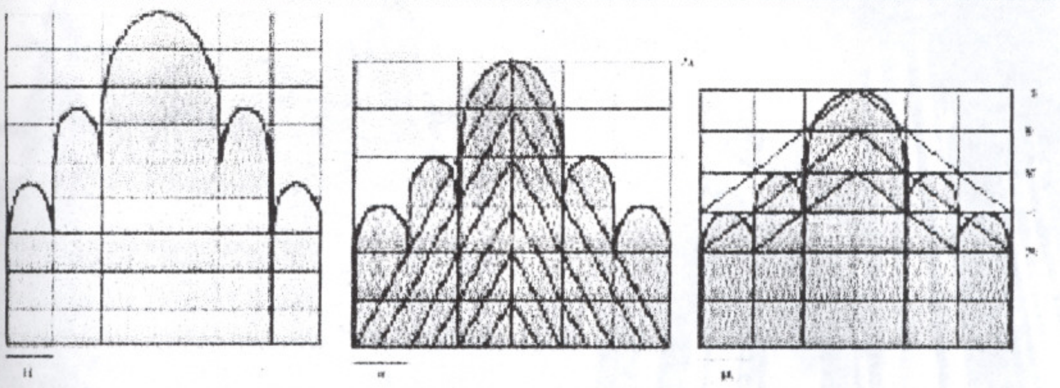


Figure 3.20.Arriving at an aesthetic perfection with the help of geometric ratio.

Feeling of rising to God was concretized with the vertical lines of the structural elements (Figure: 3.21). The structural features -rib vaulting, pointed arches, flying buttresses- entered the vocabulary of the builders during the 1120s and 1130s. These structural elements made possible to transmit the spiritualized space of the interior to the entire habitat. The interior transformed from an inert mass into an elegant configuration of lightweight, dynamic form. The meaning of the church was no longer enclosed, became part of the daily environment. To gain this end, in contrast with the continuous wall and the enclosing envelope of Early Christian church, Gothic church walls became transparent and interacted with the environment. The building technique was transformed from layers of heavy structure and closed Romanesque vaults to skeletal forms. Ribs which act like a skeleton structure transmit the weight of the vaults to the piers below (Figure:3.22). Gothic vaults and walls became so thin because of carrying only their weight. As a consequence of the structural progress wider openings were created and increased the light illuminance. Transparency offered a new interpretation to Christian light symbolism. Colored glass transformed natural light into a mysterious atmosphere in the cathedrals which seemed to prove the immediate presence of God.

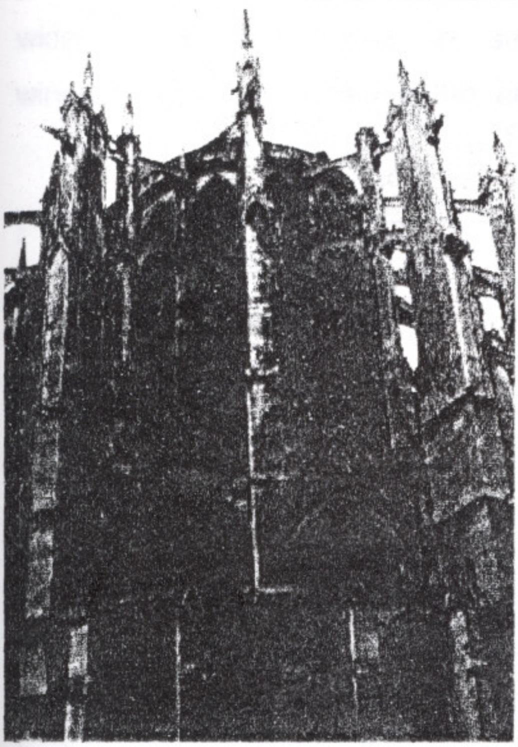


Figure 3.21. Flying buttresses.

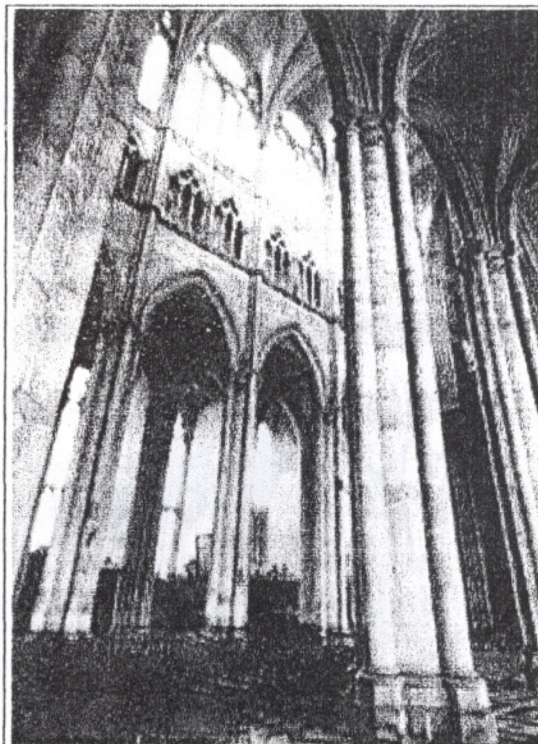


Figure 3.22. Nave of Amiens Cathedral.

3.4.3.1. Light and Wind Effect On Structural Design

Towards the Gothic period, builders increased the height of the nave to emphasize the horizontal rhythm of the building. Increasing the illumination levels became an important issue to light the upper reaches of the buildings. The builders were unprepared for the decrease in the level of natural light reaching to the floor. It was experienced that the intensity of light is proportional with inverse square of the height of light source [3].

Moreover, at higher elevations, wind speeds are significantly greater, and it's experienced before that wind pressure is proportional with the square of wind speeds (Figure: 3.23). Together with concerns

[3] Mark Robert, Architectural Technology up to the Scientific Revolution, The M.I.T. Press, Cambridge, Massachusetts, London England, 1993,p:48.

for light and wind loading, led to the introduction of exposed flying buttresses (Figure: 3.24). They resist the wind loading and contribute to wider openings. Changes in structural system led the change of window design to increase the amount if light.

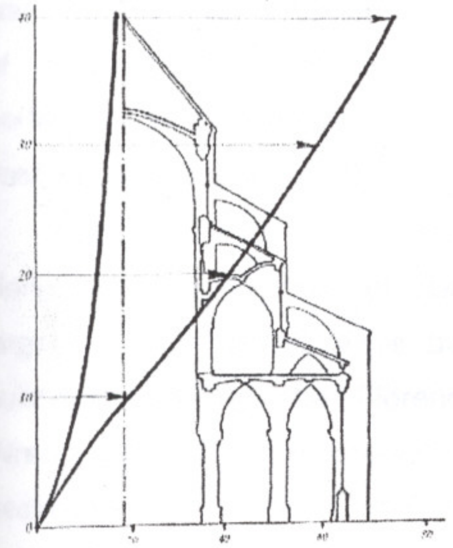


Figure 3.23.Wind Velocity Profile.

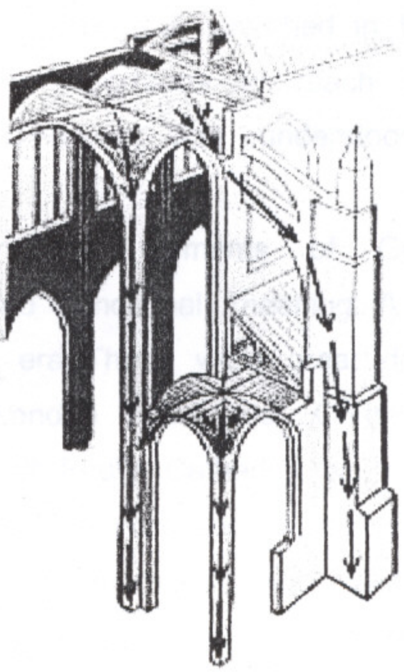


Figure 3.24. Flying buttresses diagram of forces.

3.4.4. Arcuated Structural System In Renaissance Period

Towards the end of the Gothic period, the structure was becoming structurally irrational with full of ornament. Gothic cathedrals manifested themselves with extraordinary tall steeples and in interiors mystical effect became more important than logical structure. These application expressed the end of the period.

A general understanding of the universe based on logic derived after Gothic in Renaissance period. The space concept was concretization of the cosmic order. Like the medieval predecessors, Renaissance man believed in an ordered universe and in divine perfection. Circle was accepted as the most perfect and divine form. In architecture, harmony was reflected by the central plans. This aim was satisfied by the use of elementary geometric forms and simple mathematical ratios.

They imagined the universe in terms of numbers and architecture was regarded as a mathematical science. Order was searched in terms of numbers. Proportion was the primary importance to reach at a perfection. Mathematical formula of perspective was understood to describe the space.

In contrast with functional structural elements of Gothic, Renaissance perfection of form replaced functional meaning. A few large scale cathedrals were built in the era. These were great domed buildings, including the Florence and London cathedrals. Christopher Wren proposed a double-shell dome for St. Paul's Cathedral which was destroyed by the fire in 1666 (Figure: 3.25). He proposed to replace the central tower with a timber outer dome and an inner masonry shell. His structural scheme became standard for all large dome projects of the time.

One of the main concerns of the builders in eighteenth century was building new roads and canals. In France wide roads were built for reasons of prestige rather than because of the demands of traffic. New roads made necessary a large number of bridges. This factor encouraged the progress of traditional methods of building in wood and stone. The spread of scientific spirit developed construction methods. The invention of descriptive geometry influenced building technique. They coiuld give precise form every stone to reach at a perfect proportion. The new scientific knowledge gave opportunity to the builders to use the materials in their maximum limits. They gained experience at every bridge construction and span wider openings (Figure: 3.26).

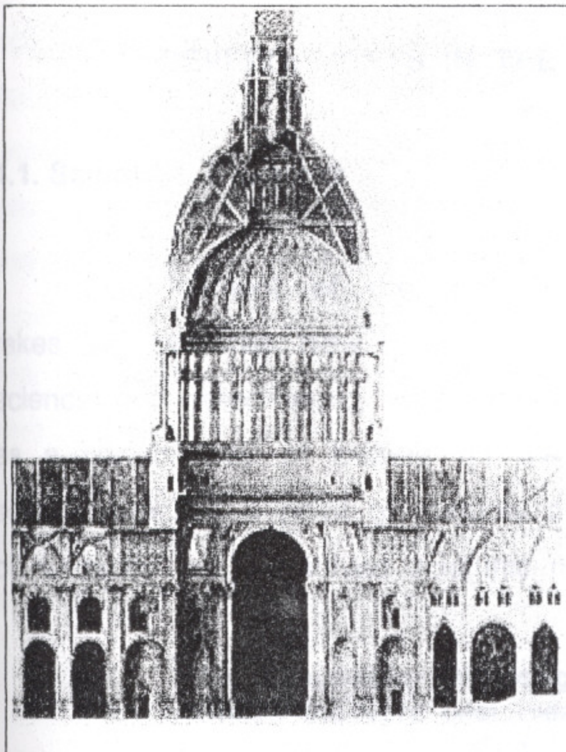


Figure 3.25.Wren's proposal for the restoration of Old St. Paul's Cathedral.

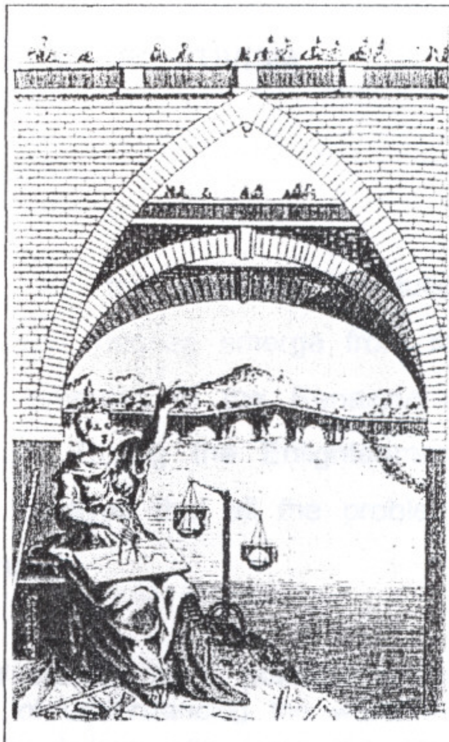


Figure: 3.26 Arcs in Roman, Gothic and Renaissance Periods.

CHAPTER 4

DEVELOPMENTS IN THE AGE OF POSITIVISM

4.1. Scientific Progress

Establishment of the groundwork for the scientific revolution takes two centuries. New inventions and new theories emerge from the science dominated world view. Positivism emerges in the Renaissance as a certain way of looking on the world. During the Enlightenment, science reaches a point of maturity. It is believed that all the problems of humanity can be solved scientific methods.

> "The enthusiastic embracing of science as a powerful means, perhaps the very best means, of understanding the world and everything in it, including human beings, was given the name positivism." (Stevens,1990, p:6.)

Positivist theory refer the idea that the proper way of doing things is to discover facts and ascertain relationship between these facts. From these relationships new laws can be set up. This process is entirely objective. The scientific revolution changes the way of builder's looking at a building. New scientific methods are introduced and the builder approaches the design with a critical eye. From now on they don't imitate the nature. It is understood that all the scientific methods are applicable to all endeavors of the humanity.

4.1.1. Perspective, Descriptive Geometry, Metric System

The most common way of representing the buildings was oblique projection before the scientific revolution. It was the standard method of Chinese and Islamic cultures and also in the pre-Renaissance Europe. It is called axonometric or isometric projections.

Perspective was the another way of drawing things. Fillipo Brunelleschi was the first known who studied with perspective. He was not only an artist of his time but also the most creative scientist and engineer. In 1435 Alberti's "Treatise on Painting" was the first study written on this subject. According to his method, a ray of light leaves each point on the object and travels through the screen or window to the eye. The image of the object on the screen is the same with the image we receive on the eye[4]. This is shown in the nineteenth century diagram (Figure 4.1). The creators of perspective were all mathematicians and all were artists at the same time. It is work of a union of art, mathematics and science. The artists learned to map the reality with mathematical rules. It is Renaissance period when perspective has been created and architects began to look at antiquity analytically.

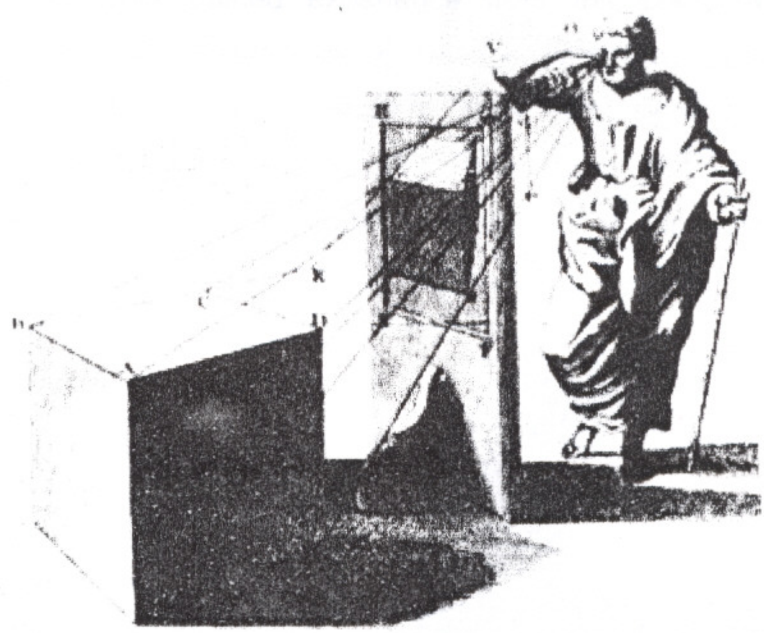


Figure 4.1. A nineteenth-century diagram to explain the perspective.

[4] Stevens, Garry. The Reasoning Architect, McGraw-Hill,1990, p:64.

Scientific research influenced building technique with new innovations: the invention of descriptive geometry and the introduction of metric system. Descriptive geometry was formulated by Gaspard Monge(1746-1818) in the last decade of eighteenth century [5]. It was the generalization of the methods of Renaissance and Monge achieved to draw the three-dimensional objects on a paper. Thus, designers has had a universal process, any arrangement of constructional elements, however complex could definitely drawn so as structure.

4.1.2. Loads, Strength of Materials, Static

As it's mentioned in the third chapter, all the structures built after scientific revolution were empirical designs having no basis in mathematical theory. Builders gained experience from the craftsman in the construction site and increased their knowledge with their personal investigations. Analytical structural mechanics was first defined by Galileo. He published "Dialogues Concerning Two New Sciences" in 1638. His work was designated as "strength of materials" (Figure:4.2).

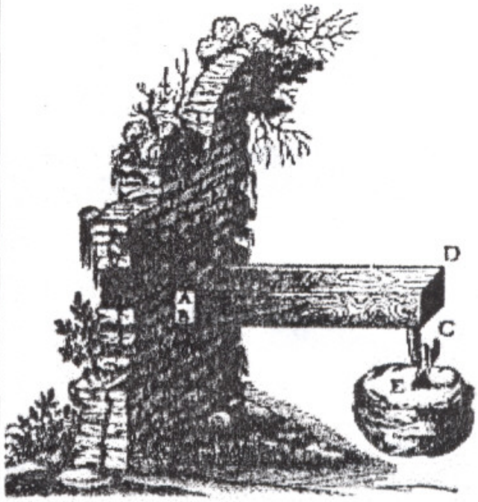


Figure 4.2.Cantilever beam in bending, from Galileo's Two New Sciences.

