Determining Factors of Complexity in Structures

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Approval of the Institute of Graduate Studies and Research

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We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Doctor of Philosophy in department of Architecture.

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ABSTRACT

This thesis analyzes the effective factors that determine the buildings with complex structural systems and the relationship between the details and this complexity.

Complexity is determined by hierarchy, geometry, integration and new details. When more than one structural system in one building is recognized, then possibly that building is a complex one. Because it certainly involves integration of the structures, hierarchical production (built) process and new details.

Complex systems, since they can be developed and formed by both truss and cable systems and likewise by shells such as grid shell and lattice shell, they all are reviewed and analyzed. The example of these systems are divided into different categories and for each category graph samples are produced.

Transparency combines inside and outside of the space. In order to enable maximum transparency, minumum use of material is needed. The more glass surfaces are used, the more maximum transparent surfaces are created.

Hypothesis, which is: new detail which covers new members, new organizations and new point details is the major factor which determines complexity.

The method of this thesis is conceptual model. During the study of this thesis, various information has been derived from books, previous researches, reports, and some information was received from firms that produce such systems. Twenty examples have been analysed, different categories have been determined and their individual graph tables have been drawn using other examples.

Different categories were compared with each other both from technical and structural aspects with the help of a model, and from the aspects of application and form; the relationship between the detail features and elements of structural features has been interpreted and conclusions were drawn.

In the light of the derived information, it became clear that the systems should not be evaluated only as structural icons with maximum transperancy, but should be percieved as structures, which can be changed according to the features of the whole building. It is stressed that for the new complex buildings to come into existence, new details have to be generated. In addition, the attention was drawn to the application process of these details and to the importance of their relation to structural geometry. The complexity of appearance in the complex buildings, in fact, is the reflection of the details on. Complex buildings were designed to target the inner and outer spaces simultaneously. However, complex buildings were proved to be complex entities during the application process with the preparation of necessary details, sometimes with the unification of more than one detail and form.

Keywords: Complex Buildings,Light Structures,Detail,Maximum Transparency.

ÖZ

Bu tez karmaşık strüktürel yapıların olabilmesi için etkili faktörlerin ne olduğunu ve detayla sözkonusu complex yapı ilişkisini inceler.

Karmaşık sistemleri hiyerarşi, geometry, bütünleşme ve yeni detaylar belirler. Bir binada birden fazla yapı sisteminin gözlemlenmesi o binanın karmaşık yapı olduğunun birincil göstergesidir. Bu yapıların genel özellikleri ana yapı ile bütünleşmeleri, yapım aşamasındaki hiyerarşi ve yeni detayların varlığıdır.

Karmaşık sistemler, makas ve kablo sistemlerinin birleşiminden oluştuğu gibi kabuk (grid shell ve lattice shell) gibi yapılardan da oluşabileceğinden bu sistemler yeniden incelenip gözden geçirilmiştir. Sistemlerin örnekleri farklı kategorilere ayrılmış ve her kategori için, grafik örnekler geliştirilmistir.

Şeffaflık mekanın içi ile dışının bütünleşmesini şağlar. En yüksek derecede seffaflık için minimum malzeme, maksimum cam kullanılmalıdır.

Tezde kavramsal model yöntemi kullanılmıştır.Bu tez sürecinde kitaplardan, önceden yapılmış araştırmalardan, raporlardan ve bu sistemi üreten firmalardan bilgi edinilmiştir. Yirmi örnek incelenmiş, farklı kategorileri saptanmış ve bunların grafik şemaları örneklerden yararlanılarak çizilmiştir. Farklı kategoriler birbirleriyle hem teknik ve yapısal yönden, hem de uygulama süreci ve biçim açısından kıyaslanmış ve

kullanılan detay nitelikleri ile yapısal özellikler arasındaki ilişki konusunda yorum yapılması yolu ile sonuca gidilmiştir.

Bu bilgiler doğrultusunda, sistemin sadece azami saydamlık ve yapısal bir öge olarak degerlendirilmemesi, aynı zamanda tüm mekanın özelliklerini de değistirebilen bir yapı olarak görülmesi gerektiği ortaya çıkmıstır. Karmaşık yapıların ortaya çıkması için yeni detaylar üretilmesi gerektiği vurgulanmıştır. Ancak bu detayların uygulama süreçlerine de dikkat çekilmiş ve bunun yapı geometrisi ile de ilişkisinin önemine değinilmiştir. Kompleks yapıların karmaşık görüntüsünün aslında detayların dışa yansıması olduğu görülmüştür. Kompleks yapıların mekanın içi ile dışının oluşması hedefiyle kurgulandığı, ancak uygulama safhasında gerekli detayların hazırlanmasıyla bazen birden çok detay ve yapının birleşmesi ile oluştuğu için karmaşık yapı olduğu ortaya çıkmıştır.

Anahtar Kelimeler:Karmaşık Binalar,Hafif yapılar,Detay,Maksimum Şeffaflık.

To My Family

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Special thanks go to my family for their patience and loving encouragement, who deserve much more attention than I could devote to them during this study.

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LIST OF SYMBOLS/ABBREVIATIONS

(Which are used in chapter 5 Model)

Mbs-Main Building Structure

Btr-Between Two Tension Rings

Ws-Whole System

Ctwss-Cable Truss within Steel Shell

Imbs-Infront Of the Main Building Structure

Sdbtmp-Spaning the Distance between Two Masonry Parts

If-Infront Of Frame

Bvmf-Between Vertical Members of The Frame

Imbs-Infront Of Main Building Structure

Ct-Cable Truss

Rsc-Rings Supported By Cables

Ttc-Tree Type of Columns Supporting From Various Points

S-Simple

Hsct-Horizontal Simple Cable Truss

Sgspct-Suspended Glass System with Prestress Cable Truss

Tss-Triangulated Steel Shell

Vhoct-Vertical And Horizontal(3d) Organization Of Cable Truss

Dct-Diagonal Cable Truss

Vscg-Vertical Struts Which Carry Glass Pieces Some of These Verticals Are Supported By Cables

Phmbs-Partially Helps Main Building Structure to Carry the Roof Struts

Afd-Arches Forming a Dome

F-Frame

Tr-Tension Ring

Hct-Horizontal Cable Truss

Vct-Vertical Cable Truss

Trc-Tension Ring Cable

Vg-Vertical Glass

Gss-Glass Surface with Spiders

Rf-Removal of The Formwork

Ptf-Partially Temporary Formwork

Ss-Steel Sheel

Ct-Cable Trusses

Fss-Formation of Steel Shell

Sscg-Struts Supported By Cable Glass

Bc-Branches of Columns

Vssct-Vertical Steel Supports Of Cable Trusses

Vssctvssphctpg-Vertical Cable Trusses Which Correspond To Vertical Steel Supports Prestressing Horizontal Cable Trusses Prestressing Glass

Wss-Whole Secondary Structure

Emei-Every Member Having Equal Importance

Ctss-Cable Truss Supporting Shell

Cbctmbs-Cable Between Cable Truss And Main Building Structure

Mmbs-Minimized Main Building Structure

Occp-Opposite Cable Connection Points

Em-Elongate Members

Bca-Between Cable and Arch

Bcct-Between Cable and Cable Truss

Hct-Horizontal cable truss

Vct-Vertical Cable Truss

Gss-Glass surface with spiders

B-Branches

Ssf-Steel Shell Formation

Ss-Stell Shell

G-Glass

V-Verticals

Wpglsvc-While putting glass layers some verticals are supported by cables

P-Pre-stressing

Ssc-Struts supported by cables

Rp-Removable partial

F-Formwork

Mf-Movement of the formwork

Mb-Main Buildings

Vs-Vertical Supports

3dovhct-3d organization of and horizontal cable truss prestressing glass.

