The Concept of Equilibrium and Its Effects of Change From Static to Dynamic on Architectural End-Products

By

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ABSTRACT

All of the objects/buildings on the earth can stand due to their structural orders. Standing of a structural order without suffering any damage (broken down, collapsing...) is the result of their state of equilibrium. The most important factor effecting the state of equilibrium of any structural order is the force of gravity. Differantiation in the structural orders formed under this stable effect can be explained by the change in the concept of equilibrium. Therefore, analysing the change in architectural and engineering end-products could only be done by understanding the change in the concept of equilibrium.

Scientific developments are the basic factors causing the changes in the concept of equilibrium. Reflections of these developments on concrete products is both in the types of load transfer of structural order and in visual expression of order.

Consequently,in the scope of the thesis, depending on developments in the science, reflections of the change in the concept of equilibrium on concrete products is tried to be explained by structural and geometrical analses. Expression of these analyses are made through the relationship between equilibrium and movement. It is concluded that the change in the structural orders basing on an acceptance of basic physics that "an object is either stable or movable "; is from structures having no motion to structures having any kind of motion (having tendency to move and/or moving). In other words, it can be said that, this change is from immobile structures having whole connection with the ground, to structures trying to remove from the ground.

At the end, in today, it is possible to discuss about solutions having different equilibrium orders that is seen/will be seen basing on scientific developments. Generally it is possible to classify these solutions as solutions that can be expressed by different geometrical orders or solutions towards to be independent from the force of gravity.

İn the light of these determinations the aim of the thesis is to determine changes in the concept of equilibrium and to analyse their effects on structural end-products and to give some clues about their future effects.

Keywords: Structural equilibrium, structural balance, gravity, geometry, energy, structural order.

ÖZ

Yeryüzündeki tüm nesneler/yapılar sahip oldukları strüktürel kurguları sayesinde ayakta durabilmektedir. Bir strüktürel kurgunun herhangi bir bozunuma (kırılma, çökme, yıkılma v.b.) uğramadan ayakta kalabilmesi onların denge durumunda olmalarının bir sonucudur. Herhangi bir strüktürel kurgunun denge durumunu etkileyen en önemli etki yerçekim kuvvetidir.Bu sabit etki altında, oluşturulan strüktürel kurgulardaki farklılaşma denge kavramındaki değişimle açıklanabilmektedir. Dolayısıyla, heykeltraşlık, mimarlık ve mühendislik ürünlerinde görülen değişimi analiz etmek denge kavramındaki değişimi anlamakla mümkün olmaktadır.

Denge kavramındaki değişimlere neden olan temel etkenler ise bilimdeki gelişmelerdir. Bu gelişmelerin somut ürünlerdeki yansıması, hem strüktürel kurgunun yük aktarım biçimlerinde hem de kurgunun görsel ifadesindedir.

Dolayısıyla tez kapsamında bilimdeki gelişmelere bağlı olarak denge kavramındaki değişimin somut ürünlerdeki yansıması, strüktürel ve geometrik analizlerle açıklanmaya çalışılmıştır. Bu analizlerin ifadelendirimesi denge-hareket ilişkisi üzerinden olmaktadır. Temel fiziğin "bir nesne ya durağan ya da hareketlidir" kabulüne dayanılarak strüktürel kurgulardaki değişimin; hareketi barındırmayan strüktürlerden, hareketi barındıran (harekete meyilli ve/veya hareketli) strüktürlere doğru bir değişim olduğu kabulüne varılmıştır. Bir başka ifadeyle; bu değişimin yere tam bağımlı hareketsiz denge kurgulu strüktürlerden, yerden kopmaya çalışan strüktürlere doğru olduğu söylenebilir.

Sonuç olarak da günümüzde gelinen noktada bilimsel değişimlere bağlı olarak görülen/görülebilecek olan farklı denge kurgulu çözümlerin tartışılması söz konusudur. Genel olarak bu çözümleri farklı geometrik düzenlerle ifade edilebilenler ve yerçekimi etkisinden bağımsız olmaya yönelik olanlar şeklinde sınıflandırmak mümkün olmaktadır.

Bu saptamalar doğrultusunda tezde amaçlanan; denge kavramındaki değişimlerin saptanarak bu değişimlerin strüktürel sonuç ürünlerine etkilerini analiz ederek, gelecekte bu etkilerin nasıl olabileceğine dair bazı ipuçlarını ortaya koymaktır.

Anahtar kelimeler: strüktürel denge, görsel denge, düzen, yerçekimi, geometri, enerji

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CHAPTER 1

1. INTRODUCTION

1.1. DEFINITION OF THE PROBLEM

Architecture has always been considered and examined in an area where art and science intersects. In this intersection, architectural products has been examined either from the point of social sciences (cultural, political, economic...) or of epistemology (topological, technical, mathematical...).

In this context, when architectural products are considered, it is seen that **"standing"** and **"spanning"** had been accepted as the main problems and the scientific researches had been headed towards solving these problems. This situation is also valid for periods when new constructional materials have begun to be used in architecture and engineering. Therefore, structural orders and their expressions are effective in the evolution of architectural end products.

Until the beginning of 20th century, architectural products have been built to express truth, unity, mystic, and religious values. From the beginning of 20th century, architecture has been in an effort to understand "building" in the scope of spatial orders. The elements of building and all the factors that effect the building whole have been studied considering their effects on space. In addition to this, it is possible to see some different approaches that have accepted building as an artful object and have basically considered the form of structural order, such as futurist, expressionist, and constructivist approaches.

On the other hand, lately, buildings are analysed and understood with the relationships between **building-structure, space-structure, material-structure...** and under the description of **spatial structure, artful engineering, structural architecture, structural engineering in the intersection of architecture and engineering.** The common acceptance in these analyses is the wholeness of structure and space that are two basic concepts for a building. However, in this whole, it is necessary to analyse structures in a different scope because from any natural object to an artificial one and finally, to the buildings, in every part and whole there is a definite structural order that keeps them standing. **A structural order of any piece or a whole basically means how they stand at equilibrium.**

Consequently, one of the main problems for architectural end-products is the **"structural equilibrium"**. Therefore, in a retrospective perspective, it is necessary to consider the change in structural order as a result of the change in the concept of equilibrium. The concept of equilibrium; on the other hand, is related with several disciplines with which the relations have to be examined.

Accordingly, prevalent attitude; examining and classifying the structure in a historical perspective only including the material and technological (constructional) does not sufficient. Also, when it is considered that, developments in material and technological innovations did not bring radical changes as for developments in equilibrium, this determination become much more valid.

Physics, mathematics, sculpture, architecture and engineering are the basic areas that are directly related to the concept of equilibrium. In general, **"gravity"** which can be taken as the basic factor in explaining equilibrium is a physical characteristic that can be studied in physics. On the other hand, **"geometry"** that is used for analysing the concept in concrete objects is a sub-branch of mathematics. When the evolution of different disciplines are examined, a completely new architectural scene can be set up under the concept of equilibrium. In other words, the developments in physics and mathematics have at the same time affected the evolution of structural orders.

As a result, the change in architectural products is directly related with the state of equilibrium. In other words, the changes in equilibrium concept effect the architectural end-products. Therefore, in order to understand the changes in concrete products, it is necessary to analyse their state of equilibrium and to show how equilibrium concept effects to the end-products.

1.2. THE AIM OF THE STUDY

The aim of this thesis is to state the changes in the concept of structural equilibrium, and to analyse their effects on the end products.

The concept of "structural equilibrium" is not thought independently from "gravity" that influences all things on the earth. This immutable influence has been searched according to different forms of structural equilibrium. The important factors that effect the change in structural equilibrium are the developments taking place in the scientific ground. Because, in parallel with scientific evolution, the changes in structural orders, are considered according to their connection with ground and their structural elements.

The definitions related with the aim of the Study:

- Equilibrium is taken as the basic concept in the constitution of any structural order.
- The concept of equilibrium has changed in connection with some scientific developments.
- The evolution in structural equilibrium effects the architectural and engineering end-products physically and visually.

1.3 THE METHOD OF THE STUDY

Within the scope of this thesis, changes in the concept of equilibrium have been given by considering its relationship with different disciplines. These changes have been analysed under the basic concepts, as static and dynamic equilibrium, which are common in different disciplines and in different historical periods. Each basic concept has defined one period of the evolution. In this way, this systematic conceptual order, at the same time, includes partially a historical perspective. By secondary concepts (gravity, geometry, energy) determining conceptual order, reflection of change in the concept of equilibrium has been exemplified through the products of sculpture, architecture and engineering.

In this study, the structure and its geometry is examined under the concept of equilibrium, and discussed in terms of **visual expression** and **how structural whole stand.** Also, the concept of equilibrium can be discussed for physical characteristics of an object/building, which may be mentioned in relation with tectonics of the building eg. material, light, textures. In this study, the concept of equilibrium is independently from these kinds of expressions. In this context, analysis of physical structures has been made through;

a- the geometric expression according to the part and whole relation.
b- the principles of load distribution of the structure.

This analysis has been made nominally through evolution of the examples that are determined by considering basic concepts in the evolution of the equilibrium.

In this sense, in second chapter, basic concepts, which are effective in the formation of the other parts of the thesis **(balance, structural balance, equilibrium, and structural equilibrium)**, have been defined. For providing true understanding of the thesis, it is important to give the definition of the concept of structural balance and structural equilibrium that are used in different areas for different aims in a common direction. Also, the general concepts **(static/dynamic equilibrium)** that determine the evolution of periods and secondary concepts/tools **(gravity, geometry and energy)** which provide the analysis of the concrete products have been defined.

In third and four chapter, after explaining the scientific developments, each general concept in the scope of the secondary concepts have been explained by analysing the examples visually (based on geometry). In the analysis, sculptural products have been examined firstly because the sculptural products hold up material depending on the structural order without having any spatial organisation. In this way, structural orders and changes in these orders can be observed more easily by analysing of these small-scale products. In the direction of the thesis, analyses have been made for the products whose structural expression is stressed, especially considering the products having static equilibrium.

In the last chapter of the thesis, the discussion areas of the concept of equilibrium are explained by considering scientific developments and the changes in the understanding formal design of architectural end-products. At this point, on the one hand, some examples are tried to evaluate with some geometric definitions (non-dimensional geometry, fractal geometry...) based on gravity, on the other hand, some utopic orders of equilibrium are searched. In this way, some clues in contemporary structural products, which will be the references of the future design, can be found.

CHAPTER 2

2. GENERAL DEFINITIONS

2.1. DEFINITIONS OF THE MAIN CONCEPTS

In the universe, all of the systems and phenomena, events and objects taking place in these systems are , directly or indirectly, in an interaction with each other. In this interaction, each elements in the system is under some mutual effects. The stated situation under these mutual effects bring about the situation of "being in balance".This situation provides the continuity of motion of universe orderly.

The word balance and equilibrium are used with different meanings in different disciplines. Since differentiation in meaning reflected to terminology, it is necessary to make these concepts clear (balance / equilibrium) that will be used in this thesis.

2.1.1 The Concepts of Balance and Structural Balance

A general definition is made for the concept of balance including all branches. So, it is possible to mention both the situation of balance of any object and the situation of balance of any phenomenon or event.

- **Balance**

The concept in the **International Relation**, sub-branch of Political Science, is defined as a **balance of power**. In economics, on the other hand it is defined as **a balance of trade** and **balance of payments**. (ekonomi sözlüğü, 1995) The concept of balance, used in these areas, does not often determine equality between different variables; it refers to the definition of a situation relatively. It is used, similarly, in **trade** for explaining the relation between export and import. Meaning does not determine equality between them.

When we look at applied sciences; we see that; **in biology**, balance as the concept of **"balanced polymorphism"** means "maintenance in a population of two or more alleys in equilibrium at frequencies too high to be explained, particularly for the rarer of them, by mutation balanced by selection. In this explanation, the aim is to determine the situation of different alleys in a population, eg. the relation between heterozygote alleys and homozygotes alleys."(McGraw-Hill, 1986,p.38)

In general, it is possible to say that the concept of balance is used for a common aim in these areas. Consequently, balance is the proportional expression that shows differences in the direction of necessities of each discipline. Moreover, the situation of balance provides continuos growth of any situation in these disciplines.

In addition to these areas, it is possible to see the concept of balance in discipline of design and its visual products and expressions: In **landscape design, balance is;** a state where all parts of a design or landscape are no parts needs to be moved added or subtracted. (Bell, 1993, p.195) Like in the other areas, the concept of balance is explained as a visual expression in a whole/composition.

In Architecture, there are some definitions similar to the preceding one, which are based on the visual expression of the concept of balance, where, balance is used for the impression of visual equilibrium in a composition. In this definition, "the impression of visual equilibrium" is evaluated as the rate of orderliness in a whole.

Parallel to these explanations, in the study, **the concept of balance is used to determine the visual situation (the rate of orderliness) of the whole (buildings, sculptures).**

After these determinations and definitions, to explain the concept of **structural balance,** firstly, it is necessary to explain the term of **structure**.

- **Structure**

In general, the definition that was found by Margit Staber is completely valid. "In her book "Concrete Painting as Structural Painting", she seeks a definition of structure that enables us to formulate the conjunction of scientific and artistic, of rational and aesthetic. She found a contemporary definition in the biological writings of Wolfang Wieser; **"Structure should be understood to mean a network of relationships of elements or elementary processes"**. Structures appear when elements combine into a meaningful whole. The wholeness where we discover and examine structures are called as a system"(Kepes, 1965, p.6), also, Lancelot L.Whyte's explanation of structure as **"a definite arrangement static or changing of localisable parts"** (Kepes, 1965,) is more definite, but they are similar in the basic meaning. In both definitions, two important points are;

a- combination of the elements / parts

b- formation of a meaningful whole/a definite arrangement

- **Structural balance**

In the light of general explanations, within the scope of architecture and engineering, structure can be defined as an orderly system that keeps any object or building standing stable under necessary load transfers.

Under the specified concepts of **"balance"** and **"structure"**, **structural balance is defined the rate of orderliness of a situation which is formed with relations (formal and proportional) of the elements of structural whole/ composition.**

2.1.2 The Concept of Equilibrium and Structural Equilibrium

In comparison with **"balance"; the concept of equilibrium**, which is used specially, is discussed as a expression of a quantitative state.

- **Equilibrium**

In Economics, equilibrium defines "a numerical value of an intersection of supply and demand" in **Product Market.** (Pekin, 1985)

When we look at the applied sciences, in **Chemistry**; **chemical equilibrium**, is a state of chemical system in which the rate of formation of reactants from products (Brown, 1977, p:424). In this definition, the factor determining the state of balance is **"being in a equality state"**.

On the other hand, in **essential physics, equilibrium** is the state of an object when it is not acting upon by a net force or net torque. An object in equilibrium may be at rest or moving at uniform velocity-that is, not accelerating (Hewitt, 1992, p.714).

In these definitions, essential point is that, in addition to quantitative Equality State, such state of equilibrium is provided under the definite forces. These definite forces are factors that provide equilibrium in economics and are physical forces which the most important of which are gravity, live loads, dead loads...in physics.

These definitions in theoretical disciplines are also valid in disciplines of design. **In landscape design**; **equilibrium is**, the state where all parts of a composition or design are in balance with one another, where all visual forces and tension are resolved (Bell, 1993, p:196). In the scope of **architecture and engineering, equilibrium** is defined as **"a state of balance between opposing forces that is either static or dynamic".**

- **Structural equilibrium**

Taking these definitions into consideration, **structural equilibrium** can be defined **as the state of stability of a structural order, where, this state of stability is provided by the neutralisation of physical forces.** As it is seen, this state of stability is equal to the quantitative Equality State in theoretical disciplines.

2.2. DEFINITION OF THE EVOLUTION IN STRUCTURAL EQUILIBRIUM AND SECONDARY CONCEPTS FOR UNDERSTANDING THE EVOLUTION

The reflection of the evolution in the concept of structural equilibrium to the end products can be explained with the relationship between **gravity** and **structural order.** This evolution is from the structural orders which is in a strong connection with ground, to the structural orders that are trying separate from the gravity; that is whose connection with land has weaken, and even to movable structural orders.

Another important point is change from static to dynamic occupied by developments in scientific area. Accordingly, with the scope of the concept of equilibrium, it is possible to find a common order that has an evolution both in architectural end products and in scientific disciplines (physics and mathematics). With such a common order, this evolution can be given completely. So, in accordance with the one of the basic assumptions of physics, that is, **"anything on the earth is either static or dynamic"**, where the concepts of static and dynamic are determinants in such an existing common order. Because, in essential physics, static is used for defining the immobility, dynamic is used for defining the mobility.

In this connection, the evolution includes a change from static equilibrium to dynamic equilibrium. The concept of static equilibrium is used for structural orders that do not include any kind of movement. In contrast, the concept of dynamic equilibrium is used for structural orders that include any kind of movement (potential or kinetic movements). In fact, each structure includes some internal movements that are different from the movement mentioned above (being stretched, wrapping etc.). Here, with the phrase of "**potential movement"**, the tendency towards movement in a structural order is defined; where the motion in physical senses is explained as the **"kinetic movement"**.

Besides, when any situation of an object or a building is discussed, structure gives us intuitively effects of concepts eg. Stability, solidity and rigidity that we hardly tend to associate with structures. Also, the very idea of structure is synonymous with stability, static and the rigid organisations of elements in space (Tzonis, Lefaıvre, 1995). Parallel to this, statics known as, an elementary branch of the science of structures, actually ignores movement. In other words, we can only discuss structures that have static equilibrium but in reality, this is not valid. So, at this point, it is required to distinguish **"being static"** from **"having a static equilibrium"** because each structural order that exists without destroying is a stabile.

Stability as a general concept refers to **being static**; being static is defined by the concept of equilibrium and it is valid for structural orders having either static or dynamic equilibrium.

In general, naturally no building could be erected without the knowledge of the laws of stability (Macdonald, 1994) in connection with this, to provide the state of equilibrium of form requires to have some basic structural requirements;

a- geometric stability; it is the property which preserves the geometry of a structure and allows its elements to act together to resist load.

b- Strength and rigidity; the application of load to the structure generates internal forces in the elements and external reacting forces at the foundations, and the elements and foundations must have adequate strength and rigidity to resist these.(Macdonald, 1994)

- **Gravity**

Physical requirements stated here are directly related to the different kinds of load transfer of the structure. Such load transfer is occurred between **elements in order** and between **the structural whole and the ground**. The degree and the form of the connection of structure with land physically determine the relationship between the *structure and gravity*. In addition, the quality of this relation is one of the most important determinants in differentiation between static and dynamic. So, one of the basic concepts/tools that determine this differentiation is **"GRAVITY"**. In this study, under this concept; products having static/dynamic equilibrium order were examined and analysed from the point of load transfer and their connection types with land.

The pull of gravity, known intuitively, explained theoretically by Isaac Newton in 1665 had became the most important natural effect in the constitution of structural order of artificial elements physically. Experimental studies in concrete products directed towards understanding the gravity and resisting to it in different types especially seen in the products of sculpture. Many of these studies are made by illustrating man's body. There may be a lot of reason for this; 1.skeleton is also a structure, 2. it is alive, it can state in equilibrium in different conditions. These studies explained later in chapter 3-4 are important because of their effects on architecture.

Actually, three coordinates defined in Cartesian system are equal both in character and in importance. However, our earth is pervaded by the pull of gravity, in this way, the vertical one is separated as the standard direction. Thus, vertical effect has become determinant in the perception of spatial orientation. Such as; an important thing to provide perception of the Companile in Pisa earlier than surrounding buildings is having a different vertical effect of it against pull of gravity (Arnheim, 1977). Accordingly, difference between static and dynamic equilibrium in concrete products, showing the relationship between gravity and structural order (load transfer and connection type with land) become important in the scope of relationship between gravity and vertical axis. In relation to this, understanding the elevation of a structural whole is important in structural analyses.

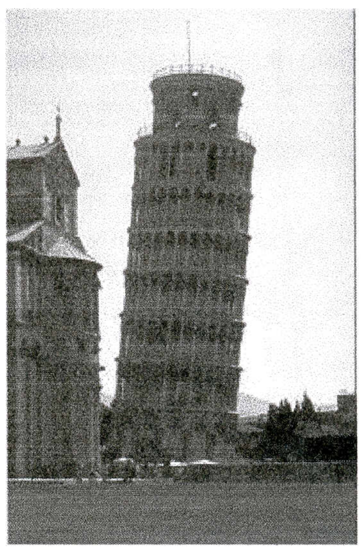
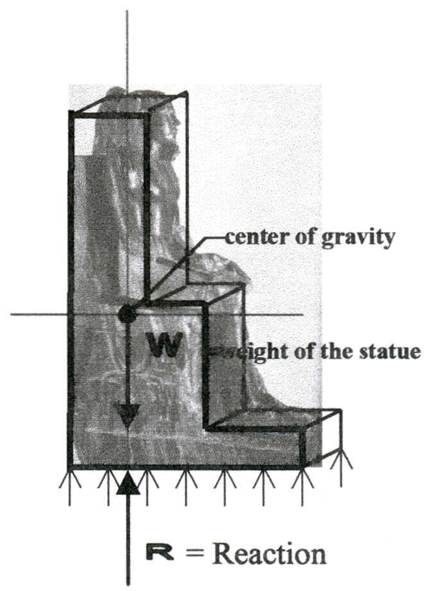


fig.2.1 Companile in Pisa (source: cibernet.it/thebox/pisa)

- **Geometry**

Any structural order, at the same time, is a formal whole and the structural function of any object/building is perceived through this form. Consequently, in determining the change from static equilibrium to dynamic equilibrium, formal analysis is also required, in addition to the analysis based on structural function. In other words, there is a direct relationship between form and structure of the buildings. On the other hand, to understand the changes in form can be analysed by geometry. Therefore, formal analysis has directly been developed concerning the **"geometry of form"**. Formal changes in the transition from structural equilibrium to dynamic equilibrium can be understood by geometrical analysis. So, by geometrical analysis, of this sculpture. In this state, system is stable. (fig.3.3) While the width of lower surface that provides the connection with the ground increases the "R" force, at the same time it decreases the distance between centre of gravity and the ground (fig.3.4). In this way, it prevents the moment effect that could be occurred. In this sense, for structural order having static equilibrium, another common point is observed that the distance between centre of gravity of it and the ground is minimum.



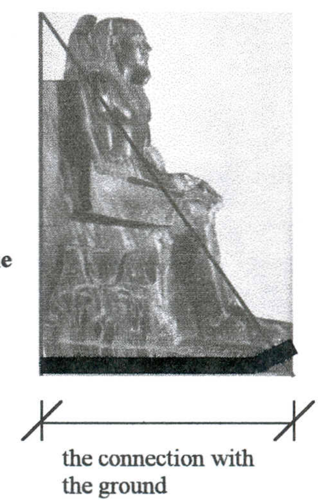


fig.3.2 fig.3.3 fig. 3.4

fig.3.2 Old kingdom seated statue of King Chephren (2500 B.C.)(source:Mıchalowski,1968)

fig.3.3.The structural analysis of the statue of King Chephren

fig.3.4.The connection with ground of the statue of King Chephren

This physical requirement is shown clearly in Rodin's sculpture. Filled mass, on which the man figure sits, of Nude Balzac Sculpture of Rodin (fig.3.5), has a function to decrease distance between centre of gravity and the ground.

fig.3.5. Nude Balzac Study, Auguste Rodin, (source:Schodek, 1993)

The same analysis can be made for all types of Egyptian sculptures [standing figure (fig.3.6), seated figure (fig.3.2), block statue, scribe statue, dyad and Triad, squatting or kneeling figure, colossal statue (fig.3.7)] and for Greek sculpture in archaic period (fig.3.8). Such as; Standing figure similarly resist to gravity with its weight as if one column (fig.6.1). In addition to these examples, there are solutions having order of static equilibrium that show some differences in point of load transferring.

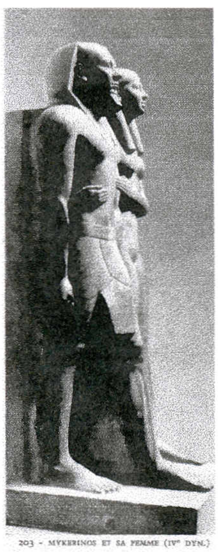
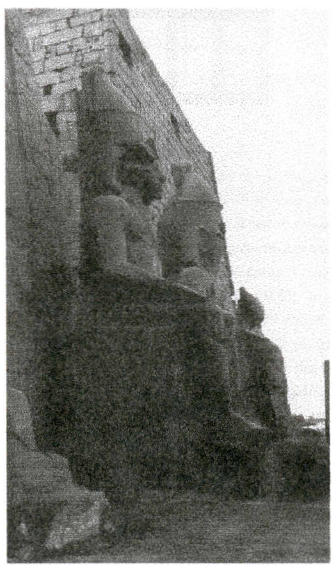


fig.3.6



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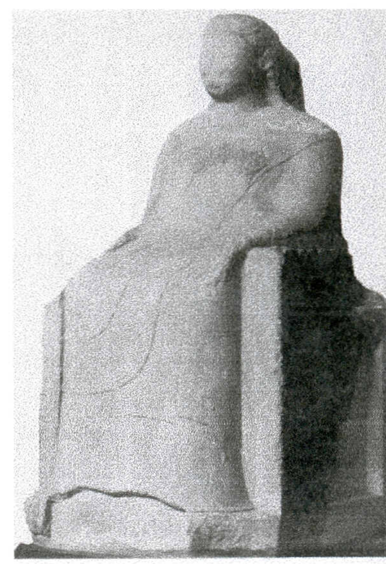


fig.3.8

fig.3.6. Standing figure in Egypt (source:Mıchalowski, 1968)
fig.3.7. Colossi of Rameses II (source: Rykwert, 1996)
fig.3.8. Seated figure from near Didyma, 560 BC.(source: Boardman, 1996)

In the example of seated figure of Imhotep (fig.3.10) (late period in Egypt, 750-332 BC) and also of kouros (archaic Greek) (fig.3.9), different from the others, the entire weight of sculpture is transferred to the ground at different points. The important point here in this is the symmetrical distribution of load transfer at different points (fig.3.11-3.12). The kouros stands firmly on both feet, with the weight evenly distributed (Biers, 1980).

Another important point is that, although both of two structures are structures having order of static equilibrium, unlike the sculpture in Egypt [nearly all stone standing figures have back pillars that provide connection with land as a whole (Turner, 1995,p.855)] the kouros standing figure stands without a back support.(fig.3.11) These kinds of examples can be accepted as the examples of intermediary periods inevolution from statics to dynamics.

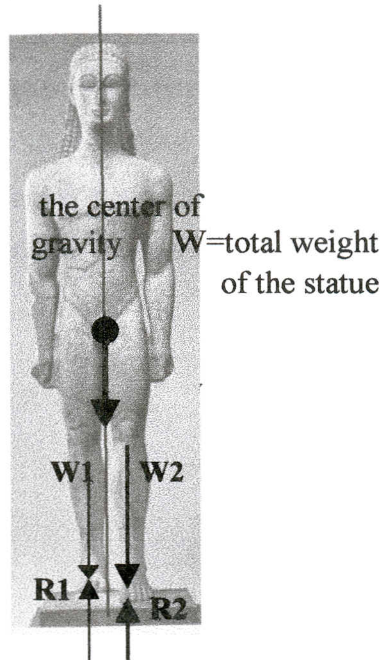


fig.3.11

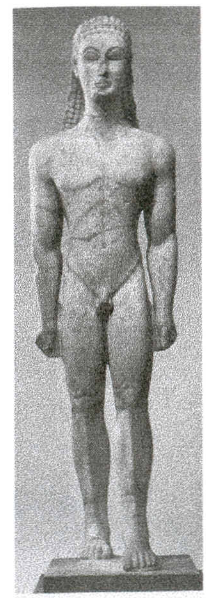


fig. 3.9

fig.3.9 A Kouros, Archaic phase of Greece (source:Biers, 1980)

fig.3.10. Seated figure of Imhotep, late period (750-332 BC)(source:Turner,1996)

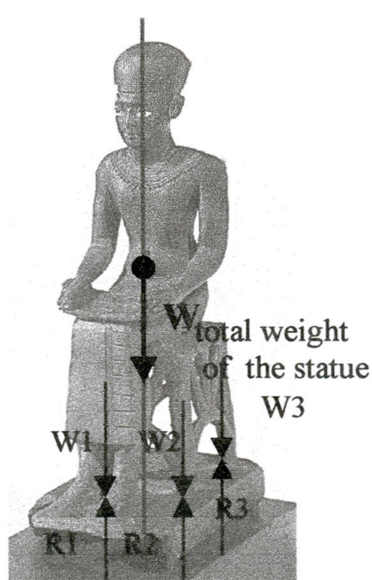


fig.3.12

fig.3.10

fig.3.11 The structural analysis of A Kouros, Archaic phase of Greece

fig.3.12 The structural analysis of the Seated figure of Imhotep

Generally, in architectural and engineering end-products, solutions having static equilibrium also examined through similar characters. Some of these characteristics had been described by John Ruskin; "Egyptian and Greek buildings stand for the most part by their own weight and masses, one stone passively incumbent on another" (Baker, 1996, p.27). This is also valid for buildings of Mesopotamia (fig.3.13) The tombs (pit-graves, mastabas (fig.3.14), pyramids (fig.3.15) and chapel tombs) in Egypt are closest examples to this kind of order. Similar to sculptures Standing figure (fig.3.6), Seated figure of Chephren (fig.3.2), the most important characteristic of tombs that are developed from mastabas is their resistance to gravity with their masses.