[5] Benevelo, Leonardo. History of Modern Architecture, ,1971, p:205.

However, the builders did not have much knowledge about load, strength of materials or theory of structures until nineteenth century. The terms "stress, strain" were used on structural design when W. J. McQuarn Rankine (1820-72) clearly defined them in his book entitled "Applied Mechanics" published in 1858. " Stress is the load per unit area of the section over which it acts. Strain is the change in length of a unit length of the material " (Singer, 1980,p:494).

Builders, especially engineers, gained experience with the spread of the scientific spirit into all Europe and the desire to learn the limits of the use of traditional building materials and systems. C. L. M. H. Navier (1785-1836) published a standard textbook in 1826 that comprises the theory of how beams resist loads and deflects under them. Eaton Hodkinson (1789-1861) studied available experimental results and carried out many tests. According to the results he produced a workable theory of the column.

A comprehensive development of graphic statics, took place in Switzerland and Germany (Figure: 4.3). This study was originated by Gaspard Monge (1746-1818) of Ecolé Polytechnique, Paris, as early as the 1780s. Projective geometry was developed by Carl Culmann and applied it in the practical design of railway bridges (Figure: 4.4).


Figure 4.4. Salginatobel Bridge, Robert Maillart, 1930.

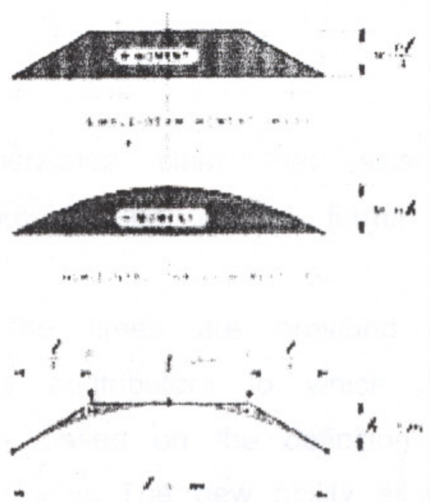


Figure 4.3. Graphic Analysis of Salginatobel Bridge.

He taught to profit from moment diagrams in designing the bridges. According to his graphic statics method an engineer could see the possibilities of form while making the analysis. He was also the first professor of engineers of the Federal Polytechnic established at Zurih in 1859.

As it is seen in the initial applications of iron, development of reinforced concrete is also the result of intuitive structural sense and empirical applications of simple tests. In Koenen's book "Das System Monier" it's recognized that the volume -changes of steel and concrete are nearly equal. This means that the adhesion between the two materials is adequate to transfer the internal forces.

As a consequence of all these static theories, the method of designing structures changed from empirical to analytical theories. Parallel to the changes in building types, scientific content of the work in construction increased during nineteenth century. With the establishment of the strength of material's theories, new body of technical specialists "engineers" were needed. They found how the structures share and transfer the loads to the foundations while drawing things with mathematical rules. Scientific understanding of the building technology enabled the engineers to use the appropriate materials, construction systems and reduced the risk of errors.

4.1.3. Analytic Geometry

Towards the modern age, it becomes clear that existing Euclidean geometry is incapable to provide the curved forms to enclose the large scale buildings.

The three-dimensional forms of the times are provided by analytic (Cartesian) geometry, the primary contributors to which are Pierre Fermat and Rene Descartes. It is based on the definition of geometric shapes by the mathematical formulas. The new ability allows a mathematically precise description of complex forms. This geometric system defines the point in space with the help of three axes, are labeled x, y and z. Descartes shows that every Euclid geometric forms and new extraordinary curves can be expressed in analytic geometry [6].

Analytic geometry expresses the extraordinary curves with simple equations. One example of interesting curves is called Lame curves (Figure: 4.5), all of which are generated by the same equation.

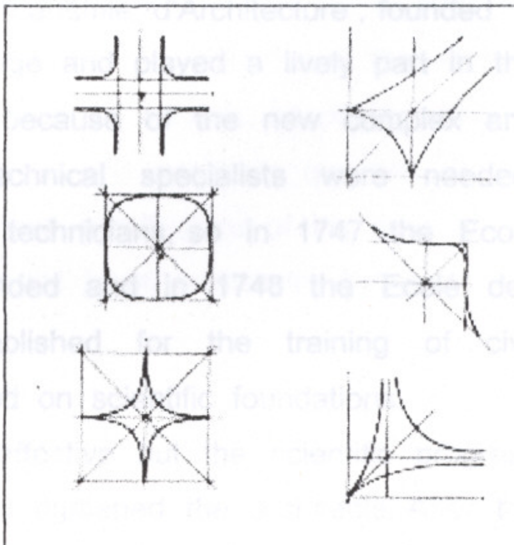


Figure 4.5. Different Lame Curves.

4.2. Effects of Education on Structural Design

Industrial Revolution has changed the social and cultural order of Europe because of transformation from agrarian, handicraft economy to a machine-dominated one , from the home workroom and shop to the mill and factory. The need for large span buildings increases such as railway stations. Many of these were designed with Neo-Clasic and Neo-Gothic exteriors. It was recognized that the only way to break out of the impasse of historical reference was to look for a completely new aesthetic forms which would suit the requirements of functional

[6] Stevens, Garry. The Reasoning Architect, McGraw-Hill,1990, p:167.

efficiency, ease of construction and structural logic. Parallel to the changes in building types, scientific content of the work in construction has increased during nineteenth century. With the establishment of the theories of the strength of materials, architects refuse to learn these technical knowledge. The division of the master builder's profession into architect and engineer was first seen in France in eighteenth century.

Within these various developments of the building technology, architecture was first taught at the Academie d'Architecture , founded in 1671. This institution had great prestige and played a lively part in the cultural life of the time. Meanwhile because of the new complex and extensive tasks , new body of technical specialists were needed. Academie refused to teach to the technicians, so in 1747 the Ecolé des Ponts et Chaussees was founded and in 1748 the Ecolé des Ingenieurs de Mezieres was established for the training of civil engineers. The teaching was grounded on scientific foundations.

At first Academie was more effective but the scientific progress expanded the tasks of engineers and tightened the architects. After the revolution of 1789 , the Academy of Architecture was closed down for a while but then, it was merged with the Academy of Painting and Sculpture and founded Acedemie des Beaux-Arts. Meanwhile, the engineer's position was strengthened and a technical school called Ecolé Polytechnique was founded in 1794 to train engineers. Some more schools with same studies based on mathematics and physics were founded, too. These technical schools were followed by many other countries. In 1806 in Prag, in 1815 in Vienna, in 1825 in Karlsruhe new technical schools were founded.

The engineers educated from these schools learned to built with the new materials iron, concrete and glass. These materials have come to be used more and more for the buildings. With the introduction of industrialized iron and establishment of theories of it, two professions moved further apart more.

A new class of designers emerged who were interested with the new laws of construction within the art form. They were interested in the use of new materials and appropriate structural forms. All these designers had engineering background because architects were conservative to use the new materials in building construction. Structure became a work of engineers.

Architects educated from Acedemie des Beaux-Arts prefered to design small-span masonry and timber buildings some more time by using the old 'rule of thumb'. They designed Neo-Clasic and Neo-Gothic exteriors for new types of buildings such as; schools, hospitals, palaces. They were interested only in the formal and aesthetic qualities of the buildings. William Morris (1834-96) defines architecture of his time as "a stylistic exercise, that nothing to do with the basic relationship between man and building" (Benevolo, 1971,p:180).

On the other hand the split between the architecture and engineer had a positive effect on structural development. For the first time structure was a work of a profession. To appreciate fully the qualities of a structure, engineers tent to learn the laws of stability and follow every innovations in building technology.

There are four stages in the development and use of a new building material: imitation, inappropriate application, conceptual application and appropriate use. When iron and concrete are introduced, the use of these materials expands quickly with the desire of engineer. The advantages of their physical properties are not obvious in initial uses. They imitate the traditional stone and wooden structures. Inappropriate applications are seen. Understanding the physical properties takes time and passes with the first three stages. This time takes approximately 150 years with engineers. The accumulation of a greater body of knowledge and practical understanding results in new methods of design and construction. Thus, specific forms begin to appear with appropriate use of materials. New materials and development in use will be mentioned in chapter 5.

4.3. New Theories

Besides the scientific revolution, new theories towards the modern architecture give birth to the skeletal structures design. There is a basic line of thought and action. When a new theory of architecture is established, it does not only establish a new way of thinking but also a new range of forms.

Towards the modern architecture rationalism, functionalism, open space theories emerge from the social, technological and cultural developments. These theories are scientific outlooks and closely related to a new idea of freedom. Progress in skeletal structure give an opportunity to the architect to give form his ideas. Le Corbusier see the column as a symbol of freedom. Skeletal structure is understood as a new interpretation of roofs, walls and openings. Conceptual use of structure is integrated with the modern space. At this point structure becomes a work of architect again.

4.3.1. Rationalism

Rationalism derived from the scientific thinking on architecture in eighteenth century. In 1753 Essai Sur L'Architecture was published by Abbe Laugier. He claimed that the source of architectural beauty was to be found in divine nature. He focused on the simple elements of pediment, column and architrave of the primitive hut. Simple, clear, structural elements were the source of architectural beauty. This idea was accepted by the Enlightenment thinkers. Especially in France designers worked to establish a theory of architecture upon it. The work of Etienne-Louis Boullée and writings of Claude-Nicholas Ledoux were the product of these new ideas. They supported the way of rejecting the theory of proportions and the classical orders. Their principle of beauty was based on clear, simple geometric solids. The character style of the building had to come from its massing, not the decorative use of the classical orders (Figure: 4.6).

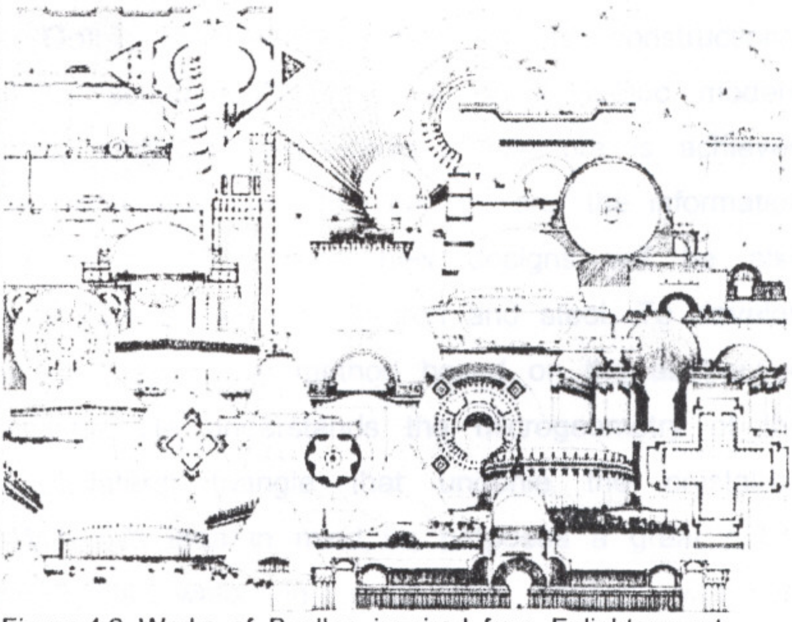


Figure 4.6. Works of Boullee inspired from Enlightenment Rationalism.

Their works were architecture of Enlightenment rationalism and the product of universally valid laws of architectural form, derived from nature. Boullee's designs were the initial applications of modern movement.

The term "rationalism" was also used by Viollet-le-Duc (1814-1879), who was the greatest restorer and specialist of his time of French architecture and built Neo-Gothic buildings. Rationalism based on logic, created a modern style of building with appropriate use of recently introduced materials. He pioneered rationalism while the others were intending to create a new style out of the old with traditional materials. Observing the details of construction of numerous early buildings is convinced Viollet-le-Duc that many of the principal stylistic elements are originally derived from the demands of the construction process or the physical laws governing structural forces. All the innovations spring from the adaptation of these laws to the buildings according to the appropriate use of material for various structural elements. He explores the structural problems of Gothic architecture and finds out that stability is achieved with organic configurations of interdependent parts. For him there is nothing confused or mysterious about the rational Gothic architecture; clarity of its constructional system, economy of its solutions. According to Viollet-le-Duc modern designers can profit by studying how Gothic architecture is achieved organic solutions with stone , and then they can transfer the information into solution in iron (Figure: 4.7). These new designs will be also rational which create a new architecture of iron and steel. To develop the organic solutions he proposes a method based on the abstraction of the nature's principles. He understands the microgeometry of the universe and the equilateral triangle that underlie the crystalline structure of matter. With this idea in mind, he proposes a great public hall for 3000 people, its walls in stone, but vaulted with an extraordinary polyhedral iron structure (Figure: 4.8). Purest modernist Buckminster Fuller actually followed Viollet's polyhedral concept.

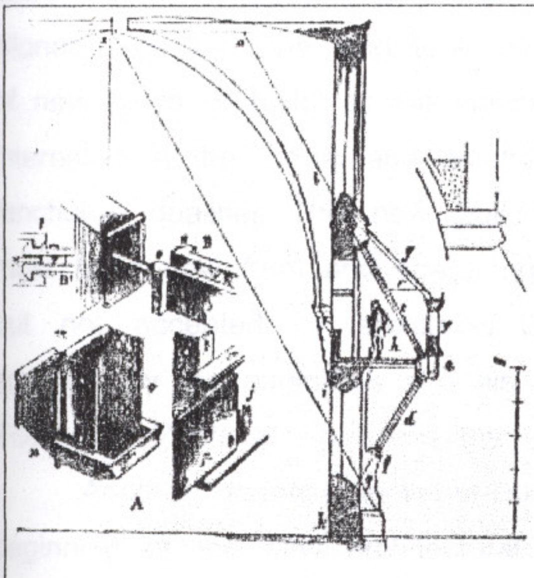


Figure 4.7. Example of Modern Structure, using iron, based on 'Gothic' Principles.

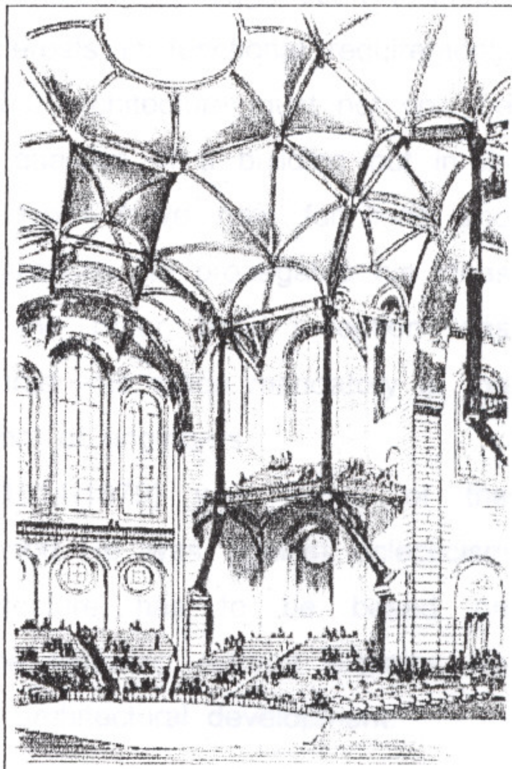


Figure 4.8. Concert Hall

Some well-known twentieth-century designers, most of them having backgrounds in engineering as well as in architecture, continued to work in tradition of Viollet-le-Duc's structural rationalism. These include Robert Maillart (1872-1940), Pier Luigi Nervi (1891-1979) and Fazlur Khan(1930-1982).

4.3.2. Functionalism

Functionalism derived from the science dominated social life of eighteenth century. There is close relation between rationalism and functionalism. Until the mid of the eighteenth century, architects designed a very small range of buildings: monumental structures for the state, palaces, churches. Architects were interested in the perfect proportion and aesthetic qualities of these buildings.

With the beginning of industrialization new types of buildings were demanded such as factories, warehouses and hospitals. However there was not any precedent form for these buildings. Jean- François Blondel was the one who took an interests in functional requirements of new types of buildings. He claims that architecture must not only be interested in the formal and aesthetic qualities of a building but in its functional qualities. The new building types have new functions and must have new form and space organizations. He propagates his ideas but not accepted by architects. On the other hand, reception was provided by the engineers and his course was made mandatory at the Ecolo des Ponts et Chausées, the school of engineers.

Another theorist, Viollet-le-Duc (1814-1879) was aware of the beginning of the new architectural period. He was against eclecticism and supported the idea that architecture has to be based on functionalism and truth of material. The following excerpt explains his thoughts of the time that influence the architectural development.

> "A thing has style when it has the expression appropriate to its use... We, who in the fabrication of our machinery, give to every part the strength and the form which it requires, with nothing superfluous, nothing which does not have a necessary function, in our architecture foolishly accumulate forms and features taken from all sides, the results of contradictory principles, and call this art" (Mark,1990, p:175.).