Rct-Roof cable truss

C-Columns

Gol-Glass at one level

Ct-Cable Tensed

Fb-Final Balancing

Rf-Removal of the formwork

Rc-Reinforced Concrete

Chapter 1

INTRODUCTION

Architecture is the art of space and it is based on some physical and technical principles and the actual project. Structures are important as they define space. Space is determined by certain physical units. There are many types of forms and ideas of decorations and ornaments. Also, there are many differences of the look of the primary elements and the created spaces. But how do we produce these room units? This is the main question that architecture focuses on. Sometimes traditional methods are used to build up by "stones laid down on stones", sometimes modern technology is used to build up "brick by brick".

Complexity determined by hierarchy, geometry, integration and new details. More than one structural system for some building is recognized. This kind of buildings determine integration of the structures, hierarchical production (built) process, geometry and new details. For complex systems hierarchy is a necessary requirement. Structural hierarchy combines different levels, increasing in size, complexity, function and structure, material contents and power. One of the important aspects of this hierarchical build-up is that units are cooperating with each other and they are having a number of common goals once they become the elements of a complex structure.

Some building types become more and more complex in time, and when doing so, move up the steps of a structural hierarchy as shown figure 1.1 and 1.2. When we look at the history of architecture, a trend shows where complexity and hierarchy go hand in hand. As a general rule, complexity goes together with increased levels of hierarchy, where increased levels of hierarchy correspond to increased size in organisms (buildings where increase levels of hierarchy). The only visible limitations we can see in time of this hierarchical process are regarding space and matter.

Figure 1.1 Dubai Marina Building

Ref: [www.epcocorp.com/Featured_Projects.htm]

Figure 1.2 Apple Store 767 Fifth Avenue

[New York City Ref: www.content.techrepublic.com.com/2346-10878_11-28...]

Complexity and dematerialization are the important issues in this matter. The demand of having a totally glass surface, created some other types of details.

Complexity is an important concept to learn because if an architect knows about complexity, this means he will be able to design more transparent and more minimal buildings. These systems are the systems that cause minimization of the visual impact of the supporting elements and maximization of the transparency. In order to understand these systems, it is necessary to understand configuration and behavior of arches, shells, and trusses and cable systems. Grid shells and cable systems are explained in Chapter 2.

The limits of this thesis are transparent and light complex structures. For example, The new types of shell structures are very light because of their details. In the solution nothing is arbitrary. Each detail, joint, each bearing, reflects the way in which steel and glass behaves, plays role in the idea of transparency and creates an immaterial space. In a structure all the elements that form the structure, lie in a correct relationship with one another. So each part, each section can be identified as being an integral part of the logical reasoning behind the whole structure.

The thesis aims to discuss the relationship between the new details and lightweight and transparent complex structures. For this reason, the factors that play important roles for the development of the complex structures are analyzed at length and as a result of this analysis a conclusion is drawn. Research objectives of this thesis is to find what the factors are which forms the complexity. The body of the thesis consists of four chapters except for the introduction and conclusion. In the second chapter, the types of structures that form light and complex structures are generally investigated. They are trusses, cable systems, arches and grid shells. In the third chapter, the major characteristic features of the complex structures are the point of focus where the individual buildings were samples. They are structural hierarchy, geometry and integration. In the fourth chapter, the sample buildings were analyzed in detail. Because the others have same in characteristics twenty cases are studied to classify types of the systems according to their structural characteristics and their geometry, which are listed in Appendix A. A conceptual model which is in the fourth chapter only includes ten cases because the others have same in character. The relation between these structures and integration to the main building structure, complexity, geometry, and construction process are discussed with this approach. One for each type is chosen. With the help of different examples, schematic drawings of structure for each category are drawn in Chapter 4. These drawings show the advantages of these structures not only in their measurable properties, but also immeasurable properties such as dematerialization.

Models for these structures are determined in Chapter 4. From three types of models, which are conceptual, mathematical and graphical, conceptual model were used. The methodology of comparison is used for different cases in order to discuss the relation between structural and spatial characteristics by considering the rational and immeasurable properties, and with recommendation conclusions are drawn.

In this thesis, whose aim and the content are stated above, in order for the necessary hypothesis or conclusion to be drawn inductive research techniques were used. I intend to derive results by studying many examples in limited topics. All relations between all items are considered in the related conceptual models, as analyze and also question the relationship between parts, the point of focus is systems approach [Reichenbach, H, 1985, Berköz, S, 1975]. In order to define all different properties of forming, that have direct effects on the process, the outcomes of the model are analyzed using the systems approach method. The related model is prepared in order to expand the possibilities of architectural forming of the complex buildings. However, in order to detect the architectural forming alternatives that might be placed in the model the reproductive method is used. (Berköz, S., 1975)

The strategy suitable to the systems approach contains the following steps:

1-defining the problem,

2-determining the decision making criteria,

3-synthesizing the alternatives,

4-analyzing the alternative systems using the related models,

5-selection of the optimum alternatives

Within the above steps, only the first three were used. Later on, the systems approach method is used in order to form the model that shows the possibilities of architectural forming in complex buildings.

In the conclusion of the thesis, the analysis of the criterion which enables the existence of complex buildings are interpreted, and the hypothesis, which is: having new details is the major factor which determines design of new types of complexity. In order for the complex structures to exist the major factor is to enable the possibility of new details (new member types, new organization or new point detail) is conceptually proved. In addition to this, the placement of these new details in the whole system carries an importance. Thus, it is shown that hierarchy is involved in the process, too. Although integration and geometry carry an importance for complex structures, however their importance is not inevitable.

Chapter 2

CONTEMPORARY CHANGES IN BUILDING STRUCTURES

This chapter generally focuses on the structure itself in the new and light complex structures. In order to understand these systems, structure systems are analyzed in a general manner and then truss, cable truss and grid shell systems which are used in light new complex structures, are explained. The working principle of each system is described and in some of the structures the process and details are analyzed when necessary.

2.1 Structural Systems in General

Structural systems which have common behavior features compose structural system types. This classification is done by considering common features not by differentiating all factors between systems as far as the most of sources on structural systems are concerned. This method is used to make it easier to explain system behavior. For instance, I. Schodek, (1980), categorized structural systems based on the subtitles listed below:

1.Trusses-cable trusses

2.Bracing and Supports

3.Beams

4.Columns

5.Continuous Structural Frame Systems

1.Slabs

2.Membranes

3.Shells

According to D. I. Schodek,(1980) the above structural systems are primary structural units, or they are maintained by aggregations.

1.Slabs under the title of horizontal planes

2.Walls, Shear Walls, Shear Walls formed by trusses and frames under the title of vertical systems

3.Shear walls, frame systems, tubular systems and some other special systems under the title of high rise structural systems

4.Suspension systems, shells

5.Foundations

D.P. Billington,(1975), explain the development of structural systems in a historical frame and define them in three major types such as structural systems with common scales, wide span and high rise structural systems.

A. Hodgkinson in (1974), classifies structural systems according to the structural materials and points within the elements of the same structural systems designed with different materials.

Among the structural systems, there are some basic behavior differences (internal stress distribution and strain) which must be differentiated from each other considering their scales and proportions. First, different structural systems in each group must be classified again according to their types of stress in order to find out their similarities. In this case, the structural systems, which take place in literature, can be classified as below. (Al, 1992)

Wide Span Structural Systems:

1. Compression Systems: Arches, vaults, domes, positive curvature shells
2. Tension Systems: Cable systems, membranes, inflatable systems, negative curvature shells.
3. Compression and tension systems: trusses, space trusses, space frames.
4. Bending Systems: frames, slabs, shear walls.
5. Composite systems such as, suspended bridge systems.

Among these systems the behavior of vaults and domes can be roughly explained by the behavior of arches, the behavior of membranes by cables and the behavior of oddly curved shells by the behavior of arches and cables and the behavior of space frames by behavior of trusses.