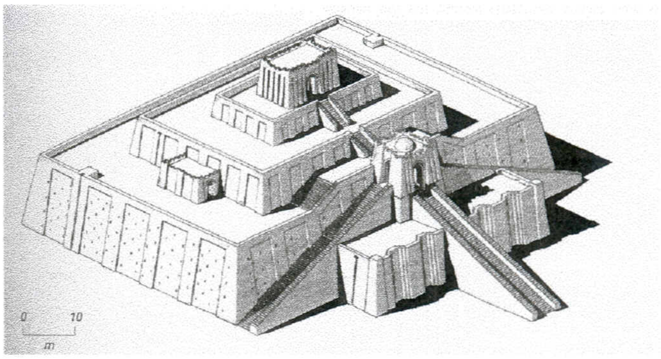


fig.3.13

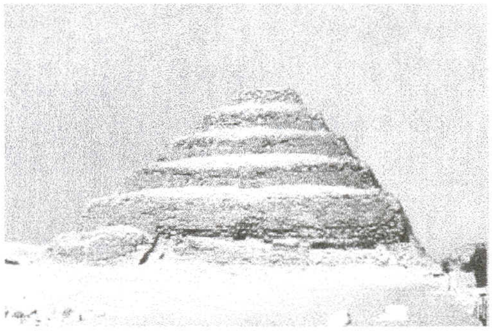


fig.3.14

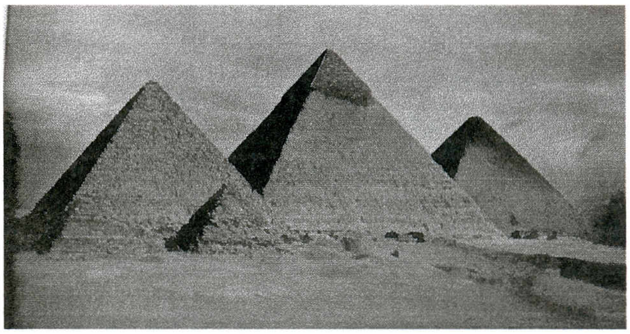


fig.3.15

fig.3.13 Ur, Ziggurat of Ur-Nammu (2112-2095 BC) (source:Turner, 1996)

fig.3.14 Sakkarah mastabas (source: Mıchalowski, 1968)

fig.3.15 Giza pyramids in Egypt (source:Mıchalowski, 1968)

When the connection between lower surface and height of Cheops Pyramid is analysed the relation between the building and the ground can be understood. The rate of the surface to the hight is one of the most important factors in providing the stability of the building (fig.3.16). Increasing the hight of the building by keeping the lower surface constant carries the centre of gravity from the ground. This situation may demolish the stability of the building with effect of "moment" by lateral loads.

Load transfer occurs by transferring weight of stones, which constitute the pyramids, vertically to ground (fig.3.17). Equilibrium state of building that show totally compression effect is determined with R=W. Here, W=Total weight is the sum of weights of the stones. It is accepted that this total weight is a singular load in the centre of gravity of pyramid. Generally, **load transfer had been achieved by transmitting the weight of stone columns that constitute the pyramid vertically to "the ground".**

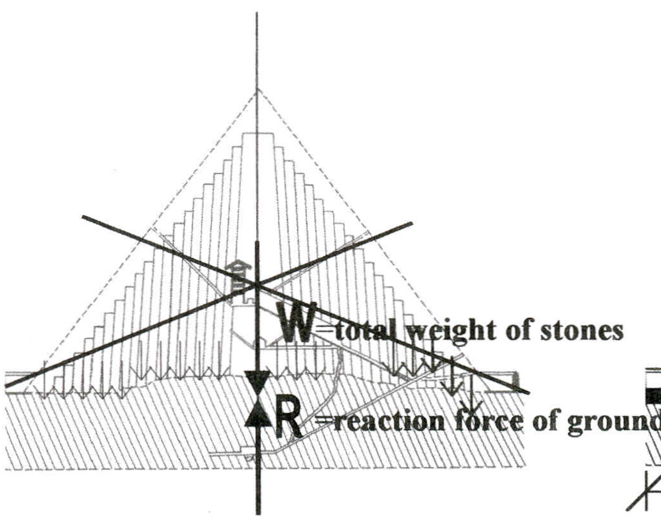


fig. 3.17

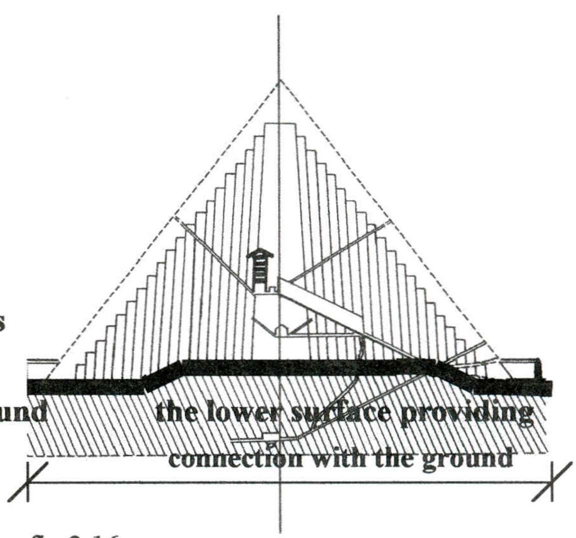


fig.3.16

fig. 3.16 Relation between the lower surface and the height of Cheops pyramide

fig.3.17 The structural analysis of Cheops pyramide

Similar to the sculptures (Imhotep, Kouros) structural orders in Egyptian and Greek temples also has static equilibrium. The connection of these buildings with the ground occur through elements that directly constitute building.

In Greek temples, such as Hephaisteion (fig.3.18), Athens, all elements that are in connection with the ground have structural characteristic. Each element transfers its load and loads of elements to the ground through its geometric axes. The stability of these structural elements and so, the stability of entire building occurs through the rigid connection of them with ground. Such rigid connection is under the auspices of the foundations which localise through its own direction, of structural elements (walls, columns)(fig.3.19) (seminar, 1992).

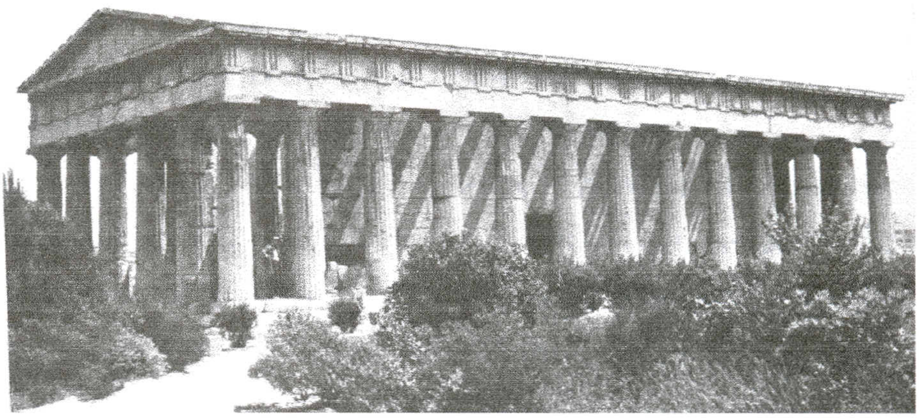


fig.3.18 The temple of Hephaisteon, Classic phase of Greece (source: Biers, 1980)

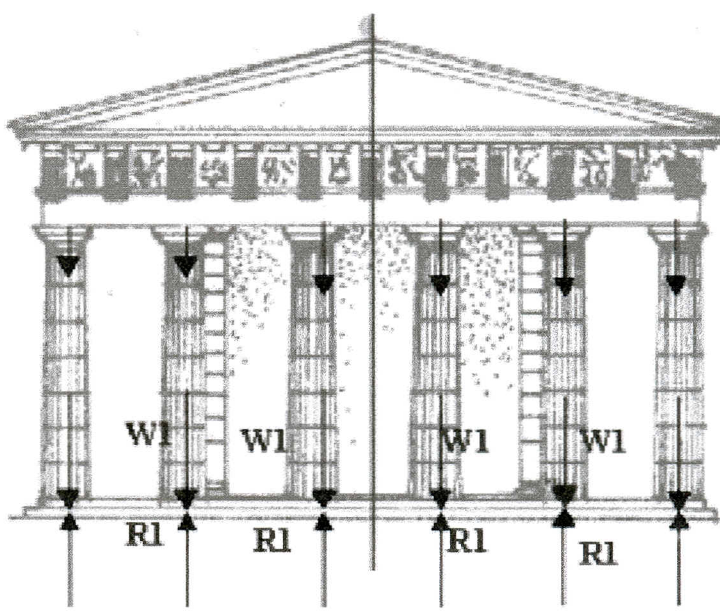


fig.3.19 The structural analysis of the temple of Athens (source: Baker, 1996)

Accordingly, it can be said that there were two connection types that are continuous wall and single column. Lots of studies on these connection types were made by R. Martin. (fig.3.20)

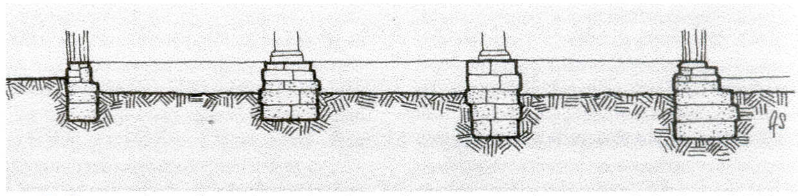


fig.3.20 Delos, third century BC, section showing single column type (source: Mark, 1993)

Also, the forms of columns in load transfer are effective. Columns are connected with each other on the foundations; in this way, building acts as a whole. This is explained by Alexander Zannos in "Form and Structure in Architecture", that, "the column of classical Greek architecture had a cross-sectional area that decreased with weight, it form clearly related the stability of a stone body resting upon as well as transferring its transferring its loads to the grounds" (Zannos, 1987, p.19)

Arches and vaults that were firstly used by Roman architects were accepted the later stage of the post-beam systems and they did not differ from post-beam systems in point of the structural order. They are designed as circular architraves that transfer the loads directly to columns or pilasters (Zannos, 1987, p.29). All of the elements constituting the structural order acts in compression such as fig.3.21. "The forces generated within the arch by internal reactions then act to confine the voussoirs." (Mark, 1993 p.67)

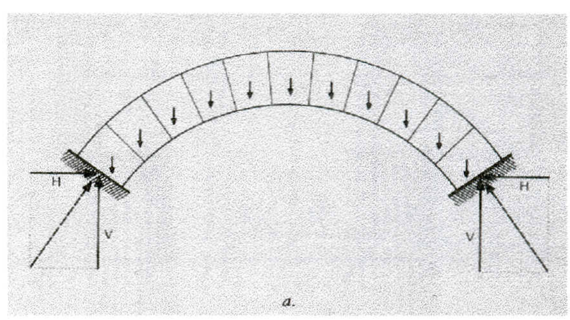


fig.3.21 Internal reactions of an arch (source:Mark, 1993)

The connections of this structure with the ground are same with the connections in Greek Temples and Egyptian temples (fig.3.33).

In a structural order, indirect load transfer is first seen in Gothic architecture such as in Bourges cathedral (fig.3.22). There are three expedients providing such transfer; the pointed arch, the vaultrilo and the flying buttress. These three expedients in Gothic architecture were used together. (Kostof, 1985, p.332). The flying buttress relates to both the adoptions of the groined vault and the pointed arch. Its function simply is as a linear brace to resist the focused thrust of a vault or of wind loading on a great load (Mark, 1993, p.108). However it acts only in compression like the other elements. Also the pointed arch distributes loads more effectively. The load rib provides the distribution of loads into four points. In this way, loads are transformed into the linear elements (columns) and then into the ground like the post and beam system (fig.3. 23-24).

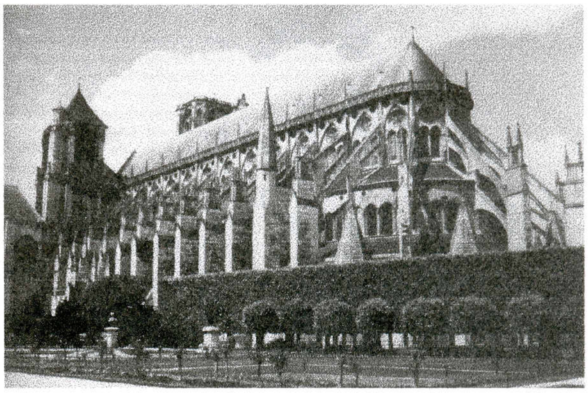


fig.3.22 Bourges Cathedral, 1195 (source: Mark, 1990)

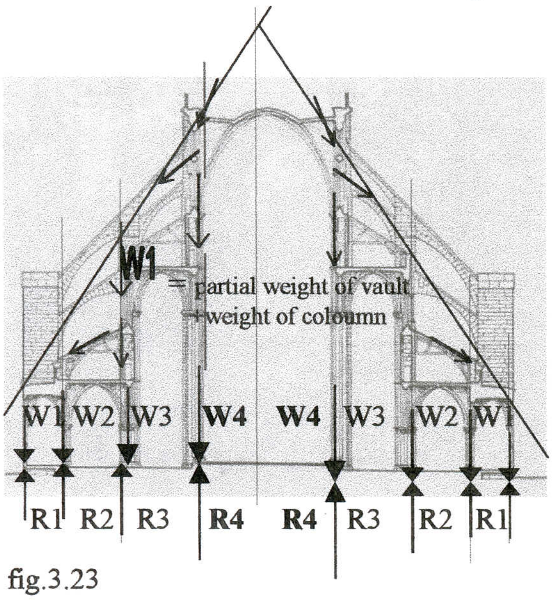


fig.3.23

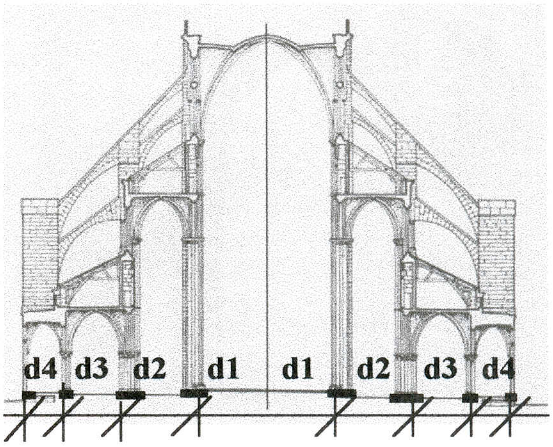


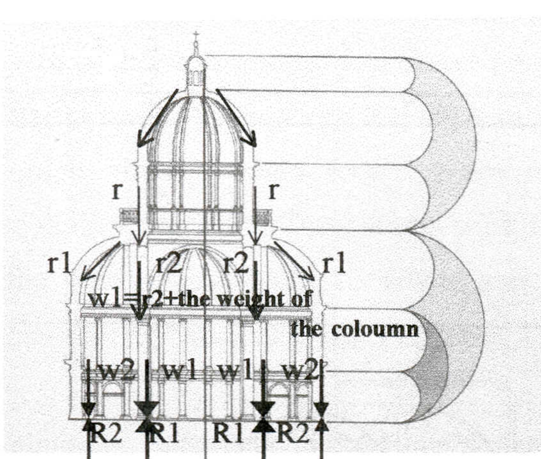
fig.3.24

fig.3.23. Structural analysis of Bourges Cathedral

fig.3.24. Relation between structural whole of Bourges Cathedral and ground

Additionally, pyramidal organisation seen in structural orders of Renaissance, in which round arch had been used, is based on indirect load transfer (fig.3.25). The dome at the centre, semi-domes and chapels are the basic elements in the order. The connection of the dome consisting of main arches with to ground had been achieved through triangular and spherical parts. These parts transmit the weight of the dome to the arches. In this way, the order providing continuity of the load transfer had been constituted. Such a continual load transfer had been from the dome to drum, to the arch of the nave, to the arches of the aisle and the chapels. The continuity had shown a distribution of the loads in pyramidal order (Furnari, 1995) (fig, 26-27).

fig.3.25 Santa Maria Della Consolazione in Todi (source:Furnori, 1995)



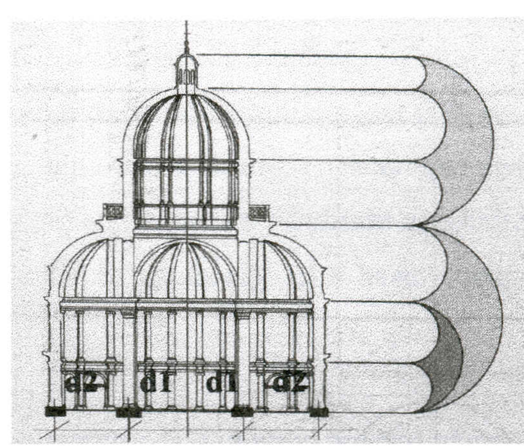


fig.3. 26

fig.3.27

fig.3.26 The structural analysis of Santa Maria Della Consolazione

fig.3.27 Relation between structural whole of Santa Maria Consolazione and the ground

In general, elements in structures having static equilibrium order show a compression effect in the direction of its vertical axis. In the other words, the gravity is seen as a unique natural influence that affects the building. Because the building, in fact, resist to other external loads with its weight.

At this point, another clever feature that provides stability of structure is symmetrical load transfer. In this short of examples, symmetry is valid for the distribution of weight where it is the weight of structure. Deformation of symmetry in load distribution causes deviation of structural order from the state of equilibrium to deformation.

3.3.2 Analysing The End-Products In The Scope of Geometry

The situation of structural balance of the static wholes has similar characteristics to their state of the structural equilibrium.

Generally, the products having static equilibrium show "orderliness" in a maximum level. This principle is nearly equivalent to L.Whyte's definition of "stable form". According to him; "Stable forms are those in which all arbitrary variables have vanished" (Kepes, 1987, p.24). Vanishing varieties means using simple geometrical forms that constituted with some definite rules. Rudolph Arnheim explains this as; "Order has come to mean a reduction to simple geometrical shapes"(Arnheim, 1987, p.162) And these geometrical shapes represent the concepts of simplicity, symmetry, regularity etc. These forms that are expressed with different definitions (exact forms, simple forms, certain forms...) are point, line, plane, triangle, rectangle and circle.(Evans, 1995) These forms constituting the solid geometry indicate a definite the state of symmetry. L. Whyte sees the state of symmetry as a basic reason constituting "maximum order" (Kepes, 1987)

Similarly, according to Rudolph Arnheim, symmetry is a highly ordered theme. Thus, it can be said that structural orders in the state of static equilibrium balance usually associated with symmetry. Besides, visual influence of three-dimensional forms that based on solid geometry is one or two dimensional as a result of the state of symmetry.

Accordingly, symmetry is not only a constructive principle but also is an aesthetic principle for structural orders in the state of static equilibrium. Also, the concepts of symmetry and balance have been used together, until fifth century (classical phase of Greek) in sculpture and until at the beginning of twenty century in architecture. It is known that for many ancient architects the guidance came from geometry. "They derived the relative proportions of elements in plan and a few simple geometrical figures (Euclid's elements), most notably the square and a few triangles with specified ratios of base to height (1:1, 1:2, 1:8, 3:4 and 5:8) Along with the organisational concept of symmetry, this helped to create buildings with clear rational orders." (Gelernter,1995,p: 40)

Egyptian sculpture and architecture are constituted of basic elements, which have exact forms. Sculptural products especially those in the Early Dynasties (2925-2575 BC) generated by cubic forms. No geometrical differentiation or pulling has been seen in the statue of Standing figure. The statue is perceived as a rectangular prism. (fig.3.28) Also each elevation of the statue is admitted as a geometrical plane. Boardman has defined these kind of solid objects as "areal shapes" geometrically. He had emphasised that "only giving simple shapes to stone block forms these sculptures. Such as an erect quadrangular pier for a Kouros or a cube is surmounted by a solid rectangle for a Seated Figure"(fig.3.29). (Boardman, 1996, p.38) Same analysis can also be made for Egyptian pyramids and some Greek statues in archaic period. Arnheim explains this two dimensional visual expression in these products that "three dimensional statues are composed from a set of planes related to one another at right angles. There are a front face, a top face and a back face and there are two similar side faces. The symmetrically conceived seated figures of ancient Egypt are well known as prototypes of this method "(Arnheim, 1977, p.57)

Egyptian pyramids are one of the most perfect examples of architecture exemplifying the solid geometrical order. Parallel to the mathematical developments of the period, "they were governed by the geometric definitions of triangle (such as a 3:4:5 triangle) and the rules governed the relationship of the parts to the whole, that, this theory was first applied in 1904 by Auguste Choisy" (Turner, 1996, p:825) .

Each side is composed of a triangular plane. The real form and perceiving are the same(fig.3.30).

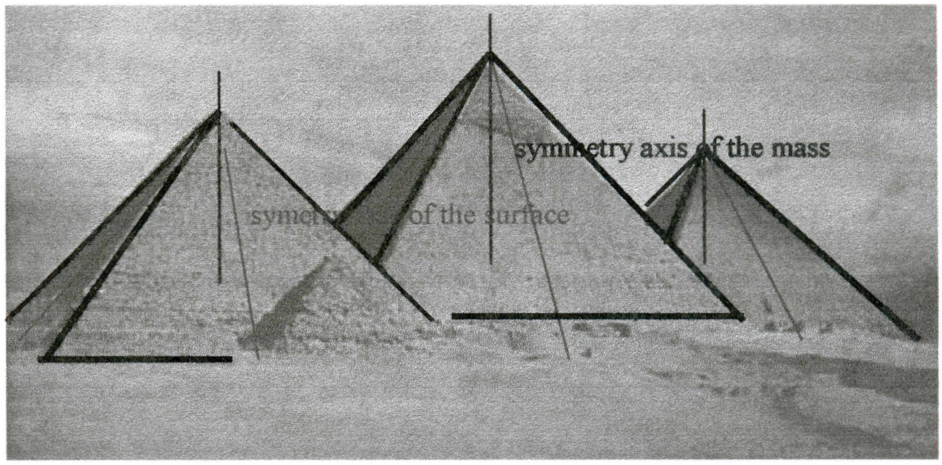


fig.3.30

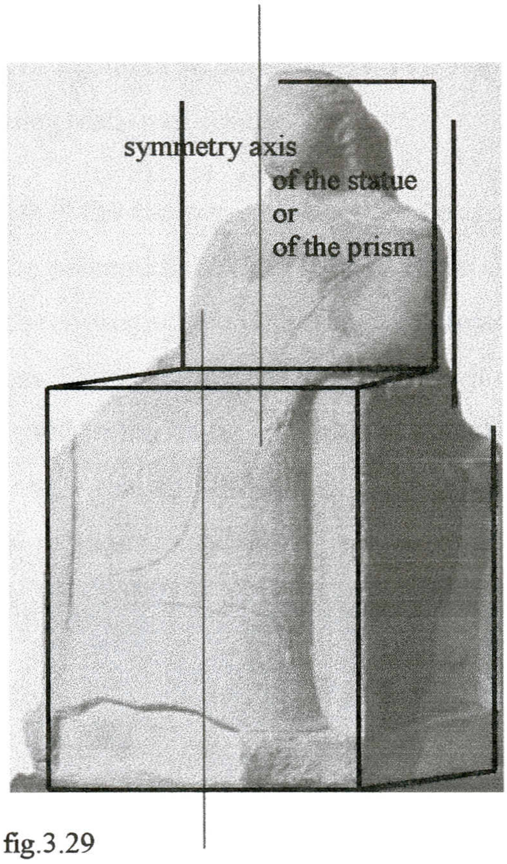


fig.3.29

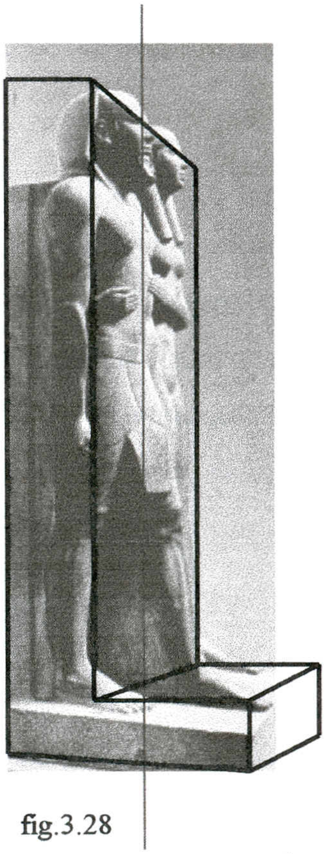


fig.3.28

fig.3.28 The geometrical analyses of the standing figure (Egypt)

fig.3.29 The geometrical analyses of the seated figure (archaic Greek)

fig.3.30 The geometrical analyses of the Giza pyramids

Some sculptural products that are in the state of static equilibrium, as it is explained above, are not single wholes. The statues both in the late period of Egypt and in the archaic period of Greek it is possible to see some geometrical decomposition. However, decomposition in structural wholes does not change the perception of statues as geometrical wholes (fig.3.31-fig.3.32) (ımhotep, kouros....).

Similar kinds of decomposition in a solid whole have also been partly observed in Egyptian and Greek temples. (fig. 3.33). This kind of destruction is the result of post–beam system used for the temples. Such that Hephaisteion Temple in Athens has a general order that is consisted of exterior colonnade, entablature, interior walls and pediment. The characteristics that are mentioned above such as symmetry, two-dimensional perception, solid geometrical forms, are also valid for the whole of the building. Columns providing the decomposition have a rhythmic order, which cause the building to be perceived as a whole. So each side of the temple is perceived as a whole consisting of geometrical forms (fig.3.34). The walls behind the columns are also effective in the creation of solidity.

The symmetry that is the basic principle in the design of Greek temples is also the basic feature in the perception of their state of static equilibrium. The importance of symmetry of pieces consisting the whole in Greek temple is explained in "Ten books on Architecture" as; "Since nature has designed the human body so that its members are duly proportioned to the frame as a whole, it appears that the ancients had good reason for their rules, that in perfect buildings the different members must be in exact symmetrical relations to the whole general scheme" (Morgan, 19).