These and many similar observations had enormous influences to the architecture in twentieth century, in America as well as in Europe. In USA, Chicago School was founded. The importance of the school for the history of architecture lies in the nineteenth century when the argument between the architects and the engineer begins. Chicago School designed pure forms, which would unite construction and architecture in an identical expression. The famous phrase "form follows function" was asserted at this time and was generally ascribed to Louis Sullivan.

In Europe it was understood that ornamentation was unnecessary in the last decade of the ninetieth century. Before I. World War AEG Turbine Factory by Peter Behrens (Figure: 4.9) and the factory by Walter Gropius and Adolf Meyer were built (Figure: 4.10). They were the respectable designs for the architects of the time. There is no style and ornament care on these buildings. This is modern architecture based on function.

Walter Gropius pioneered the modern architecture and founded Bauhaus in Germany. Bauhaus architects attempted to find the functional form of the new type of buildings. The functional form is also the new beauty. The new beauty is discovered when its form serves the function and if it is well made of well chosen material. Functionalism is integrated with open space. To express the openness, walls has transformed into a light curtain of iron and glass. Continuity of the glass curtain and emphasizing a functional element "staircase" has achieved by the skeletal system.

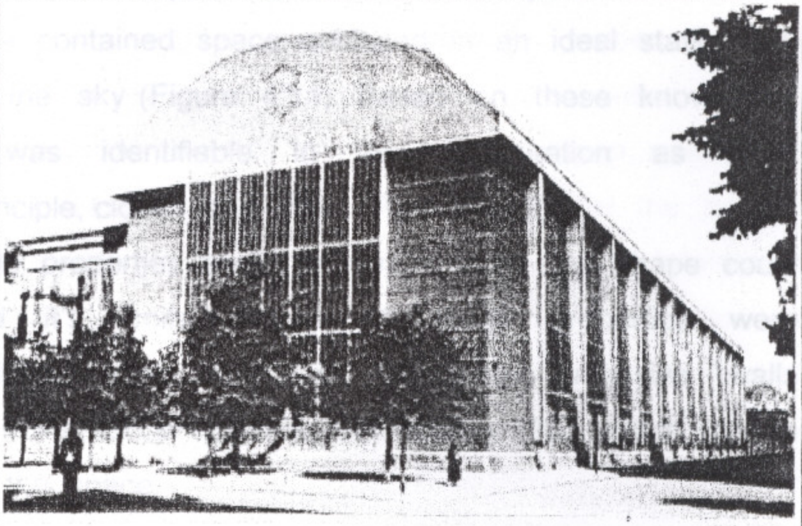


Figure 4.9. AEG Turbine Factory, Peter Behrens,1909.

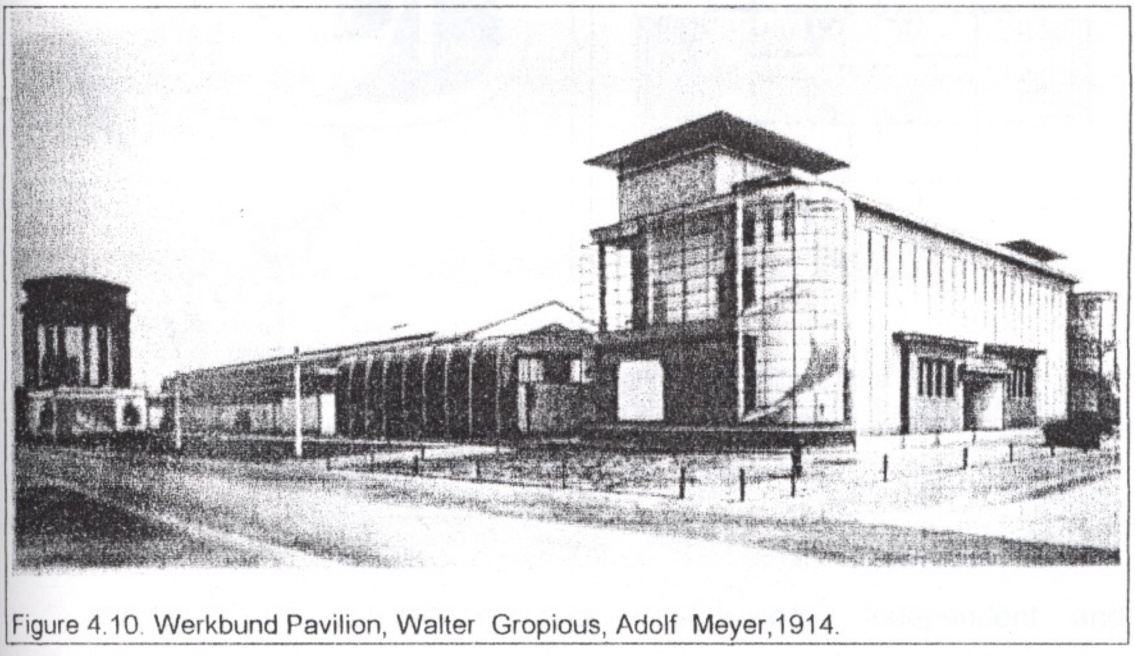


Figure 4.10. Werkbund Pavilion, Walter Gropious, Adolf Meyer,1914.

4.3.3. Openness

A new type of space perception "open space" derived from the science dominated world view. The origin of open space is connected directly with the theory of Copernic. Before his theory it was believed that universe was a contained space, enclosed in an ideal static form by the sphere of the sky (Figure: 4.11). Based on these knowledge, traditional space was identifiable in its configuration as form, discontinuous in principle, closed and static (Figure: 4.12).

It had tangible properties: scale, proportion and size. Shape could be measured and it's limits defined. All these properties were concretized with load-bearing structures. Continuous massive walls limited the space as interior or exterior. Domes identified exact spaces and vaults directed the space.

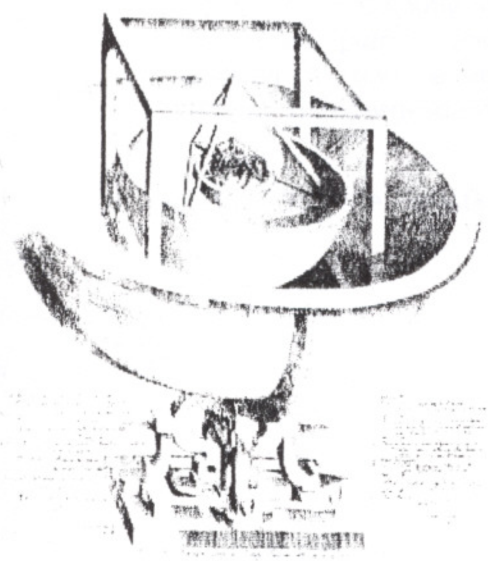


Figure 4.11. Illustration of relationship between the five Platonic bodies and the planets.

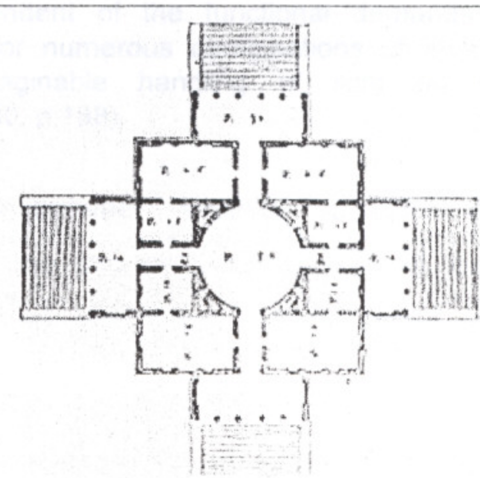


Figure 4.12. Villa Capra (Rotunda), Vicenza, Italy, Andrea Palladio,1554.

After Copernicus ideas, space has become independent and relative to the moving objects in a solar system which is open and infinite. Space has percepted as "continuous, unbounded or unlimited in every direction". Contemporary designer rediscovered the value of enclosure and the definition of the architectural space. The foundation of Modern Architecture has constructed on a "fluid, natural" space. It's possible with a "free / open" plan.

Skeletal system has given an opportunity to designer for the interpretation of indoors as outdoors. Buildings have been seen as finite objects demonstrating the infinity of space around them, raised off the ground to encourage its uninterrupted continuous flow. Open space has concretized in various ways. Frank Lloyd Wright destroyed the box to achieve a dynamic interaction of interior and exterior space. Interaction and functional domains were defined by means of a juxtaposition of horizontal and vertical planes (Figure: 4.13). In 1914, Le Corbusier defined the basic concept of the free plan in connection with his Dom-ino houses. (Figure: 4.14)

> "We have than produced a way of building -a bone structure- which is completely independent of the functional demands of the house plan... allowing for numerous combinations of internal disposition and every imaginable handling of light on the facade" (Norberg-Schulz, 1980, p:188).

He understood the relationship between skeletal structure and open space. A free plan has made the stories independent of each other and allowed for a meaningful and economic use of space and wide windows interacts nature with indoors.

Figure 4.13. Isabel Roberts House, Frank Lloyd Wright, Chicago, 1908.

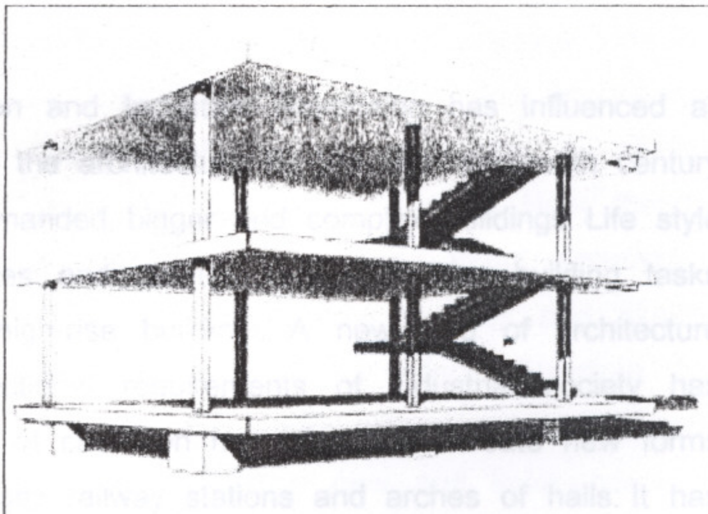


Figure 4.14. Dom-ino House, Le Corbusier, 1914.

Mies van der Rohe was also fully aware of the possibilities of skeletal structure and said:

> "The free plan and clear construction cannot be kept apart. The structure is the backbone of the whole and makes the free plan possible. Without the backbone the plan would not be free, but chaotic and therefore constipated". (Norberg-Schulz, 1980, p:190).

He achieved a synthesis of the structure and free plan with Barcelona Pavilion (Figure: 4.15). Space defining screens were combined with steel skeleton which gave order to the free plan.

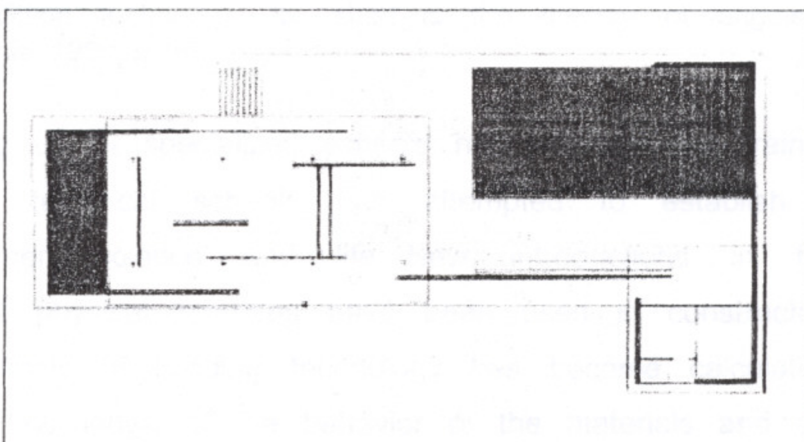


Figure 4.15. German Pavilion, Ludwig Mies van der Rohe, 1929.

4.4. Conclusion

Scientific Revolution and Industrial Revolution has influenced all the professions and also the architecture. By the late nineteenth century industrial society has demanded bigger and complex buildings. Life style has changed in the cities and created numerous new building tasks such as: theaters, halls, high-rise buildings. A new kind of architecture related to the new functional requirements of industrial society has emerged. The application of cast iron has allowed to create new forms such as suspension bridges, railway stations and arches of halls. It has become evident that the new architecture is architecture in iron. However architects refused functional thinking and ferrous materials. They focused on Neo-Classic and Noe-Gothic styles.

Parallel with industrial revolution, scientific revolution emerged in eighteenth century. While the buildings were becoming more complex than classical architecture, the knowledge of building technology could not be understood by an architect. It transformed from a science dominated by geometry, to a mathematical method. Architects left the new scientific methods to specialized people.

> We are in the midst of a transformation of the building industry. Arts and crafts are being replaced by science and technology - or should I say science guided design and mechanized production technology for short- is the domain of engineer. (Ritchie, 1990, p:46).

The setting up of specialized schools has provided the trained engineers. These technical schools has attempted to establish a connection between science and life. New introductions in the mathematical and physical sciences have been used in construction technology. The basis of building technology has become calculation methods, precise knowledge of the behavior of the materials and the knowledge of the fundamentals of static. Advanced methods has begun to influence the building design more and more.

New material such as iron, glass and concrete were added to the building industry. Scientific progress made it possible for the materials to be utilized more aptly. Production of steel and development of reinforced concrete transformed the structure to a skeletal construction and singled itself out from the envelope. New theories were established and new way of thinking and forms occurred. In twentieth century the relationship between new theories and skeletal construction was connected again by the architects. Structure has become an independent part and relationship with space has become more free. All these events has created a new and independent art form. It is the new art of structural design.

CHAPTER 5.

SKELETAL SYSTEMS

Nineteenth century is the period of new materials and developments in construction methods for architecture. These new materials in structural configuration lighten the structure and provide a new appearance to the building. The subject matter of this chapter is the scope of new space organizations based on the use of skeletal systems.

During this century, long-span roofs of railway stations and exhibition halls have been built. High-rise buildings are developed to meet the needs of businessmen who want their offices to be as near as possible to the center of the city. The designers gain experience while building new forms and learn the appropriate use of materials. These events have created a new and independent art form. It is the art of structural design. The idea that architectural style can arise primarily from technological considerations is encouraged.

5.1. Timber

Timber construction is consciously developed in America. While the population of the United States increased with the immigrants from Europe, demand for houses have arisen in all parts of the countries. There was plenty of timber but not enough carpenter. The demand was met by the invention of the "Balloon Frame" which was the first application of mass production in building technology (Figure: 5.1). Its development began in the little township of Chicago. The timbers could be cut to length, marked, numbered and delivered to the site. A man could built his house alone with a bag of nails and assembled the ready-made doors and windows.

The opening of passenger railways in Britain created a demand for long-span roofs. The initial applications of roofs were erected with wooden elements. The greatest of all wooden roofs was at King's Cross Station, London. It was built with two great barrel - vaults carried by semicircular arches of 105ft span (Figure: 5.2).

Later on, trusses are developed to be an alternative to the arch. They have been erected before their mechanics were fully understood. However the use of wood in arch and truss was short-lived. Wooden roofs corrode rapidly and replaced by wrough iron.

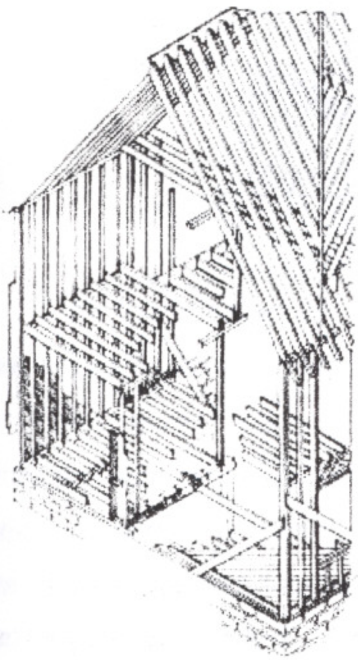


Figure 5.1. Balloon frame for a house in USA.

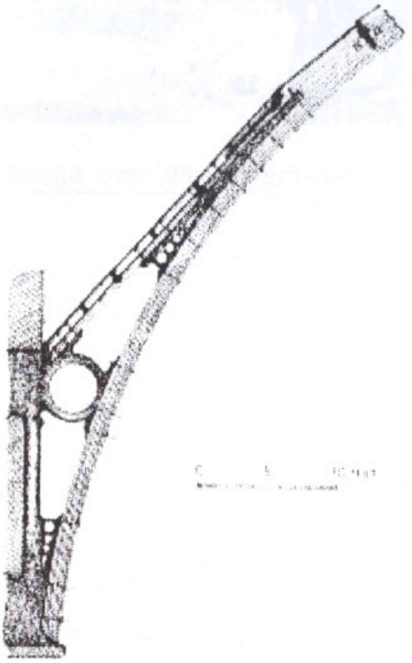


Figure 5.2. Wooden arch of King's Cross Station

5.2. Iron

The structural use of iron is first seen in England in bridges. Abraham Darby completes Coalbrookdale bridge over the River Severn in 1779. It is a great monument in the history of building technology but not a great structural art. It is the imitation of a Roman arc and its form is not appropriate with iron. It is hard to see the forces which are transferred to the ground (Figure: 5.3).