Arches, cables, trusses and frames can maintain most of the other structural systems and common load combinations as they are basic structural units.

These units can be added to each other in order to form various unique structures. [Wilson, 1971]

2.1. A the Capacity of Integration of Structural Systems

Unique structural systems can be formed out of the integration of various systems or addition of systems without integration. The integration of structural systems can be exemplified by shells which have both positive and negative curvature. These structures integrate both cables and arch systems. Systems which are added without any integration can be exemplified by suspension bridges, which combine cables, beams etc.In order to determine the unique features of any structural system, structures have to be divided into their components of structural units.

In order to examine architectural form potentials of structural systems, different systems which are combined to form a unique structural system and their individual features must be taken into consideration as a whole, and along with the main structural systems.

2.1. B The Features of Structural and Architectural Forms

Architectural form factors define a building's planar features in relation to its mass. The main planar feature of a structural form can be identified with a structural system of linear and planar elements. The planar features of architectural and structural forms must be analyzed one by one and independent from one another since they might display diverse conditions in various other situations. 3D organizations of planes form masses, or geometric surfaces might form structural masses.

The existence of form additions which is considered independently from the primary structural system does not usually influence the main structural system itself considerably in ordinary buildings. However, any added structural system, if it depends on the main structural system, would influence the behavior of the primary structural system in a negative or positive manner.

2.1.C Planar and Linear Addition Forms

The constructive elements that are made of planar and linear additions might form the surfaces of the architectural form. But, there are exceptions when they do not follow the structural form.

When architectural form is an instrument of expression, the combination of all the forming features of nine architectural form factors (the scale of a structural form, proportion, type of form of additions, type of form of subtractions, planar and linear addition types) might establish architectural forming options [Al, 1992]. However, Al's explanations do not cover the structural features of suspended glass systems,because of the total dependency of one system in SGSPCT to the other.

In this thesis, in order to explain the features of new light and complex structures,trusses,cables, cable trusses, and grid shells are analyzed as main structural units forming new complex structures. It is necessary to understand cables and trusses in order to understand cable trusses and it is necessary to understand arches and cables in order to understand grid shells. Cables, trusses, and cable trusses can be viewed as unit structures, whilst grid shells can be understood by understanding arches and cables.

2.2 Structural Units Which Form The New Complex Structures

This part of the thesis gives general information about cable trusses and grid-shells. The subjects of cable trusses are based on my master's thesis, which is called 'Spatial Characteristics of Suspended Glass System with Prestress Cable Truss'.

2.3 A Cable Trusses

Cables take the shape of a parabola when the load is distributed. This is the same

shape that was selected also for the cable trusses. Moment is taken in the same way like an ordinary beam. The two cables act jointly in the cable truss system as shown in Fig 2.1. The tension increases in one cable, and decreases in the other under any given load. Since pre-stressing is applied to the cables, they always remain in tension. The shape of the cable truss takes the shear force. The stuts between the cables are in compression. [Rice, Dutton, 1995; Muschamp, 2000; Atakara, 2000]

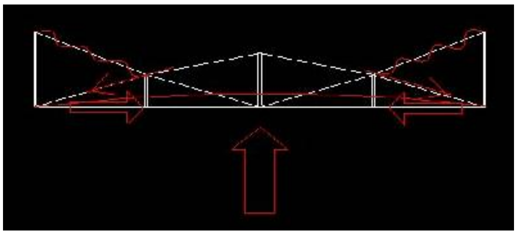


Figure 2.1 The tension increases in one cable and decreases in the other

under a given load in the cable truss.

Existance of two cables stabilize each other.When all of the pre-stressing force has

been overcome in either of the two cables, the geometrical deformation becomes important as shown in Fig. 2.2. In order to realize this need for geometrical change, hinges have been included at the connections between the trusses and the glass.Glass is the surface , which is attached to the cable truss. Thus, the deformation of the truss is not dangerous any more for the glass. This guarantees the behavior of the cable truss under loads and also of the glass surface. [Rice, Dutton, 1995; Muschamp, 2000]

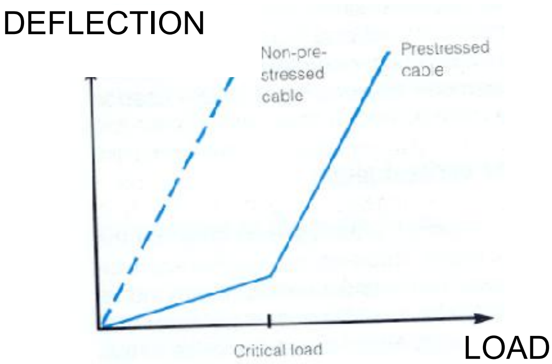


Figure 2.2 Influence of pre stressing on the resistance of cables [Rice, Dutton, 1995].

A-Pre-stressing in Cable Trusses

One cable elongates with an increase in tension, the other shortens as it loses tension. By this effect the efficiency of the system is doubled. The stiffening effect is another advantage of the pre-stressing which is shown in Figs. 2.3-2.4 by considering a wire pulled horizontally, while a vertical downward load is applied to its center.

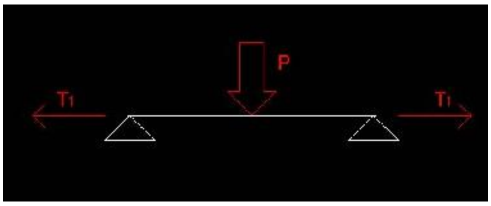


Figure 2.3 A vertical load p is applied.

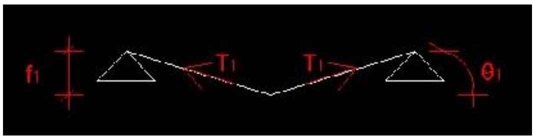


Figure 2.4 The cable then undergoes a deflection.

An increase in pre-stressing reduces the final deflection as shown in Fig. 2.5.

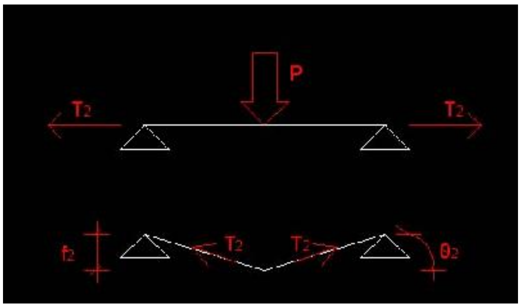


Figure 2.5 P is applied but highly pre-stressed cable undergoes a smaller deflection.

As the pre-stressing force of the wire increases, the angle necessary to take the shear will be reduced under constant shear. The pre-stressed cable truss behaves according to the same principle as shown in Fig. 2.6.

The aims are;

-To reduce deflection,

-To achieve a system without any struts as upper and bottom chords.

When there is a major deformation in order to respond a load then perceivable

> deflection comes into action. The pre-stressing effect is less important in the case where the shear may be taken without significant deformation in a normal structure. It is necessary that all the factors that will decrease the level of pre-stress, must be predicted when the cable truss is considered. For example, changes in temperature, or possibility of having an inadequate initial pre-stressing should be considered. La Villette, was made for a 15'C temperature difference between the cables and the main structure, which can cause a loss or gain of pre-stress. Since the design allows the unloaded cable to go slack under extreme loads, the system remains just as strong, even if the pre-stress is less than intended. The only consequence of this under high stress (or overstress) is that there would be an increase (or decrease) in the structure's deflection, because of the load range where the pre-stressing is effective. [Rice, Dutton, 1995]

The pre-stressing serves for the rigidity of the system in the lower load ranges. Pre-stressing the tie rod results in compression in the horizontal member, compression that grows with the increase in tension is shown in Fig. 2.6.