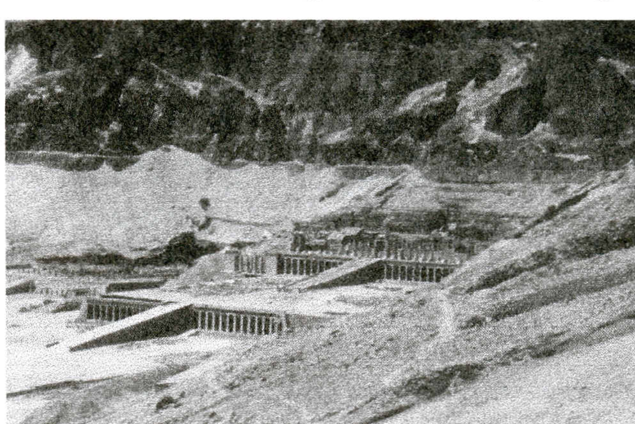


fig.3.33 The temple of Hatshepsut, Deir el-Bahri, Egypt (source:Kostof, 1985)

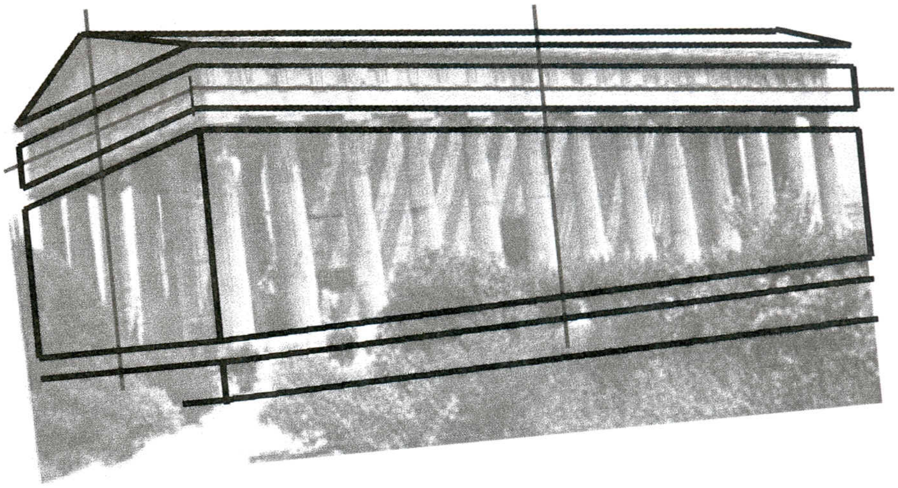


fig.3.34 A geometric analysis of Hephaisteion temple, Athens

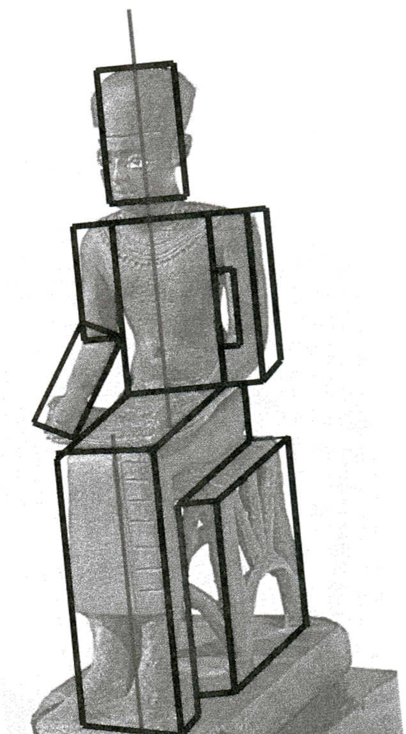


fig.3. 31

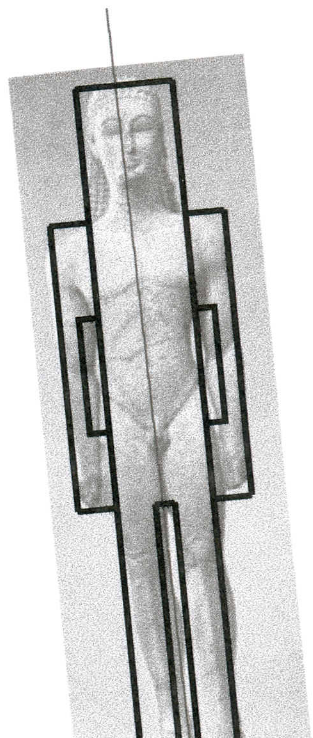


fig.3.32

fig.3.31 The geometric analysis of the statue of Imhotep, Egypt

fig.3.32 The geometric analysis of the statue of Kouros, Greek

The differentiation in the geometry of elements of bearing structures is due to the use of arch and vault in Roman architecture. However, using a curve based on symmetry expresses a solid geometry (semi circle). Additionally, symmetrical use of elements in a structural order results in the perception of the building as a mass/a whole of masses. This geometrical approach is so clear that vault-construction system has been based much more on solid geometry than on a structural function (Zannos, 1987)

Geometrical destruction/differentiation of elements in bearing structure is more clever in Romanesque and Gothic architecture. Such as in Bourges cathedral (fig.3.35), Pointed arch and flying buttress has been the basic elements constituting the differentiation. Pointed arch had caused impairing in the form of the solid semi-circle. Using line and curve together had provided flying buttresses. Nevertheless, the form still based on symmetry. Symmetrical locations of all elements in structural orders and the concave characteristic of all curves in the whole are effective in constitution of a geometrical compact whole.

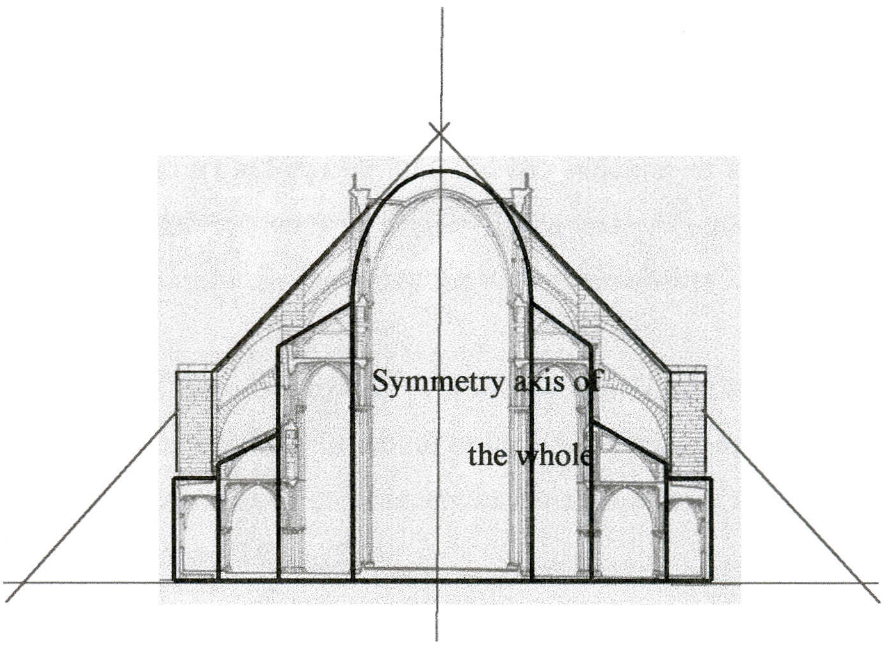


fig.3.35. The geometric analysis of the Bourges cathedral

Perceiving the building that had been really existed from the parts as a compact whole is much clearer in Renaissance architecture. The whole having a solid geometry had been consisted of simple geometrical pieces. In the pyramidal order, each elevation is composed of segments of a circle and rectangles. The geometrical analysis of Maria della Consolazione in Todi shows clearly a visual balance of the structural order having static equilibrium.(fig.3.36)

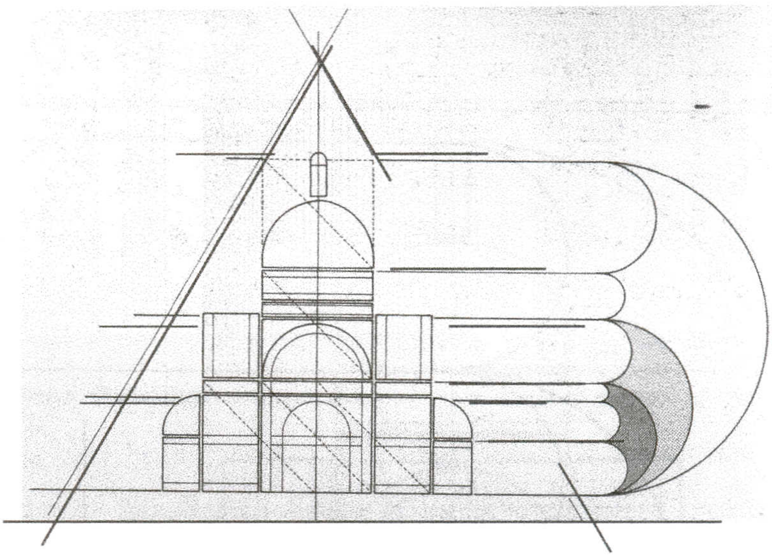


fig.3.36 The geometric analysis of Maria della Consolazione in Todi(source:Furnori,1995)

3.3.3 Analysing The-End products in The Scope of Energy

Both the state of structural equilibrium and the situation of structural balance, of architectural end products that have been analysed under the title of both gravity and geometry brought a common concept along with **"Immobility".**

Visual influence of the products analysed can be expressed through the concept of immobility. In other words, a structural order having static equilibrium is visually immobile (The importance of this concept in the definition of the static equilibrium was given in the chapter 2.2 and 2.3)

In the scope of gravity, structural orders having static equilibrium are stable with load transfer through the vertical axis and their rigid connection with the ground. The characteristics are valid for all parts in the order. This kind of connection with the ground brings about being immobile of the structural order. At this point, in the direction of the acceptance of physics that "each stable object having any distance from the ground has a certain potential energy", all structural orders having static equilibrium have a potential energy in certain degree. Nevertheless, the energy in these kind of structural orders is sufficient for the standing of order that is wholly connected to the ground. In other words, the potential energy is kept in minimum for the orders having static equilibrium.

In the scope of geometry, formal characteristics of the structural orders bring visual immobility along with. Because the rate of orderliness of the structural orders having solid geometry is in a maximum level. In other words, there is not decomposition that causes visual mobility in any orders. This is so clear that, such decomposition is not seen in the kouroi and kouros in the archaic phase of Greek and especially in the Egyptian statues. Man figure in the statue of the Standing figure (fig.3.6) has only been consisted of a single relief. It has an effect of solid stability. Many statues like Seated figure in Egypt and Seated figure in Greek (fig.3.8) exemplify this situation.

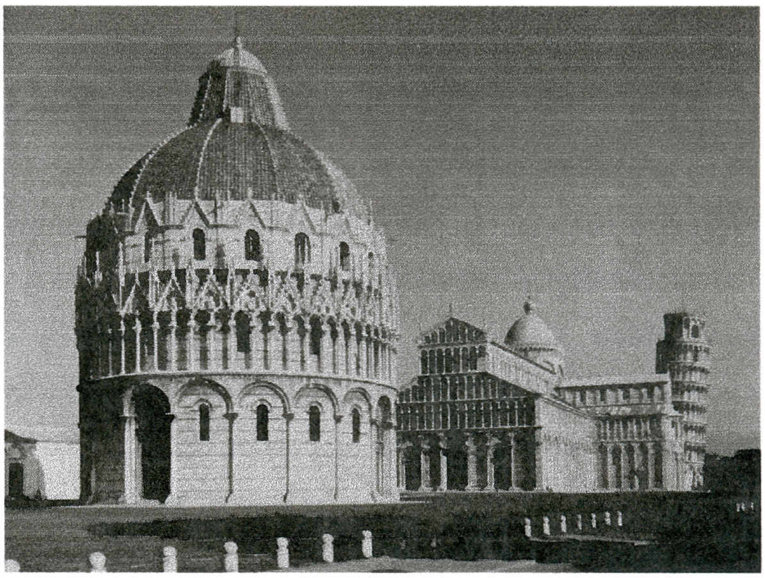


fig.3. 37 Baptistery in Pisa (source:: Kostof, 1985)

The connection type of the structural orders having static equilibrium with ground is effective in determining the situation of immobility in its visual effect. They connect to the ground with a right angle in the direction of their geometric axis. In addition to this, being a greater of the surface of connection with ground is clarified the situation of immobility of the formal whole. Rudolph Arnheim explains this situation with illustration of the Baptistery of the cathedral (fig.3.37.); "We note that at the ground floor, only a few weak elements spell out the dividing line between building and ground. Taken as whole, the ground looks like a shaft that announces no intention of slopping at ground level. And the cylindrical building displays a definite centre. This central bulk establishes a kind of symmetry."(Arnheim, 1977)

The situation of symmetry based on vertical axis in formal order is an important factor in the perception of the whole according to its situation of immobility. Because, symmetry represent the "order" and orderly forms have a minimum potential energy.

Also, the situation of symmetry causes perception of the form as a whole/mass that lead to different results. The relationship between the parts in a system can bring forth the effect of potential movement (see chapter 4.2). On the other hand, while the orders are perceived as a whole with symmetry the effect of potential movement is possibly reduced. And it also eliminates visual tension that can be resulted from being together of different forms.

One of the effects that provide having a minimum potential energy of structural orders is being greater of the proportion between height-weight of the order. Because increasing the height by keeping the weight stable (increasing the proportion) increases the potential energy of the order. This can be explained in other way that; decrease in the proportion of the lower surface to height leads to increase the distance from the ground of the centre of gravity of the order. By this way, the order shows a tendency of falling by the effect of move.

3.3.4.General Evaluation of Structural Wholes Having Static Equilibrium

As a consequence, the general characteristics that the result of analysing the structural orders having static equilibrium with the concepts gravity, geometry and energy are;

- Structures resist external loads by their own weights,
- Each element in the whole transfers loads based on its weight and acts under compression. (Direct load transfer),
- The load transfer of structures has a definite symmetry,
- The centre of gravity of the mass is close to the ground. (the rate of the lower surface to height is high),
  - The state of structural equilibrium achieved by depending on the ground wholly,
  - Structural orders having static equilibrium whole depend on the force of GRAVITY,
  - Structural wholes having static equilibrium is stable,
- Structural orders having static equilibrium have a solid geometrical forms,
- Perception of structural orders having static equilibrium are two-dimensional,
- Structural orders having static equilibrium are in not only structural but also visual relation with the grounds,
- Structural orders having static equilibrium are the orders having a solid symmetry depending on a vertical axis,
  - The state of structural balance is achieved by a state of symmetry with respect to vertical axis of the ground,
  - Consequently, structural orders having static equilibrium show a maximum degree of orderliness,
- Structural orders having static equilibrium do not have potential energy that provides any effect of movement,
- Potential energy of structural orders having static equilibrium is sufficient only for providing standing,

As a result;

- Structural wholes having static equilibrium are immobile wholes having maximum rate of orderliness depending on the gravity.

CHAPTER 4

4.DYNAMIC EQUILIBRIUM

4.1. THE CONCEPT OF DYNAMIC EQUILIBRIUM

Rigid body mechanics, as it is explained in chapter 3.1 is a sub-branch of mechanics, while dynamics is a sub-branch of the rigid body mechanics. Dynamics is concerned with the accelerated motion of the bodies (Hibbeler, 1995, p.3) However terminologically, dynamic is described as the state of mobility of an object/a building. Parallel to these definitions, **dynamic equilibrium** is used **to define the state of stability of the mobile objects (visually and physically).**

4.2. DYNAMICS AND THE DEVELOPMENTS IN SCIENCE

4.2.1 Developments in Physics

With Modern Science, beginning with Renaissance, dynamic is realised as a subject for research. Alexander Zannos explains the outcomes of the new Age as;

> "The Renaissance marked a new beginning in the development of the theoretical science of statics. For the first time since the Hellenistic Age, with the exception of one or two isolated cases during the Middle Age, problems concerning the laws of statics, mechanics and the strength of materials were explored in scientific treatises. Research became more systematic and led to the study, discovery and establishment of current theoretical knowledge in the fields mentioned above" (Zannos, 1987, p.48).

However, the studies of Nicolaus Copernicus (1473-1543) about celestial motion are the initial ones. He had explained that all phenomena related to space proceed from the same cause namely Earth's motion (Wısner, 1973). According to him, the celestial motion could be analysed in terms of geometry and motions of the objects were regular, circular, and continual (Yıldırım, 1997). Nevertheless, the most important studies in this area, which is reflected to studies in engineering, belong to Leonardo Da Vinci (1452-1549) and Galileo Galilei (1564-1642). Galileo had suggested using geometry in analysing terrestrial movements, and in this connection, he had constituted mathematical basis of dynamics. Also, he had used this analysis in structural mechanics. In the basis of Galileo's new approach to the nature, there is a concentration on matter and motion (Math. , p.329), His most important experiments are about using pendulums and falling bodies (Hibbeler, 1995). Contrary to Aristotelian concepts such as rigidity, essence, natural and violent motion, Galileo had used new concepts such as distance, time, speed, acceleration, force, mass, weight...(Math. , 19..) Moreover, he had used his scientific knowledge for the strength of engineering materials and structures (Darkov, 1969, p.11). So, one of the early studies having scientific importance can be examined in the study of Galileo published in 1638 (fig.4.1). This was an analytical study about how resistance is achieved against bending forces. Galileo had believed that the cantilever beam was held fast solely by tensile resistance of its fibbers and that they were equally stressed (Elliot,1994)

Generally, first studies that have been related to the analysis of movement by reducing it into structural mechanic belong to Leonardo da Vinci. "The sketches in his Notebooks are the examples of the relationship between force-length tension when they are in equilibrium"(Zannos, 1987, p.49). The Notebooks also describe a machine for determining tensile strength.(fig.4.2)

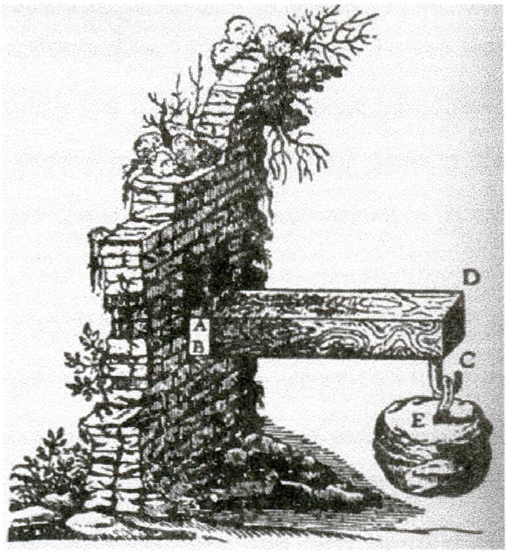


fig.4.1

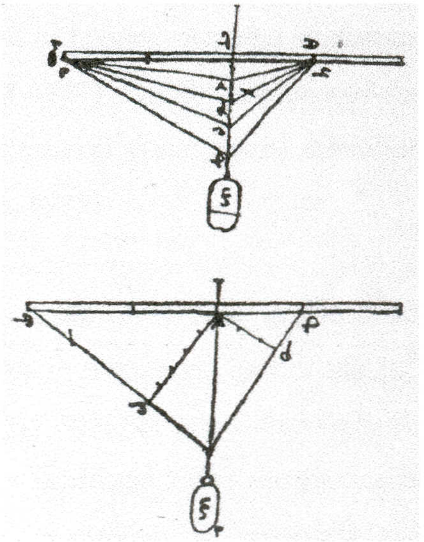


fig.4.2

fig.4.1 Galileo's analysis on the strength of a cantilever beam. (source: Elliott, 1994)

fig.4.2 One of the Leonardo da Vinci's sketches on structural equilibrium (source: Zannos, 1987)

Approximately at the same time, the other study that included various analyses was Giovanni Alfonso Borelli's (1608-1679) work of De motu Animalium. It was one of the most important products of mechanics. Borelli, in this study, applied a simple mechanical principle to human beings and to some animals for analysing different movement (Wesffall, 1995, p.113) (Fig.4.3). The figure shows analysis of the relationship among bone-muscle-articulation-load and the comparison between bone and lever.

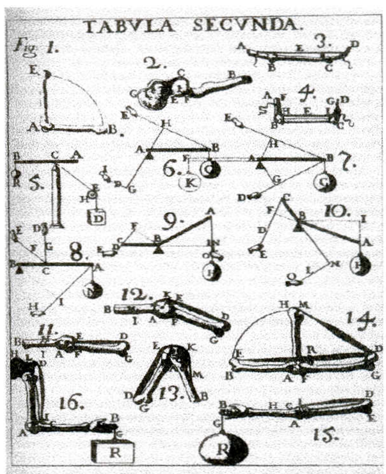


fig.4.3 G.A.Borelli's De Matu Animalium (source:Westfall, 1995)

The following study; related to dynamics and mechanics after Galileo is the study of Robert Hook on the phenomenon of elasticity (1678). He discovered that elastic deformation is proportional to the force that causes it to happen. Another important study on dynamics belonged to Isaac Newton (1642-1727). His formulation of the three fundamental laws of motion and the law of universal gravitational attraction are the most significant works in dynamics (Hibbeler, 1995)

The fact that compressive stresses as well as the tensile ones exist in the cross section of a beam subjected to bending was discovered in the second half of the 18th century as the outcome of a series of tests conducted with the great thoroughness (Darkov, 1969, p.12). Significant developments in mathematics and mechanics in the 18th century had provided studies related to the strength of materials and structures. Among the studies of Leonhard Euler, Jacob Bernoulli and C. A. de Coulomb, Euler's solution to the complex mathematical problem buckling in 1757 had the most particular importance.

In 19th century, great developments in industry gathered the new discipline of engineering and general scientific studies on statics, mechanics, dynamics as "structural mechanics".And, studies on these have continued to constitute a new conveyor system with new materials. In general, a new way of perceiving structural problems has influenced the development of contemporary architectural forms more than anything else and is a direct product of advances in science(Zannos,1987, p.51).

4.2.2 Developments in Geometry

Euclidean (ancient elementary) geometry that had been used until Renaissance had only concerned with the ratios and equalities of lines, areas, and angles. The nature of everything had been understood in terms of bigger than, lesser than or equal to (Arch.79, 1990, p.74). Geometric forms had expressed ideal space.

Nevertheless, elementary geometry had not been sufficient for the studies in Renaissance to understand and express the real nature. (Gamkrelidze, 1991). At this point, Analytical geometry/Cartesian geometry had been applied to surpass this insufficiency. Cartesian geometry that was the invention of Rene Descartes in 1628, after Euclid had been accepted as the most important renewal[1]. Descartes had foreseen the principal advantage of algebraic geometry to describe more complex curves produced by compound mechanical motion (Evans, 1995, p.400). And, he [1]had calculated a curve in space by reducing it to a straight through simultaneous equation.

One of the most important tools for the geometrical expression of the object, is perspective. Studies in perspective appeared together with projective geometry can be seen in the same period. According to critics and historians, Renaissance architecture is accepted as architecture of perspective. However, perspective constructed with Alberti's technique, on the "base square". Seeing perspective as a representative tool for three dimensions, he had also showed the relationship between the pieces of an object (Furnari, 1995). These studies of Alberti were

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[1] The analytical geometry of Fermat and Descartes differs essentially from any synthetic system of g eometry in that truth in it is established by means of algebraic, not logical.(source:Stevens, 1990)

collected in his book "On paining" in 1435.After Alberti's studies, it is possible to see a lot of people studying on different methods of perspective. Piero's central perspective (1470s) is an one of these.

Stereotomy that means the cutting of solids was also related to "geometry" (Evans, p.179). The theory of stereotomy had been the most important theories affecting architecture in Baroque, Rococo, Neoclassical, and Gothic; even until Modern. With the method of stereotomy complex forms could be drawn on a plane. The other important studies had been Brunelleschi's proportioned perspective works, Girard Desargue's theorem of four point involution, Durer's (renaissance artist) proportioned works of perspective adoption.

In 18th century, Gaspard Monge had regarded a new branch in geometry; Descriptive Geometry" (1799)[2]. Descriptive geometry had defined configurations in space by their orthographic projections on two fixed "reference planes" perpendicular to one another. The line of intersection between the two reference planes was treated as a hinge, which then opened out into a single flat surface. With this approach of Monge, intersections of plane, conic, spheric, and ellipsoidal surfaces freely oriented in space are shown the state of penetrating, cutting, intercepting and touching each other at any angle with various combinations (Evans, 1995, p:324). As a result of similar studies continuing in 19th century in applied area, mathematical calculations of various forms was made it possible to use them for constituting different formal orders.

From 19th century, Differential geometry had arisen under pressure of a number of problems of the descriptive geometry. The most important problem was tangent. Introduction of differential geometry into geometry made it possible to give a precise meaning to such intuitively obvious concepts as "tangent, curvature, area of a curved surface... (Gamkrelidze, 1991)

[2] The fundamentals of descriptive geometry are based on the principles of orthographic projection. In descriptive geometry the theory of orthographic projection is applied to the drawing-board representation and solution of engineering problems more advanced than those usually encountered in an elementary course in engineering graphics.(source:Pave, 1967)

With differential geometry, the concepts such as Non-Euclidean geometry, non-dimensional spaces, non-commutative algebra, infinite processes, non-quantitative structures had appeared. Accordingly, mathematical expression of different formal order could be scientifically made.

4.3. THE REFLECTIONS OF THE CONCEPT ON ARCHITECTURAL END-PRODUCTS

In physics, a body in equilibrium moving uniformly at constant velocity is said to be in dynamic equilibrium (Hibbeler, 1995, p.271). In the scope of the study, the concept of "movement" which is the basis of dynamic has been considered as a general concept. Additionally, as it is mentioned in chapter 2.2 **the concept of dynamic equilibrium,** in this study, **have been used for expressing the state of equilibrium including any kind of motion (potential, kinetic) of a structural order.**

In this definition, the description of dynamic, different from its usage in physics, does not only express being mobile in physical sense but also express visual motion. Therefore the definition of the concept of equilibrium that has been discussed on architectural-engineering end-products is an expression of an equilibrium state in which structural orders have minimum the rate of orderliness visually and they are stable due to indirect load transfer.

The first examples of structural wholes having dynamic equilibrium are the sculptural products of classical phase of Greek. Nevertheless, examples are seen much more lately in architectural-engineering products. Beginning from 1900, it is possible to see this kind of structural order both in products of sculpture and of architecture.

4.3.1. Analysing The End-Products In The Scope of Gravity

4.3.1.1. The End-Products Having Potential Energy

Two basic characteristics that provide standing of a structural order "**the way of load transfer**" and "**the rate of dependency on the ground**" must be discussed to understand the resistance of the structural wholes having dynamic equilibrium against **"the force of gravity".**

Generally, the structural wholes having dynamic equilibrium have an indirect load transfer and the clearest characteristic of such an order is **"destruction" in the load transfer. The rate of dependency on gravity is noticeably reduced.** In other words, the lower surface of a whole providing connection with ground, which is an important factor structural equilibrium, had decreased in comparison with the whole. However, the factor is determinant in the state of stability like structural orders having static equilibrium. Consequently, the order having dynamic equilibrium depends on "the ground". Nevertheless, **they can mostly defy the force of "GRAVITY".**

Purest examples of the structural wholes having dynamic equilibrium are Greek statutes (except for those in archaic period), because materials and technology are not determining factors of the wholes. The products can only be analysed through physical necessities mentioned above.

Structurally, the clearest characteristic in the statues is partial load transfer that is not based on symmetry. The Kouros in classic phase of Greek (fig.4.4) can examplify this characteristic.

The connection of the statue to the ground had not been achieved with a single surface. The statue had been tied to the ground of three points (fig.4.6). So, the load transfer had been achieved by these three points. Supporting point of the right foot and the column are basic elements in the load transfer (fig.4.5). The statue is inclined to the left side. Inclination had shifted the centre of gravity from main support point R1 to R2. This situation had caused a force of moment (M).This force

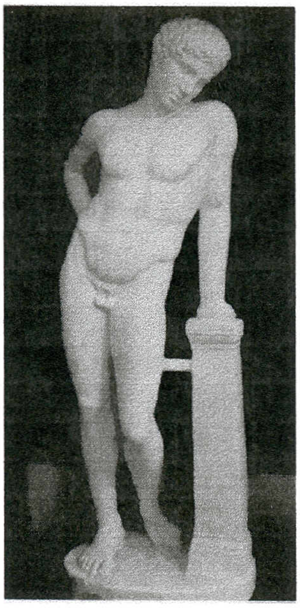
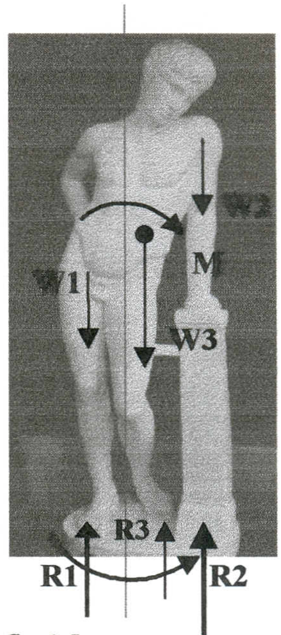


fig.4.4



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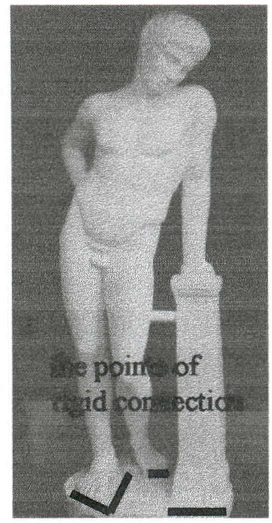


fig.4.6

fig.4.4 Boy Athlete, copy of original of about 410 (source:Boardman, 1996)

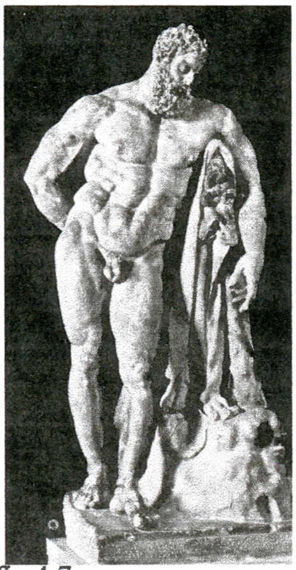
fig.4.5 The structural analysis of Boy Athlete

fig.4.6 The connection between the ground and the statue

had been mostly restricted by the column/support elements acting under compression with left arm. As a result of the greatness of the height of the centre of gravity from ground, a horizontal secondary support had been used.