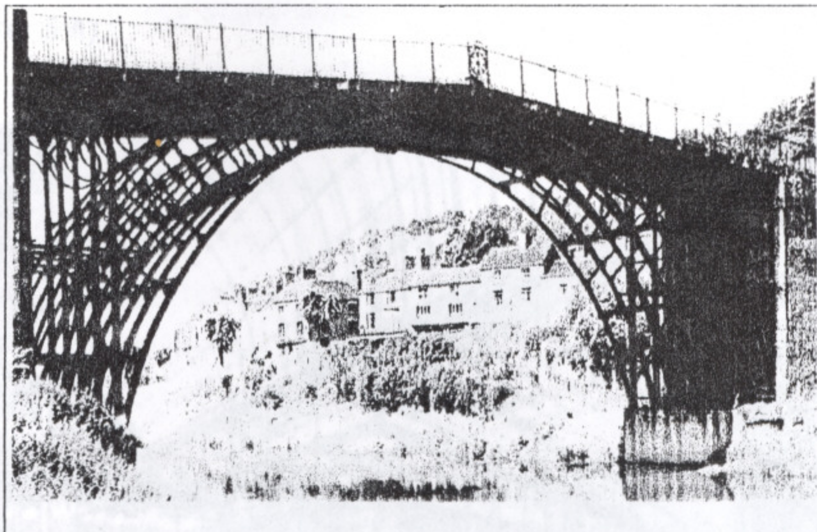


Figure 5.3. Coalbrookdale bridge over the Severn river.

In the nineteenth century the argument about iron begins among the theorists. Ruskin (1819-1900), for instance, wrote 'The Lamp of Truth' in The Seven Lamps of Architecture maintaining that "the time is probably near when a new system of architectural laws will be developed, adapted entirely to metallic construction" (Ruskin,1886, p:39). He asserted that "the material of architecture is not iron, so the roofs and pillars of the railway stations, and churches are not the true architecture" (Ruskin,1886, p:39). The proportions and laws of the structure of architecture have been determined by wood, clay and stone. The employment of iron would be leaving these principles.

In contrast with Ruskin's ideas, M. Jobard argued that "The new architecture is architecture in iron. Architectural revolutions always follow social revolutions" (Giedion, 1959,p212). Sigfried Giedion also had the same ideas as M. Jobard's and wrote the book Space, Time and Architecture. He was aware of the coming up of the new laws of metallic construction.

During the nineteenth century, new building types, some of which were large scale structures were built with iron and glass. A new spatial image was developed mainly in connection with new building tasks. Designers tried to manage the combination of openness and flexibility with a spatial order. The first large scale world exhibition was organized in London in 1851. Crystal Palace has been built by Joseph Paxton for the exhibition and marks a turning point in the history of architecture (Figure: 5.4).

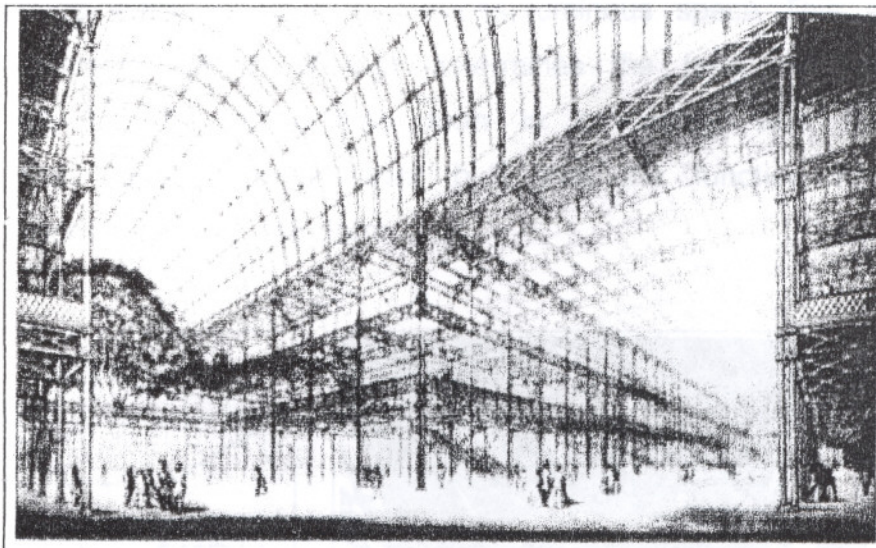


Figure: 5.4. Crystal Palace, Joseph Paxton, London, 1851.

In this building it is for the first time that iron and glass have been utilized as an architectural material. Technology determined the form of the building and the process of construction. In the mean time the prefabricated elements were produced in the factory and assembled in the site. Walls and roofs were made of glass to incorporate openness and flexibility. The Crystal Palace was recognized as a manifestation of a new kind of architecture, which proved the general belief in scientific and industrial progress.

A new spatial order has been derived with skeletal structure. In 1871, a building for the Menier Chocolate Company has been erected in the bed of a river to supply the power from the water-wheels between the piers. The iron frame structure was virtually a bridge that spanning the piers. In this building the loads from the frame were transmitted through continuous bow-girders to the masonry piers (Figure:5.5).

Another splendid example of iron and glass construction is Galerie des Machines at the Paris exhibition of 1889 by Contamin and Dutert (Figure:5.6). The skeletal structure creates a light, dynamic effect and with continuous walls of glass, a limitless, luminous space. This is another initial example that technology determines the form with its rational structure. At the same time form is connected with the function. It is the biggest building ever built that the function and structural rationalism determine the form.

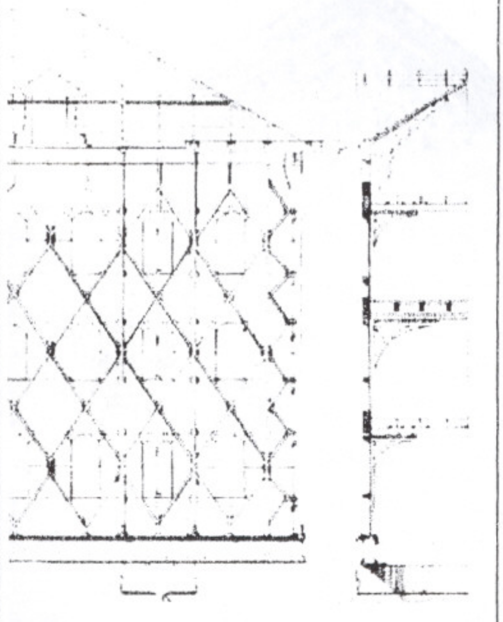


Figure 5.5 Menier Chocolate

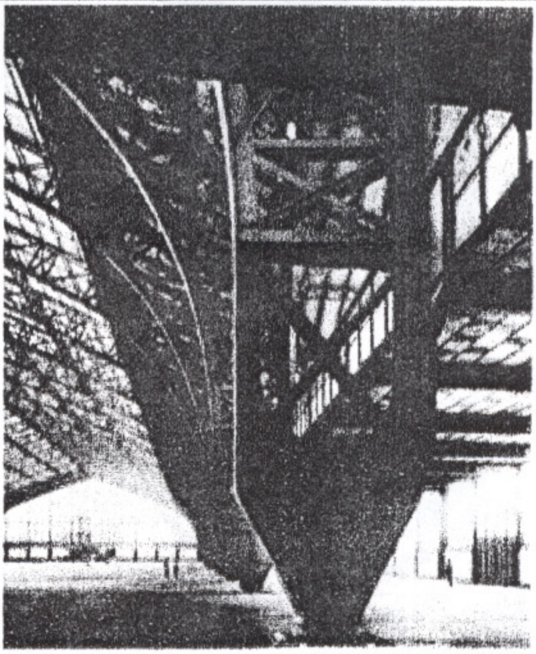


Figure 5.6 Galerie des Machines

The architects of the Chicago School introduced a new type of construction, called the iron skeleton . At that time it was called the Chicago Construction. William Le Baron Jenney who was one of the pioneers of Chicago School had played an important role in the reconstruction of Chicago and built the Home Insurance Building in 1884 (Figure: 5.7). It was the first high-rise building with a fully skeleton construction. With the complete steel skeleton it was possible to built the walls at several levels independently and simultaneously. The interior of the building was open space , with continuous , uninterupted floor areas .

Jenney seeked for the most economical forms of building to provide economical construction , open interior space , and a maximum admission of natural light. With the introduction of the sheet glass a new style of facade which displays the internal arrangement of the structure was made possible. They introduced the horizontally elongated window :Chicago Window (Figure: 5.8)

Figure 5.7. Home Insurance Building

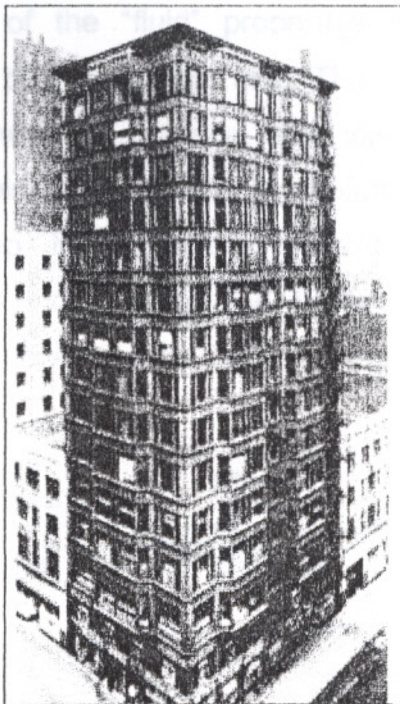


Figure 5.8 Chicago Window.

5.3. Concrete

In nineteenth century, builders have accumulated the knowledge of the durability and moldable qualities of concrete. However, an independent, innovative concrete structure was not built in this century.

On the other hand, iron was used in Coalbrookdale and in Crystal Palace.

Firstly it has accepted as fire-cladding material. By 1900 dozens of different reinforced concrete fire-proof floor slabs were erected. After various applications, concrete has begun to be realized as not just a fire-cladding for steel but also as a building material in its own right. Steel and concrete have been applied as a single inseparable unit. In early days of reinforced concrete the same methods of timber and iron constructions were also used. The method of reinforced concrete beam and slab construction has been patented in 1892 by Hennebique (Figure: 5.9). It was a conscious application of the "fluid" properties of concrete to create a structural whole of the beam and the slab. This is known as the T-Beam. It is a convenient way to increase the load-bearing capacity of the members of a reinforced concrete skeleton frame construction. That was the first step in designing reinforced concrete according to its own properties. Edmond Coignet and François Hennebique invent some new methods of construction but not any memorable forms.

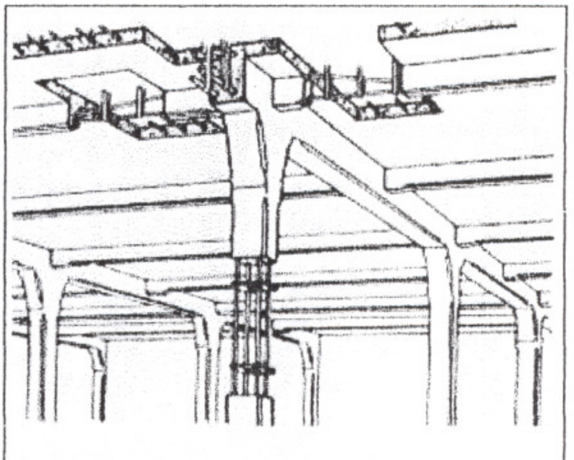


Figure 5.9. Beam and Slab Construction.

Auguste Perret (1874-1955) has a great role in making reinforced concrete a major building material in modern architecture. He used the ferroconcrete skeleton to reach at a flexible planning in his 25 bis Rue Franklin apartments in 1903 (Figure: 5.10). This building which still stands the pioneers of concrete construction. He was a pupil of Hennebique. First he worked on the concrete Stauffacher Bridge (Figure: 5.12). As it is seen from Coalbrookdale, this bridge is an imitation of a masonry bridge because he doesn't know the structural behavior of concrete at that time.

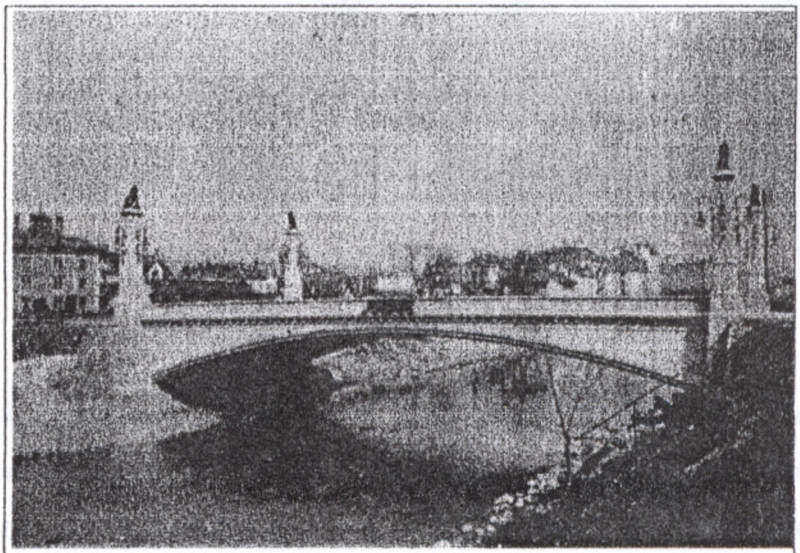


Figure 5.12 Stauffer Bridge, Robert Maillart, 1899.

With the experience he gained from each bridge he constructed, he made each one lighter than the one before. Tavanasa Bridge was his first aesthetic masterpiece, which was a three-hinged hallow-box arch (Figure:5.13). In 1930, he built his most famous bridge Salginatobel Bridge with the help of graphic statics (Figure:4.4). For Maillart, the idea of form came from right out of the analysis itself. His aim was always to lighten the structure and spanning wider without adding more material anywhere. To reach at a perfect solution he eliminated all that is nonfunctional; thus everything that remained was immediate part of the structure.

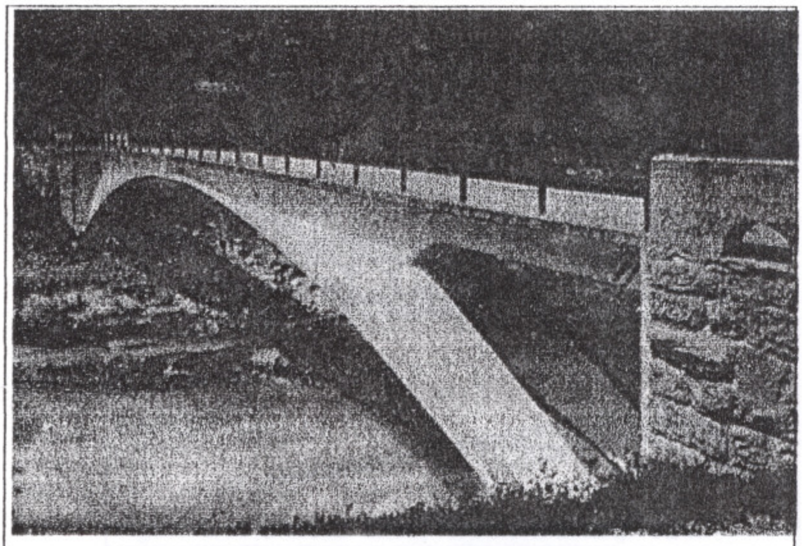


Figure 5.13 Tavasana Bridge, Robert Maillart, 1905.

He also built concrete roofs, floors and walls. In the Chasso shed, he played with form to show the technical and aesthetic possibilities of the structure(Figure: 5.14). Within that discipline, he designed a warehouse in Zurich in 1910. Floors were built with beamless slab. His design proposal derived from a new way of thinking about floors. He imitated the semi-Doric columns with hyperbolic-framed capitals. He defined these structural elements as beautiful and rational(Figure: 5.15).

These capitals show that structural design is not only a question of mere applied science. Knowing the technical possibilities do not guarantee that design will possess artistic qualities. The designers intend to find aesthetics of structure and it comes right out of the designer's imagination.

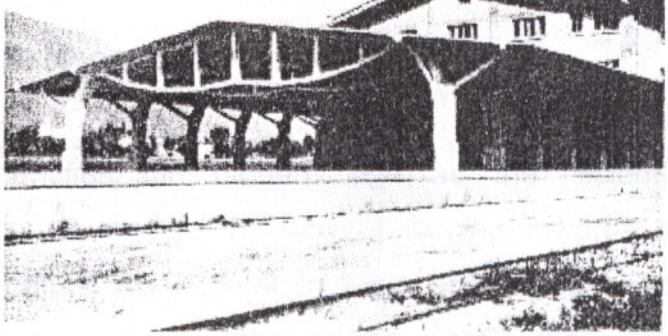


Figure 5.14 Chasso shed, Robert Maillart, 1924.