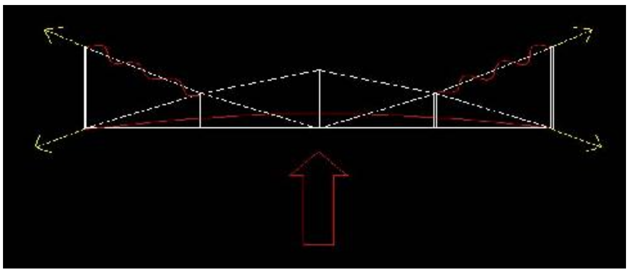


Figure 2.6 The cable truss.

2.4 Suspended Glass Sytems with Pre-Stress Cable Trusses (SGSPCT)

Below figure is the typical cable truss which was shown cable,strut,tube,v-brackets and glass.

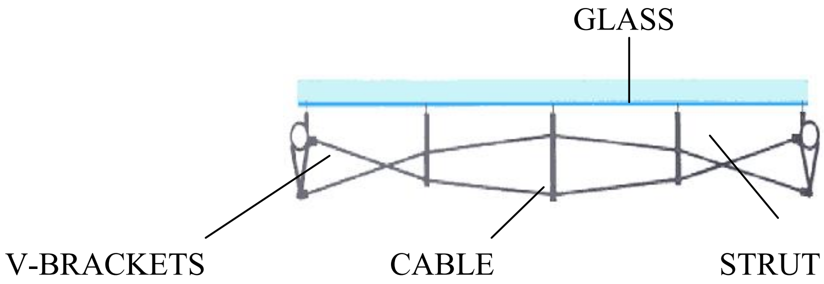


Figure 2.7 Cable Truss Members [Rice, Dutton, 1995].

Other building elements that can be in the suspended glass system with pre-stressed cable truss (SGSPCT) can be classified as following.

-Parts of the main building structure which are in interaction with SGSPCT,

- Tube structure,

- The cable truss system, itself,

-Glass and its support points.

All knowledge, which are given in this chapter, is based on the same module which is known as ‘Serres’, because this module includes all possible parts in itself and this gives opportunity to explain other types of SGSPCT easily. Fig. 2.39 shows the hierarchy in the structure and how this hierarchy is effective in putting certain parts together during the installation of the cable trusses on site.

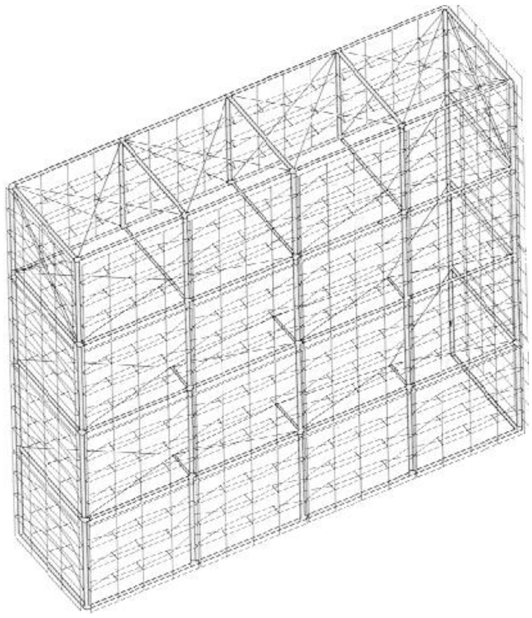


Figure 2.8 Framework of the cable truss and stability [Rice, Dutton, 1995].

According to this hierarchy, each element bears the load of those subordinate to it. All the elements of the hierarchy serve the plane of glass and its supporting elements. The tube structure is the frame that is placed just inside the plane of glass, which consists of 8x8m tubes, 300 mm in diameter. This structure is to support against wind. This supporting truss in Paris Science Museum includes tension member rods between 30 and 55 mm in diameter because of the pre-stressing. The bigger cable trusses that are shown in Fig.2.8 decrease the need for wind bracing for the glass surface. So the observers see only the plane of glass. System is detailed to give this effect of the suspended glass system. The plane of glass is held by an array of identical support points that also help in realizing the same effect. Even the glass surface has a structural role in SGSPCT.

The great glass walls of the Cité des Sciences at La Villette at La Défense in Paris known as Serre. Serre is a standardized and widely applied type of SGSPCT, which also contains all possible elements of hierarchy in SGSPCT.

2.4.1 Glass Features

New architectural forms tend to use more glass. Glass is being used to support long term plane loads rather than the short-term loads.

Mechanical strength of the glass, theoretically, to separate the molecular layers of the challenge 3000 MPa (1Mpa = 106 Based on the forces required Ъ F N/m2), we get the value. In fact, the values obtained are far below the theoretical value. Strength of glass used in our daily life in the 30 to 100 MPa between. To be issued at the result, the mechanical strength of glass, as mentioned above, specified by the surface states.

Structural integrity of all pressurized glass should be verified by both analysis

and testing. Unpressurized glass may be verified by analysis only with an ultimate minimum design safety factor of 5.0. The prototype verification option is not available for glass. Protoflight test of glass should be configured to simulate flight boundary conditions and loading. For glass protoflight testing, the total time during load, dwell, and unload should be as short as possible. This testing should occur is an inert environment to minimize flaw growth. Care should also be taken to configure protoflight hardware to prevent overloading and bonded joints during test. Recommended minimum design and test factors for structural glass bonds:
Ultimate strength: 2.0
Test factors qualification:1.4
Test factors acceptance or proof:1.2
(http://docs.google.com/viewer?a=v&q=cache:p_lpu_LENeQJ:www.faa.gov/about/office_org/headquarters_offices/ast/licenses_permits/media/RLV_Safety_Critical_Structures_Guide_v2.3_112205.pdf+cam+emniyet)

Glass has many strength characteristics that the traditional materials like timber,

masonry,steel or concrete don’t have. It is a unique construction material. Glass fails through a combination of the stress level and the size of the cracks on its surface. Glass has specific problems in the detailing of its connections. Glass does not distribute stresses through plasticity, while materials like steel can resist stress concentration. Glass is brittle; not ductile. Glass is being used in exciting new structural and architectural forms. Developing design methods for the use of glass as a structural element in buildings, is the aim of many projects in order to have beams and columns in these structures being made out of glass. [Rice, Dutton, 1995]

Glass is fragile and does not resist fissures that spread immediately into total

> breakage. I order to increase the glass's capability to resist stress, the industry has developed several techniques that do without modifying the nature of the glass itself. Ductile materials having the function of absorbing local stresses and preventing the total breakage when a fissure occurs can also achieve this 'New mathematical methods are being developed to allow engineers to design structural glass elements. The new method is termed "crack size design" and places emphasis on the understanding of cracks and crack growth, rather than on limiting stresses. The basics of the method have been established, and work is in progress on applying it to different applications. Studies involve theoretical and numerical modeling and experimentation. [Houlsby, Porter, 1999]

Glass combines unique architectural possibilities with extraordinary mechanical properties. Because of its brittleness, engineers are anxious of using glass in a structural capacity, but glass has high strength, stiffness and durability. Structural glass shows high resistance against the force of tension and compression.

Glass structures are developing rather in the way that stone structures developed in

> the middle ages, by pragmatism and trial and error. Engineers, who invariably have to stand responsible for structural failure, have no real codes or structural data to design with, and are forced into accepting the recommendations of the glassmakers, or into a programmed of testing which demonstrates that a proposal is sound. This usually means the construction of prototypes. [Wigginton, 1996]

Structural glass facades depend on the quality of the glass and aesthetic appearance.

> The exterior glass is generally 10 or 12 mm thick and this glass are heat soaked toughened glass either clear or solar control. [Rice, Dutton, 1995]

Glass has a structural role but this is not being a column or a beam. We can classify the main glass products available on the market as:

- Toughened glass,

- Laminated glass,

- Wired glass.