Similar structural analyses can be made for all Greek Statues such as Fernase Herakles (fig.4.7), Doryphoros (fig.4.8), and Apollo Belvedere (fig.4.9.). Polykleıtos's Dorphoros had been analysed physically that; The man rests his weight on his right leg while the left is pulled back and to one side, with the foot resting lightly on its toes. (Biers, 1980, p.216)

In the analyses of these examples some small differences can be seen. In the statue of Apollo Belvedere, the weight of the arm without the robe would cause bending moment in it, which in turn can lead to the development of high tension stresses along the top surface of the arm and compression stresses along the lower surface. Marble is weaker in tension, so the arm is highly susceptible to breaking off. The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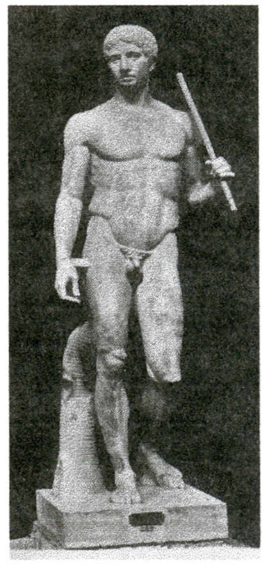
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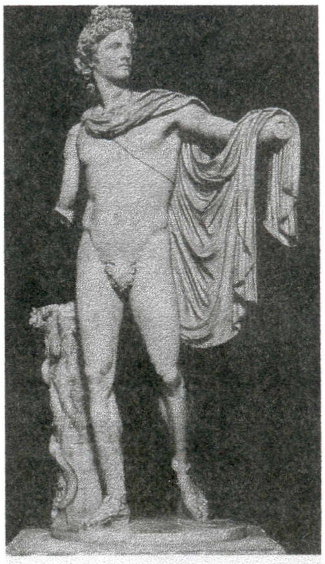


fig.4.9

fig.4.7 Fernase Herakles, The Hellenistic Age (source: Bieber, 1961)
fig.4.8 Doryphoros of Polykleitos (source: Carpenter, 1960)
fig.4.9 Apollo Belvedere, The late classical period (source: Boardman, 1995)

robe, however, provides a stabilising function by acting as a compressive strut, keeping bending from developing in the arm (Schodek, 1993, p.55).

However, the most important difference is seen in bronze statues of Greek in which support elements such as tree trunk and robe had not been used. These statues had achieved their structural equilibrium with internal tension and rigid connection with ground. The surface of rigid connection is quite lesser when it is compared to the whole because bronze material resists tension stresses. A bronze statue of Heracles is one of them (fig.4.10). In this example, the most effective element in the state of equilibrium is the left hand of the statue. The effect of force caused by moment on the left hand had increased the inner force in shoulder and in this way, excess force on the right is equalled. Resistance of the statue to inner forces wholly depends on bronze material.

Myron's Diskobolos is more advanced example to the dynamic equilibrium (fig.4.11). One of the most important points in the statue is that internal forces are too much. This situation is clearly understood from the elevation (fig.4.12). Connection with ground had been achieved only with two points. When the statue is examined completely, it is seen that there is a force of moment towards the left side because the centre of gravity out of the points where the connection with the ground

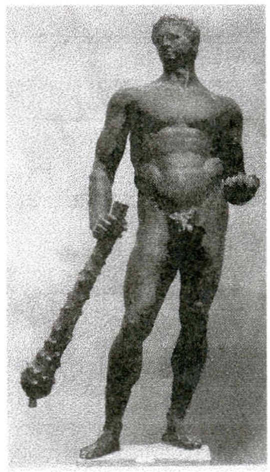


fig.4.10 Heracles Lencbachtype (source:Boardman, 1995)

had been achieved (R1, R2) (fig.4.12). In other words, there is an **asymmetric load transfer**. In this situation, resistance of the statue to the tension is carried especially by the left foot with its material.It had protected from being out of the state of equilibrium towards the left side. This can be understood clearly, when the marble copy of the statue is analysed (fig.4.13). Remaining statue in equilibrium depends on a support element. The load had been transmitted into both sides through reducing tension in the right foot by a support element In addition, second elevation of the statue shows the moment towards front side. The force of moment of the right arm location of the foot and its material cause restriction of force of moment toward front side.

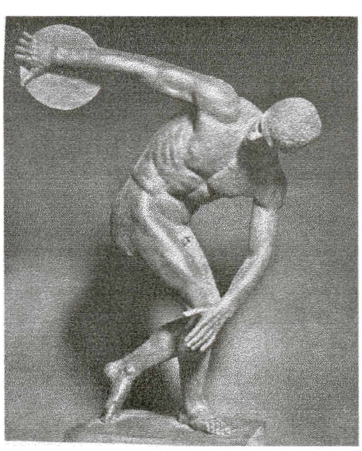
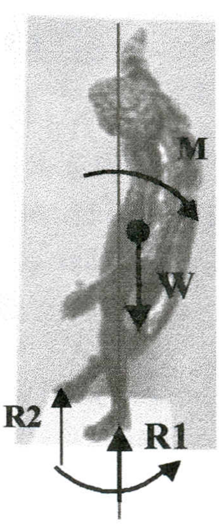


fig.4.11

fig.4.12



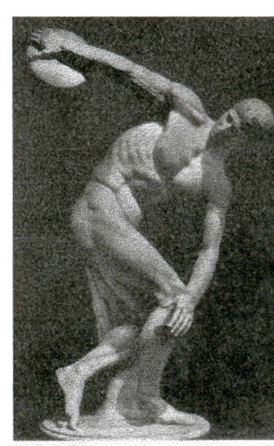


fig.4.13

fig.4.11 The Bronze copy of Myron's Diskobolos (Carpenter, 1960)

fig.4.12 The structural analysis of Diskobolos

fig.4.13 The marble copy of Myron's Diskobolos (Biers, 1980)

Approaches towards the statues in classical period had changed due to the effects of scientific developments beginning with Renaissance.Three dimensional statues having high essence is often seen in this period. The most clever characteristics in the statues had vertical effect in structural sense and different resistances against gravity.

The most important studies in this period constituted the beginning of Modern Sculpture belonging to Auguste Rodin (fig.4.14), Koben, Siva and Edgar Degas (fig.4.15-16).William Tucker emphasizes these studies as "a sense of gravity, of a strong relation between the form of the object and the ground on which it lies, has been central to the most vital modern sculpture since Rodin". (Tucker, 1988, p.145)

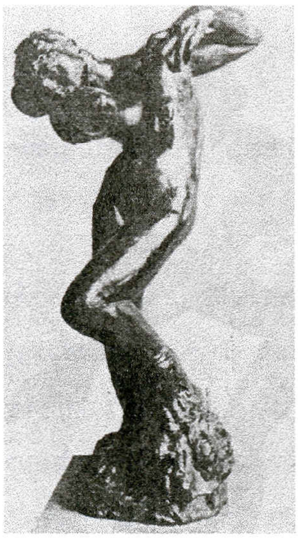
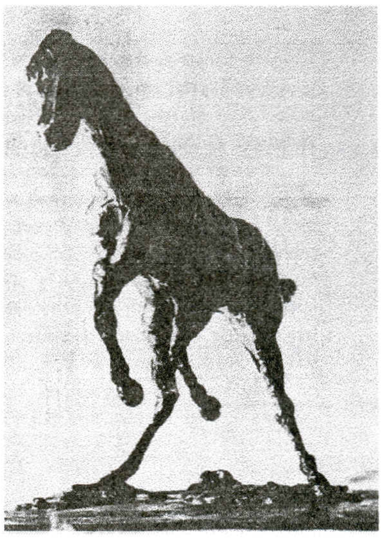


fig.4.14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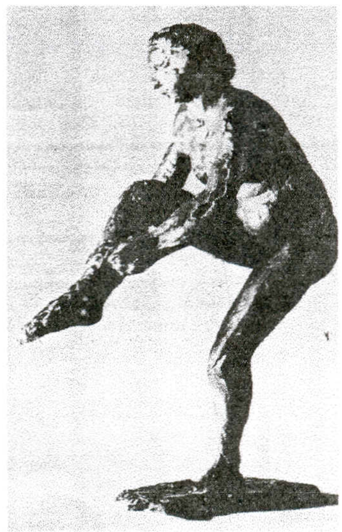
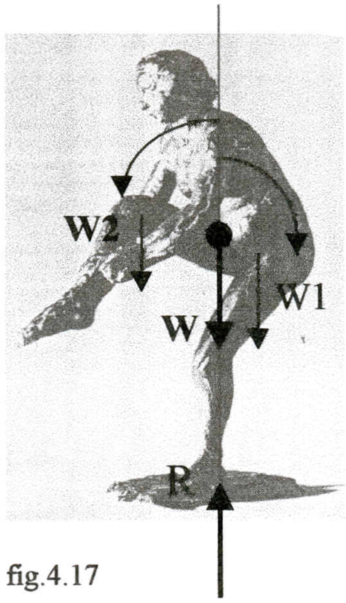


fig.4.16

fig.4.14 Auguste Rodin, Meditation,1885 (source:Tucker, 1988)
fig.4.15 Edgar Degas, Horse Clearing an Obstacle,1865-81 (source:Tucker,1988)
fig.4.16 Edgar Degas, Dancer Putting on her Stocking, 1896-1911 (source:Tucker, 1988)

Structural analyses of these studies clearly show the structural change in the relation between load transfer and connection type with the ground. One of them is Degas's Dancer Putting on her Stocking (1896) (fig.4.17) Degas's statue had highly defied to the gravity and dependency on ground had notably been decreased. Asymmetrical load transfer and the stability of the statue had been achieved by small rigid connections (fig.4.18). To stabilize the statue, the dimensions of the base of the



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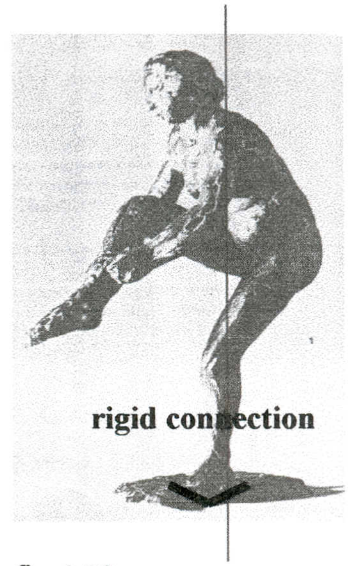


fig.4.18

fig.4.17 The structural analysis of Edgar Degas's "Dancer Putting on her Stocking"
fig.4.18 The rigid connection between the statue and the ground

sculpture are adjusted to pass the vertical axis from the center of gravity.(Schodek, 1993)

After 1900's, abstract expressions based on geometry had replaced the sculptural products in which the state of equilibrium in man's motion had been reflected with a realistic approach. It is possible to find common structural characteristics in these products that have been analysed by different approaches in the history of architecture such as; Futurism, Cubism, Constructivism. These characteristics basically do not differ from the ones discussed above for sculptural products of Greek, Roma and Renaissance periods. In other words, physically maximum resistance to gravity (minimum dependency with the ground, a symmetrical load transfer) is the most basic characteristics of the orders. Differences of the end products had resulted from differences of the rate of these characteristics in different formal orders. Material's resistance to tension is generally determinant in these proportional differences.The studies of designers such as Boccioni, Kasemir Malevich, Rodchenko, Vlademir Tatlin, Antonio Pevsner, Naum Gabo... had became the avat-garde in the design of these kind of sculptural products. The studies of Naum Gabo based on equilbrium are the most notable ones (fig.4.19-20-21). These studies effected in the studies of Max Bill, Kenneth Snelson etc.

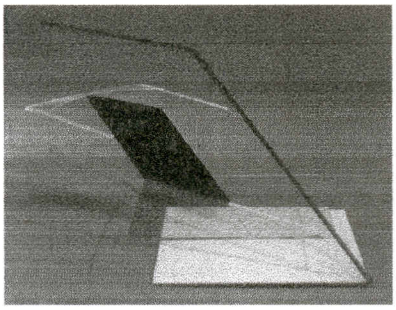
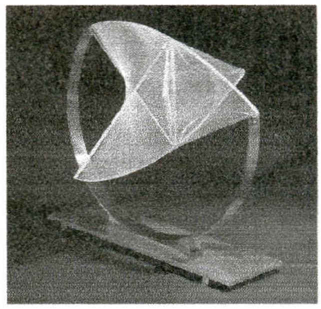
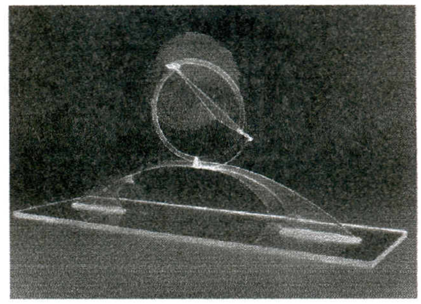




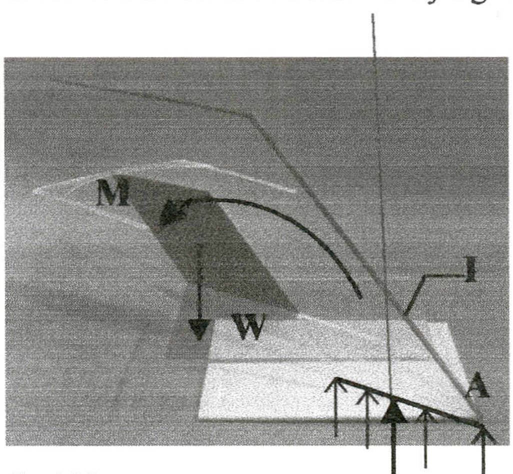
fig.4.19 fig.4.20 fig.4.21

fig.4.19 Monument for an airport, Naum Gabo, 1932-48 (Nash, Merkert, 1985)

fig.4.20 Construction in space: Arch, Naum Gabo, 1929-37 (Nash, Merkert, 1985)

fig.4.21 Construction in space: Suspended, Naum Gabo, 1957-65 (Nash, Merkert, 1985)

One of them is the study of "Monument for an airport" (1932) that is a whole consisting different parts.(fig.4.19) As a result of the type of locations of the pieces, the statue has a moment in counterclockwise(fig.4.22). This moment had been restricted by the rigid connection with the ground. The part of "I" stands with the resistance of steel and with the support of the part of "A". In the study of "Construction in space"(1957) (fig.4.20), weaker connection with the ground and asymmetrical load transfer are the factors effecting the state of equilibrium. Stability of the order had been achieved by rigid connection.(fig.4.23)



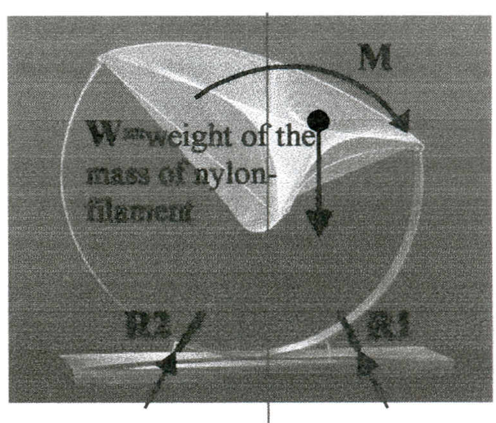


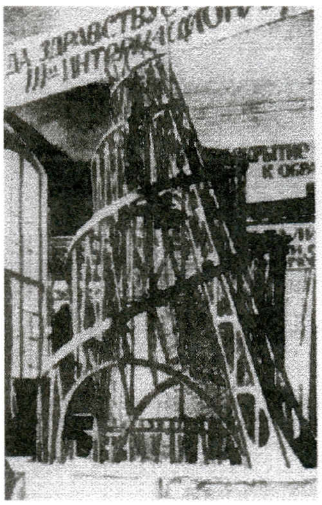
fig.4.22 fig.4.23

fig.4.22 The Structural analysis of "Monument for an airport"

fig.4.23 The Strucutral analysis of "Construction in space"

In the direction of mentioned structural characteristics, the structural orders having dynamic equilibrium that beginning from the Greek has just appeared in architectural-engineering end-products after the beginning of 1910's. Basic characteristics of all sculptures having dynamic equilibrium and providing indirect load transfer is the using of cantilever connections. First physical analysis of a cantilever beam had been made by Galileo in 1638. Nevertheless, this kind of a structural order could not be used in architectural products.

At the end of 19th century with the invention of steel and concrete, cantilever elements had become the basic characteristic of structural orders having dynamic equilibrium. "Monument to the third International" designed by Vlademir Tatlin in 1919 was one of the first examples in which the cantilever is used. (fig.4.24) Although it is structurally unclear, it is possible that a cantilevered girder is the main element of the structural order. In this situation, the weight of the cone had been carried by the girder through bending. (fig.4.25) Consequently, the weight of the cone had indirectly been transmitted to the ground.



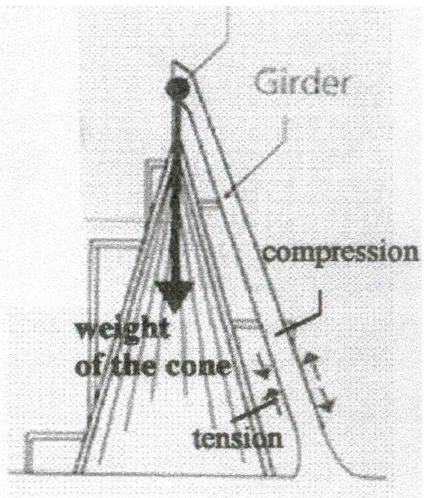


fig.4.24 fig.4.25

fig.4.24 Monument to the third International, V. Tatlin, 1919 (source:Schodek, 1993)
fig.4.25 The structural analysis of Monument to the third International (source:Schodek, 1993)

One of the first examples where cantilever elements had largely been used is F.L.Wright's Kaufmann House (fig.4.26) (Moholy-Nagy, 1956). So, the strongly cantilevered Kaufmann House is the important example of resistance to gravity.

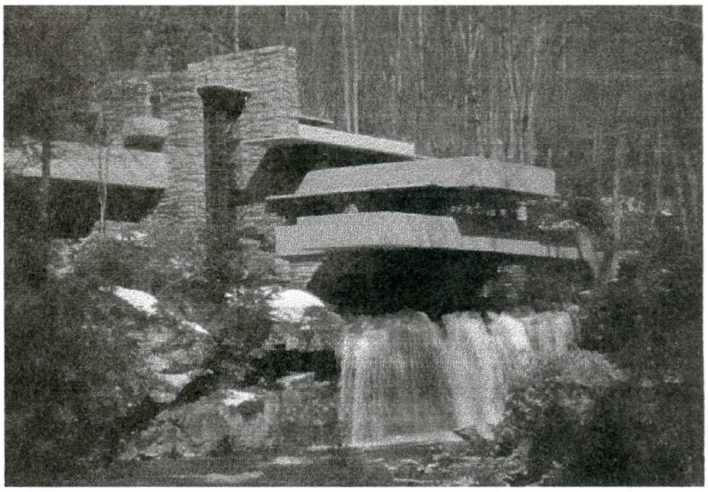


fig.4.26 Kaufmann House, Frank L.Wright (source: Curtis, 1996)

The characteristics that provide the analysis of cantilevered system under the definition of dynamic equilibrium can be clearly shown in the Reallon River bridge (fig.4. 27).

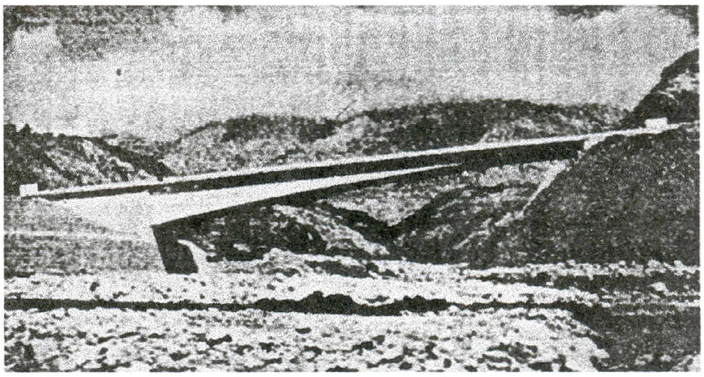


fig.4.27 The Reallon River,France (source:Zannos,1987)

Another example is P.L.Nervi's Municipal stadium (fig.4.28) The force of moment resulting from the weight of the roof had been restricted by cantilevered connection. (fig.4.29) The canopy at the entrance of the main hall of the Termini Railroad Station in Rome is somewhat different. (fig.4.30) "The beams of the hall jut out as cantilevers to form the cover". (Zannos,1987,p.171) (fig.4.31)The column had been accepted as a cantilevered beam under double sided momentum. Searches towards cantilevered structures reached a level in which this system became the main order constituting the whole of the building such as in the design of Asplund's Domino Tower (fig.4.32), twin blocks in Madrid(fig.4.33) and Shoei Yoh's Matsushita Clinic in Nagasaki. Both (fig.4.34)two buildings are physically under the effect of force of moment. Standing against gravity resulted by cantilever connections of buildings with ground.(fig.4.35)

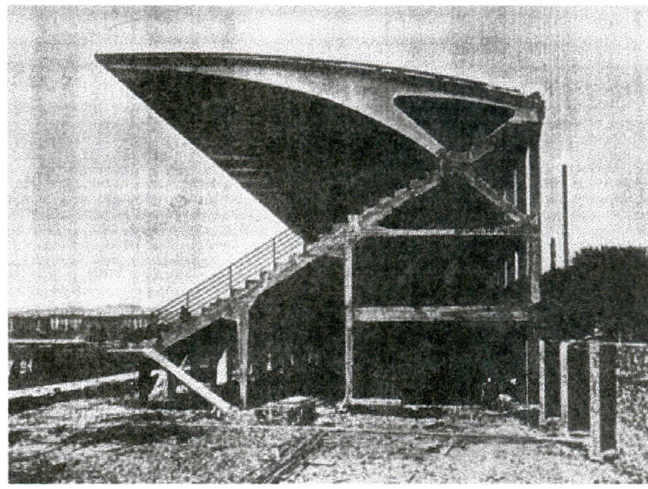


fig.4.28 P.L.Nervi's Municipal Stadium, 1928, Florence,(source:Arnheim, 1977)

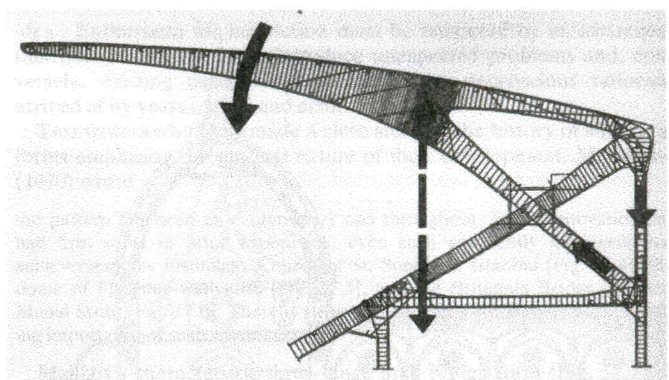


fig.4. 29 P.L.Nervi's Municipal Stadium,free body diagram (source:Holgate,1986)

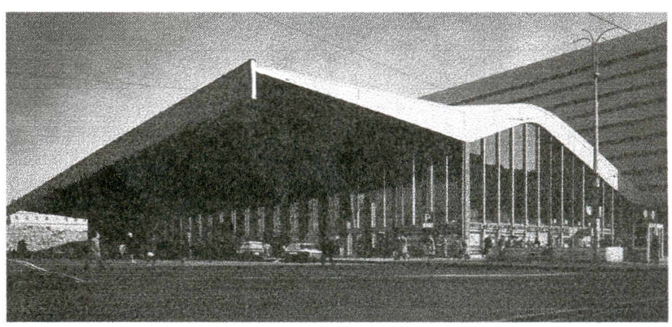


fig.4.30 Termini Railroad Station, L.Calini&E.Montuori, 1951 (source: Mattie, 1994)

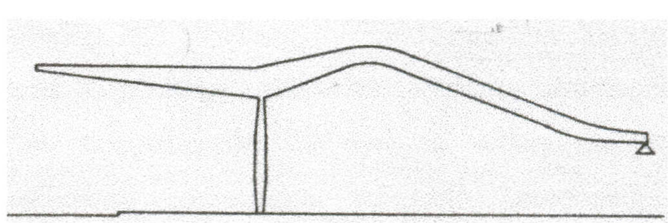


fig.4.31 The structural order of Termini railroad Station (source: Zannos, 1987)

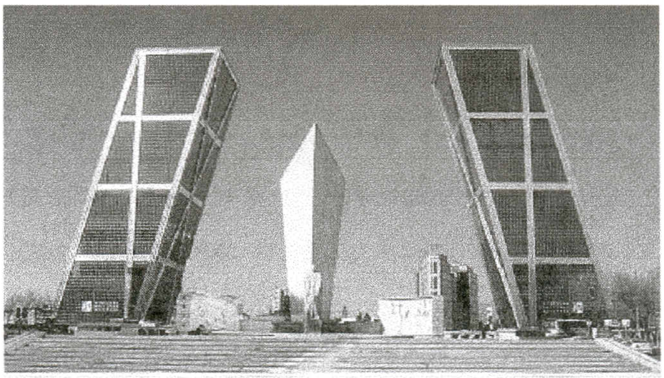


fig.4.33 Twin blocks, Madrid

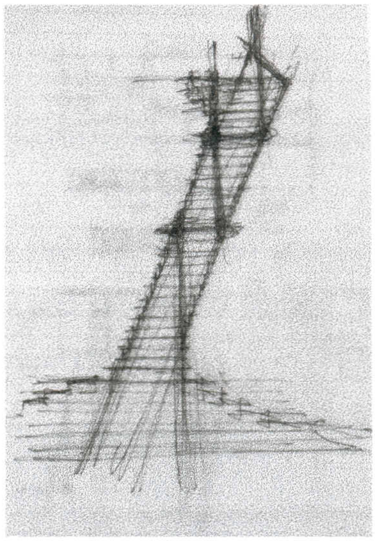


fig.4.32 Asplund's Domino Tower (source:"Bırkerts, 1994)

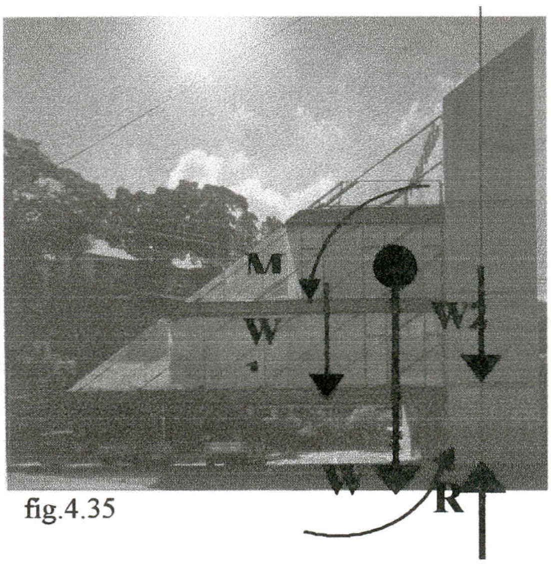


fig.4.35

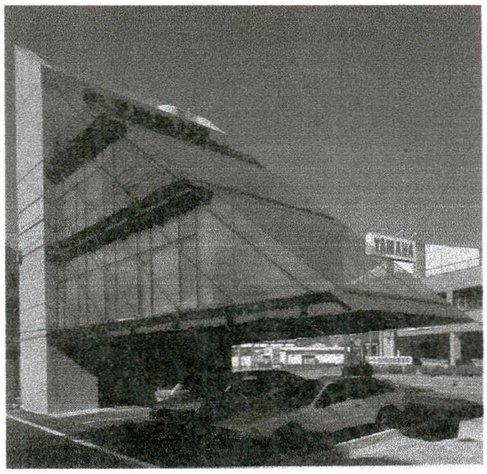


fig.4.34

fig.4.34 Shoei Yoh's Matsushita Clinic in Nagasaki (source: Vitta, 1991)

fig.4.35 The Structural analysis of Matsushita Clinic

In addition to steel and reinforced concrete, different structural systems (cable structures; tensegrity structures; membranes; shells) had also been effective in constituting structural orders having dynamic equilibrium. In this way, both in sculptural and architectural engineering end products different solutions having dynamic characteristic had appeared. Especially, cable and tensegrity structures became effective in constituting extreme examples for dynamic orders. Cables generally transmit loads of secondary components to main components. Therefore,physically each component in the order did not directly related to the ground. As a result, the surface providing connection with the ground had rather been decreased.

The dynamic caracteristic of cable structures can be exemplified with Santiago Calatrava's sculptures. In his study of "Wooden Tower Toros"(fig.4.36) there is a force of moment resulting from the location of cubes and indirect load transfer between cables and cubes. Load transfer between cubes and cables and tension in the cables had prevented demolishing the state of equilibrium (fig.4.37).