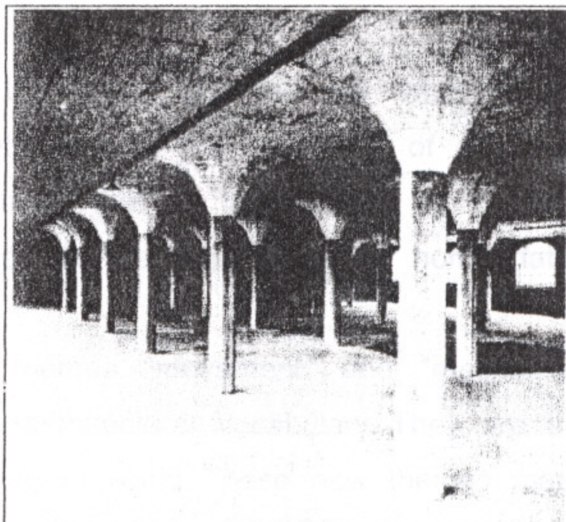


Figure 5.15 Floor of Geisshubel Warehouse, Zurich, Robert Maillart, 1910.

CHAPTER 6

ADVANCED STRUCTURAL SYSTEMS

6.1. Characteristics Of The Modern Age

Martin Heidegger identifies the modern age as the "scientific world". Developments in science change the way of looking towards the life processes of physical nature. An interest in logic and the analytical approach to natural and cultural phenomena are the basic characteristics of the modern age. Analytical approach to nature is achieved by "scientific method". Nietzsche mentions that "scientific method distinguishes the nineteenth century" (Nalbantoğlu, 1997,p:18). Method means the type of researching the objects within the limits of objective research areas. If it is possible to test and interpret the world in numbers, then it may be put under the command and use of human beings.

In architectural discourse the break between the ancients and moderns occured in the nineteenth century. The questions of architects have changed from "what" to "how" that is from object to process. Process is the fabrication based on the experience of homo faber which projects the final product.

In twentieth century new themes "movement" and "mechanical processes" have entered into the architectural vocabulary. They are the reflection of the emerging technological world. These new themes mean the breaking away from the platonic idea of a static world from which nothing can be added or taken away, a concept which dominates architecture since the beginning. Twentieth century architecture is seen to be indeterminate and containing both permanence and transformation.

The modern society can be seen as a development towards lightness. With the mass production of cars we move faster and space becomes lighter and more open. Developments in communication from telephone to internet people become closer and are exposed to different cultures more easily. This way of life "being closer" destroyed the borders. New building technologies improved with these social concepts. New materials like steel, glass and concrete, skeletal frame and skin construction allowed architects like Le Corbusier, Mies van der Rohe and Eero Saarinen to create the initial light and open buildings which are parallel to a vision of an open society. These completely new forms were impossible to imagine based on pre-Industrial Revolution ideas.

A new formal understanding and aesthetic of the architectural object emerged in the twentieth century. Structural aesthetic changed with the new basic principles and laws. Gropious, who is the founder of Bauhaus pioneers this theme and maintains: "As history shows, the concept of beauty has changed along with progress in thought and technique". (Hartoonian, 1994, p:35). A similar statement is declared by Nervi "Every improvement in the functional and technical efficiency of a product brings about an improvement in its aesthetic quality (Holgate, 1986, p:67). For him the result is truthful style and its characteristics are structural essence, a necessary absence of decoration, a purity of line and shape. If a building is correctly designed structurally, beauty shines from the correctness of the structure. It is not a matter of which material you use, but more about how you use it. Truth to material is a tenet of the Modern Movement.

Innovation derives from technology, new modes of calculations and new theories with the architect's intuition. Developments of structural design in the Modern Movement are based on new inter-relationships of theories of statics and dynamics, on pure mathematics and on the development of construction techniques, the use of new materials and the architect's intent. Knowledge of building technology changes from craft to scientific knowledge and materials changes from natural to organic. The foundation of structural design is the knowledge of material. These are the iron to steel, reinforced concrete to prestressed concrete and lightweight concrete, glass in large panels, metal sheets, aluminum and a large number of plastic materials which offer a wide variety of new forms and types of structures. Industry invents and develop these new forms of load-bearing structures. Skeleton structures, shells, folded plate structures, suspended roofs have appeared. The free span of the bearing structure becomes wider and wider. Structures explored in this chapter are based on the knowledge of the principles of statics. These principles defines; "a state in which opposite forces of equal strength serve to cancel each other out" [7]. There are different building materials and construction systems for the statically necessary bearing structure, for the encasement of interior as well as for the surfacing outside. Designers give plastic expressions to the static principles to reach at a perfect form. These forms are based on analytic geometry and computer makes all these three dimensional forms calculable.

The performance of the structural element is determined by its form which is designed according to the knowledge of the properties of material. The greatest change in structural design resulted with the tensile strength properties of materials and developed due to the increased tensile strength of the materials. In recent years impressive progress and important changes have taken place in structural design with the use tensile capability of the materials. This chapter explores the relationship between advanced structures and formation/definition of spatial organization according to the forms and properties of materials.

6.2. Form Active Structures

Form active structures are those based on the principle that the loads are carried through the shaping of the structural surfaces. The

[7] Aspects Of Modern Architecture, Architectural Design, Academy Editions, London, 1991.

new carrying capacity is obtained not by increasing the amount of material used, but by giving it a proper form. These structures both carry and cover the space. Included in these structures are compressive shells, tensile cables networks and air-supported tensile membrane structures.

6.2.1. Compressive Form - Active Structures

At the turn of the century, characteristics of reinforced concrete developed quickly and many of the plastic shapes and forms have been created. Master builders developed the structural solutions and new forms, stretching the performance of the concrete to its limits. The maximum efficiency of concrete obtained from its fluid property is achieved through the introduction of load-bearing surface structures *'shells'* in the early 1920's. Most of the thin shell structures are based on three dimensional curves: "the cylinder, the sphere, the hyperbolic paraboloid and the folded plate" (Figure: 6.1).

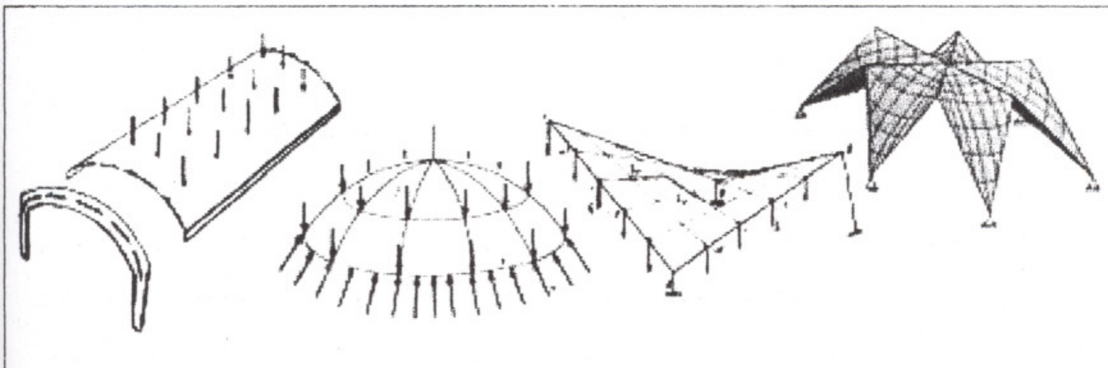


Figure 6.1. The cylinder the sphere, the hyperbolic paraboloid and the folded plate

The recent history of architecture can be seen as a development towards lightness. Shell is the one way of creating the lightness and great flexibility of modern form. One of the first uses of a relatively thin-shelled concrete technology is by Eugene Freyssinet for an airship hangar at Orly in 1921 (Figure: 6.2). It is an early twentieth century example of massive buildings that are weightless. It is essentially a huge elongated ribbed barrel vault and curvilinear movement is recognizable in the concrete structure (Figure: 6.3). It is an advanced model of Gothic ribbed barrel vault.

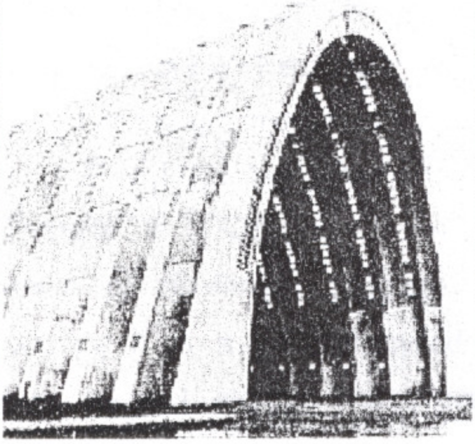


Figure 6.2. Airship Hangar, Eugene Freyssinet, Orly, France, 1921.

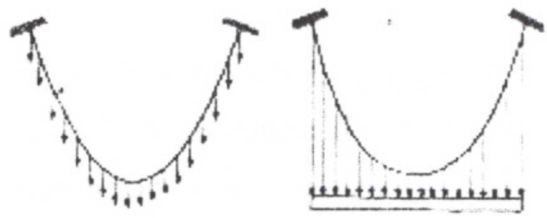


Figure 6.3. Funicular Forms.

Concrete shells have flourished in the 1950's and enjoyed great popularity among architects and engineers. They are at the extreme of structural design. It allows to solve the multitude of possible forms for shells. With the invention of computer in 1949, the designer has the capability of determining the stresses within a structural member 10.000 times faster than ten years ago.

To explore fully the qualities of a material the designer must know a lot about it. This requires an intuitive ability to read a building as a structural object and technical knowledge as well. Nervi explained his idea as:

> "It's obvious that engineering and the mental make-up produced by engineering do not suffice to create architecture. But it is just as obvious that without realizing the techniques of engineering, any architectural conception is as non-existent as an unwritten poem in the mind of the poet" (Architectural Review, 1958, p:118).

Before the material can be effectively utilized, industry must be adopted to the new conditions. Appropriate use of material and construction methods determine the form of the structure. The industry has an important role in reaching at new methods of design and construction technology. With a great body of knowledge and practical understanding, specific forms which are appropriate to the new material begin to appear. Pier Luigi Nervi realized the potentialities of concrete and in such an imaginative way created the unforeseen forms.

Pier Luigi Nervi designed a large hangar for Marignane airport in Marseille in 1935 (Figure: 6.4 , Figure: 6.5). A structure of a basket-weave of reinforced concrete ribs support a thin shell of reinforced concrete. It is a part of cylinder and also an intersection of a series skew parallel arches. The precast pieces are lifted into the place by jacks. The role of Nervi here was also thinking the fabrication process.

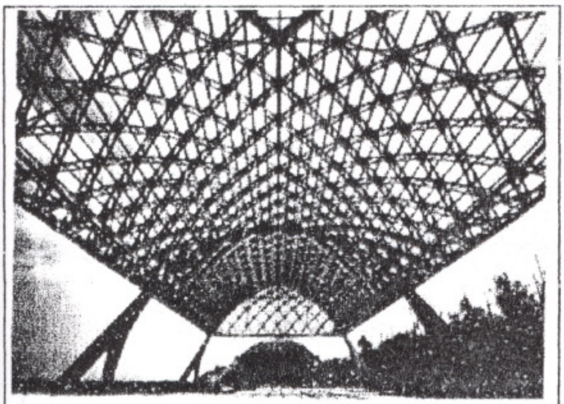


Figure 6.4 Air Force Hangar, Nervi, Orvieto, 1935.

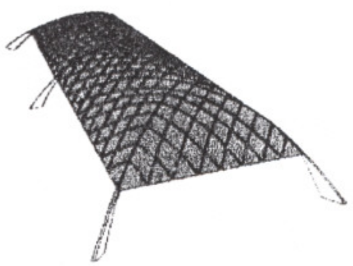


Figure 6.5 Cylindrical Roof.

One of the earliest concrete shells was built to house the first planetarium, created by Carl Zeiss Company. Its reinforcement is composed of triangularly tied steel bars. It is almost a geodesic dome and gives a wonderful impression of light-weightness (Figure:6.6 , Figure:6.7).

Figure 6.6 Framework for the Zeiss Dome.

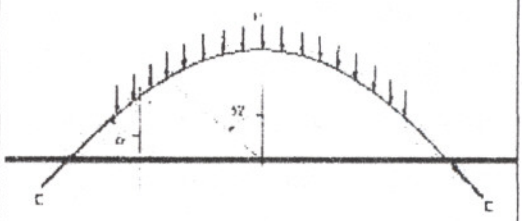


Figure 6.7 Forces applied on Dome.

Concrete shells have an important disadvantage. They are difficult to construct. These structures require a formwork. The formwork for such shells are complex and expensive. It is also a problem to pour and set concrete on a curved surface. For this reason ruled surface structures are designed. A ruled surface is one on which lines can be drawn. A doubly ruled surface is called a hyperbolic paraboloid (Figure:6.8 , Figure: 6.9). Both of these ruled surfaces can be constructed with straight formwork and easy.

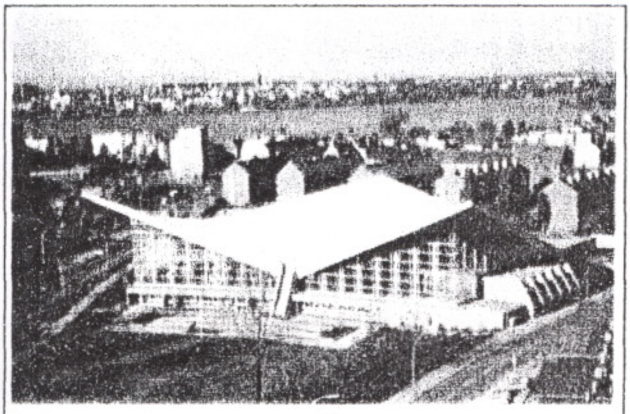


Figure 6.8 Hyper shell roof, Hamburg, 1967.

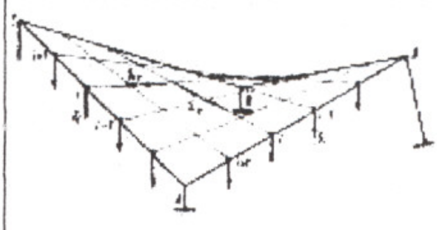


Figure 6.9 Hyper shell provided by lines.

Understanding the behavior of elasticity in structural concrete enabled Nervi to achieve the full potential of the cantilever (Figure:6.10). Tensile forces on the top and compression forces beneath the cantilevered beam are clearly realized. Eduardo Torroja is also aware of the structural elasticity and natural strength of certain shapes in concrete. By taking away redundant material, the scheme develops towards an economic, structural and visual balance (Figure: 6.11). The roof of the TWA terminal building is proposed by Eero Saarinen from a parabolic geometry of which is composed of four cantilevered shells (Figure: 6.12). He expressed the lightness of the terminal with the cantilevered construction and the delicacy of glass curtain wall. This method allows the space to define itself beyond its enclosure. All these engineers' desire is to push the structure to its expressive limits. Their buildings don't contradict the basic laws of statics. In fact they make a positive expressive virtue of the inherent logic of the structure.

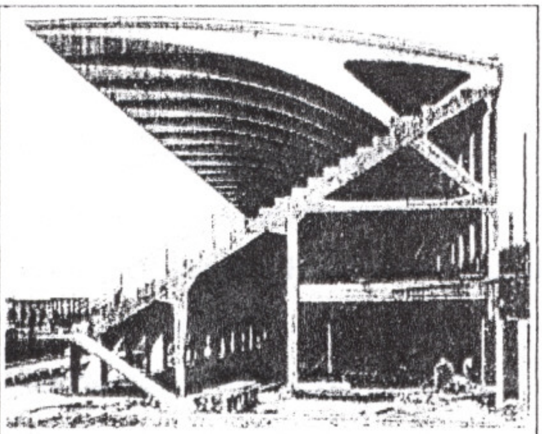


Figure 6.10 Cantilever Roof, Nervi.

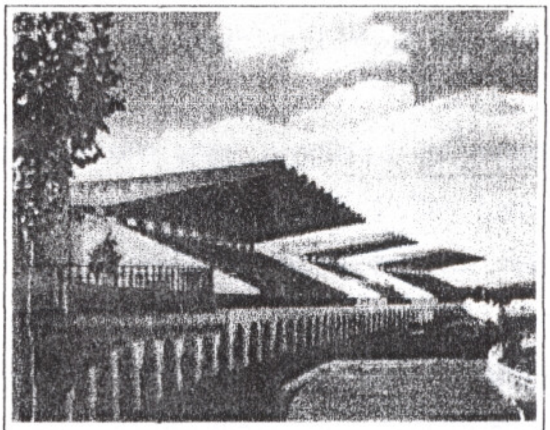


Figure 6.11 Cantilever Roof, Torroja.

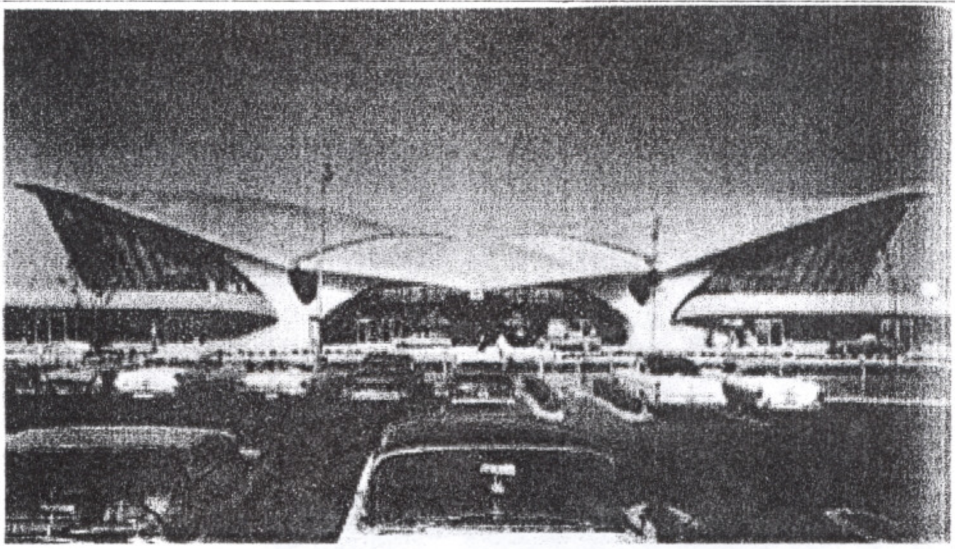


Figure 6.12 TWA Terminal, Eero Saarinen, 1962.