Structural glazing systems including SGSPCT use toughened glass.

A. Toughened Glass

Glass toughening is achieved by heating glass up to 620ºC in a toughening furnace, followed by a quick cooling process at exit. The external layers reach a lower temperature than the internal layers, thus creating compression on the external face and tension on the internal during the cooling process. Areas of compression and tension within the glass are balanced when the glass is not loaded.

The capacity of the glass increases to sustain applied loads by compression /tension

situation. The glass will retain its integrity, if the loads applied to the glass do not create a force sufficient to overcome the compression created by the toughening. Toughened glass has an excellent resistance to be impacted and to take concentrated loads. But in the event that the external load should overcome the compression/tension balance, the breakage will spread throughout the glass pane and cause it to crumble. So all cutting and drilling of holes in the glass pane for the structural glazing system must be done before the toughening process.[Wigginton, 1996]

Laminated and wired glasses are less resistant to the breaking load than the toughened glass

so panes do not crumble when broken. Two types of toughening are;

1-Vertical toughening:

Tongs fixed to its top edge suspends the glass during the vertical toughening process. The glass softens and elongates, leaving tong marks along the top edge during the heating process. This can cause inaccuracy in the shape of the holes, which is unacceptable for the system, which requires very strict tolerances. [Rice, Dutton, 1995]

2-Horizontal toughening:

This process eliminates the above problems as the glass is heated in the furnace while moving on ceramic rolls. The process is limited by the width of the furnace, which is normally about 2 meters.The temperature variation must be less than 1% inside the glass. Tests are performed on samples, and the whole process is checked electronically by means of microprocessors during the production. The glass distortion should not exceed 0.1% after toughening. [Rice, Dutton,'1995]

2.4.2 Connections Between Glass and Cable Truss

The figure below shows the countersunk hole in the glass.

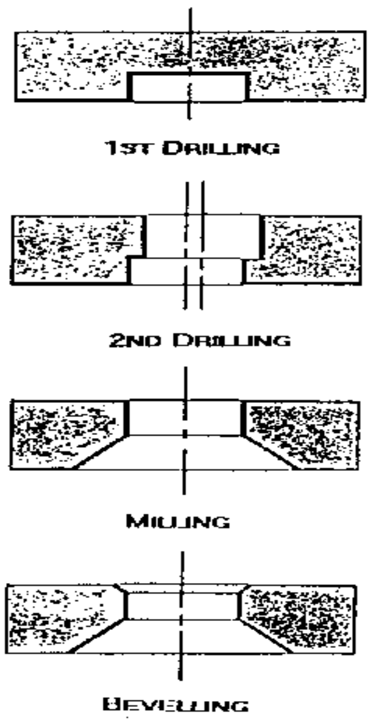


Figure 2.9 The countersunk hole in the glass [The window glass company limited, 2002].

For the best performance in structural glazing a perfect hole is essential. The hole must be drilled on both sides, to avoid dents on the opposite side of the drilling. It creates stress concentrations, which reduce the overall load capacity, if the centers of the drilling are not aligned, the holes may be offset under loading. The first and second drilling on glass are set up in order to meet in the milling area. So the third operation of milling will eliminate any misalignment. [Rice, Dutton, 1995].

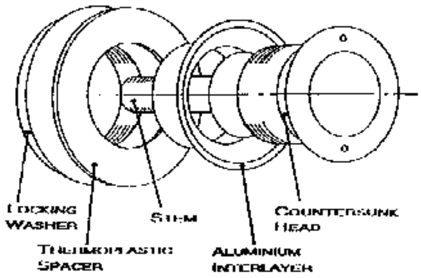


Figure 2.10 The articulated bolt [Houlsby, Porter, 1999].

The fixing of the articulated bolt (figure 2.41) to the toughened glass pane is a responsive operation and requires a predetermined torque. It cannot be superimposed on a scaffold or in bad weather conditions. It must be executed indoors on a horizontal bench, or preferably in the factory before shipment to site. The production of glass panes requires high performance numerically controlled equipment that permits drilling precision tolerances of the order of 1/10mm and a modern high quality horizontal toughening plant. [Rice, Dutton, 1995].

2.4.3 The Tube Structure in SGSPCT

The structure of the cable truss determines the geometry of the whole system. The secondary structure of the stainless steel frame creates the geometry by determining the modulation of the SGSPCT. But these tubes and the geometry of them might lose their importance when different types of SGSPCT are considered.

The tube structure of Serre is combined to the main building structure by two large concrete cylinders, which are claimed in stainless steel. These can be accepted as parts of the main building structure. They are generally 24 m in height. They provide the horizontal support, which is needed every 8m, at each panel intersection as shown in Fig. 2. 11

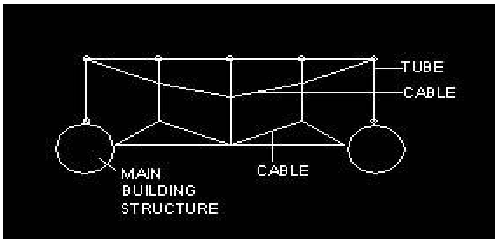


Figure 2.11 Principle of the structure.

The tubes behave as simple beams between the two nodes. Fabricated tubes are joined with a cast node where the tubes cross. They are strong enough and aesthetically considered.

The horizontal tubes carry the weight of the glass and their own weight, and the weight of the maintenance equipment. The small cable trusses are not attached to the horizontal tubes, but they are attached to the vertical tubes, and these verticals tubes act as beams on a vertical surface, which transfer the loads from the cables to the nodes. Also there might be some cable trusses in some other buildings, which act as columns, and transfer the vertical loads to the base.

The horizontal tubes behave as compression members, which form a horizontal wind-bracing system with the pre-stressed tie rods. All this system carries the wind loads towards the main building structure. Thus, the tubes at the upper part of the structure also form a part of the horizontal wind-bracing beam.

For a large wall opening, the suspended glass assembly is the ideal solution. Acting

> as one unit hanging from the head of the structure, the glass wall not only provides a transparent, weatherproof membrane, but it also forms a structural wall. This wall gives a possibility to be interrupted by tempered glass doors or revolving doors to provide access where required. All joints, usually 3/16" are sealed with structural silicone, adding rigidity to the structure' [Rice, Dutton, 1995]

The cable truss, as the only horizontal support system (vertical in some other cases, or both) for the glass, consists of two single strand cables, in which the connections of them to the tubular structure are shown in Fig. 2.11. The glass attachments have a certain amount of freedom, which creates a possibility for the glass and the truss to move independently while maintaining the lateral support of the facade against the wind.

2.4.4 V Brackets Between Cable Truss and the Tube Structure

Cable truss is formed by two cables, which are parabolic in shape, and tensioned one against the other. Struts are used to depart the cables from each other. V- brackets support the ends of the cables by being attached to the columns of the tube as showing in Figure 2.7.

These cable trusses are positioned horizontally inside the tube structure as shown Fig. 2.12. Struts and cable truss hold the glass in a given position. Struts are fitted with fixing located behind the plane of the glass and at their connection with the cable truss.

The cable truss can change its horizontal shape and position under load, because each

> cable truss is pre-stressed to 2 tones per cable, but under maximum load, one of the two cables can 'lose' its pretension and the load being taken by the other cable alone. [Rice, Dutton, 1995]

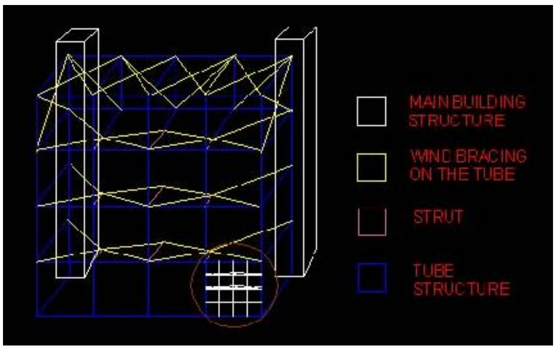


Figure 2.12 Suspended pre-stressed cable structure members.