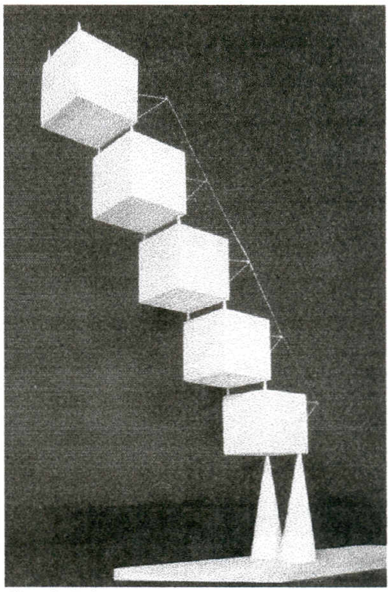


fig.4.36

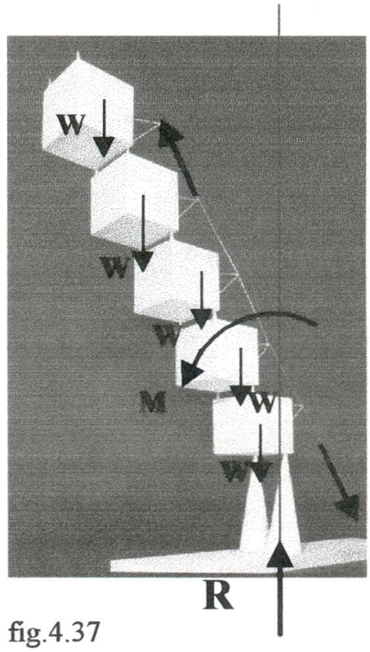


fig.4.37

fig.4.36 The sculpture of "Wooden Tower Toros", S.Calatrava (source:B.Gap, 1989)

fig.4.37 The structural analysis of The sculpture of "Wooden Tower Toros"

In the other study seen in fig.4.37a, the stability of the order in spite of unexpected location of linear elements that carry cubes had been achieved by cable components.

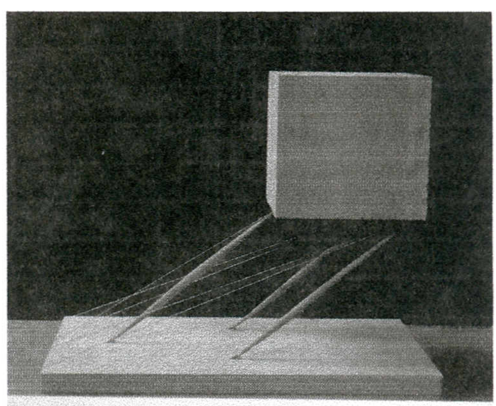
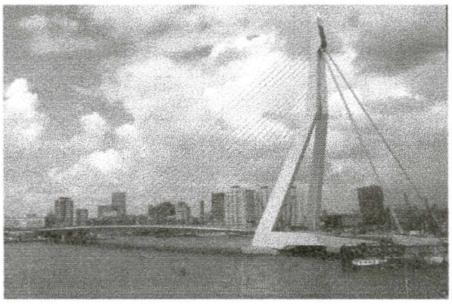


fig.4.37a One of the Calatrava's sculpture, (source. Tzonis, Lefaivre, 1995)

In architectural-engineering products, bridges can be seen as the best examples of these kind of orders. (fig.4.38 ,fig.4.39 , fig.4.40)

fig.4.38



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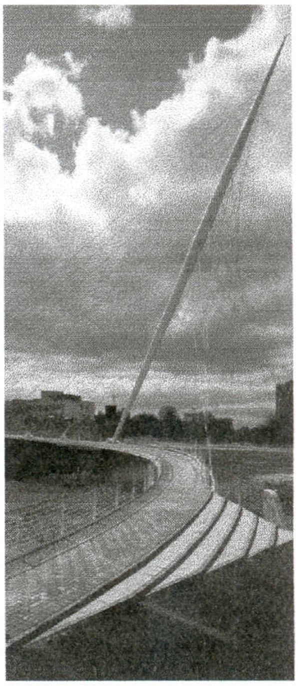

fig.4.40

fig.4.38 Alamillo Bridge, S.Calatrava, Seville, Spain,1987-92 (source: Jodidio, 1998)
fig.4.39 Erasmus Bridge, Berkel&Bos,1997 (source. Berkel&Bos, 1997)
fig.4.40 Trinity Bridge, S.Calatrava, Salford, England, 1993-95 (source: Jodidio, 1998)

In the Calatrava's Alamillo bridge (fig.4.38) the weight of the deck is transmitted to pylon through cables in one direction (indirect load transfer). The pylon having inclined asymmetric location transmits its own weight and weight of the deck to the ground. The connection of the order with the ground had been provided only by lower surface of the pylon.(fig.4.41) Altought Ben van Berkel's Erasmus Bridge resembles to Alamillo bridge physically, it is not an extreme example as much as Alamillo. The pylon is a whole consisting of horizontal and vertical components. The structural equilibrium is among frontal cables, back stay cables, the pylon and the deck. Berkel had explained this structural order as "the horizontal foot of the pylon hugging the slender road deck the fact that the back stays also connect to this horizontal component meant that the support strucutre now took the form of a bracket. The high placement of the back stays resulted in a bending moment in the diagonal pylon: this moment was exploited so that the bend could be permanently fixed" (Berkel&Bos, 1997).

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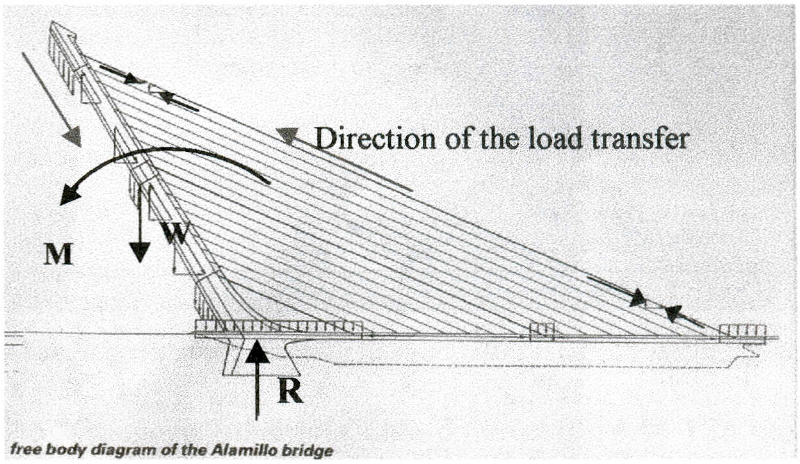


fig.4.41 Alamillo Bridge, free-body diagram, [source (background): Webster, 1992]

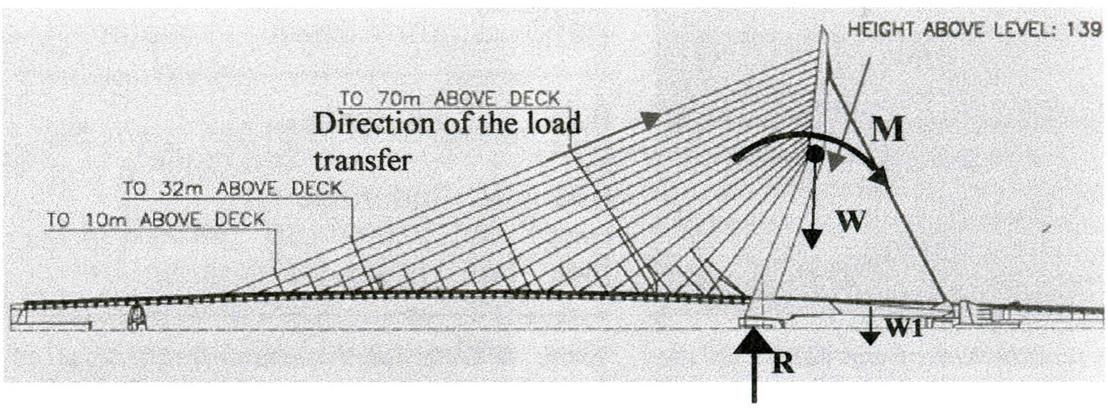


fig.4.42. Erasmus Bridge free body diagram, [source(background): Geurts, 1998)

Tensegrity structures that have based on indirect load transfer have an important place in forming structural order having dynamic equilibrium. Tensegrity structures invented by Kenneth Snelson in 1948, have the purest expression of this principle; "in a pure tensegrity structure the compression members (struts) are suspended in a net of pure tension members" (Robbin, 1997, p.25). Snelson applied this system to his own sculptures.In Easy Landing sculpture (1977), the connection of the structural order with the ground had been achieved with three point. For the stability of the system internal forces in cables and compression components must be in the state of equilibrium in any nodal point (fig.4. 43).

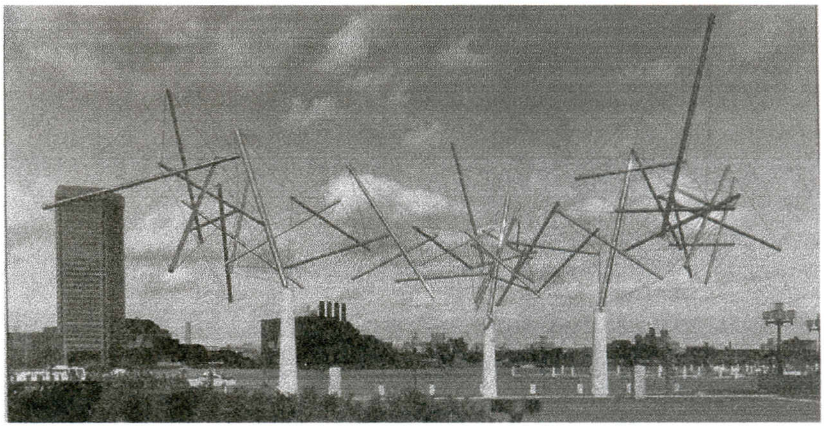


fig.4.43 Easy Landing sculpture, Kenneth Snelson, 1977 (source:Robbin, 1996)

The other example is the "Cantilever" that is a little different.(fig.4.44) In this example, the important problem of the order is the compressive forces that could occurred in lower cables. The problem had been solved by using pretensionary cables (Schodek, 1993) (fig.4.45).

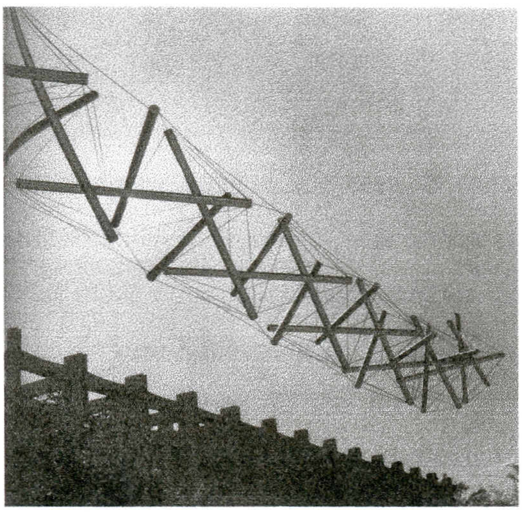


fig.4.44

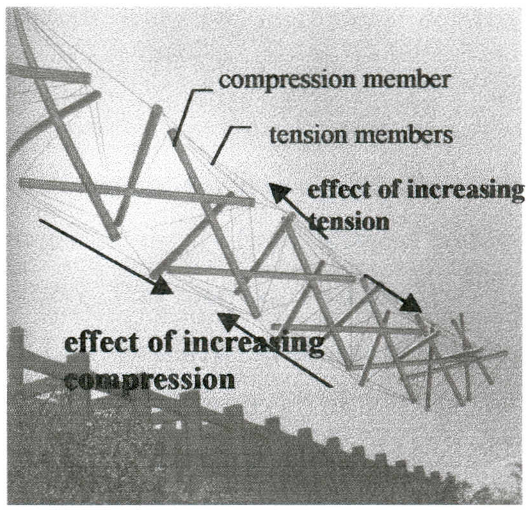


fig.4.45

fig.4. 44 Kenneth Snelson, Cantilever (source:Schodek, 1993)

fig.4. 45 Kenneth Snelson, Cantilever, free body diagram

Tensegrity structures have not been used effectively in architecture as in Snelson's sculptures in point of having dynamic characteristic. This system had used in architecture through some adaptations. First examples of them are shown in Buckminster Fuller's studies that based on Snelson's theory. (1962) He has used tensegrity structure in buildings as a single-layered dome and then D. Georges applied this system as a multilayered grid.

4.3.1.2 The End-Products Having Kinetic Energy

Kinetic motion, until the beginning of 20^{th} century had only been valid for building components such as wheels, doors, figures etc. However, especially in Renaissance, the idea of analysing the kinetic motion and reflecting it to end-products had appeared after the scientific developments. Nevertheless, these ideas were not reflected to the structural products.(Tzonis-Lefaivre, 1995)

Although Wöfflin analysed some works reflecting kinetic motion, in Renaissance and Baroque art and architecture (Tzonis, Lefaivre, 1995). Kinetic motion, from 1910's have appeared as a criteria especially in design of sculpture. In 1912, the futurists had written about movement in sculpture, including mechanical devices (Marter, 1991, p.147).

Kinetic structural orders seen in sculptural, architectural-engineering products are not completely mobile. These orders are tied to ground rigidly from different points. The most important characteristics of the order is that there is a single state of equilibrium. Such an order is stable, a. when it is immobile b. when it is immobile; there is a change in the location of the structural element in each phase of movement. Blates Lowry explained these findings based on Calder's mobiles sculptures that;

> "Because we can see the mobile at the very moment at which it starts to move as well as at the moment it comes to a stop, this object can be said to have a dual state of existence. Between different points in time –from start to stop to start again- the mobile is alternatively in a state of motion and a state of rest. These two states are unified, held together for us, because we are able to see the metal shapes of the mobile during both states. The metal shapes are our points of referance for comprehending the motion of the mobile and for giving a form to the mobile while it is at rest" (Lowry, 1967, p.225).

Alexander Calder's mobiles are one of the most important studies in which the concept of kinetic had been directly reflected. The state of equilibrium of these structural orders are explained with the concept of "rotational equilibrium". The mobile in the figure (fig.4.46) is in a state of equilibrium where the moments resulting from the weights of each horizontal element are equal. In this situation the order is in a rotational equilibrium (fig.4.47) (Schodek, 1993). Similar analysis is also valid for his study of Mobile-Stabile (fig.4.48). Movement of the statue depends on any external force and the statue moves by joints nodes.

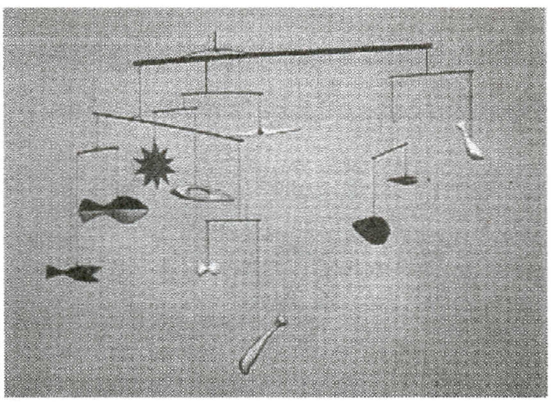


fig.4.46

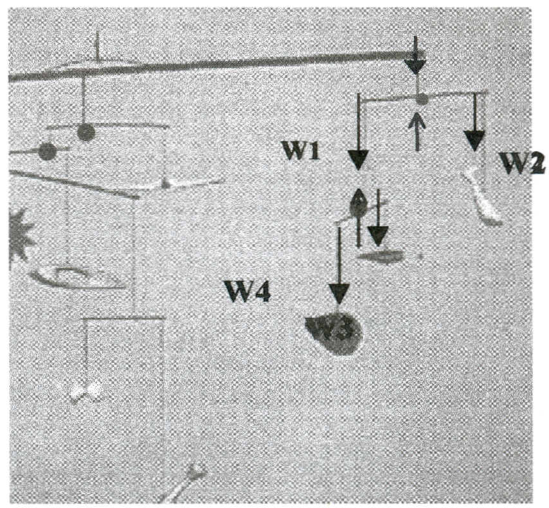


fig.4.47


fig.4.48

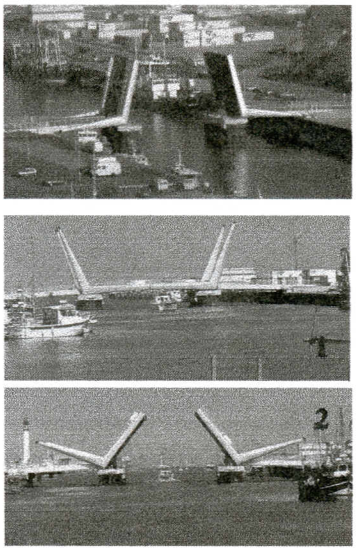
fig.4.46 Seascape Mobile, Alexander Calder, 1947 (source: Webster, 1992)

fig.4.47 The Structural analysis of Seascape Mobile

fig.4.48 Mobile-Stable, Alexander Calder (source: Schodek, 1993)

Contrary to sculptural products in which movement had been achieved by small details of connection, in architectural products, movement of an order is due to different mechanism. Pascale Sewrin's Battle of Texel drawbridge (fig.4.49), S.Calatrava's Kuwait Pavilion (fig.4.50-51), The bridge in Kiel (fig.4.52) can be given examples to kinetic structural orders.

Texel bridge is composed of two movable decks. Although the stability of the order is achieved by a hydroulic mechanism when it is in motion, the type of the load transfer have an importance in this state of stability. In the first location, there is a state of equilibrium in which the weight of horizontal element (deck) is effective (like a simple cantilever beam). In the second location, the force of movement resulting from the weight of the deck in vertical state had been restricted by the pylon in horizontal location and hydraulic mechanism.(fig.4.53)



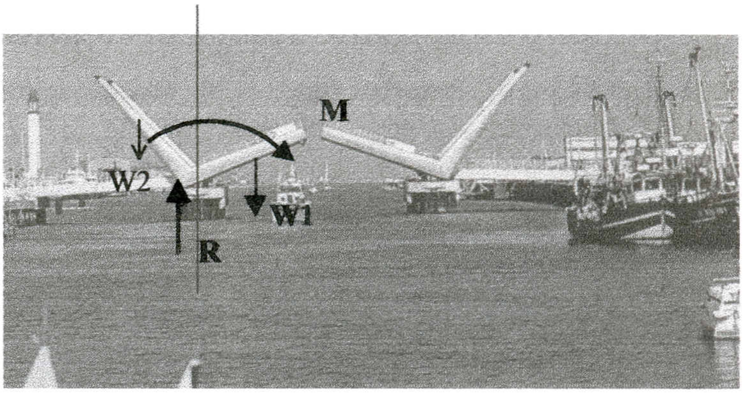
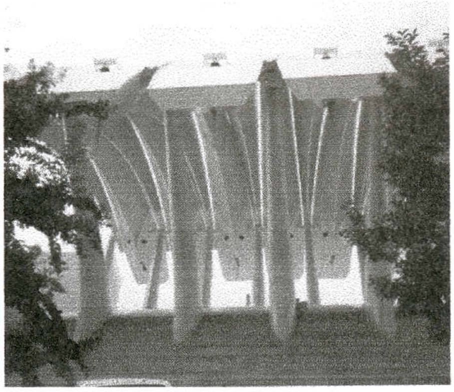


fig.4.53 The Structural analsis of Battle of Texel drawbridge while it is in motion

fig.4.49 Battle of Texel drawbridge, Pascal Sewrin, Dunkerque, France, 1994 (source:Roig, 1996)

Kinetic roof of Calatrava's Kuwait Pavilion (fig.4.50-51) is composed of curvilinear pieces. The order when it is covered is stable under the asymmetrical load transfer (like a cantilever beam). There is a lightnees of roof and the effect of the mechanical system in the motion of pieces. The force of motion that is directed towards to right when the order is covered.It is transformed to the force of moment towards to left when it had been open.



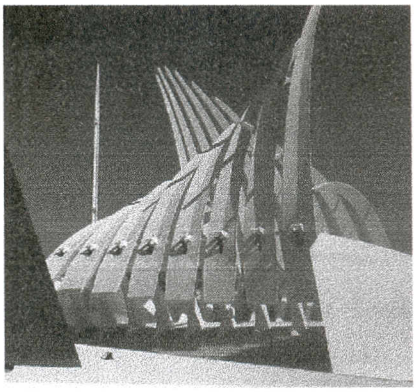


fig.4.50-51 Kuwait Pavilion, S.Calatrava (source:D.Güner's archive and Tzonis, 1995)

The bridge at Kiel is a little different from the others.In this example,instead of a rotational motion,there is folding motion.Motion of the order had been mostly achieved because of a mechanical system. During the motion, a strong force of moment occurred in clockwise direction. is restricted by cables.(fig.4.54) The bridge is under the effect of a cantilever,when it is both covered (fig.4.52b) and uncovered.(fig.4.52a)

fig.4.52 The Bridge at Kiel, (source. Holgate, 1997)

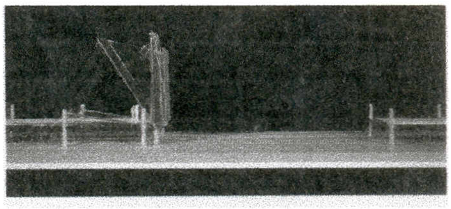


fig.4.52a

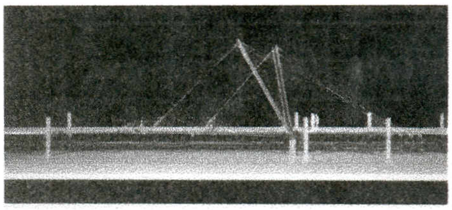


fig.4.52b

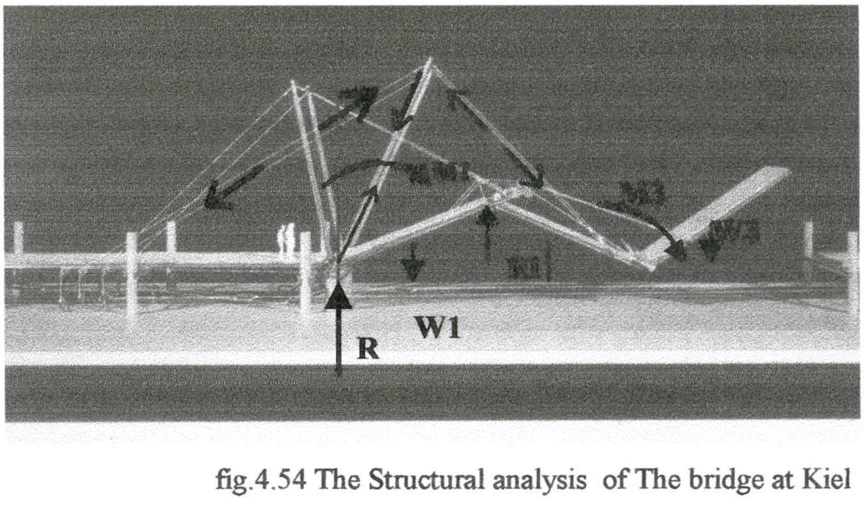


fig.4.54 The Structural analysis of The bridge at Kiel

4.3.2. Analysing The End-products in The Scope of Geometry

Main characteristics of structures having dynamic equilibrium in a state of balance are not very different from characteristics when they are in structural balance. The characteristics that are determinant in the state of structural equilibrium such as destruction, asymmetry,... are generally influential in the state of balance. The most important feature of them is that they are not a single whole but a whole consisting of pieces. Therefore, in addition to geometrical expression of the whole, geometry of pieces are also effective in the determination of dynamic equilibrium. The structural orders having dynamic equilibrium are the orders whose rate of orderliness is small. In the light of these general decisions, following characteristics determine the state of structural balance of structural orders having dynamic equilibrium;

- Not consisting of a single exact form (pyramid, cone, cube),
- Asymmetrical location of the pieces in the order,
- Asymmetrical combination of different geometries.

Destruction in geometry (formal complexity) which is the most important characteristic of the structures having dynamic equilibrium, in sculpture, began with the classic period of Greek (Zannos,1978). In the products of this period, destruction was determined the dynamic equilibrium, rather than geometry of elements. Additionally, perceptional effect of destruction could only be analysed through geometrical abstractions.

Destruction and formal differentiation with respect to vertical axis in the figure of Classic phase of Greek produced axid asymmetry in the torso (fig.4.55).

Also, similarly, The Doryphoros of Polykleitos dispels the rigid axial symmetry by introducing "chiastic" contrast between physical left and right . That is a bent knee and raised heel opposing a knee kept taut and a floot set flat, and a bent forearm and lifted hand oppose an arm hanging idle along the other flank (Boardman, 1996, p.105) (fig.4.56)

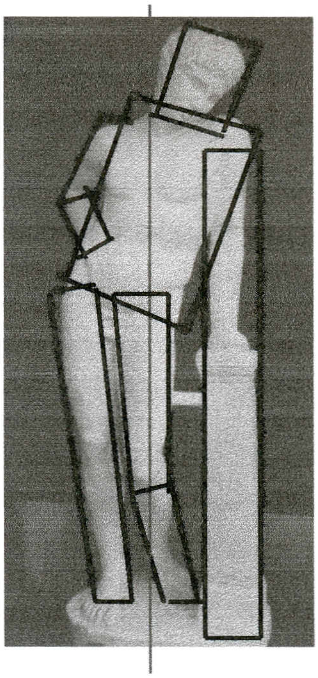


fig.4. 55 Geometric analysis of the statue of Boy Athlete

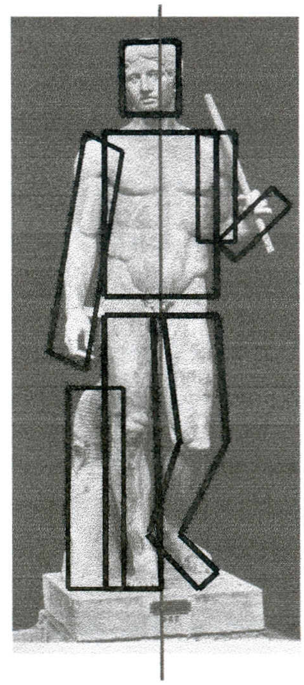


fig.4. 56 Geometric analysis of the statue of Doryphoros

In the sculptural products until 1900s, similar geometrical analyses can be made such as Degas's figure standing (fig.4.57). The difference in statues in Renaissance period was clarified a reflection of three dimensional geometry to statue, which had began with Classic Greek. Basic characteristics of statues in this period is destruction (Arnheim, 1977). One of the first and clearest example is seen in Myron's Diskobolos in which asymmetric order seen in frontside had been reflected to side elevation. This feature had become much more advanced in Edgar Degas's statue of Dancer Putting on her Stocking.

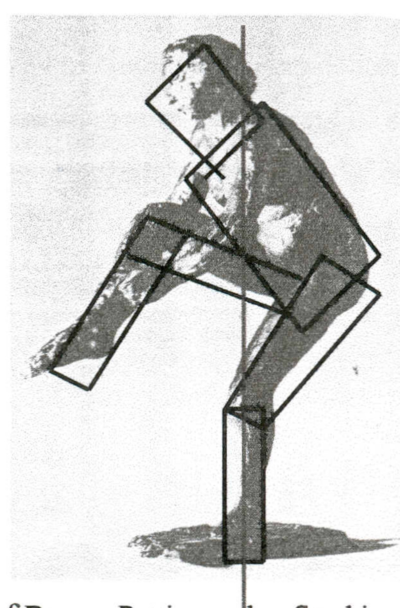


fig.4.57 The Geometric analysis of Dancer Putting on her Stocking

By 20th century, reflection of the developments in geometry and physics to sculptural and architectural products have increased. One of the first examples of this reflection was the statues of two cubist painters; Gleizes and Metzinger. They used the concept of fourth dimension in order to formulate their statues with the effect of Riemann geometry in 1912. They defended insufficiency of Euclidian geometry for identifying the real space interms of geometry and defended the necessity of Riemann's theories (Albert Gleizes and Jean Metzinger, Cubism, 1912, London, 1913, pp.25-28). In 1920's as a result of the effect of Einstain's Relativity Theory, fourth dimension in the field of design constituted new approaches such as Cubism, Futurism, Constructivism etc.

These interactions in geometrical orders of both sculptural and architectural-engineering products was reflected the following features;

- using exact and free shapes together
- using perforated and solid geometries together
- using curved and straight geometries together
- using points, lines, planes masses together
- using horizontal and vertical forms together (Moholy-Nagy, 1956)

As it has mentioned, having a dynamic characteristic consisting of different geometries had resulted by an asymmetrical location in the whole. The formal order constituted of the minimum rate of orderliness. Accordingly, contrary to the concept of "symmetry" that is used for determining the maximum rate of orderliness of an order, the concept of **"asymmetry" is determinant for dynamic orders.** One of the first examples is the "Monument to Third International" designed by Vilademir Tatlin, in which curvilinear elements was located asymmetrically with linear ones.

In Gabo's statue of Monument for an Airport (1932) (fig.4.58) following characteristics decrease the rate of orderness of the whole;

- using geometrically different forms;Angled rectilinear planes (Nash-Merkert, 1985),

- using different geometries; Angled Rectilinear planes-linear shapes,
- asymmetrical location of geometries with respect to each other and to the whole.

Also, in the study of "Constitution in Space" (fig.4.59) (p.134), using concav and convex curves together, using a linear element together with a plane and the asymmetrical location of a plane element decreases the rate of orderliness of the whole.