1950's French architecture was based on the relationship of art and technology. The aesthetic expression of structures gains importance again in the post-war years with the rapid erection of industrial and cultural buildings. Jean Prouvé designed a wide spanning system of parabolic vaults and attached curtain walls in glass and steel to CNIT (Figure: 6.13).

Compressive form-active structures are also produced in metal. After World War II another important person, Buckminster Fuller came into prominence. He transferred the technology developed by war into building industry. He used the new materials like plastics and lightweight metals. The strength to weight ratios of these new materials gave an opportunity to create new forms of buildings and construction systems. He was the great inventor of his time and pioneers the use of technology in architecture. Fuller seeked the maximum performance from a minimum material. He worked on the space frames and geodesic domes that are mass produced in quantity and easily transportable by a helicopter. He managed to integrate design and technology with a technical background to form the building's expression (Figure: 6.14).

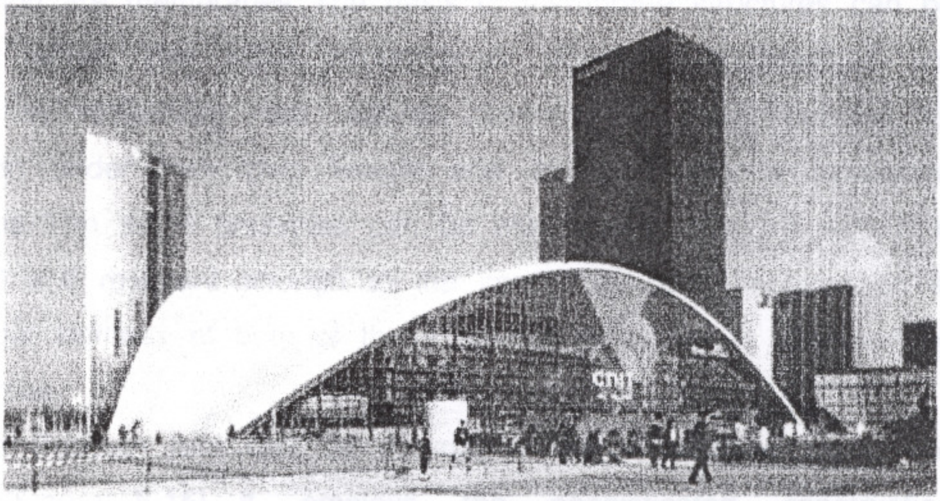
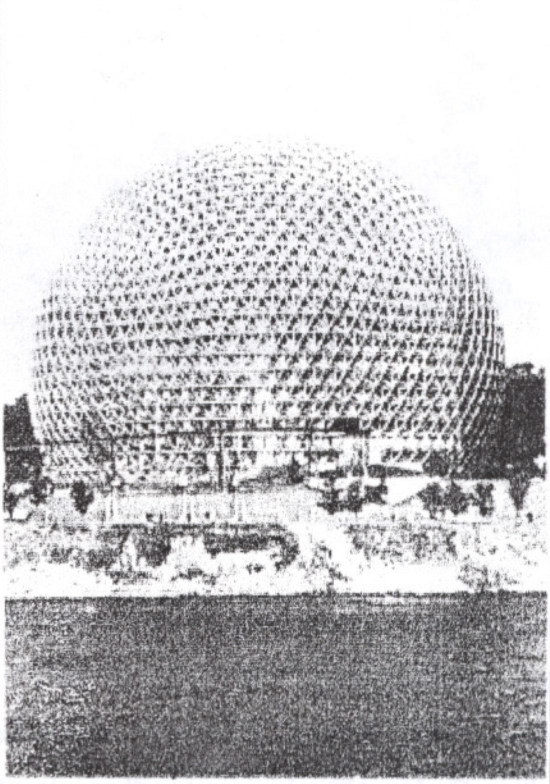


Figure 6.13 CNIT, Jean Prouvé, Paris, 1955.



Fuller 6.14 US Pavilion, Buckminster Fuller, Montreal Expo, 1967.

6.2.2. Tensile Form - Active Structures

Membrane structures are also form active structures. Shells in pure tension are membranes. The basis of membrane structures can be found in nature. The initial experimental works of membranes are achieved by observing the natural forms like soap bubbles. Its deformation under their own weight and applied loads is similar to membranes. The same principles can be observed at spider's web. It is lightweight and resistant enough to the impact of loads imposed on it. The internal stiffness of both of these natural structures is achieved by tensile forces.

The Bedouin tent can be exemplified as a primitive membrane structure (Figure: 6.15). It employs the sophisticated construction techniques within the limitations of the available materials. It consists of a tent that resist the tensile forces and masts for the stability of tent under compressive forces.

Figure 6.15 Bedouin Tent.

Virtually, the development of membrane structures has taken place after the Second World War. The reason can be explained with two factors. After the war, new materials which have the appropriate qualities of lightness, stability and strength were developed. On the other hand structural design problems were solved with new techniques. Frei Otto realized the importance of membranes for the future. Since the 1960's, Frei Otto, Horst Berger and David Geiger pioneered the idea of using membrane for architectural structures. They claim that only membranes are truly lightweight, that is to say that only the membranes are suitable to span the long areas. They have infinite organic form possibilities but are also disciplined by the laws of nature. The new forms are generated with double curvature geometry (Figure:6.16).

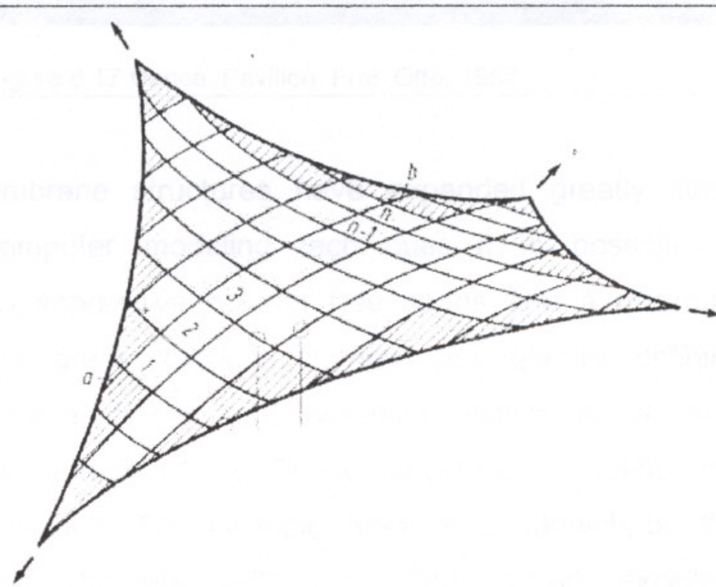


Figure 6.16 The principle of a double curvature membrane.

Architectural ideas can expand through almost boundless three-dimensional space of membranes. Membrane structures give opportunity to designers to discover all the unexplored potential of the transparency and lightness. These structures are generally designed for a high degree of flexibility (Figure:6.17). Despite their durability, membrane structures have significance that they are temporary structures and are rarely used for conventional buildings. Nevertheless it is still hard to imagine a municipality building to be enclosed with a membrane roof.

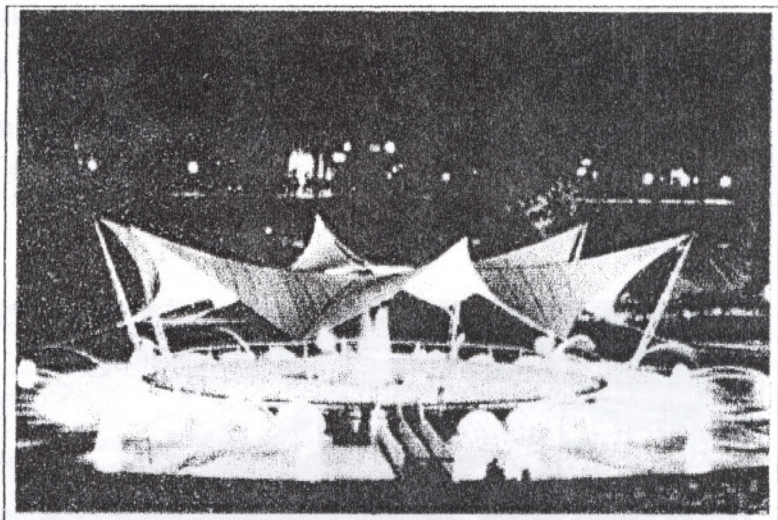


Figure 6.17 Dance Pavilion, Frei Otto, 1957.

The possibilities of membrane structures have expanded greatly since the development of computer modeling techniques. It is possible to enclose large areas with impressive column free spans and a minimum amount of material. The great freedom is now possible in defining these new convex-concave forms and volumes which is a new interpretation of indoors and outdoors. These structures redefine the meaning of inside and outside. The Olympic Stadium in Munich, by the architects Behnisch and Partners with Frei Otto is an excellent example of this new integration of space and structure (Figure:6.18 - Figure:6.19).

The scheme was the first of a competition for the necessary stadiums of the 1972 Olympic Games in Munich. The committee set the themes. The building had to reflect the nature of democratic post-war Germany. It should have minimum impact on the natural and visual environment, blending as far as possible with landscape. Transience could be managed by temporary structure. Günter Behnisch possibly inspired by Frei Otto's roof for the Montreal Expo of 1967 and the theme of transience, decided to propose a membrane roof structure for the stadium. The scheme was considered to be an outstanding realization of the competition themes. However except Frei Otto, this complex roof was claimed unbuildable by the engineers of the time (Figure:6.20). The roof modified for stability reasons and erected with Otto's wide experience of tensile structures without any major changes in form.

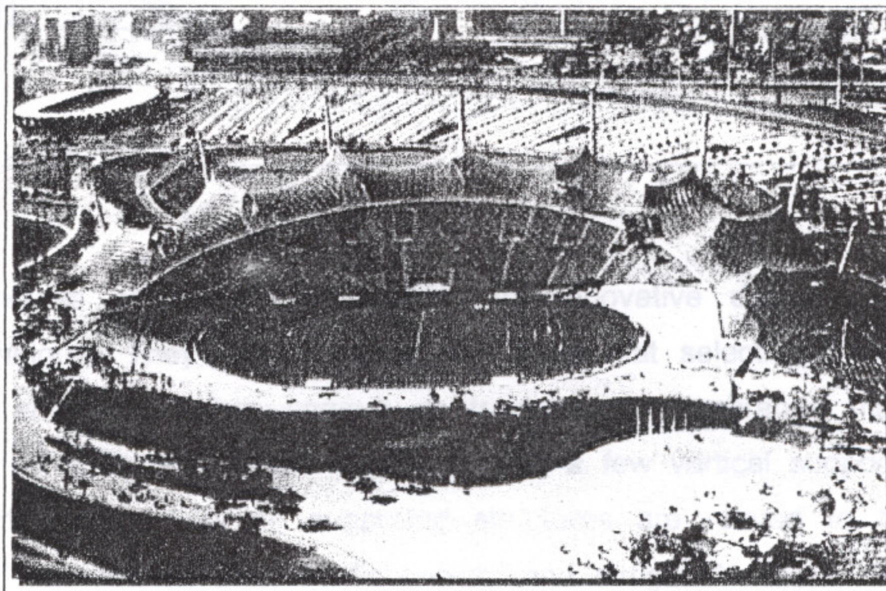


Figure 6.18 Munich Olympic Stadium, Günter Behnisch, 1972.

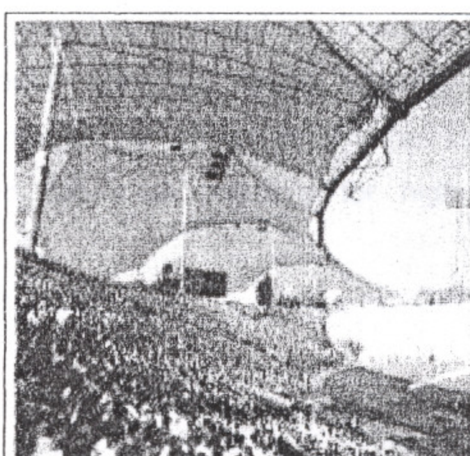


Figure 6.19 Impression of the Completed Roof.

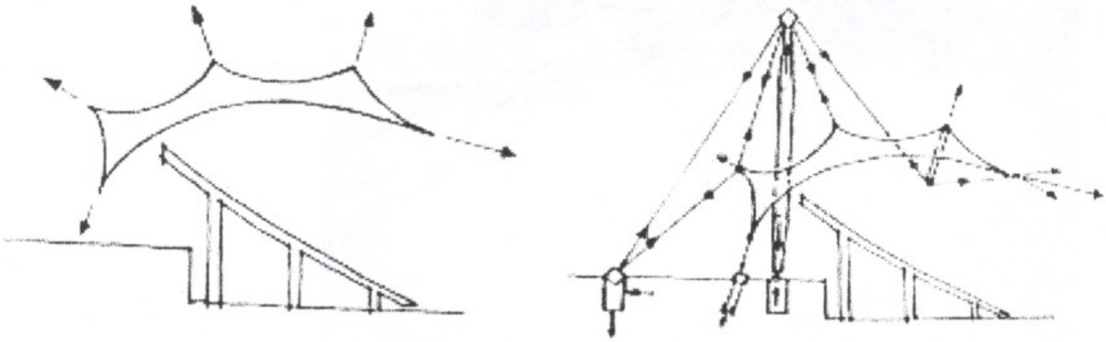


Figure 6.20 Scheme of The Structure.

Membranes serve new possibilities for innovative designs and building techniques. They can be walls and roofs that selectively allow light, sound and heat. Either opaque or transparent membranes mark the boundaries of large volumes resting on just a few vertical supports.

The development of air supported structures are related to the properties of membranes that are lightweight and airtight. At Expo 1970 in Osaka, Walter Bird and Geiger Berger designed the USA pavilion enclosed with an air supported structure. It was reinforced by diagonal cables (Figure:6.21). The low pressure inside maintained the skin in tension by supporting it against a lower outside air pressure. Another building technique introduced at Expo '70 was the Fuji pavilion that had been enclosed with high air pressure membrane structure (Figure:6.22). However, air supported structures could not find much chance for applications because of their disadvantages. Air pressure in the inner space disturbs people and cataclysmic failure is possible for high air pressure supported structures.

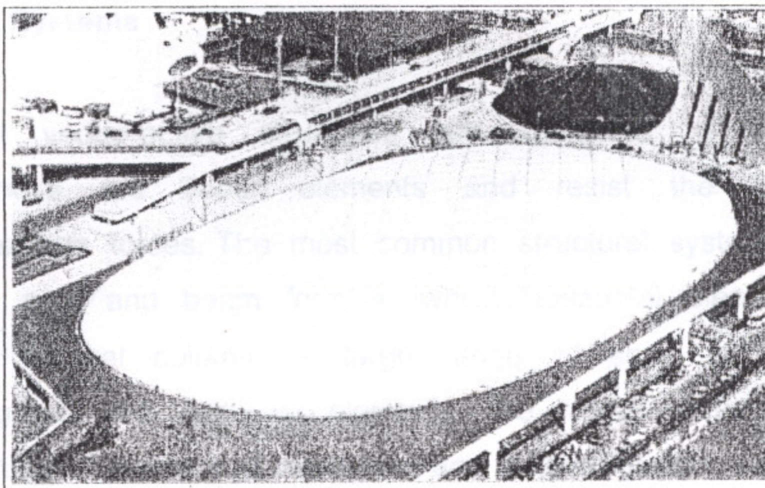


Figure 6.21 USA pavilion, Walter Bird and Geiger Berger, Expo in Osaka, 1970.

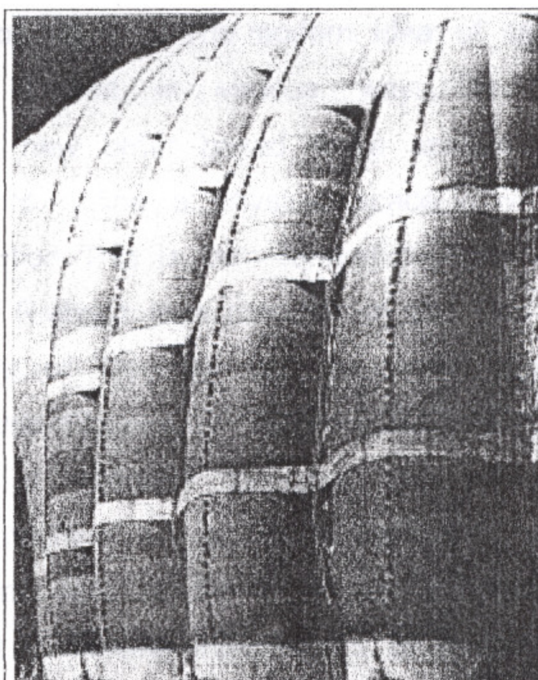


Figure 6.22 Fuji pavilion, Murata and Kawaguchi, Expo in Osaka, 1970.