2.4.5 Method of construction of SGSPCT

The elements that can be in the suspended glass system with pre-stressed cable truss (SGSPCT) can be classified as following.

-Parts of the main building structure which are in interaction with SGSPCT,

- Tube structure,

- The cable truss system,

-Glass and its support points.

Putting the structure together: [Rice, Dutton, 1995].

1-Pre-assembled tubular elements founded on site.

2-The first three levels are welded and braced with scaffolding.

3-Last level is pre-assembled at the ground level.

4-Last level lifted into as a single entity.

5-Cable trusses for wind bracing are installed and then the other cable trusses.

6-Glazed assembly put in place.

Installation of the truss cables on site: [Rice, Dutton, 1995].

1-The small struts are positioned at the ground level,

2-Assembly of the cables, which make up truss system,

3-Hosting,

4-Fixing to the tube (framework).

5-Pre-stressing the cables.

6-Repeating the operation:

7-Addition of the glass surface.

According to this hierarchy, each element bears the load of those subordinate to it. All the elements of the hierarchy serve the plane of glass and its supporting elements. The tube structure is the frame that is placed just inside the plane of glass. This structure is to support against wind by a thinner supporting truss. This supporting truss includes tension member rods between 30 and 55 mm in diameter because of the pre-stressing. [Rice, Dutton, 1995]. The bigger cable trusses decrease the need for wind bracing for the glass surface. So the observers see only the plane of glass. System is detailed to give this effect of the suspended glass system. The plane of glass is held by an array of identical support points that also help in realizing the same effect. Even the glass surface has a structural role in SGSPCT.

2.5 Gridshells

Shape and strength of a double-curvature shell is a gridshell structure, but made of a grid instead of a solid surface. The grid can be made of any kind of material steel, aluminum, or even cardboard tubes.

The grid is actually a double layer, with two laths in each direction. This is necessary in order to combine the required degree of flexibility with sufficient cross section for strength.

Figure 2.13 Details of a joint from the gridshell [http://www.wealddown.co.uk].

Steel grid shell structure at Queen Elizabeth II Great Court in British Museum.

Figure 2.14 Views of the Great Court. [ωωω.en.academic.ru]

The glass and steel roof is made up unique steel members connected at unique nodes and glass windowpanes making of glazing; each of a unique shape because of the undulating nature of the roof.

Chapter 3

MAJOR CHARACTERISTICS OF CONTEMPORARY COMPLEX STRUCTURES

The major characteristics of new complex structures are listed below.

1- Level of Complexity,

2- Structural Hierarchy,

3-Geometry,

4-Integration,

5-Existence of New Details.

First, this chapter will introduce the concept of 'level of complexity', and after the other characteristics will be studied.

3.1 Level of Complexity of New Light Weight Structures

In this thesis, the new groups of systems that consist of other multi-support systems are called complex structures. Also this chapter introduces the hierarchic order, geometric structure, and the integration of systems within the main structure, as well as many other newly established details that have not been studied before, because the issue of complexity can be explained in relation to these concepts.

Looking at the twenty analyzed examples within this thesis, there are 6 different degrees of complex structures. They are listed below in an order.

1^{ST} DEGREE: Simple cable truss.

2^{nd} Degree: ‘Serre’ verticals on the same plane with the cable truss.

3^{rd} Degree: instead of struts there are cables which are connected to the main building structure.

4^{th} Degree: certain degree of integration between the main building structure and the suspended system.

5^{th} Degree: Use of Complex geometries

6^{th} degree: two different types of integration coexist.

In this thesis the concept of complexity is analyzed and classified via suspended glass systems with pre-stressed cable trusses. In addition, twenty different buildings are analyzed (see appendix A) and complexities of different degrees are ordered as above. These are named as 1st degree, 2nd degree, 3rd degree, 4th degree, 5th degree and 6th degree complexities.

If simple cable truss is applied on the buildings which are analyzed, then the degree of complexity is 1st degree. If verticals which are on the same plane with the horizontal cable trusses, as it is in ‘Serre’ , then the complexity is of 2nd degree. If the use of horizontal and vertical cable trusses is applied together on the buildings, then the degree of complexity is 3rd degree. This type contains struts. These cables are connected to the main building structure. If a secondary building structure is supported by the main building structure, and if partial integration (semi integration) is the case, then the complexity is classified as 4th degree. If the geometric structure of the building is more complex then simple geometries, then it is classified as 5th degree. If there are two different types of integrations applied to the analyzed building then it is classified as 6th degree.

3.2 Structural Hierarchy

Structural hierarchy can be seen in all natural forms and elements of nature. Biological structures grow, and the material that keeps them together supports this growth. The structural hierarchies in nature inspire large-scale structures and man-made forms. Form and function together always expresses a visual harmony.

3.2.1 Contemporary structural forms and hierarchy

In the middle of 20th Century, with the influence of Nervi, Candela and Buckminster Fuller, a new dimension has opened for long span structural forms. The aim was spanning long distances with the use of minimum of structure; however, they were not economical to construct. With computer-aided design and manufacture, contemporary forms can now be constructed and they share their origins with nature, using appropriate materials that are intrinsic to a structure's evolutionary development.

The forms function as shells in structures. They can easily bend and they can be compressed. They also have the properties of steel. In addition, these structures are produced using digital technology during fabrication procedures, in order to allow connectivity and the construction of shapes that have little or no symmetry or repetition. For this purpose some traditional erection procedures were used. For instance, the Gateshead Music Center which has a repetitive and hierarchical form and the British Museum which has a roof with a homogenous shell are the two distinctive structures to compare.

With the industrial revolution, some important structural engineers have started to use intermeshed, lightweight, flexible structures. These structures use more open, more efficient, lightweight systems. The role of tension forces has been increased gradually as opposed to the traditional structures. Most of the time, these structures hide their slender interior structures. In this thesis, the concept of hierarchy especially describes and focuses on the order of the load distribution on the elements that maintain secondary structure systems. This order is directly related to the actual process of construction.

3.2.2 A Prefabricated Building Systems

There are some typical systems which are used in housing construction. A conventional on-site system consists of many different aspects such as casting the concrete slab on form, building walls by brick on brick system, using mechanical equipment's which are partly pre-produced, using kitchen equipment which are pre-produced or pre-painted such as boards, and working benches, along with all the other carpenter works, rooms are painted at the site; industrialised concrete (allbetong) system, figure 3.1, or wooden balloon system, figure 3.2.

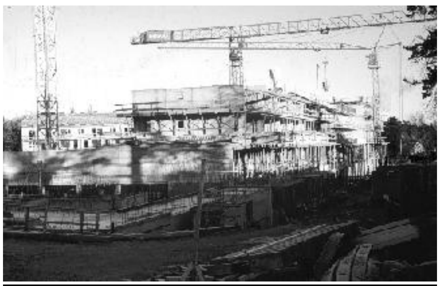


Figure 3.1 Allbetong system [Schömer G.E., 1977]

Figure 3.2 Wooden balloon system [Schömer G.E., 1977]

Small size space enclosing element system, 600 mm width of the elements in

concrete, pre-produced carpentry. One or two story high wooden housing during the 1960s 70s, not any longer in production. Area of the elements up to 5,0 sqm (small element). Area of the element" means elements to create architectural space. [Schömer G.E., 1977]

Figure 3.3 Lightweight concrete system [Schömer G.E., 1977]

Prefabricated elements in size like a part of the room or the whole wall of the room.