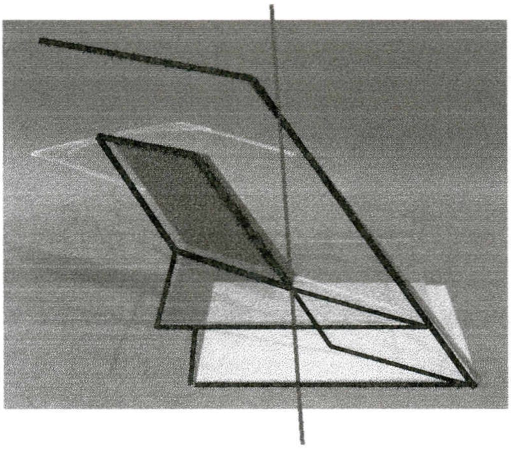


fig.4.58 The geometrical analysis of Monument for an Airport

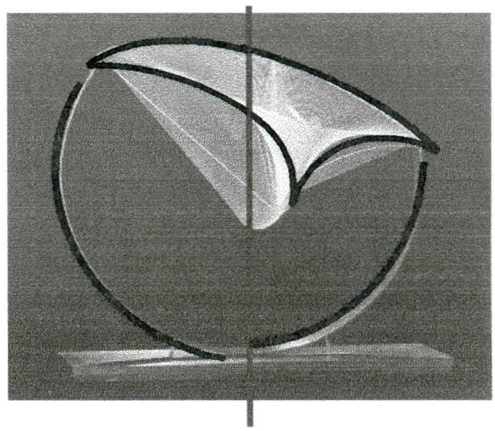


fig.4.59 The geometrical analysis of Construction in space

Using cantilever that is effective in constituting dynamic character physically, is also determinant in geometrical expression of the orders. Like F.L.Wright's Kaufmann House, using cantilever elements constituted a structural whole of exact forms with vertical and horizontal elements. More recent example is Reallon River Bridge(fig.4.60). In addition to the asymmetrical feature of the Bridge with the cantilever of eight percent slope and differentiation in geometry of cross section are the features implying "dynamic" characteristic (Zannos, 1987).

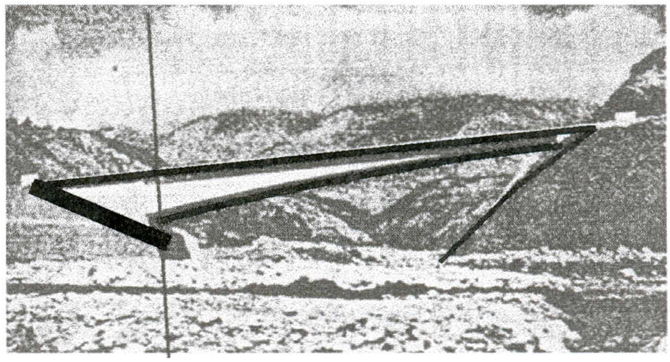


Fig.4.60 A geometrical analysis of The Reallon River

Another example is Termini Rail Road Station which have a structural order consisting of linear elements. The roof having a free curve has an asymmetrical feature within itself. Asymmetric location of vertical bearing components and the use of cantilever increased dynamic effect (fig.4.61).

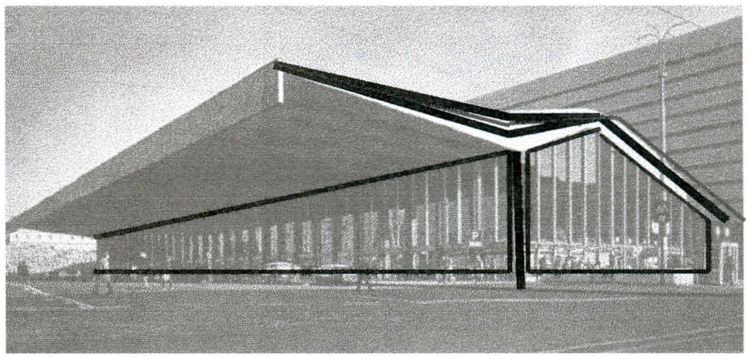


fig.4. 61 A geometrical analysis of Termini Rail Road Station

A similar dynamic order can be seen in the design of Kansai International Airport (1994) Main Building Roof (fig.4.62). The free formal order in the curvilinear roof that is more clear in this order attracts attention. Although the relation between curvilinear form and vertical bearing elements that provides the connection with ground is not clearly perceived, it is possible to see a clear structural order especially when the crosssection of the building is analysed. Similar features can be seen more clearly in Calatrava's Kuwait Pavilion building consisting of linear elements.

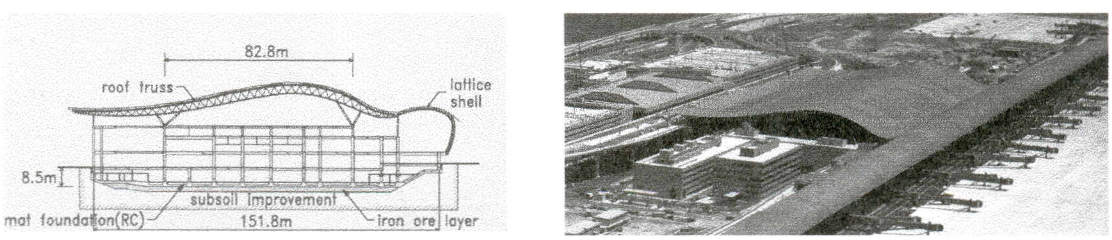


fig.4.62 Kansai International Airport, (source:N.Uchida, K.Taga, 1998)

In contrast to these examples that show the effect of cantilever on horizontal forms, it is important that cantilever is also effective on vertical formal orders. Calatrava's Communication Tower in Barcelona (fig.4.63) and Communication Tower Alicante (fig.4.64) buildings can be examples of dynamic formal orders in vertical axis, which is achieved by cantilevered connection. Especially, Communication Tower is an example because of its asymmetrical feature in the whole including an inclined "Z" form, a curve and a linear element together.(fig.4.65)

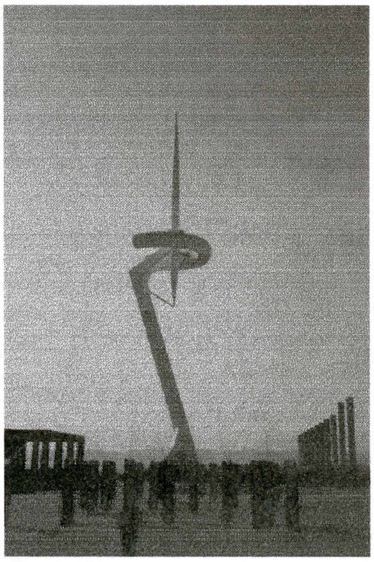


fig.4.63

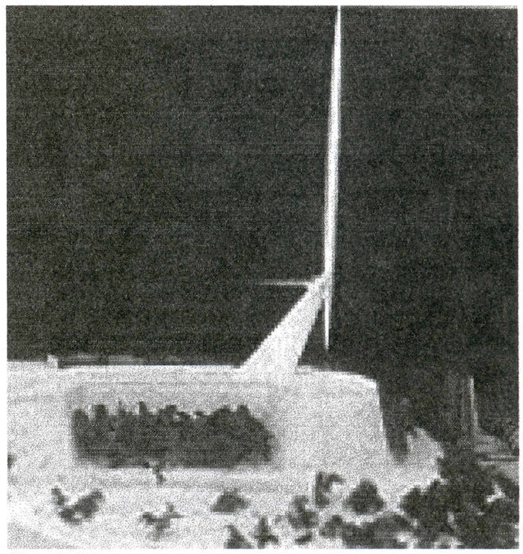
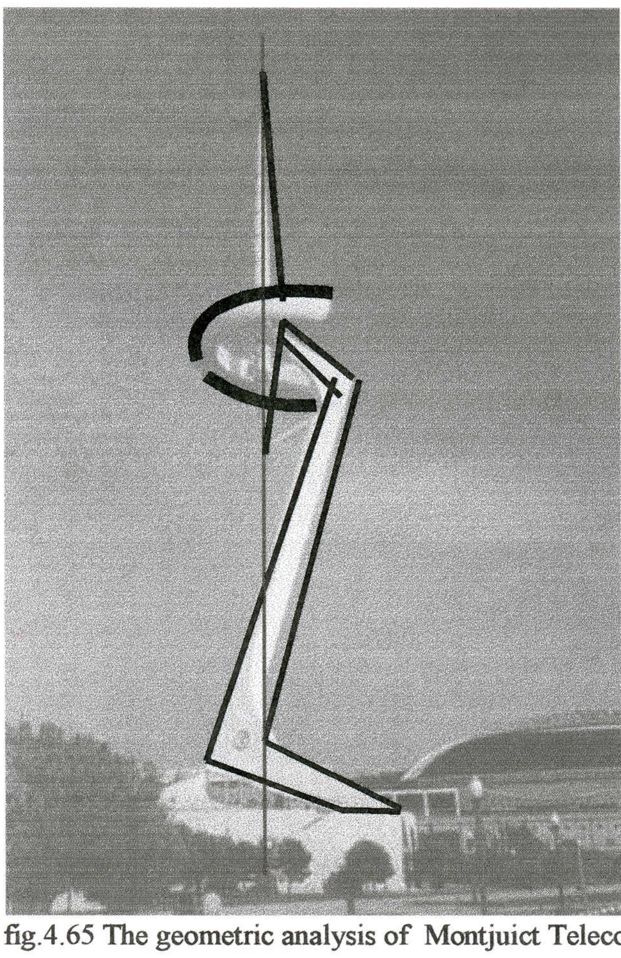


fig.4.64

fig.4.63 Montjuic Telecommunications Tower, S.Calatrava, Barcelona , Spain, 1989-92 (source: Deniz Güner's archive)
fig.4.64Telecommunications Tower of Alicante, S.Calatrava,Alicante, Spain,1993 (source:Jodidio, 1998)



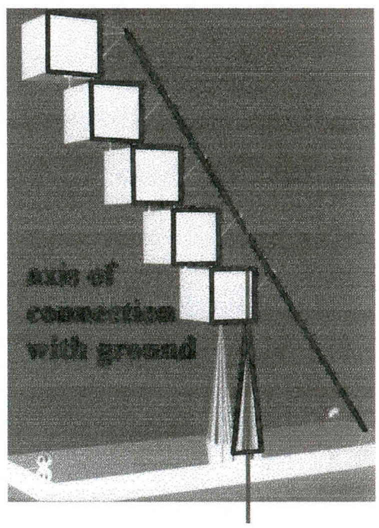


fig.4.66

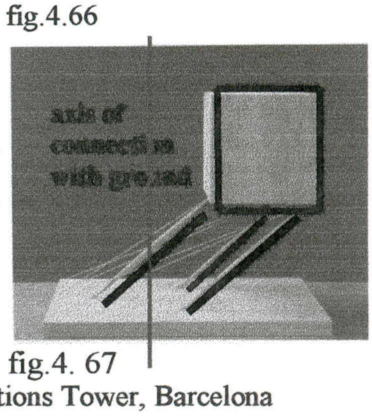


fig.4. 67

fig.4.65 The geometric analysis of Montjuict Telecommunications Tower, Barcelona

fig.4.66 The geometric analysis of Wooden Tower Toros
fig.4.67 The geometric analysis of One of Calatrava's sculpture

In the second half of 20^{th} century, as a result of scientific developments especially tensile systems, effective use of cable systems and the invention of tensegrity systems have an important part in the convention of different geometries.

In the study of Calatrava's Wooden Tower Toros, use of linear (cable) together with mass (cubes) and asymmetrical location of the orders with respect to vertical axis had provided a dynamic feature of structural balance (fig.4.66). His study of the statue seen in fig.4.67 has also maximum dynamic feature.

Contrary to this kind of statues in which different forms had used together, studies of Snelson included similar forms. In these studies, only linear element had been used. Repeated use of linear elements with different angles (Robbin, 1996) (fig.4.68) is the basic idea in the constitution of dynamic order. Also, cables are longer in comparison with the rigid elements; this hinders the perception of the end-products as a whole. The pieces is firstly perceived; in other words, location of the pieces is more important than the location of the whole. Nevertheless, as it is seen in the cantilever statue of Snelson (fig.4.44), it is clear that asymmetrical location of the whole increases the dynamic feature of the order. In other words, it decreases parallel with the rate of orderliness.

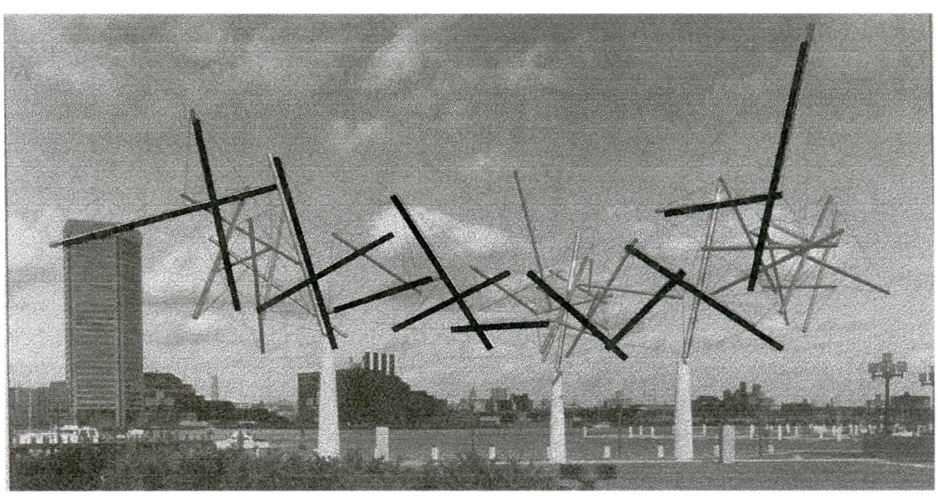


fig.4.68 Easy Landing sculpture, Kenneth Snelson, 1977 [source (background): Robbin, 1996]

Similar to examples in sculptural pruducts, the effect of tensile elements in the constitution of different formal orders is also seen in architectural products. In the design of bridges that are the purest examples of structural orders, this search is clearly perceived. Alamillo Bridge (fig.4.69), and Erasmus Bridge (fig.4.70) are some of them. In S.Calatrava's Alamillo Bridge in Seville, the situation of balance of the order is between a deck and a pylon. Following characteristics provide the dynamic effect of this order;

a-) asymmetrical location of the pylon in the plan,
b-) vertical asymmetrical location of the pylon with respect to deck (the ground)

Therefore, the order, visually, is an order of equilibrium between two lines having nearly equal thickness.

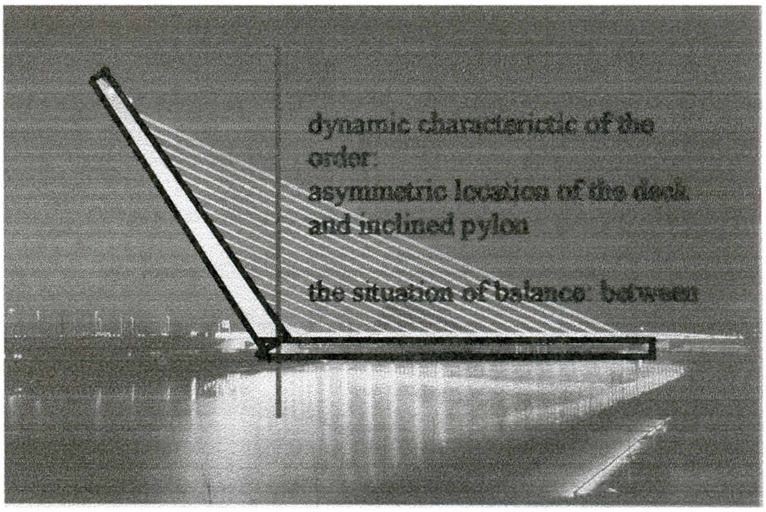


fig.4. 69 The geometric analysis of Alamillo Bridge

Although Erasmus Bridge in Rotterdam is similar to Alomillo in respect to basic characteristics, it has some differences. In this example, formal asymmetrical order of the pylon was expressed.

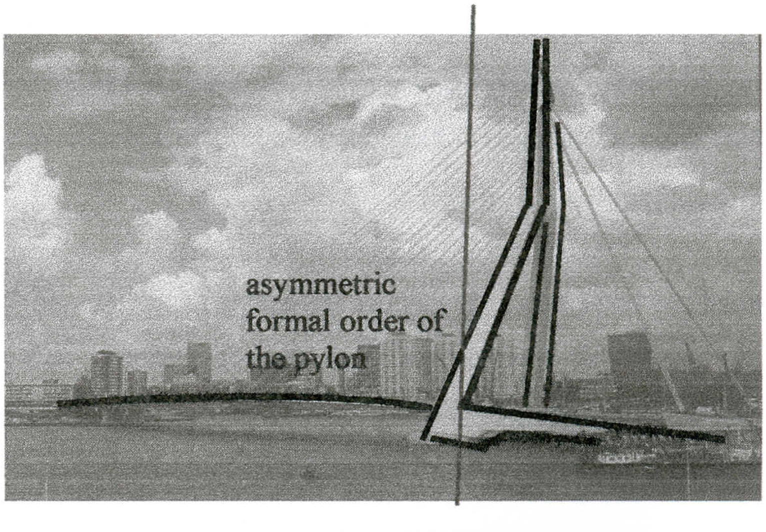


fig.4.70 The geometric analysis of Ben Van Berkel's Erasmus Bridge

4.3.3 Analysing The End-products In The Scope of Energy

In expressing the physical and formal identities of a structural orders that is in dynamic equilibrium, as a whole; different movement perceptions result from different energy types should be examined seperately.

4.3.3.1. The End-products Having Potential Energy

All the products having dynamic equilibrium (except the ones that have kinetic energy) also have a maximum potential energy because these products show a visual tendency towards motion. This fact was directly explained by Rudolf Arnheim with the concept of **potential energy** (Arnheim, 1977); by Jonathan Block with the concept of **perceived motion** that is based on potential energy (Block, 1987); by Tzonis and Lefaıvre with the concepts of **potential movement**, **pregnant moment** and **implicit movement** based on potential energy (Tzonis-Lefaıvre, 1995); by Simon Bell with the concept of **visual energy** (Bell, 1993).

Common point in all of these concepts is that the orders having dynamic equilibrium also have effects of visual motion. The factor, which can be accepted as the cause of this motion effect was described by concepts such as potential energy, visual energy, etc. These acceptances are also valid in physics (Chapter 2.2).

A structural order being influenced by motion, visually, is originated from the conditions that are the reflections of a natural motion and if no such condition exist, originated from the formal order of the structure. These two conditions are explained by Tzonis—Lefaıvre with the concept of pregnant moment. They mostly used this concept for statues.

Rudolpf Arnheim accepts the concept of **potential energy** as a basis and explains the main formal relations that consider the dynamic effects and the perceptual identities of these relations (vertical-horizontal, solid-hollows, weight-height) on this basis. He argues that the changes on the vertical axis are influential on the potential energy of the structural order (Arnheim, 1977).

Jonathan Block, as in the acceptance of Arnheim, agrees **on the concept of potential energy** of physics. He states its equivalent definition in three dimentional design. According to him, potential energy of a structural order is related with its tendency to fall. As this tendencyof fall increases, it also increases the potential energy of the order. In other words, standing in spide of gravity requires potential energy. In this resistance, as potential energy of the order for falling increased, potential energy of that order is also increased, too (Block, 1987).He had explained this situation by compairing between Staebler's works of Left-sided Figure Standing(fig.4.71) and Wedged Man Standing(fig4.72) According to him, Left-sided Figure Standing appears to be resisting gravity: this creates a strong sense of potential energy. Contrary, Wedged Man Standing is in the process of succumbing to gravity's pull.(Block, 1987 , p.69)

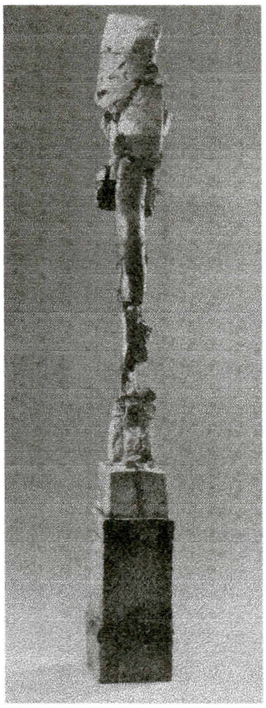


fig.4.71

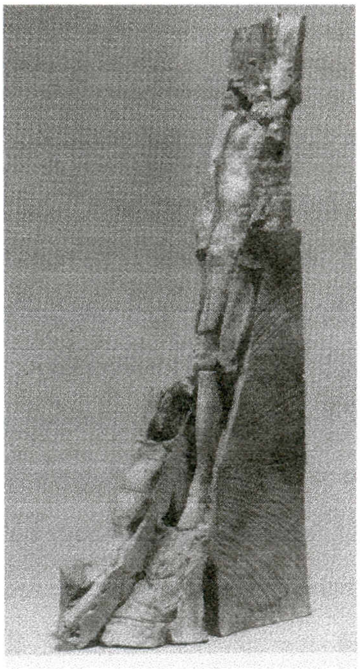


fig.4.72

fig.4. 71 LEFT-sided Figure Standing, S. De Staebler, (1981-82)(source:Block, 1987)

fig.4.72 Wedged Man Standing, S. De Staebler, (1981-82)(source:Block, 1987)

The potential movement, pregnant moment, implicit movement concepts of Tzonis and Lefaıvre are the base on potential energy, too. Their concept of potential movement determines a state of having a direct tendency to a motion. Pregnant moment, on the other hand, is an equivalent of a visual expression of a physical force that sets a structural order into motion (Tzonis, Lefaivre, 1995).

Simon Bell's visual energy definition is accepted as an effect that provides the potential movement's perception based on the location of the elements in the order. According to these definitions, it is possible to make the following general definitions;

- The orders with physical and formal characteristic as stated above (indirect load transfer, asymmetrical formal order) have high potentiel energy,
- High potential energy indicates an order's inclination towards motion and this movement type can be classified as **"potential movement"**
- By keeping in mind that these types of structural orders are connected to the ground, it can be concluded that potential movement is either escaping the ground or falling on the ground.
- The effect of motion about falling on the earth is the result of visual perception of force of movement that was in physical equilibrium.

Sculptural products that reflect the human movements are the leading samples in which potential movement can be perceived most evidently. These works, started to be seen in Classic Phase of Greek , gained more importance in Hellenistic Era. So that, movement became distinctive characteristic of Hellenistic Art (Bieber, 1961, p.5). The most important example of them is Myron's Discobolos (fig.4.11). This statue has a dynamic equilibrium order reflecting the characteristic of movement in two angles. The first one because it directly reflects a movement that can be done by the inner energy of a person, and the second one, as can be seen in fig.4.12, because it has a visual moment affect, possesses a potential movement toward falling. Boardman explains the relation of this work with the movement as: "Myron's Discobolos has repeadly been taken as a text on which to base a homily on the representation of motion in art. And it is indeed suggestive of a higly intelligent and eminently logical mind to choose a pose coincident with a pause between the completion of one movement and the inception of another, thereby not depicting motion directly but implying its immanence in a moment of rest"(Boardman, 1996,p.83). On the statues of Degas and Rodin, which have a similar basic characteristics,the potential movement effect has reached to upper levels.

The work of Degas, named as Dancer Putting on her Stocking is one of the works that samples this situation (fig.4.16). It represents a violent movement and also has a great visual force of moment. In other words, it has a great potential energy.

As geometric forms (1910's) took the place of the works, directly reflecting the human and animal movements, different characteristics began to be seen. Relation of the elements/geometries that form the order with themselves and with the whole, is important in the perception of potential movement. In general, with this progress, "movement" played important role both conceptually and in applications, in the design approaches of the era. " The abstract artists, the neo-plasticists, suprematists and constructivists discovered that in the efforts of the cubists not so much the representation of objects and the description of their motion was the most important feature but the visual force and emotional wealth of relationships, the constructive potential of the visual fundementals" (Moholy-Nagy, 1965, p.113). So, the definition of natural movement is not a"construction of body" but a "construction of the actions of the body" (Barry,1986).

A similar work to Degas' Dancer Putting on her Stocking (1896) is Julio Gonzales' Small Dancer (1934) (fig.4.73). This statue that forms of linear elements both reflects an "action of a body" and also arouses a feeling of a movement that tries to get free of gravity (on the contrary to Degas's movement feeling aiming the fall).

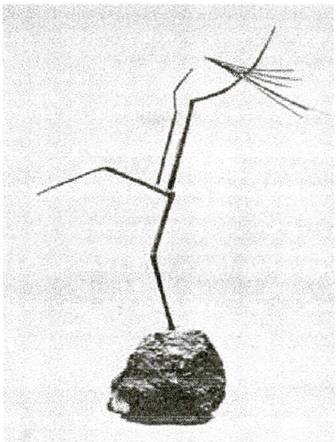


fig.4.73 Small Dancer, Julio Gonzales, 1934 (source: Tucker, 1988)

Gabos' work of Monument for an Airport (fig.4.19) gives the feeling of potential movement as a result of formal order. It shows a reverse clock-wise potential moment effect. This effect contributed by dark colored surface elements. Such that; if a superficial piece remains at the space at a certain height, its potential energy rises too, and this excess energy is directly proportional with its potential inclination toward fall.

In the statue of Construction in Space: Suspended,(fig.4.20) it can be concluded that its potential energy acquired from the location of monofilament element result a potential moment that rotates the circular element.

In these characteristics formal connections, increase of elements and scale size affect the effects that form the potential movement. In Calatrava's Wooden Tower Torso work (fig.4.36), the perception of inclination toward movement that is valid for each cube is at the highest point for the whole. The tension at the cables is perceived at maximum levels in direct proportion with the fall potential of the cubes. While structural order as a whole has clock-wise potential moment effect, the tension effect in between the cables and cubes on the other hand has a potential energy toward breaking off. As seen in fig., in his work, there is an important tension effect between the massive blocks and thin linear bars, visually. The location of the cube gives an impression that there is indeed too much weight on the bars, (Arnheim, 1977) and this increases the potential of falling of the order. The situation of the bars according to the ground is also an important factor in potential movement condition.

In contrast with the samples involving potential movement toward falling with the effect of potential moment related with gravity in Snelson (fig.4.44) cantilever or Easy Landing Sculpture works (fig.4.43) the bars are perceive as visually independent from gravity.Because bar elements' height from the ground is very much and because the weight of the elements are perceived as too small, the defined potential movement effect reaches to its maximum level.

The perceptual effects of the sculptural products having dynamic equilibrium can also be seen in the products of engineering and architecture. It is easier for simple structural order . One of the first products having a dynamic equilibrium order, Wright's Kaufmann House has a serious potential movement effect with the help of cantilever elements (fig.4.26). The evidence of cantilever creates powerful tension effect between solid and hollow. Moreover, it causes a very important potential moment effect that can be seen evidently in many structures. The Reallon River Bridge (fig.4.27) is a simple sample of these. Likewise, Nervi's Municipal Stadium's cantilever roof (fig.4.28) is under the effect of a potential movement that would cause breaking. Being thin of the roof in respect to the whole structure in the relation between solid and hollow, curvilinear effect in its geometry and its height being very high are the factors that cause potential energy perception that provides a resistance to the gravity.

In G.Asplund's Domino Tower (fig.4.32) work the location of the mass forms a potential movement effect. If the mass is inclined then potential energy reaches to its maximum level. Consequently, the inclination of the order toward fall is very much.

Likewise, Calatrava's Alamillo Bridge has a high potential effect (fig.4.38). Pylon having a very evident inclination results this. Perceptually, one way cable elements show a high tension effect. These elements are under the influence of breaking off and so, whole order with pylon, is under the influence of counter- clockwise potential movement.

Another sample is Erasmus Bridge, although its potential movement effect is less than Alamillo Bridge's (fig.4.39). Pylon singularly is under high potential moment because of inclined forms. However, when the whole order is studied, double-way cable elements decrease this effect. At this point, both for pylon and whole order there is a double tension effect. Tension effect at Backstay cables defines the break off inclination. In this situation, the whole system is under the effect of clockwise potential moment (Van Berkel&Bos, 1997). However when cables are not dominant in perceptual effect, it can be concluded that generally the order is under the potential movement effect that is based upon pylon effect.

In the structures of Termini Rail Road Station (1947) (fig.4.30) and Kansai Airport (1994), the form of the roof that are the basic elements, are under the potential movement effect with similar characteristics. The reasons of this movement effect are:

- inclination in the forms of these two orders, even though it is more evident for Kansai,
- differentiation in the cross section of the roof ,
- in addition to thin cross section of the roof, the height of the roof is very high from the ground floor.

All these characteristics define a curvilinear movement that hangs in the air. This potential energy, causing a potential movement, provides the roof being under the movement effect that resists to gravity.