6.3. Vector Active Systems

Elements of vector-active structures are subjected to axial internal forces. These are linear elements and resist the both compression and tension forces. The most common structural system of architecture is the post and beam form in which horizontal elements are supported on vertical columns. A large range of span is also possible depending on the type of elements are used. Advanced skeletal systems, trusses, suspended structures are in this group. These structural systems will be examined according to the relationship with formation of spatial organization.

6.3.1. Advanced Skeletal Systems

Every architect seeks in his own way for reactions to the technological and social realities of his time. The modern idea of space independence of enclosure is formed in various ways. De Stijl emphasizes the emergence of a new order based on a spiritualized, mechanized abstraction. In order to define a physical space, a virtual space is generated by the imagination. This is then formed by lines and edges of surfaces. Gerrit Thomas Rietveld is a member of the De Stijl group. The fundamental principles of De Stijl can be seen at his Red/Blue Chair and Schröder House (Figure:6.23 - Figure:6.24). The chair is a handmade object but it is intended to have the symbolic significance of a prototype of machine art and the character of a standardized object. The struts and rails of the chair are detailed to give the sense that one element is floating independent of the other. Walls and floors of Schröder House are designed with the same idea that all parts are hovering in a spiritual, continuous space. The significance of this spatial conception is given with the possibilities of cantilevered concrete and the transparent effect of glazing in architecture.

Figure 6.23 Red/Blue Chair

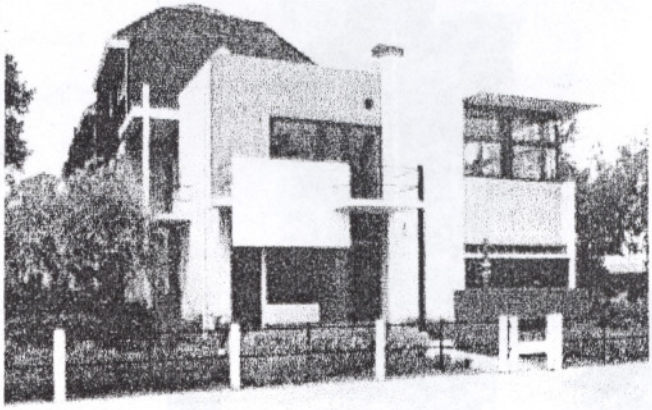


Figure 6.24 Schröder House, Gerrit Thomas Rietveld, Utrecht,1923.

For the Modern Movement, the light construction is based on abstraction and dissolving the difference between the internal and external. Lightness tends minimalism, not transparency. Transparency is about feeling - a feeling of openness or empties. In 1922, Mies van der Rohe proposed a glass skyscraper that be read in Rationalist terms. It was a minimalist solution with a glass curtain - wall and steel - framed structure (Figure:6.25). Glass was one of the most important progress in architecture. It opened interior space to the benefit and beauty of light. The dematerialization of the external skin has enabled a clear expression of the structural principle, allowing flexibility, freedom and light.

In the 1970's, the Modern Movement was furthered by the new approaches of structural design, partly based on new ideas and partly on development of new materials like new types of glasses, silicone joints and steel. Steel in the structural configuration provided a new lightness in weight and appearance. The expression of steel structures created a sense of dynamism which was accepted as the characteristics of twentieth century. The structure singled itself from the walls and expressed externally.

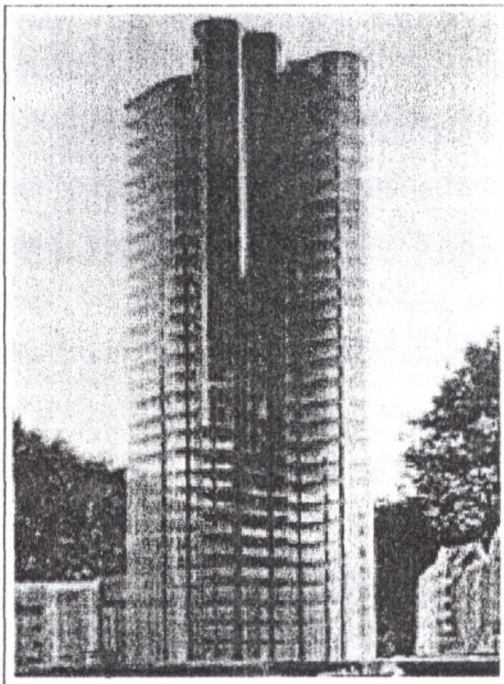


Figure:6.25. Glass Skyscraper, Ludwig Mies van der Rohe, 1922.

Improvements in the production of steel changed the way of construction also. Mass production of certain building components increased. Steel has been manufactured into elemental shapes, then fabricated as structural configurations and finally assembled in the building site. This new method of construction resulted with technological expressionism which has been applied to High-Tech architecture in 1970's. Steel structure system has been very much in the foreground and dominated the composition of the facade. It has defined more or less the outward appearance of the building. Because steel structure has been prefabricated and expressed, the design of the joints between the elements are an important aspect of the overall design which affect both the structural performance and the appearance of the frame. Structures designed for Pompidou center or Lloyd's of London were not because of pure technological solutions of functional problems (Figure:6.26 - Figure:6.27). On the other hand these two buildings presented the use of technology as an aesthetic and show the level of technology. The visual power of modern technology was used as a visual expression of modernity. The structure of high-tech has been hyper-sophisticated, never economical.

Major characteristic of High-Tech "flexibility in use" is achieved by the provision of large areas free from columns. These columns are structurally independent steel columns and building is demontable like machine. Le Corbusier described the house as a machine for living in, but he built houses that were technically primitive and didn't look like a machine. High Tech buildings look like a machine and have the same machine-like beauty. Richard Rogers explains Pompidou center as changeable parts around a permanent skeletal frame. Architecture is becoming changeable which is both permanent and transformable.

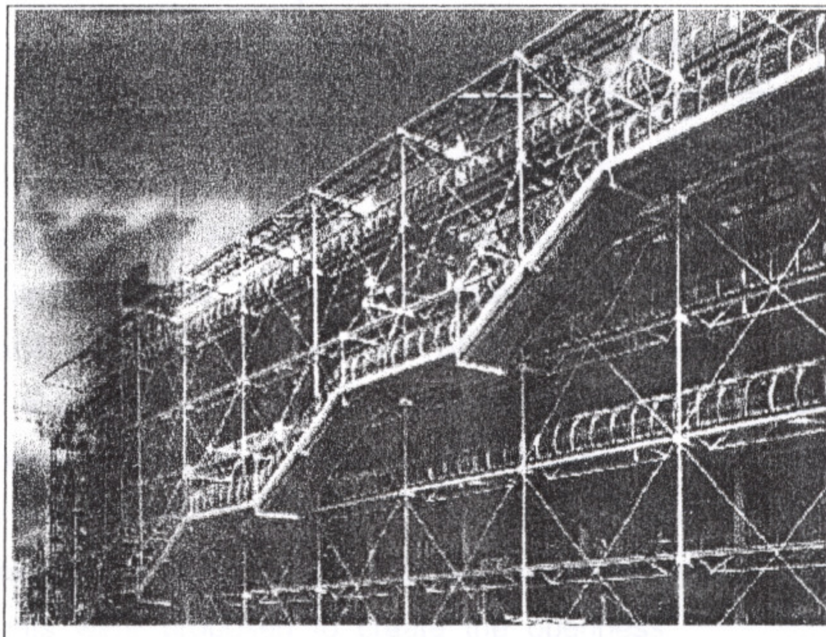


Figure:6.26. Pompidou center, Richard Rogers, Renzo Piano, Paris, 1971-9177.

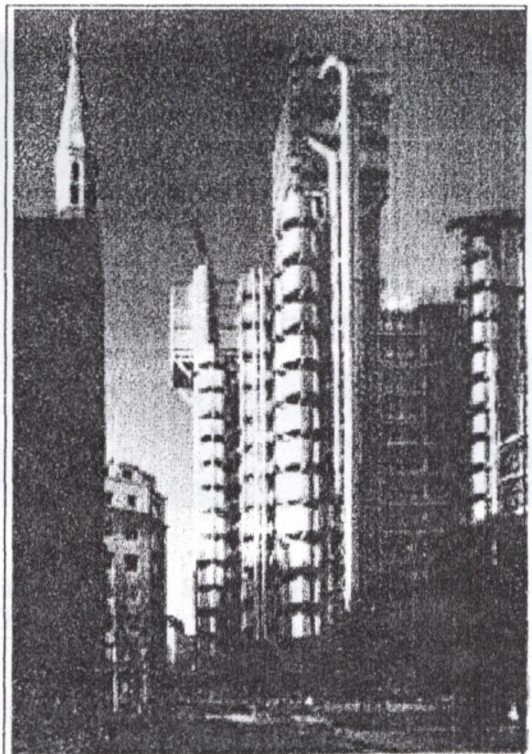


Figure: 6.27 Lloyd's of London, Richard Rogers Partnership, 1986.

The Ulm Stadthaus by Richard Meier was built by a reinforced concrete skeletal structure. The building was designed to be a public exhibition space and a location for meetings of the City Assembly and athers. Here the structural continuity and mouldability which concrete offers were exploited to create a complex juxtaposition of solid and void (Figure:6.28 - Figure:6.29). The building's public use and function were expressed through its open design. Exposed structural system and window arrangements were proposed to create the openness.

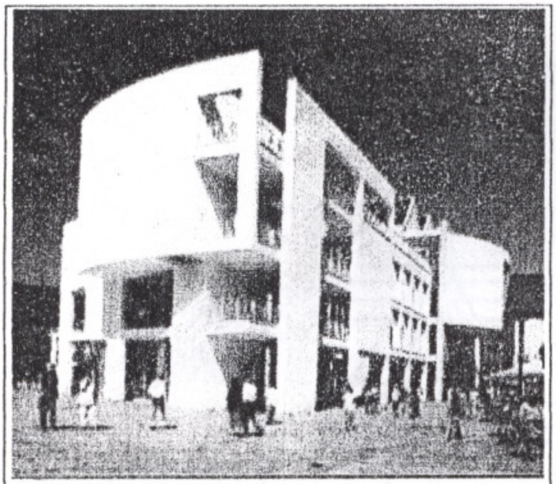


Figure:6.28 Ulm Stadhaus, Richard Meier, West Germany, 1991.

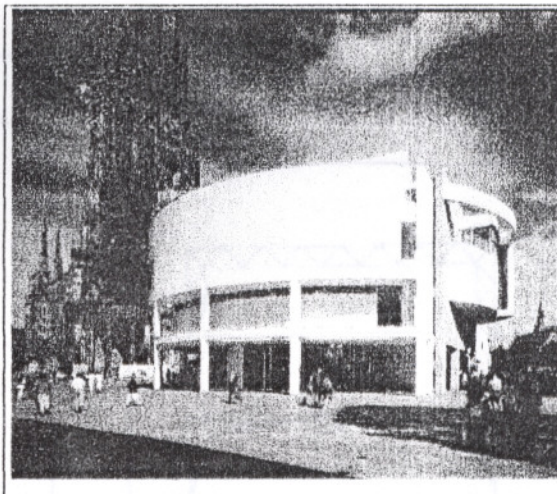


Figure:6.29 Ulm Stadhaus, Richard Meier, West Germany, 1991.

6.3.2. Suspended Structures

The tensile quality of the steel is the most important property which creates new building forms. Early tensile structures were iron constructed; from the structures of Viollet-le-Duc and roofs of factories to the iron frame of Chicago construction. It was developed with the method to prestress the concrete beams. However, the main structural and constructional precedents lie outside the field of architecture. More than five thousand years ago Mediterranean mariners find a method to sail their boats. The sailing ship utilizes all the structural principles of tensile architecture- sails refer to pneumatic forms, ropes to steel cables, sail masts to columns (Figure:6.30).

The tensile and compressive properties of steel enabled the designer to provide dramatic structures like steel trusses and suspended roofs (Figure:6.31). Long-span capabilities of steel ensure to develop "open-plan". Steel structures produce unique forms that are both elegant and dynamic. They have the advantage of being made of extremely ligth-weight elements. Tensile quality reduces the weight and give new forms to the buildings (Figure:6.32).

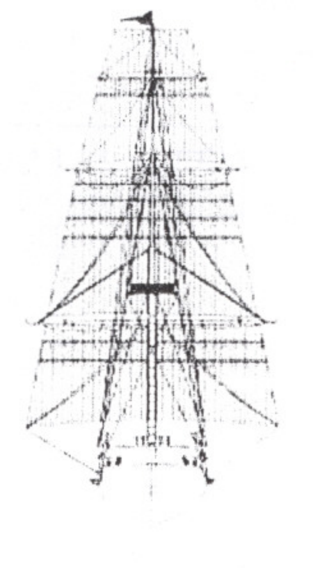


Figure:6.30 Sailboat

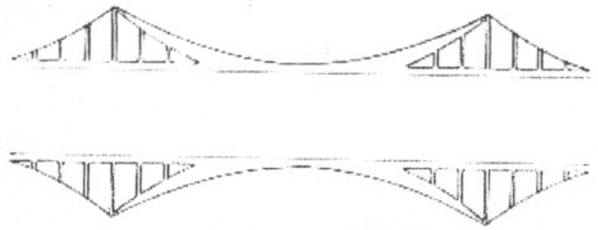


Figure:6.32 Arc Bridge and Suspension Bridge

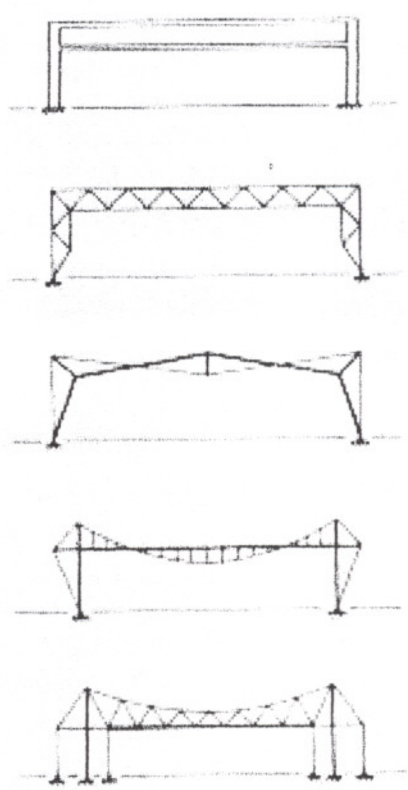


Figure:6.31 Development of suspended structures.

Suspended roofs are developed to suspended multistory buildings (Figure:6.33). Tensile quality of steel is fully utilized by suspending the floors with thin structural elements. These thin elements create the open space in the offices. The core of the building consists of a large rectangular or circular concrete shaft whose overall dimension is determined by the need to enclose the stair wells and lifts. The central shaft has stiffness to carry the full weight of the building (Figure:6.34). The structure system ensures to raise off the ground and creates fluidity of outer space (Figure:6.35).

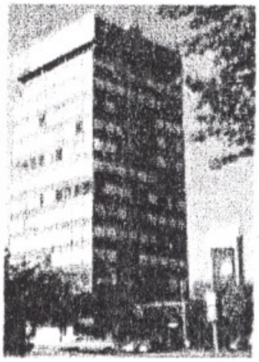


Figure:6.33
The Finnlandhaus in Hamburg, Lenhard and Andra, 1963.

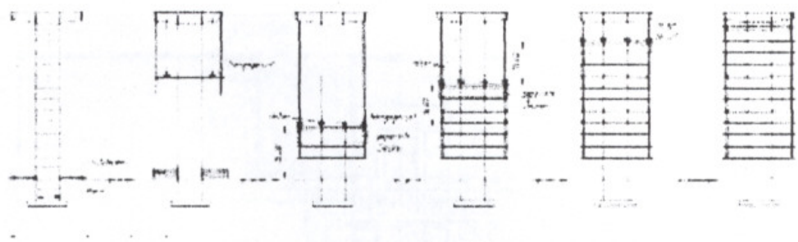


Figure:6.34 A Proposed Construction Process.