The level of prefabrication is similar to small element system. Wooden construction Anebyhus, figure 3.4, area:5,0- 12,0 sqm. House of concrete produced by Camus system, figure 3.4, area:12,0-25,0 sqm, a variation of that; Ohlsson & Skarne system, which has been developed to Skanska Prefab. The area of the elements between 12,0-25,0 sqm (middle sized elements). L-element system. The topic elements size is a. 20,0 sqm. [Schömer G.E., 1977]

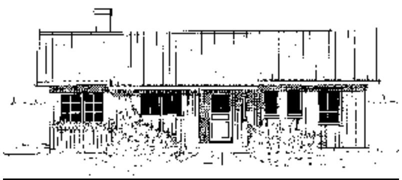


Figure 3.4 Camus system [Schömer G.E., 1977]

Figure 3.5 Ohlsson & Skarne system [Schömer G.E., 1977]

U- formed elements combined with room sized plates on each other, f. e. Techcrete;

> high level of prefabrication, like system s. The area of the elements can be 60,0 sqm (does not exist in wooden construction). U- Box unit type building system, elements by prefabricated room sized or part of the room sized element which are placed on each other or side by side. Modulenthus in wooden construction. ELCON-system in concrete, Figure 3.6. Heavy concrete system in the previous Soviet Union, Figure 3. 7. Finish like s. e. The area of the elements up to 140,0 sqm. [Schömer G.E., 1977]

Figure 3.6 ELCON-system in concrete [Schömer G.E., 1977]

V- Box units placed one upon the other vertically in a chessboard pattern; Shelley system, Figure 3.7.

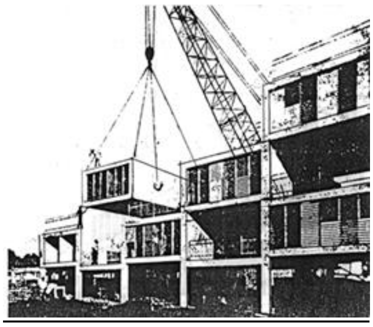


Figure 3.7 Shelley system [Schömer G.E., 1977]

Shelley system requires that the box units are placed upon each others' slab therefore

every second slab must be complete. For the coompletion of slabs more concrete is needed, or wooden construction is used for building up the floors for the same floor level. According to the Schömer system the box units are integrated and placed in each other.
Complex buildings and other type of large constructions are done using these various combinations of the system. However, an order of these systems is required during the process.

To compare the characteristic building systems we have to introduce sudden simplifications:
We compare the classified systems made of similar materials (concrete to concrete, wooden to wooden). [Göran E. S.,1977]

Prefabricated buildings are constructed by following up a certain hierarchic order. First, the foundation is completed and a generally concrete surface is constructed for the main skeleton to be placed on. Later on, the main support system is established in the same line and then the other support systems are established. The main support system helps create and carry the walls as separators, fresh and waste water pipe system, electrical network system and doorways and windows. Final touch is made by finishing materials.

3.2.3 Structural Order

Structural order has its own laws that have to be obeyed. Its fundamental building blocks are the smallest perceivable differentiations of color and geometry. Whereas visible differentiation on the small scale is not necessary to define structure, it is necessary for structural order.

Structural order is minimized when constructing modernist buildings. Those have a monumental bilateral symmetry. Both structure and function are deliberately change into some other invisible forms. Small-scale order is never used. The space isn't differentiated; there is no contrast between outside and inside, or of busy with calm areas, or of areas having distinct function. Repetition is shown as monotonous using no contrast at all. No borders are shown, and there are no connecting boundaries. Surfaces are sheer and come to straight edges and sharp corners. Finally, any natural or existing order is usually razed before building, thus preventing any connection to the surroundings.

3.2.4 Structural Transitions, Evolution and Structure

In the history of architecture, there are important structural changes or new functional processes. John Maynard Smith and Eörs Szathmáry (1995) and others (Turchin, 1977, Heylighen F., Joslyn C. & Turchin V., 1995, Heylighen, 1996) have envisaged a number of major transitions that have taken place in the course of evolution.The interactions between particles and parts in our universe are responsible for two opposite phenomena (figure 3.8): construction and destruction.

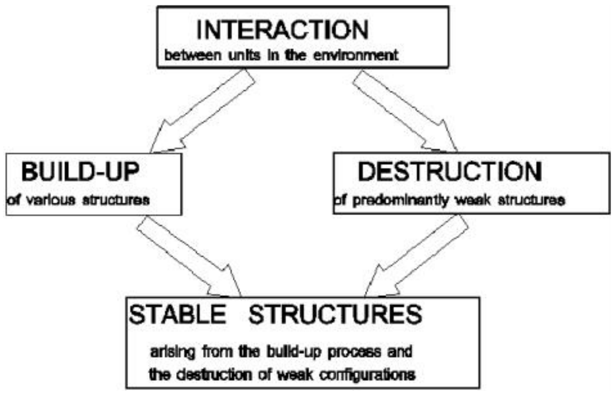


Figure 3.8 Aspects of the interaction forces and processes between particles or parts in our universe. [www.nanoscience.gatech.edu]

Construction: Interaction forces help to build-up of structures by moving the building parts in the right positions. Interactions amongst the parts of the new construction produce an interaction pattern that gives "structural stability".

Destruction:Interactions between structures and their environment are

> responsible for the selection of structures with structural stability by destroying less stable configurations and leaving the more stable ones, at least for some time.[www.nanoscience.gatech.edu]

The biological evolution by natural selection have two different aspects; first the interactions between structures, parts, or units, that lead to the build-up of structures, and secondly the destruction of configurations, with a probability of destruction that is higher with weaker structures, leading to selection for fitness. In biological evolution there is reproduction and also there are variations in reproduction.

Basic changes in structure may be very radical with respect to the original structure if this structure was elementary to start with. This is illustrated by figure 3.9(a). Changes can happen, and can be viewed, at different structural levels. Fig 3.9(a) and (b) show a change - the addition of a unit - at one particular level. (c) and (d) show a change - the addition of a unit - at one level higher. (c) and (d) represent identical processes - the difference between (c) and (d) being that the graphical presentation in (d) does not show the lower level units. (b) shows a change which is elementary, and which is also rather insignificant with respect to the original structure on the left. On the other hand, (a), (c) and (d) show elementary changes in structure, additions of an identical unit, but which are very drastic changes with respect to the original structure on the left. (a) and (d) show similar processes taking place but at a different structural level.

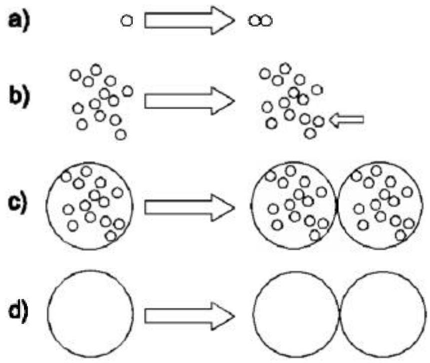


Figure 3.9 Different changes in structure by the addition of a unit. Changes at c) and d) are at a higher hierarchical level than at a) and b). d) is identical to c) but subunits are not shown. [www.nanoscience.gatech.edu]

As will be argued below, the change in figure 3.9.c (and in figure 3.9.a as well) may be considered to be a structural transition since it introduces a new structural level in a nested hierarchy such as that shown in figure 3.9.

To explore the degree of complexity we can assume a simple world where a construction may be build-up by assembling elements "a". Also assume that these building blocks are only able to position themselves in discrete positions with respect to each other, not unlike the "Lego" constructions built by children. Such a world is represented in the figures 3.10 and 3.11.