4.3.3.2 The End-Products Having Kinetic Energy

It can be concluded that the products with a kinetic movement are the orders which have a kinetic energy. Even though the mobility is realized in relation with a mechanical system, movement can be only possible by kinetic energy. Kinetic energy being put as a design criteron was done by Futurists in 1912. Their acceptances are: "... we shall have, in a Futurist sculptural composition, planes of wood or of metal, stationary or mechanically mobile" (H.Barr, 1986, p.60.). Under the guidance of these acceptances Alexander Calder produced kinetic products.

For Calder, the complex relationship between elements and the description of various types of motion were of primary consern (Morter, 1991, p.117). His work. in fig. moves on the direction in which it has visual moment effect, and by gaining a kinetic energy with the help of an effect. In other words, potential energy of the order which is acquired by its formal order turns into a kinetic energy by a force. Likewise, his work of Dancing Torpedo Shape each element independently and each described a different kind of motion (Morter, 1991,p.117). In architectural scale, this exterior power comes out as a serious mechanical system in order to provide movement. In sculpture, movement is not as independent as in the samples.

The most important architectural representative of active structural order is S.Calatrava. Swissbau Concrete Pavilion in Switzerland(fig.4.74), Kuwait Pavilion, in Spain, 1991 are samples of his movable structural orders in kinetic sense. In Kuwait Pavilion, and in other samples, the order is under the influence of high potential movement (fig.4.50-51). With the help of mechanical system this movement turns into kinetic energy.

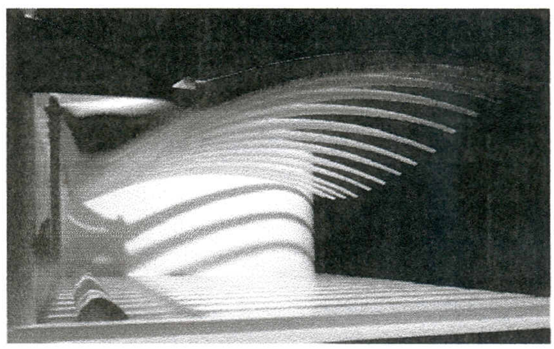


fig.4.74 Swisbau Concrete Pavilion, S.Calatrava, Switzerland, 1988-89 (source: calatrava.com/1/index)

The bridge in Kiel (fig.4.54) is different from Calatrava's kinetic roots. It has folding motion. The order shows a motion characteristic both in whole and with assistance of joint connections. We can also see works about folding motion in Frei Otto's light weight and tension stresses.

4.3.4 General Evaluation of Structural Wholes Having Dynamic Equilibrium

As a result, it is possible to make a generalizations about the structural orders which have dynamic equilibrium and which can be studied under the concepts of Gravity, Geometry and Energy as:

- Structural orders with a dynamic equilibrium have a indirect load transfer,
- Load transfer is asymmetric,

- As a result of these two characteristics connection with the ground is as little as it can be,
  - so it is stabilized,
  - thay can resist gravity in high degrees.
- The structural whole;

  a-) can constitute of usage of different forms together

  b-) can constitute of usage of similar forms

  - In both of these two conditions the whole has an asymmetrical form and order.

- In the orders that consist of only one form, an asymmerical location in respect to the ground can be recognized,

  - As a result they are orders with low systematic rates.

- Potential movement comes out as a result of physical and formal characteristics,
- Kinetic energy is formal and obtained by mechanisms,

  - They are structures in motion that can resist gravity, that have a asymmetric and geometric wholeness.

CHAPTER 5

5. RECENT STUDIES HAVING POTENTIAL FOR DIFFERENT STRUCTURAL ORDERS

It is possible to consider the development and analyse the buildings taking their structural orders as a base accordingly with the scientific developments. To which point this development has reached today and to which points it will reach in the future are some of the topics frequently discussed in contemporary architecture. However some researches on recent past and contemporary architecture have the quality of exposing some clues, at this point. Common characteristics of structures on which intense arguments are done is that these structures have different formal orders. It is impossible to examine these structures from point of view of one characteristic. Now the basic factor in architecture and in the design of architectural product is the change in the concept of space-time. In this change, scientific developments are also influential on formation of these studies that are clearly distinguished from the products having static/dynamic equilibrium

5.1 SCIENTIFIC DEVELOPMENTS IN THE 20th CENTURY

Starting with the end of 19th century, Cartesianism dominating physics and mathematics, left its position to the theories and researches that formed the modern sciences. It can be concluded that these studies are about understanding the real "universe" and motions formed within these universe (yıldırım,1997). The most important development on this subject is Einstein's "Special Theory of Relativity on the Electrodynamics of Moving Bodies" that resulted changes in the concepts of Newton's absolute space and three dimensional space related with it, which were accepted as unchangeable facts, for a long time. The theory that is the first part of Einstein's theory is based on the concept of a space-time continuum and relates to all systems moving with uniform motion, that is moving in a straight line with equal velocity (Johannes,1974, p.65). Einstein later applied this theory to all moving systems and developed the concept of general relativity. The first important formations that were influential on Einstein's works are the non-Euclidean geometry that is the discovery of the electromagnetic field by the Faraday Maxwell and

Riemanian. So, in the change process of absolute space concept we can see the curved space and four dimensional space-time concepts. These developments can be accepted as indicators of the end of mechanistic world-view (Mae-Wan Ho, 1997).

However, now the assumptions of modern sciences are changing, too and complexity theories examined within the concept of post-modern concept appears. (Jencks, 1997). Another influential development in the formation of these theories, is "quantum field theory". Quantum field theory is a physical framework that describes sub-automatic world (Kaku, 1993). It examines the relation based on the energy in between the electrons that form the matter, Mae-Want Ho summarises this change based on the theory as; Quantum theory demanded that we stop seeing things as separate solid objects with definite (simple) locations in space and time. Instead they are delocalised, indefinite, mutually entangled entities. That evolves like organisms (Mae-Wan Ho, 1997, p.44). As mentioned in this description and as in the linear systems, pieces that form the whole are not perceived as independent. So, this introduced the fact of necessity of systems being non-linear.

The most important characteristic of these systems is that they have equilibrium based on motion. Moreover, these systems are capable of **self-organisations** (Saunders, 1997). All of these characteristics influenced the concept of **"order"** which is influential on the continuity of the matter. Even though the term **"complexity"** implies **disorder** in the first place, scientists put forth that within chaos there also exists an order. The starting of these studies is the work of a meteorologist Edward Lorenz. According to him "if you let the systems run long enough, then no matter what starting values you choose, to within the resolution of the graph plotter you get the same figure although it will be built up in a different order. There is order within the chaos (Saunders, 1997).

In this new understanding of order, it is important that orders in biological systems are chosen as method of explanation. Because, biological systems are living systems that are continuous, movable, complex, and also systematic. (Pamir, 1998)It is possible to explain these kind of organisms based on complexity by the concept of "entropy" which constitutes the second law of thermodynamic, because all living organisms are completely liquid crystalline and on the condition of order of any organism, energy flow among these movable crystals is effective. In this flow, system has different order degrees. This can also be called as order of motion (Mae-Wan Ho, 1997). Michael Mcquire explains this shortly as; "systems with high entropy are low in energy while systems with low entropy are high in energy" (Mcguire, 1995). While elements that form the systems are loosing energy, this energy is used in the provision of the entropy of the system. As a result, **chaos forms the order.**

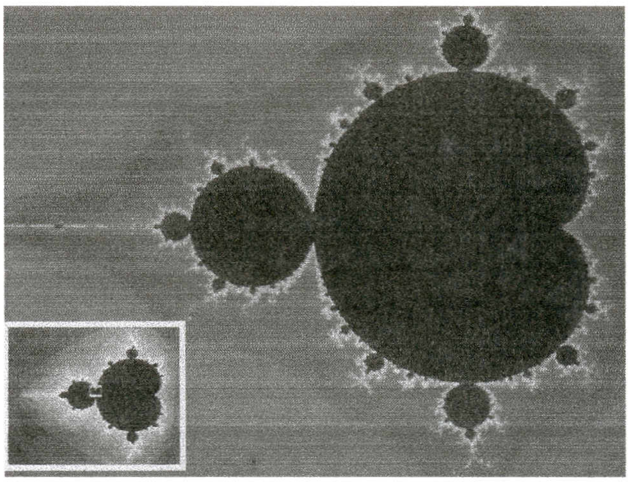


fig.5.2 One of Mandelbrot's mounds
(source.:Gleick, 1987)

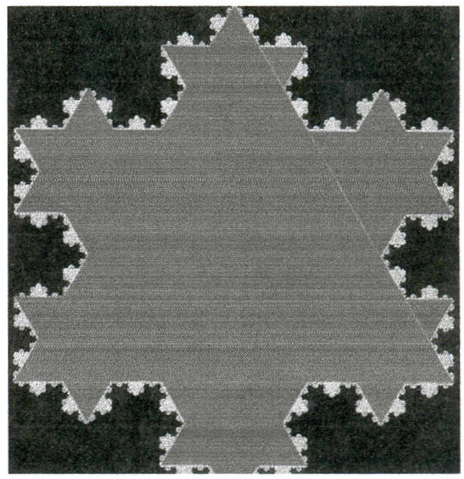


fig.5.1 Koch eğrisi
(source:Gleick, 1987)

In any case, physics accept that the level of entropy in the universe is always increasing. In this direction, the science of complexity considers that the structures of these **natural organisms have fractal dimensions.** Fractals can be accepted as a new order directed towards natural structure. Fractals involving geometrical statements were explained by H.Mandelbrot in 1960's and were named in 1975's. It shows that complex natural forms have an order. On the base of Mandelbrot's studies about disordered patterns and about infinite complex forms there is the same concept; **"self-similarity"** (Gleik,1995). Besides, he believed that "there is a fractal face to the geometry of nature. A fractal invariant under ordinary geometric similarity is called self-similarity (Mandelbrot,1983). Also, **self-similarity** means **symmetry at every level**. Koch's infinite curve is the best sample about the subject (fig.5.1). Mandelbrot's mounds are formed with the same logic (fig.5.2). Consequently, he concluded that the structure of the real nature can be understood by mathematics (for instance, a tree and its fractal expression (fig.5.3)). As a result, scientific developments, started at the end of 19th century, were the developments that brought up of the necessity of perception of the universe in a different dimension.

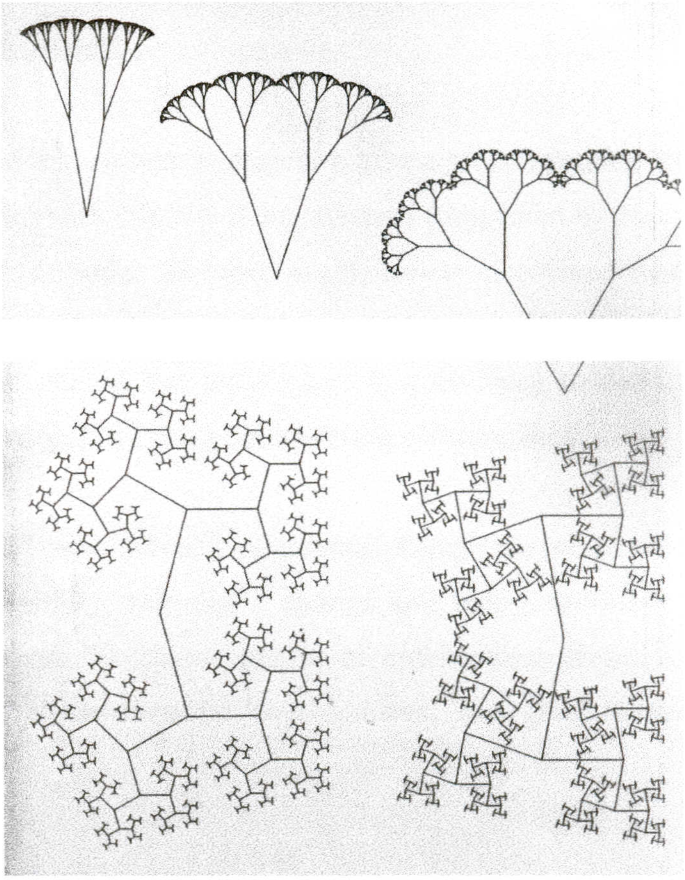


fig.5.3 Fractal tree skeletons (source:Mandelbrot, 1983)

5.2. REFLECTIONS OF SCIENTIFIC DEVELOPMENTS ON ARCHITECTURAL END-PRODUCTS

Various concepts that describe the scientific developments (non-linearity, complexity, self-similarity.), examined within the scope of post-modern science are also used in the field of architecture. The important thing, here, is how architecture use these concepts. As an application field, architecture uses these concepts according to its needs. These determinations are necessary to argue these concepts after understanding their scientific contents. In this way, it is possible to answer the general questions of Charles Jencks, stated clearly; How much is this a formalist trend? How much do architects understand of fractals, emergence theory, folding, non-linearity and self-organising systems? While the scientific developments were trying to be explained, post-modern science was under a development of trying to understand the "organic" characteristics of cosmos. Some of current architectural products also show similar searches. While some of these are designed by formal worries, some others are based on scientific developments.

At this point, it can be concluded that current architecture give a lot of attention to the concept of **"order".** In parallel with this, the living systems discovered by New Science rebut the concept of classic order. In other words, it was discovered that cosmos has **"living order"** and not "**static order".** In general in accordance with these developments, it can be concluded that architecture is a tendency to define living order concretely by the relationship among nature-living system-chaos.

The concept of **"living order"** scientifically expresses **being movable** and **continual, having an organic stability, showing a change and being nonlinear**. These concepts are used to express the characteristics of architectural products. Charles Jencks, in the light of these scientific developments, had given some principles for architecture;

- Building close to nature and natural languages,
- Representation of the basic cosmogenic truth,
- The celebration of diversity, variety, bottom-up participatory systems which maximize differences ((Jencks, 1993, pp.167-168).

Architectural products referring to these or similar principles are generally discussed in the direction of their influence on the understanding of "space". In other words, the concepts of fluid space, liquid space, nonlinear space had appeared. This, as mentioned above, is the change in the concept of space-time. Both space and time in mechanistic world-view are linear, homogeneous and separate, on the other hand, space-time in organic world-view are inseparable, nonlinear, heterogenous and contingent (Mae-Wan Ho, 1997). The organic space-time having these characteristics is expressed by the concept of "fractal space-time". Therefore, it is possible to say that architecture tries to reflect this new space understanding to the concrete product through using **"free forms".** The end product has a chaotic appearance. Another important point in the discussion is expression of the situation between order-disorder of the end product. In the science, structures in nature are set on some orders. These orders are explained by some concepts that are not involved in Cartesian system (non-dimension, fractal dimension). As a result, the concept of fractal space-time, and so, fractal geometric forms, self-similar organisation, non-Euclidean forms, motion become basic concepts discussed by current architecture. Also, these reflections can be seen in formal characteristics of architectural end-products. Consequently, these reflections on architectural end products can be collected under three basic titles with respect to their state of structural equilibrium;

- Reflections on the geometry of form
- Movable structures
- Studies based on gravity

5.2.1 Reflections on The Geometry of form

As it is mentioned, differentiation in architectural products parallel to the development in science, is mainly related with the formation of the spatial order of a building. Differentiation in spatial expression is reflected to the form with differentiation in the geometry of the building. Then instead of change in structural equilibrium analysed in products having dynamic equilibrium, the products having more complex order and including different space-structure-form relation have taken place.

Differentiation in spatial order in these products is tried to be explained with different relations such as, in the forming of a building, relationship between a whole of space-structure-form and topography, and also the concept of motion. In addition, in the formation of dimensional expression, some means like, parametric design, fractal geometry… is used.

Therefore, it is clear that, the relations between space-form, space-form-structure can be discussed from different points in these products. The reflections of scientific developments on architectural end-products and as a result of this reflections, today's some studies having potential for the solutions of the future can be classified with respect to the problem of structural equilibrium as;

a- The Studies Having the relation of Geometry-Form not reflected on structural orders
b- The Studies Having the relation of Geometry-Form reflected on structural orders

5.2.1.1 The Studies Having the Relation of Geometry-Form not Reflected on Structural Orders

In the studies analysed under this title, effect of differentiation in the concept of order clearly seen in their formal order. This can be the result of having a spatial whole based on different geometrical order or the result of formal expression of different inputs in the formation of space. So, generally, they have complex, perceptionally non-defined forms (free surfaces).

Opposed to this differentiation in the geometry of form, they have a conventional structural system. Structural order can be separated from the formal whole. The different point is that using of this conventional system is complex. Some characteristics like having connections result of complex use of forms, structural elements in different size, wide consoles... are effective in load transfer, Giving size of these complex systems is achieved by using computer programs.

Peter Eisenman's Aronoff Center for Design and Art in Cincinnati (1992-1995)(fig.5.4) is one of the buildings on which discussion stated above are mentioned.The project has a form consisting of a curve and straight lines (fig.5.4). Formal order had been formed by removing zig-zag rectangles with some angles (fig.5.5) This had provided curvilinear form of building (Jencks, 1995). Repeated use of similar zig-zag form is tried to explain by principle of self-similarity. The relation of the building with fractals is due to this characteristic.

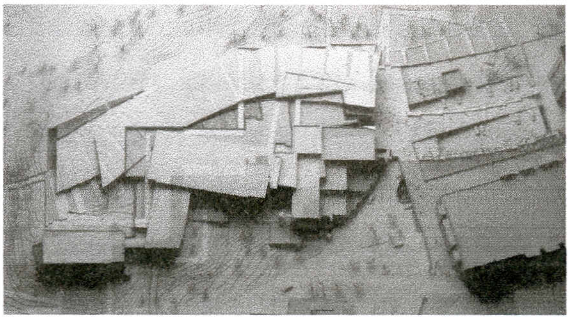
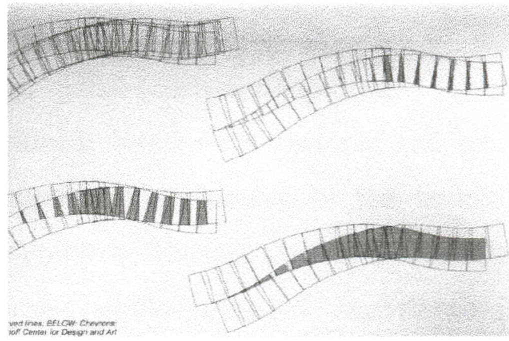


fig.5.4 Aronoff Center, P.Eisenman, 1996
(source: Eisenman Architects, 1997)



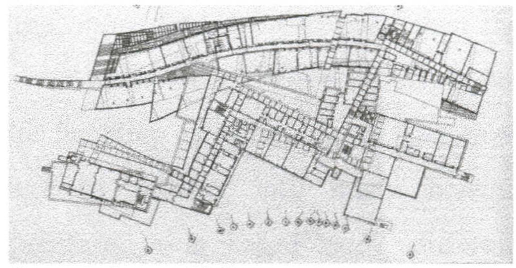


fig.5.5 Aronoff Center Design process
(Jencks, 1997)

The bearing system is composed of a rectilinear column grid.(fig.5.6) This gridal system is independed from the form of the space (A.D.9, 1997, VOL67). Because of this, load transfer, like in column-beam system, is linear. When the building's plan and sections are analysed, it is seen that there is not any difference in the dimensional expression. It is in a classical Cartesian coordinate space X,Y and Z dimensions (Lynn, 1996, p.21). Shortly, the building based on a geometrical order has a complex form that can be explained, especially in point of structural system, in Cartesian system.

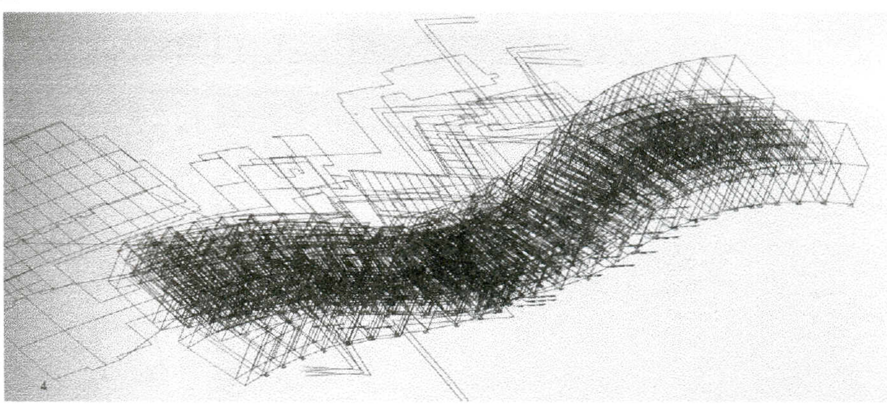


fig.5.6 The structural order of Aronoff Center (source: Lynn, 1996)

Similar geometric characteristics can also be observed in Frank Gehry's Guggenheim Museum in Bilbao.(fig.5.7) The complex formal order dominant in Guggenheim Museum is analysed and discussed from different points (technology for construction, spatial organisation, inclusion in a revitalisation program of.....). Curvilinear characteristic is also valid for both spatial (curved volumes) and formal order (curvilinear surfaces). Compound curvilinear forms with fractured and acute planar surfaced had generally provided fragmented appearance of the building (Iyanger, 1998, p.45). Some concepts (self-similarity, fractal,...) that are used to explain "order" formed by this spatial formal whole stress its importance in constitution of a new architecture. Charles Jencks explains the end-product as; "the result is a new kind of ambiguous architecture, more folded on to itself than the glass box which introduced Modernist notions of transparency. Here reflections of reflections and self-similarity of crystals, the handling of glass facets and their intersections which causes a virtual image to splinter into many layered fragments"(Jencks, 1997, no.9, p: 15). Therefore, it is based on a different geometrical order like the Aronoff Centre (using curvilinear surfaces in the characteristic of self-similarity).

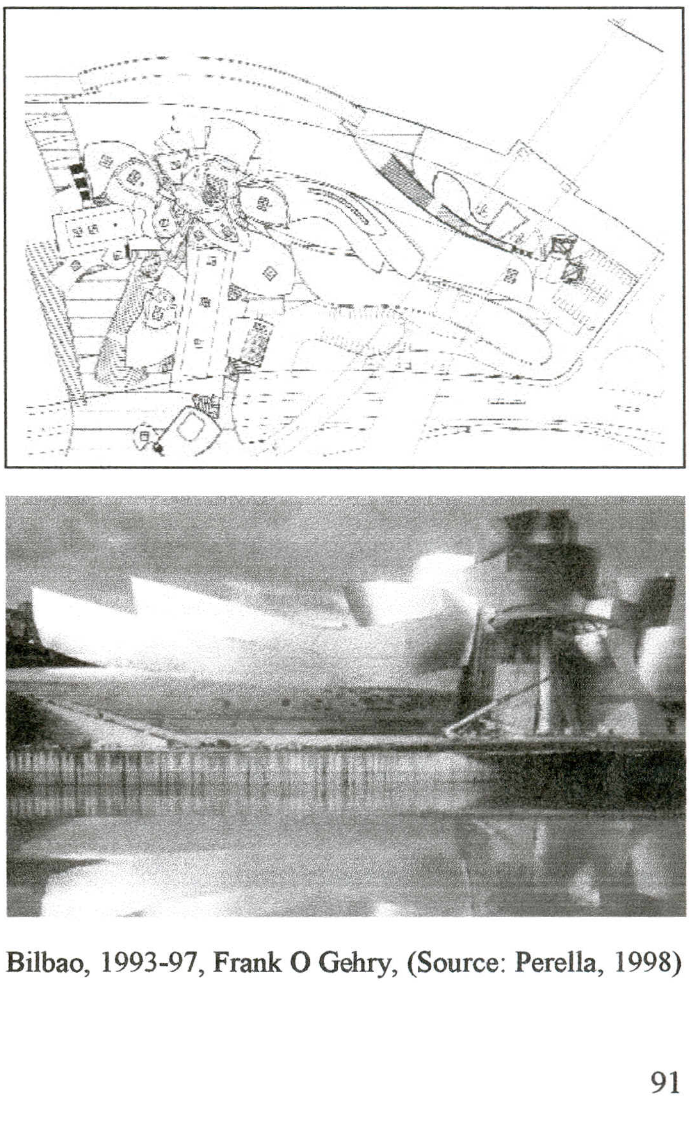


fig. 5.7 Guggenheim Museum, Bilbao, 1993-97, Frank O Gehry, (Source: Perella, 1998)

Similarly, Frank Gehry's Guggenheim Museum in Bilbao, has a structural grid providing the of standing of complex curvilinear surfaces, also the whole of the building. This system is a convensionel steel framework based on a relatively dense, separated, modular grid interconnected by diagonals. (Iyanger, 1998, p.68) Although, none of the elements in framework is a curve, the appearance of the whole is curvilinear. Analysis against gravity load and lateral wind loads had been made by using computer in each phase of the project. (Iyanger,1998) The load-transfer is linear. Some of the characteristics in structural system that force to conventional system are asymmetric location of surfaces in respect to land, wide consoles...These characteristics give the perceptional effect that is the building has a new structural order different from conventional system.

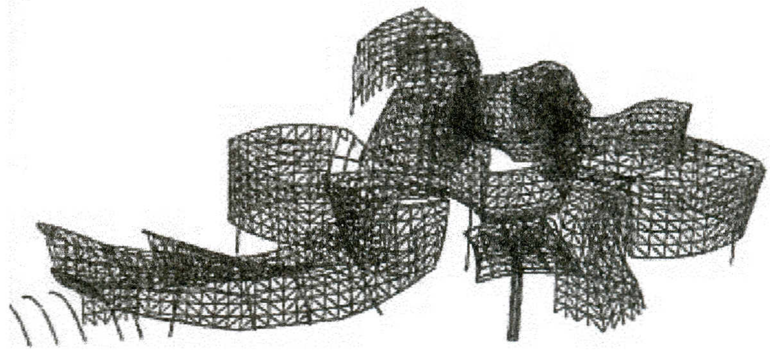


fig.5.8 The structural order of Guggenheim Museum (source: Brandolini, 1997)

NOX's Fresh water pavilion and Kas Ooesterhuis's Salt Water pavilion can be accepted as extreme examples for this kind of solutions. They have much more free formal order when it is compared to these two projects.

However, although each of them has a structural order that reflects their formal characteristics, two projects have a conventional structural system which is composed of curvilinear steel frames. Constructing such a complex formal whole requires a special method, that, it would maintain both absolute control and absolute flexibility during the construction period. As the building does not have an exact geometry, calculation of structural elements at each point in which transformation

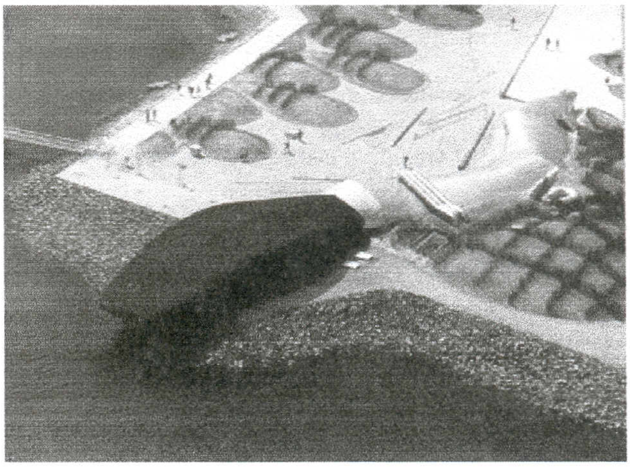


fig.5.9 NOX's Freshwater pavilion and Kas Ooesturhuis's Saltwater pavilion, 1994-97, (source: Ooesturhuis, 1998)

with geometry occur is necessitated. As a result of these requirements the concept of parametric design was developed.Because of this method three-dimensional database was constituted and its connection with three-dimensional model was constructed. By entering several parameters, change in construction and in structural order could be easily seen due to this method. (Ooetehhuis,1998)(fig.5.10-11)

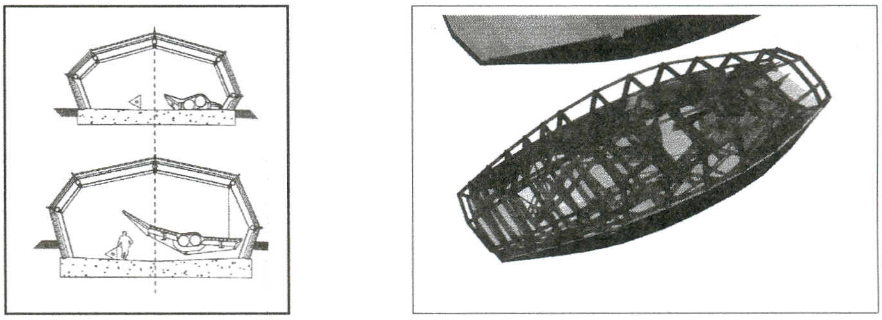


fig.5.10 The structural system of saltwater pavilion (source: Ooesturhuis, 1998)

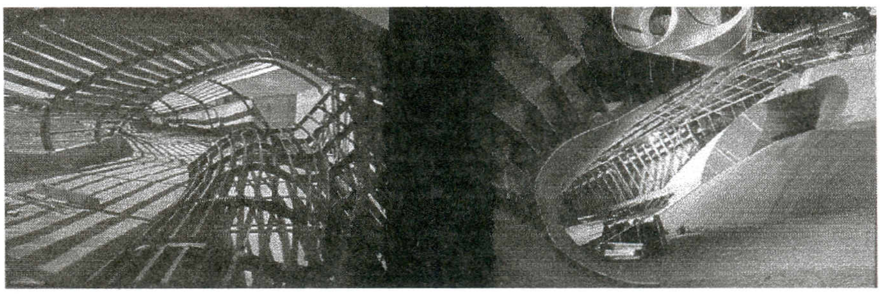


fig.5.11 The structural system of freshwater pavilion (source: Spuybroek, 1998)

5.2.1.2 The Studies Having the Relation of Geometry-Form Reflected on Structural Orders

Those are the orders in which spatial differantiation can also be seen in the solution of bearing system. Bearing system, form and space are whole. Expression of the relationship between space-movement of fluid space with surfaces is observed in the formation of structural order.