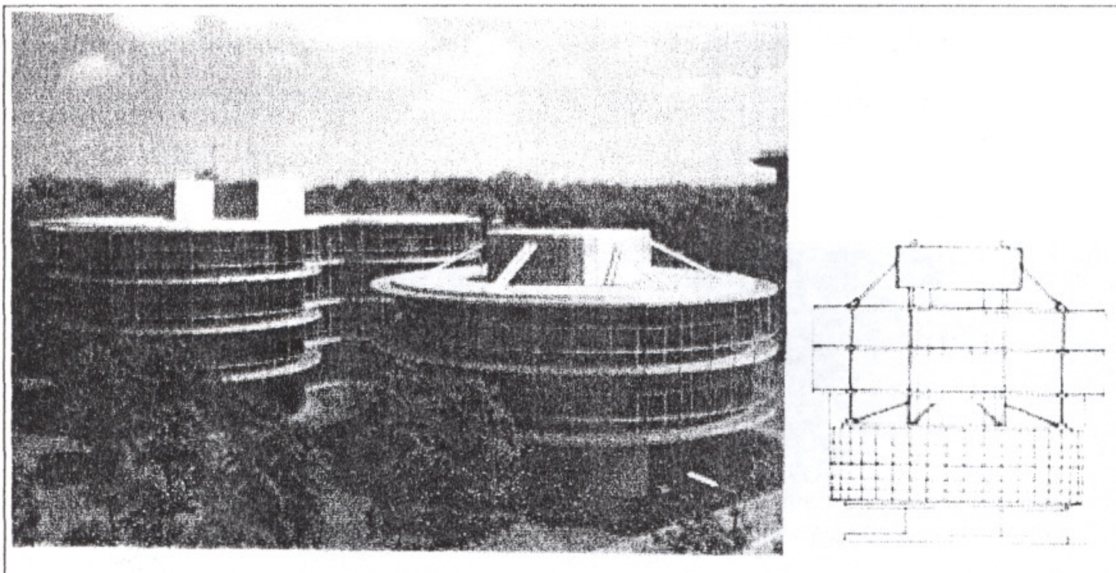


Figure: 6.35 The Bayerische Rückversicherung offices in Münich , Uwe Kiessler, 1976.

Space enclosed with suspended roofs cannot be defined with a functional requirements because the whole design is resulted with the idea of flexibility. However steel structural elements discipline the plan and general arrangement of the buildings (Figure:6.36 - Figure:6.37). The design process of the building for PA Technology is resulted in a single-story with suspended steel structure. Thin steel columns create a glazed arcade which house services, circulation and related activities. Suspended roofs enclose large areas on either side for open laboratory, office zones meeting rooms and administrative facilities.

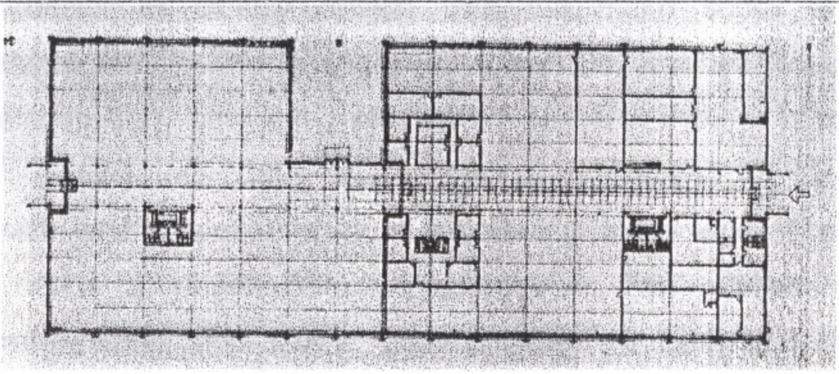


Figure:6.36 Plan of Laboratories and Corporate Facility for PA Technology, Princeton, New Jersey, 1984.

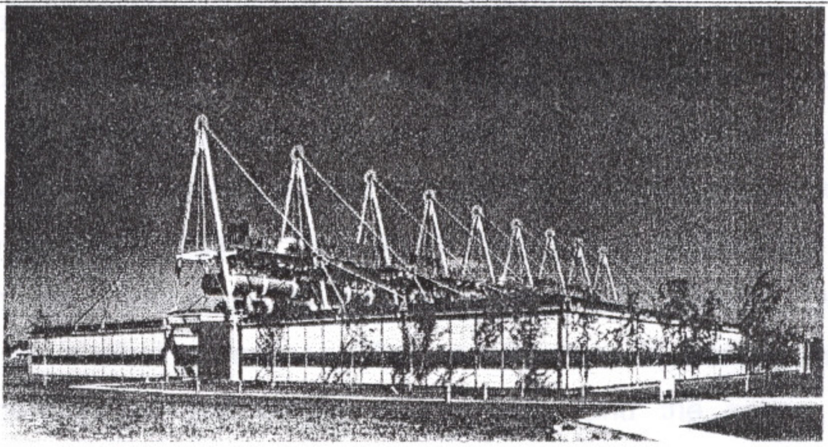


Figure:6.37 Laboratories and Corporate Facility for PA Technology, Princeton, New Jersey, 1984.

CHAPTER 7

CONCLUSION

Structural design is closely related with the major social and technological transformations. The changes in social life and technology affects the relationship between structural systems and space organization.

To recognize and evaluate what is happening today and where we stand now needs a longer historical perspective. The relationship between structural systems and spatial organizations are classified into three stages by Sigfried Gideon[8]. The first stage occurred in the architecture of Egypt and Greece. In these periods, interior space was not regarded as important. The concept of interior space could not set up an interrelationship with the structure. Therefore, there wasn't any relationship between structural systems and the formation of space organizations. Cosmic order was used in Egyptian architecture, and Euclidian geometry in Greek architecture.

The second concept of space began with the Roman period. Since the days of Imperial Rome, the formation of interior space and enclosing the inner space have become the highest aim of architecture, and furthermore, structural design has grown out of the awareness of its impacts on the formation of spatial organization. Space was determined by its enclosing masses. The construction of arches and domes was dependent on the weight of the mass and the sense of weight was part of the essential experience of classical architecture. The role of structure until the Gothic period was enclosing, covering and carrying. The order of structural design was derived from the Euclidian geometry, too ,and developed with empirical designs and craft tradition.

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[8] Gideon, Sigfried. Space, Time and Architecture, Harward University, 1982, p: lv

The third concept of space set in at the beginning of this century. In modern architecture the link between size and weight has been broken. In contrast to classical architecture, large-scale buildings have been built as lightly as possible and accordingly modern space is no longer defined by enclosing surfaces. Space has been separated from its enclosure and become boundless in every direction. The availability of large sizes of glass enabled the visual sense of openness. In this period technology has played an essential role. New technologies offer a great deal of potential for the evolution of structural systems. New forms, shapes and ideas have been derived by the technological changes.

> "No new form of architecture could have been created without a new structure, and the psychological receptiveness had to wait for its fulfillment until the structural possibilities ripened" [9].

The emergence of new structure systems bring new insights into the space order and determines the outstanding features of form. Building industry plays a crucial role in the development of structural systems. Both industry and architects must interact closely during the pre-conceptual phase of design.

Without doubt, structural design depends upon the technological systems used in architecture. Its basis is the materials and design techniques. The new materials have opened a completely new world of architectural and structural design, due to their lightness, moldability and durability. Architects discover the styles based on the materials. Structure results with a 'higher synthesis' of technique, material and form. To understand the evolution of structural design, it would be more useful to compare a classical building with a modern one (Figure:7.1).

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[9] Good Fences Make Good Neighbors? http://darkwing.uoregon.edu/~struct/

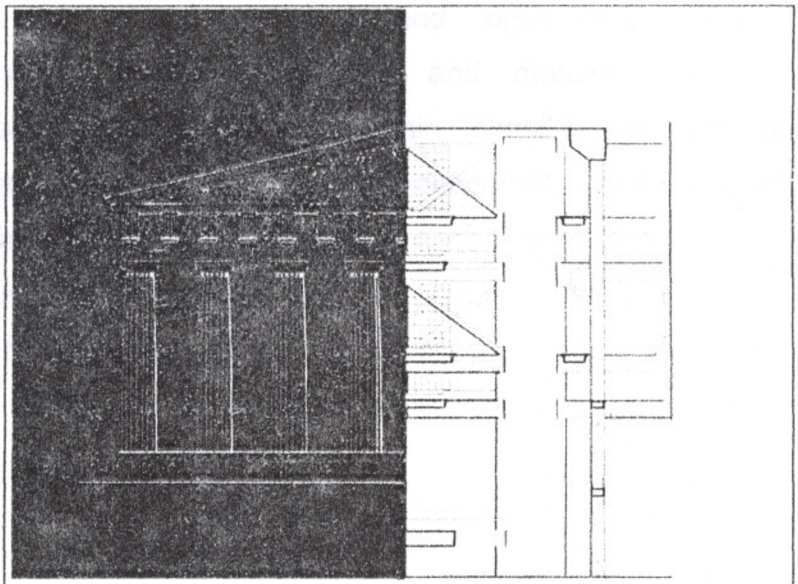

Figure:7.1 The comparison of a classical and a modern building.

However, structural system is not only a matter of new materials and but also a subject of innovative design as an integral component of the architectural design process. The physical laws which govern the behavior of materials and structures give possibility to the architects for individuality in design. For this reason, two designers would design different buildings for the same purpose. These structural forms come out of the designer's imagination.

In addition to the classification of Gideon, at present, at the end of the last decade of the twentieth century, a new relationship between structural systems and the formation of space organization has emerged. It is the consequence of a change in the basic framework of thought. The new theory is based on the chaos, or the science of non-linear systems different from the old modern linear sciences which grew from the Newtonian paradigm [10]. Traditional science was founded on the assumption that the universe runs according to a small number of simple laws, possessing a clear order and ignoring the disorder. Einstein's relativity theory is in contrast with Newton's universe of absolute space. His theory is based on the idea that the universe is a lot more creative, free, self - organizing and open than Newton supposed. Objects are delocalised, indefinite and mutually entangled entities that evolve like organisms. The main characteristics of his theory are chaos and order. Chaos can be described as a situation, where order and anti - order exist together. It arises because non-linear systems are sensitive to complexity and a slightest disturbance can rapidly build up into a major effect. However, it is capable of self organization and generating order spontaneously. Fractal geometry which is suitable for the self organization of order is constructed in order to enable the definition and accurate measurement of the property of roughness.

Architects have adopted the underlying ides of non - linear science to architecture. The new architecture has a dynamic stability like an organism. The stability of organisms is a dynamic integrity of all parts of the system. Non - linear dynamical systems theory is the study of processes in motion. However, there has been little opportunity to introduce dynamics in architecture. It can be a part of form and Calatrava tried to introduce a dynamic element into the system of the existing Ernsting Warehouse. As the doors fold, they create a canopy (Figure:7.2).

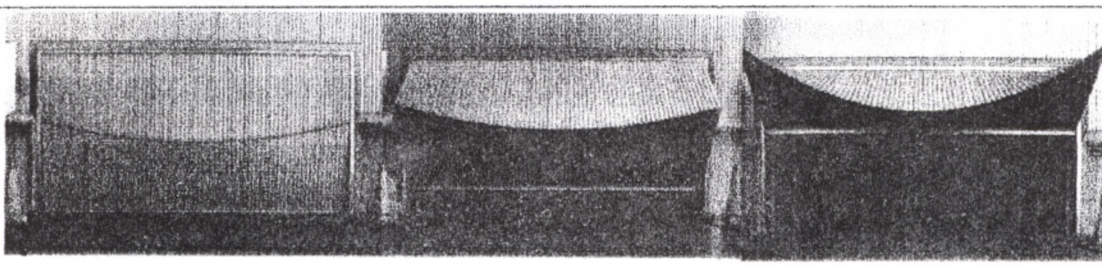

Figure:7.2 Doors of Ernsting Factory, S. Calatrava, Germany, 1985.

[10] New Science = New Architecture , Architectural Design , September- October , 1997, p:7.

Another example that the idea comes from motion is the movable bridge. It renders the interplay of the forces visible when loads occur. The bridge maintains the stability by changing the form in contrast with the static stability. Through the development of new technologies, architecture is becoming more dynamic with less material (Figure:7.3).

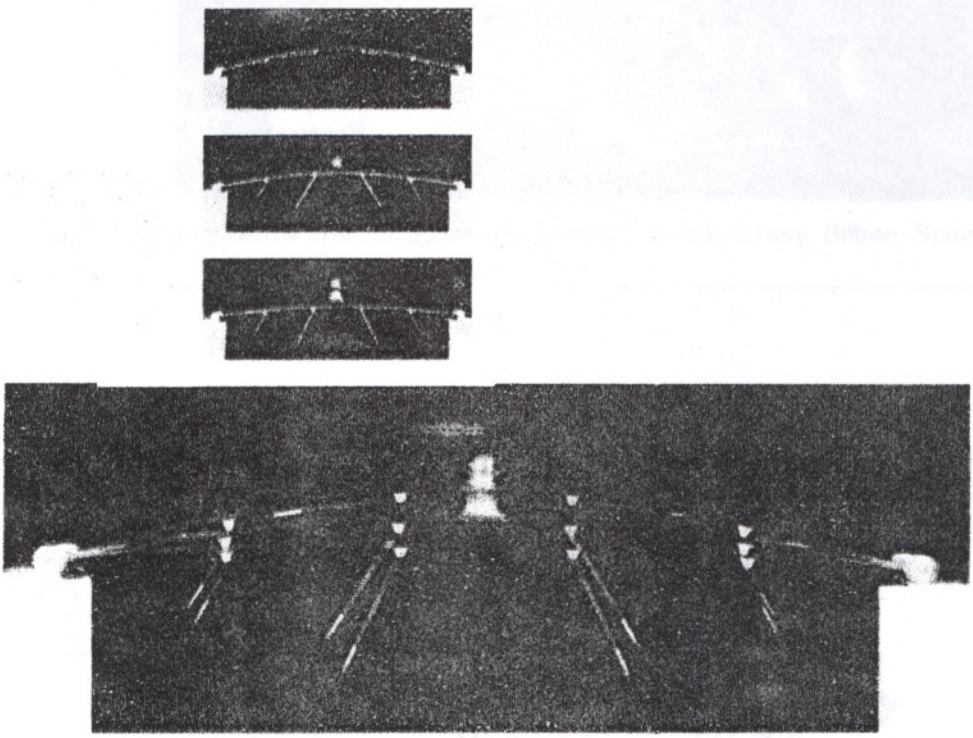

Figure:7.3 Model of Movable Bridge.

The new complexity paradigm in architecture has evolved simultaneously in different directions. Frank Gehry's last building, the Guggenheim Museum was resulted out of with the concern of organic metaphors (Figure:7.4). None of the architects has yet reached organic flexibility. Frank Gehry has approached self-organizing with the formal and spatial complexity that would have been inconceivable only a few years ago. Form is based on fractured planes and contorted curves.

The computer has enabled Gehry to generate the complexity that shows the future of architecture based on electronics (Figure:7.6).

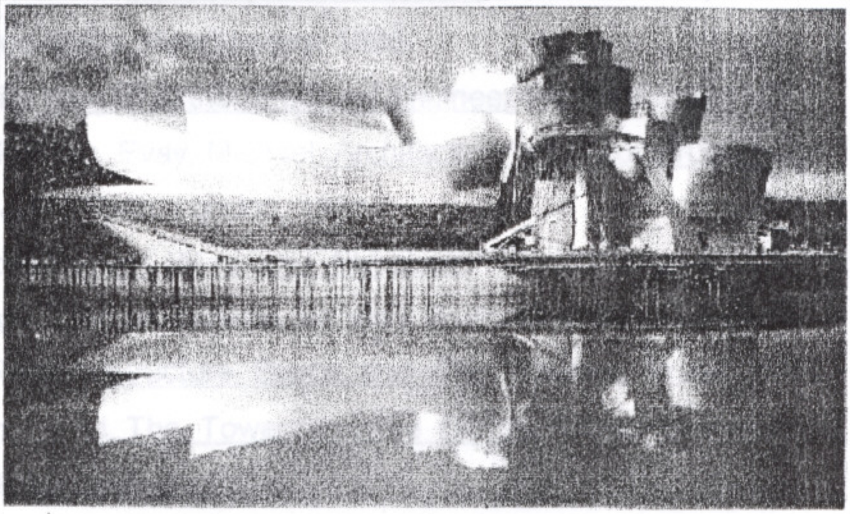

Figure:7.4 The Guggenheim Museum, Frank Ghery, Bilbao, Spain.

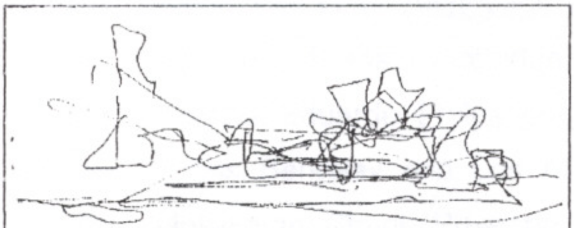

Figure:7.5 Concept Drawing

Figure:7.6 Computer Generated Image.

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APPENDIX

GLOSSARY

Arcuated: adj. To bend in an arc.

Barrel vaulting: Generated by a lateral translation of the arc.

Compress: *v.* To press or squeeze sth. into a smaller space.

Dead load: The unavoidable weight of the structure itself and the weight of all loads permanently on it constitute its dead load.

Dynamic load: Load that change value or location rapidly, or are applied suddenly.

Empirical: *adj.* Based on observation or experiment, not on theory.

Empiricism: *n.* The belief in or use of empirical methods.

Groined vaulting: Formed by two intersecting barrel vaults

Hemispherical domes: The semi-circular arch rotated.

Live load: All movable weights: humans, machines, rain, wind.

Lintel: *n.* Structural element over a door or window, forming part of the frame.

Limestone: *n.* A type of white rock, containing calcium, used a building material and in making cement.

Positivism: *n.* A system of philosophy based on things that can be seen or proved rather than ideas.

Post: *n.* Structural element set upright in the ground to support sth.

Semicircle: *n.* One half of a circle.

Trabeated: adj. Post and lintel construction.

Tension: *n.* The state of being stretched.