Daniel Libeskind's Victoria&Albert Museum Boilerhouse Extension is a special example for these kind of solutions (fig.5.12). The building is based on a special geometrical order As a result of this, it has a structural and formal order formed a spiral form consisting of inclined planes in a line. Also, load bearing system is based on a structural characteristic that supports itself. (www.wam. ac.uk/features/news)

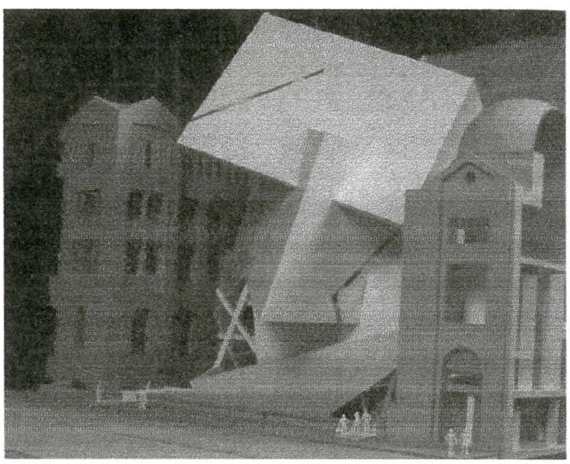


fig. 5.12

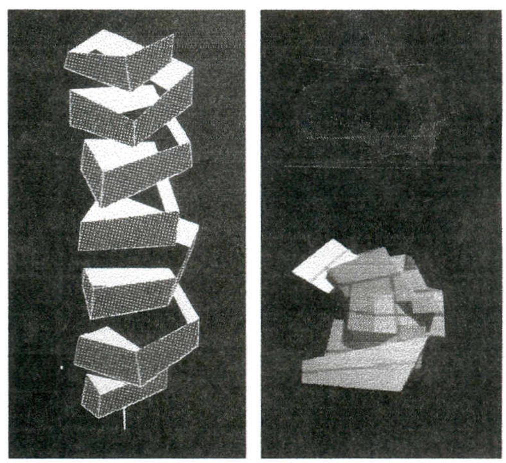


fig.5.13

fig.5.12 Victoria&Albert Museum, Daniel Libeskind, 1996-99,(source:Libeskind, 1997)
fig.5.13 The formation of structural order of V&A based on folded surfaces, (source:Libeskind, 1997)

This structural-formal-spatial order is explained by "fractal shapes of tiles". Generic pattern is the structure of the tiling (fig.5.13). So, it can be said that the order is composed of tiling patterns. In the formation of this network, organisation of the patterns is based on the concept self-similarity. This organisation is also valid for the plan, volume and detail of the building (Lıbeskind, 1997).

FOA's Yokohama Port Terminal (fig.5.14) and Virtual House can be given as examples to buildings not having a geometrical order. In the projects, the concept of motion is determinant in the formation of spatial-formal whole. All of them have a space also a formal order in which horizontal-vertical planes valid for Cartesian system did not exist. This can be expressed by the transformation of walls to floor. The continuity is achieved by curvilinear surfaces. This formal characteristic shows that distinction between building and environment is not clear. In other words, there is a close relationship between topographic geometric characteristic of a surface of the ground and the building.

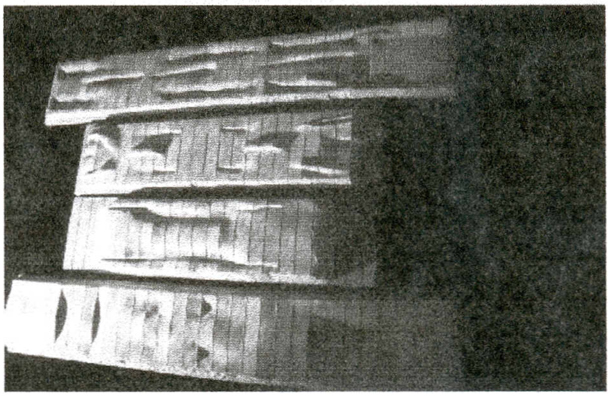


fig.5.14 Yokohama Port Terminal, Foreign Office Architects, (FOA, 1997)

In FOA's Yokohama Port Terminal, in constitution of spatial form, being of surfaces a determinative factor is also valid for structural whole because form at the same time is a structural order. Therefore, for the project, in addition to geometric characteristic of the surface of ground structural characteristic had been a reference. The surface of the ground folds onto itself, forming creases that provide structural strength like an origami construction (FOA, 1996, p.76). In this way, loads are not distributed by gravitational force through columns but by displacing stresses through the surface of the shell. This shell-like structure also became a potential solution to the lateral loads where seismic movements are so frequently produced in Japan (Quaderns, p.36).

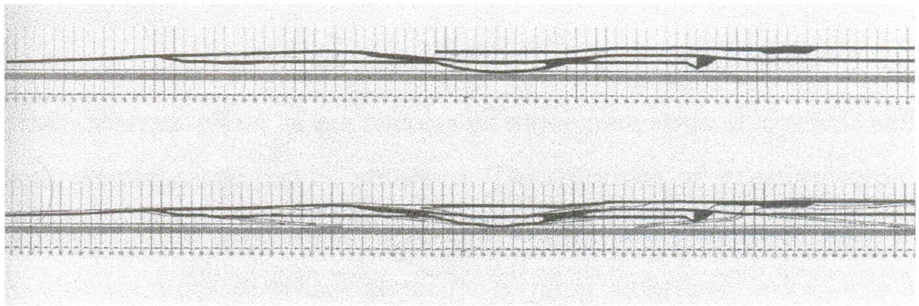


fig.5.15 The Cross section of Yokohama Port Terminal (source: FOA, 1997)

In FOA's another project "Virtual House"(fig.5.16), importance of structural order in the formation of the whole is one of the most important characteristic of it. The building was formed through folding the continual surface made using wholly Distruptive Pattern Material. The continual surface both determines spatial order and formed bearing system and also curvilinear formal order.The most characteristic quality in the project is producing the structural strength by surfaces' folds.(fig.5.17)

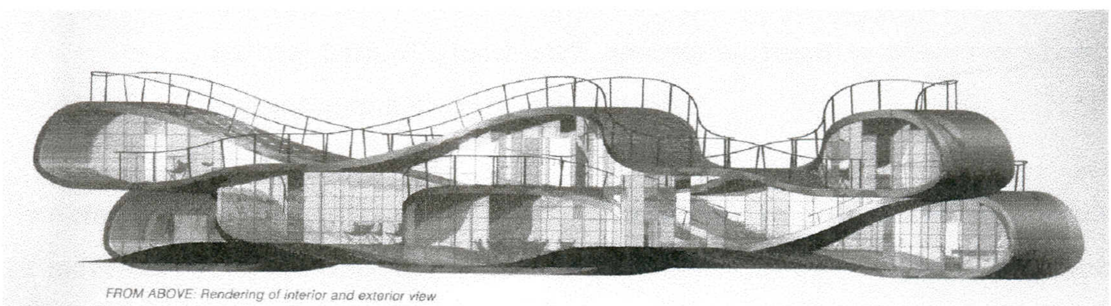


fig.5.16 The Virtual House, Foreign Office Architects (source: FOA, 1999)

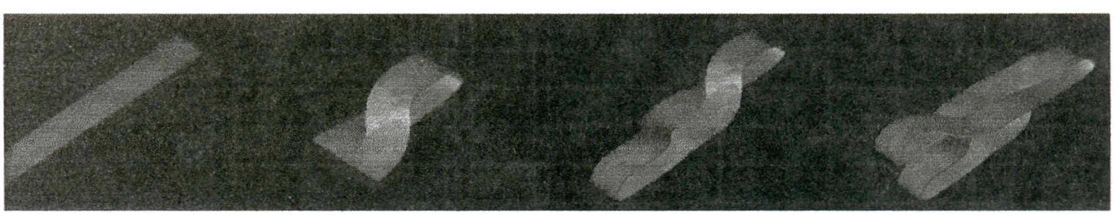


fig.5.17 The formation of structural order based on folded surfaces (source: FOA, 1999)

5.2.2 Movable Structures

In architecture, both abstract effect of the concept of movement (spatial, formal) and effect of its kinetic characteristic can be observed. The solutions of structural order moving "unchangeably" (in point of its size and form), are frequently seen in today, there are also solutions in which elements forming structural order have a kinetic movement.

One of the best examples to these studies is also analysed under the title of "Unfolding Structures" is Chuck Hoberman's. He explains these structures as:

> "They are objects that change their size and shape. Their process of transformation is smooth, fluid and continuous. Shape implies structure. Transformation implies mechanism. Each piece of an Unfolding Structure performs a dual function. Its members form a structural network that spans distances, support loads and provides shelter. Yet these same pieces are also links of a mechanism, transferring forces to create movement" (hoberman.com./fold/principles).

Movement is achieved by hinge connecting elements forming structures. As a result of movement structure constitute a definite geometrical form, its stability could be explained by a conventional system.

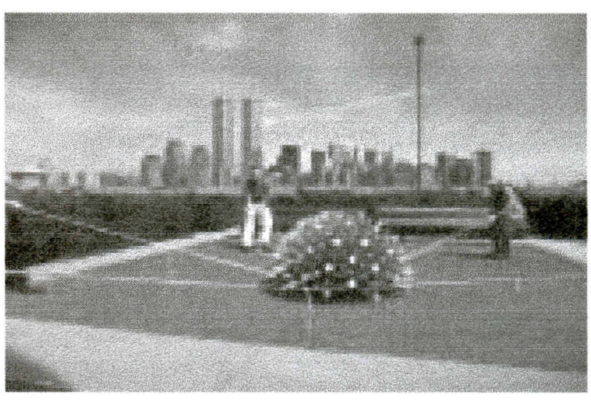


fig.5.18 Expanding Geodesic Dome, Chuck Hoberman (source:Hoberman.com/fold/principles)

Expending Geodesic Dome is one of the best example to these structures. In this system, form expands to cover spaces in different sizes, that is; structure can move both in plan and in third dimension.(fig.5.18)

Another study carrying the same principle is the Expending Hyper in California Science Centre. Movement of both two structures is through suspended cables.(fig.5.19)

Although the Iris Dome moves in the plan, it is an order opened through expansion.(fig.5.20) Structural analysis in different phase of movement was made with computer. Because structure fixed at several pavint, it behaves as conventional static structure. This realises the reaction forces and stresses to be calculated according to standard methods (source:Hoberman.com/fold/principles2).

fig.5.19 Expanding Hypar in California Science, Chuck Hoberman (source: hoberman.com)

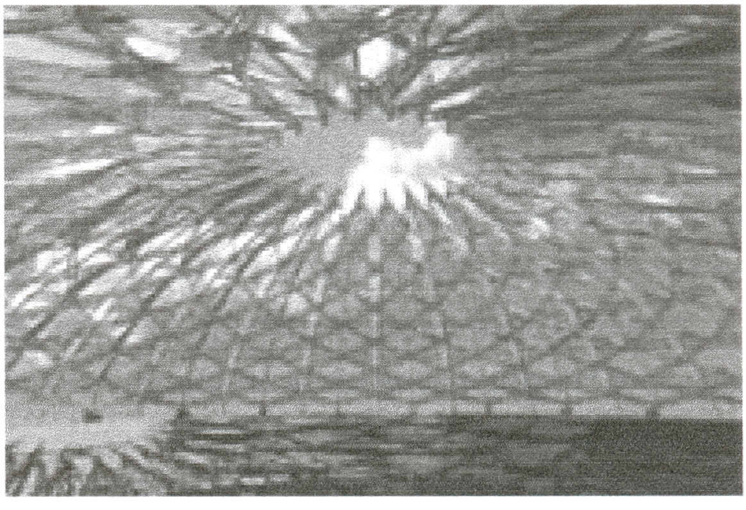


fig.5.20 The Iris Dome, Chuck Hoberman, (source: hoberman.com)

5.2.3 The Studies Based on Gravity

In the direction of the developments in the concept of equilibrium, some of the searches on structural wholes are targeted "to built the one that is off from the ground". These studies suggesting different systems that would be built because of the use of different technologies in architecture that is the result of the developments in science, are mostly utopic suggestions. Today, although there are some different solutions for architectural end-products, almost all of them are dependent on the ground, that is; gravity is the most effective in constructing a building. Studies towards to constructing a structural whole independent from the ground, despite their impossibility to materialise today, have especially been seen after second half of 20th century (1950-1970). A structural whole being independent from the ground is in two types;

a-Having a quality to change its location on the ground
b-Having no contact with the ground

Fritz Wickert explains this searches in architecture as; "The shackles of gravity are loosenning... For architectural outlook this literally means a revolution... The roof of a house takes on a totally different significance... It takes on formal value. When man achieved the ability to fly, space was perceives in a new way" (Damrau, 1999, p.29). Any more, it is believed the necessity of suggesting extreme solutions for problems instead of realistic ones. Such as; Le Ricolais's solution that is to design a street like a building for the problem of unfunctionality of loads. In other words, after doing existing a problem more complex, additional solutions can be created.

E. Albert's definition of "spatial architecture" also includes similar opinions. He explained these opinions in his conference in 1959 as; In the development process of architecture, structure that is an actual question has never been considered in a different way than that Egyptian's do and reconsidered. In a pyramid form, mass itself is always dominant. This type of form is not acceptable for our understanding. Possibility of being on a space of contemporary structure will change architectural expression. The age of space could only harmony with "Spatial Architecture" (Gürel, 1968)

In this direction, the studies of Peter Cook, Ron Herron, Lebbeus Woods, Paul Maymount, Metabolists, Yona Friedman can be examples to researches base on similar thought.

One of them is Paul Maymont's design of holiday village. It is quite utopic suggestion. (fig.5.21) In this suggestion, a net is beared by vertical element bears all of the main masses. Vertical elements, at the same time, provide horizontal circulation.

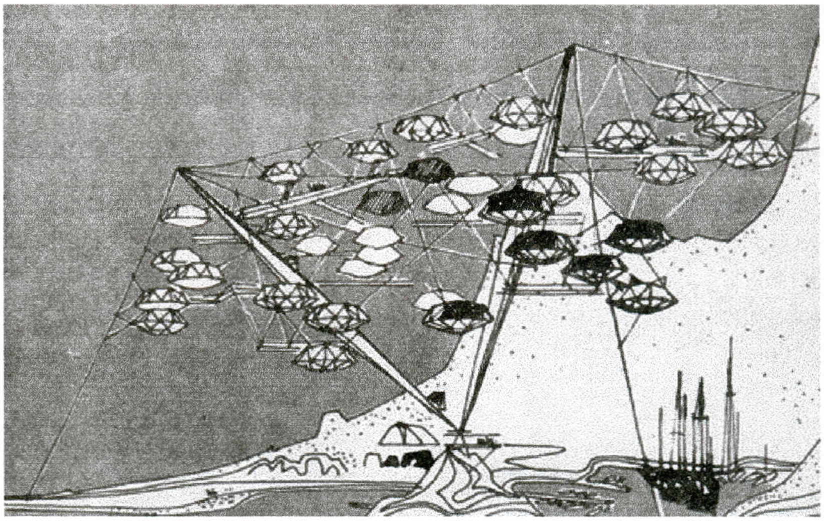


fig.5. 21 Paul Maymont's design of a Holiday Village (source: Gürel, 1968)

Similarly, in the design of Noriaki Kurokawa's Toshiba IHI Pavilion, the mass of theatre with the weight of 300 tone is wholly separated from the ground. The main mass is beared by space-frame system consisting of units in a definite number.(fig.5.22)

In these examples the situation of being independent from the ground of mass/masses physically depends on having no contact with land. These solutions can be defined as solutions that suggest stable wholes having a place in the space. Another important point in this kind of suggestions is that there is still a contact with the ground although it is indirect.

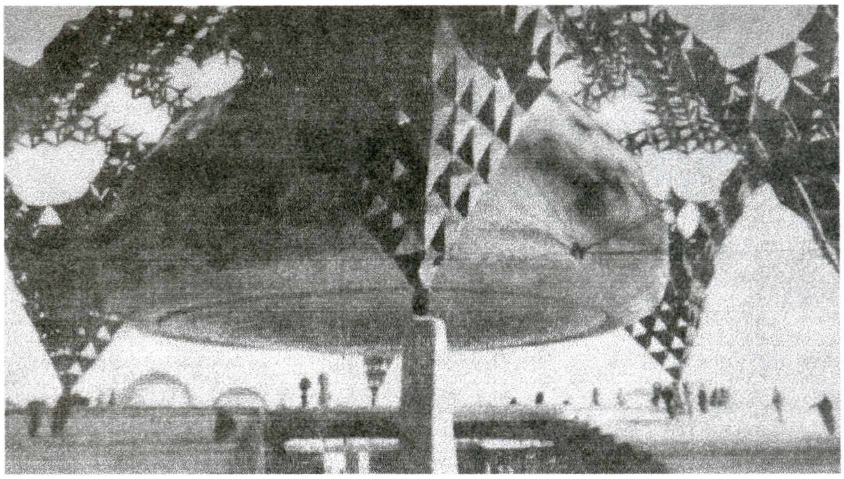


fig.5.22 Toshiba IHI Pavilion, Nuriaki Kurokawa (source:Gürel, 1968)

In addition to these examples, there is some suggestions of movable structural wholes that are not separate from the ground, but have no "specific location" on the ground. Ron Herron's Walking City (1963) is the most clear example of this kind of solutions It includes some movable units. Each unit is a city and each city could carry society to any point in the world on telescoping legs. (Jencks, 1971, p:94) (fig.5.23)

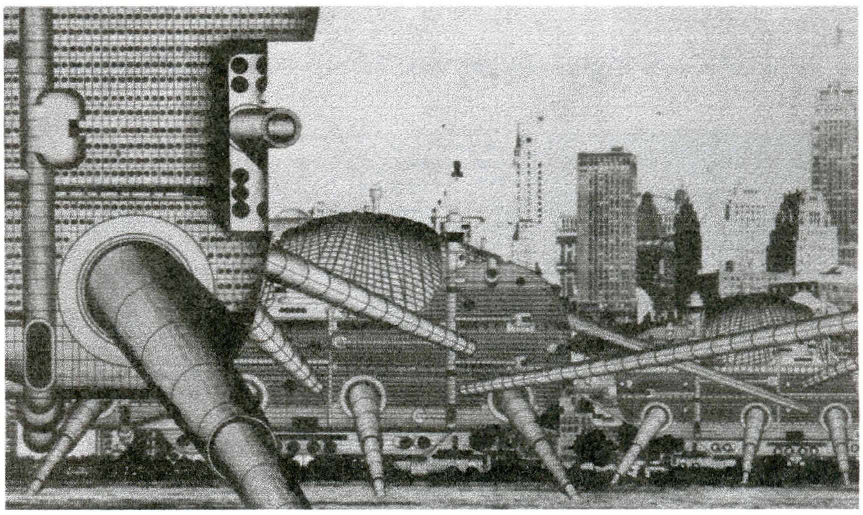


fig.5.23 Walking City, Ron Herron, 1963 (source:Jencks, 1971)

In general, in the both Herron's and other solutions, despite extreme designs force of gravity is a restrictive factor. For instance, in Walking City each whole moves on the ground, in Toshiba Pavilion, a mass remaining in the air is beared by some elements connecting with land.

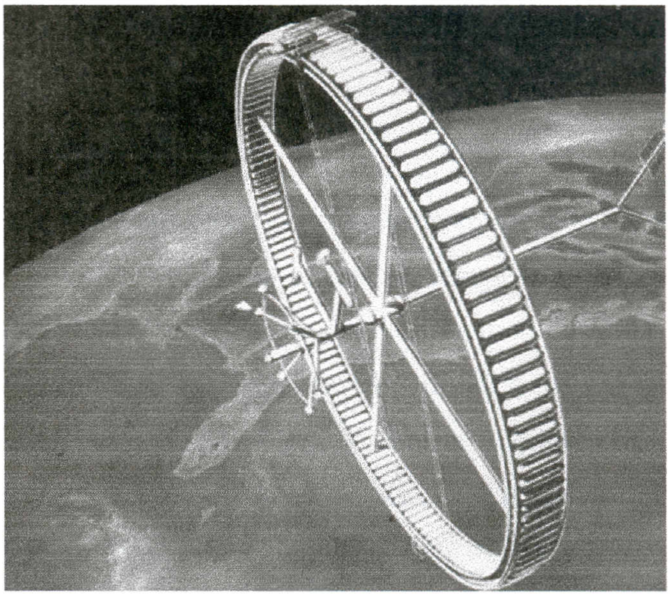


fig.5.24 Space City 1990 (source:Jencks, 1971)

Forming a structural whole that is not affected by force of gravity could only be in a place where the force of gravity is low are being searched (gravity...), such a place is only in space. Therefore, a design in which the force of gravity does not effective could be thought in the space. Today, this idea is only an utopia. It is only materialised in the movies as in the Space City 1990 (fig.24), Home from Home 1990 (fig.5.25). Home from Home 1990 shows how people might live and work in the space city.

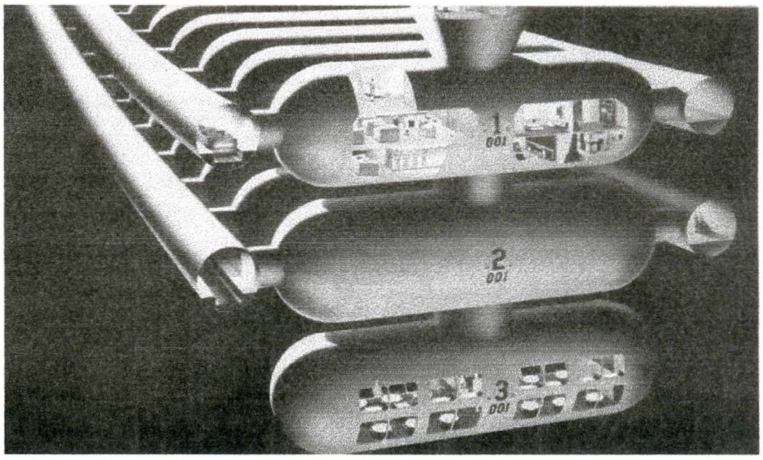


fig.5.25 Home fom Home 1990, shows how people might live in the space(source:Jencks, 1971)

CHAPTER 6

6.CONCLUSION

The thesis is originally based on the statement that, **"A structural whole basically expresses a state of equilibrium"**. Within the scope of this statement in order to determine the state of equilibrium of the end-products an analysis method based on the concepts of gravity, geometry and energy has been developed. With respect to those analyses, the necessity of using the concept of equilibrium in understanding the changes in architectural end-products was accepted as a consent. In other words; the increase in the having knowledge on the concept of equilibrium, which is due to scientific developments, is one of the basic factor in the change from static to dynamic. Therefore, in the scope of the thesis, the determinant role of the concept of structural equilibrium in the formation of end-products has been explained, and then, how the increase in the having knowledge on the concept of equilibrium in historical process effected the architectural end-products has been explained by analyses. In accordance with the titles in which analyses and evaluations had been made (these titles, at the same time, express the three characteristics of providing the understanding of the state of equilibrium of a structural whole), the conclusive statements that determine the considered change are as below;

a- Conclusive statements reached through the analyses in the scope of GRAVITY

Physically, in structural orders there is a change from **"direct load transfer"** to **"indirect load transfer"**.This general statement is the sum of the result of the differentiation;

- from "symetrical load distrubituon" to "asymetrical load distrubituon "
- from "singular (as a mass) load distrubituon" to "partial load distrubituon"
- from the wholes having the state of structural equilibrium wholly depending on "the ground" and "gravity" to the wholes in which this connection is weaker.

Today, in addition to the trend towards the extreme examples based on above mentioned characteristics, the studies including differentiation in the load transfer of structural orders can also be seen. Therefore, the changes based on gravity are towards the solutions in which the structure-form-space whole is effective in load transfer and the solutions in which the characteristic of "being indirect" of load transfer is stressed.

b- **Conclusive statements reached through the analyses in the scope of GEOMETRY**

Within the direction of formal characteristics, the change is from structural **wholes whose rate of orderliness is high**, to **order whose rate of orderliness is less**. In detail;

- The change is **from symmetric wholes** to **asymmetric wholes**, from **solid geometric wholes** to **non-euclidean geometric wholes**. In historical process, The change is geometrically from wholes depending on "the ground" to the wholes in which this connection is weaker. Today, this change is toward the solutions based on some geometric orders that is not explained in Cartesian system and formal order constituting free surfaces. In that case, some new geometric orders such as; **non-dimensional, non-linear, fractal geometry** and the concepts like; **complexity, uncertainity, indefiniteness** have become efficent.

c- **Conclusive statements reached through the analyses in the scope of ENERGY**

As a result of the change in physical and formal characteristics, it is seen that there is a change towards studies in which the effect of movement in structural wholes became important. This change is towards to both **products having effect of visual movement** and **structural order having effect of physical movement**. In today's studies, the effect of the concept of movement is prominent in design process and also on end-products. Besides the abstrct sense of that effect, it can also be seen as kinetic sense in the wholeness of space-form-structure. Parallel to this, the concepts such as; **motion-form, advanced form of movement,** and towards kinetic motion, the characteristics of solid movement such as; **foldability, structural expandability** has become determinant.

All of these changes in end-products is directly related to the increasing of having knowledge in different areas. This can be explained by the effort of architecture to understand the result of the studies of physics, mathematics, biology about universe and systems in it and to express them concretely. In this direction, in the future the scientific developments will become determinant in considerations of at which scope and differentiation can the state of structural equilibrium of a building be studied. Nevertheless, when we look at the today's developments, it is a clear reality that; **throughout the time that architecture built on the ground, resistance to the effect of gravity in different types will continue similarly with small differences. This similarity will be can more clear when there is not any radical change towards structural solutions.** In this situation, it can be concluded that **the change towards differentiation in the state of equilibrium is much more towards to movable structures and solutions in which separation from the ground against the effect of gravity is achieved as effectively as possible.** At this point, **the discussion about the concept of structural equilibrium in wholly different meaning can only be possible by achieving the possibility of building in the space where the effect of gravity is zero.**

GLOSSARY

- **Cantilever;** is a structural element which projects horizontally into space, supported at only one end.
- **Descriptive geometry;** is the science of graphic representation and solution of space problems.
- **Direct load transfer;** is a kind of load transfer in which each part of a load bearing system transfers only its own loads to the ground directly.
- **Dynamic equilibrium;** is used to define the state of stability of the mobile objects (visually and physically).
- **Entropy;** is a hypothetical tendency for the universe to attain a state of maximum homogeneity in which all matter is at a uniform temperature.
- **Fractal;** a geometrical or physical structure having an irregular or fragmented shape at all scales of measurement between a greatest and smallest scale.
- **Gravity;** is a force of attraction by which terrestrial bodies tend to fall toward the center of the earth.
- **Indirect load transfer;** is a kind of load transfer in which loads of any part of a load bearing system transfers by other parts of the system.
- **Kinetic energy;** is the energy of a body or system with system with respect to the motion of the body or of the particles in the system.
- **Kouros;** is a sculptured representation of a young man, especially one produced prior to the 5^{th} in Greek.
- **Perceived movement;** sensed movement in an object which is actually immobile.
- **Potential energy**; is the energy of a body or system with system with respect to the position of the body or the arrangement of the particles of the system.
- **Pregnant moment;** visual effect of physical moment which causes perceived movement
- **Static equilibrium;** can be used to define the stable state of the immobile objects.
- **Structural balance;** is defined the rate of orderliness of a situation which is formed with relations (formal and proportional) of the elements of structural whole/ composition.

- **Structural equilibrium;** the state of stability of a structural order, where, this state of stability is provided by the neutralisation of physical forces.
- **Translational equilibrium;** is a kind of state of equilibrium in which the body is when no force is acting to make a body move in a line.
- **Visual energy;** is the result of arranging form in such a way as to suggest a possibility of falling or other movement.

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