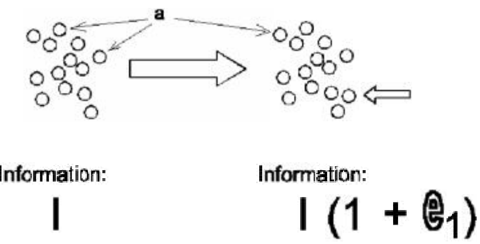


Figure 3.10 Addition of another element "a" to a construction built with identical elements "a".[www.nanoscience.gatech.edu]

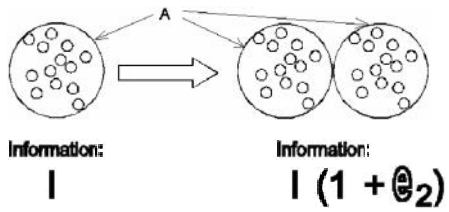


Figure 3.11Construction of a new super-structure by the assembly of two identical structures "A".[www.nanoscience.gatech.edu]

The information I, representing the construction on the left in figure 3.10, as well as on the left of figure 3.11 consists of the description of the element "a", together with the description of how these identical elements "a" interact with each other. In our examples in figures 3.10 and 3.11, these interactions are the respective positions of the elements in the drawing. The information to represent the right side of figure 3.10 only requires the addition of this extra element (its presence and position, not the detailed description of element "a" since it is already given). This extra information is small with respect to the information I, and is therefore denoted by e1.I, where e1 is a number much smaller than 1. The information to represent the right side of figure 3.11 only requires the addition of the presence and position of one extra identical structure "A" with respect to the one shown on the left in figure 3.11 (not the detailed description of unit "A" since it is already given). Again, this information is small with respect to the information I and is denoted by e2.I. The values of e1 and e2 are small ($e1 \ll 1$, $e2 \ll 1$) and both could be of the same magnitude. In a world where the building blocks "a", and "A" could only take discrete positions or ways of interactions with respect to each other, such as seems to be the case with the construction of atoms or molecules, e1.I and e2.We could have elementary values, meaning that these values could be coded by a short sequence of zeros and ones. Such elementary values are required for evolution and cumulative selection to work properly.

It must be stressed that the structure at figure 3.10 is identical to the one at the left in figure 3.11. The line enclosing the structure in figure 3.11 is just a way of representing the structure (or sub-structure) as a whole, and does not denote any additional matter or interaction forces. In fact it could have been drawn also enclosing the structures in figure 3.10 or figure 9 b. One sees in the figures 3.10 and 3.11 that, although the change in complexity with both operations may be the same (and elementary in magnitude), the structural results are very striking with figure 3.11, while hardly noticeable with figure 3.12. The change in figure 3.11 introduces a new structural level and may be denoted as a "Structural Transition".

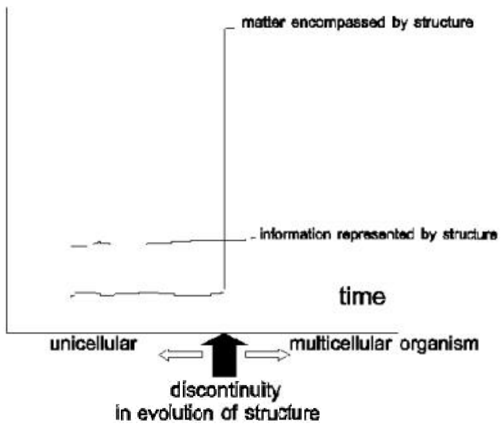


Figure 3.12 Changes in information content and matter, content accompanying a structural transition. (The slight increase in information at point T is not noticeable at the scale of the figure) [www.nanoscience.gatech.edu]

Elementary variations in information and interaction properties of the structure normally go together with gradual changes in the structural configuration (as in figure 3.10). Sometimes a structure may change in an elementary way, yet the accompanying change in structural configuration may be very profound (as in figure 3.11). Such a change, as in figure 3.11, that coincides with elementary changes in information and interaction, could be described as a "transition" or "discontinuity" in the otherwise gradual evolution of the structural properties of a structure or organism. That evolving structures or organisms can show a transition or discontinuity in structure, without violating the requirement for elementary variation has been illustrated by the simple examples above and may be further illuminated by a number of examples taken from our natural world. Figure 3.12 shows such a transition and highlights the difference between the drastic structural change and the gradual change in total complexity or information content.

3.2.5 Hierarchy in General

The processes described in the previous paragraphs, where constructions may join to form a new super-structure at a higher structural level (as in figure 3.11), may be repeated (by repeatedly running through the kinds of changes illustrated by figures 3.9.a, 3.9.b, and 3.9.c) where these super-structures act as elements in newer and bigger structures. This hierarchy in layers or levels is depicted in figure 3.13. Arthur Koestler (1967, p60, fig. 4) produced a comparable drawing, and Herbert Simon (1982) has described various attributes and advantages of such hierarchies.

Simon, a nobel laureate in economics but who contributed to artificial intelligence

> and sociobiology, illustrated the functional advantages of hierarchy by the parable of the two watchmakers Tempus and Hora, one of them using a hierarchy of sub-systems, and showing why complex biological or artificial structures tend to be organized into nested hierarchies of repeated subunits.

> Koestler (1967, pp. 45-47) elaborated on this parable showing how much more robust a mechanism with subassemblies is. Although a watch with sub-assemblies requires a bit more material, it is much easier to construct, and disturbances have a much more localized effect, and can be much more easily cured. [Koestler (1967, pp. 45-47)]

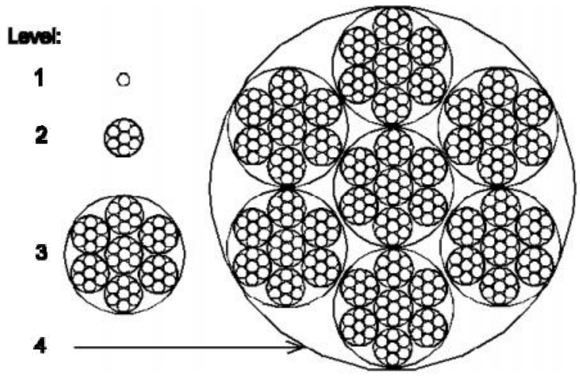


Figure 3.13. Structural hierarchy, where constructions join to form super-structures.

[www.nanoscience.gatech.edu]

The iteration of this joining-process leads to a structural hierarchy with several levels such as the levels 1, 2 and 3 in this figure which are based on an initial structure O. Nine different formations of hierarchy are recognized from twenty cases which were studied within this thesis. These are listed below.

1.Group: Arches and compression rings+cable truss and glass.

2.Group: Main Building Structure+Tension Rings Cables+vertical glasses+glass surface with spiders.

3.Group: columns-branches of columns+steel grid shell+glass.

1.Group: steel grid shell+cable trusses+glass.

2.Group: Main Building+cables+cable truss+glass .

3.Group: Masonry+steel grid shell+glass.

1.Group: Main Building structure+vertical steel supports of cable trusses+vertical cable trusses which correspond to vertical steel supports+pre stressing+horizontal cable trusses+Pre stressing+glass.

2.Group: Verticals+cable trusses+glasses.

3.Group: Main Building Structure+verticals+Glass.

3.2.6 Recent Examples with Derived Hierarchies

There are two recent examples presented and demonstrated in this part. A building designed by Foster and Partners Architects, London, UK, with the partnership of Buro Happold Engineers, London, These are great examples for the integration of form, function and man’s creativity. They simply imitate nature by integrating natural principles and then use materials in new ways accordingly.

The forms are constructed by using compression and bending at a maximum level. They mainly function as shell structures. The forms rely on the superior properties of steel that concrete does not have. Connectivity and the construction of shapes that have little or no symmetry or repetition found place with the support of digital technology used during fabrication procedures, using traditional erection procedures. Below is a comparison of the Gateshead Music Center, with defined primary, secondary and tertiary hierarchy (repetitive and hierarchical) and the British Museum Great Court roof with a homogenous shell behavioral hierarchy (free form surface using mathematical principles of surface tension found in nature).

A. The Gateshead Music Centre Roof

The roof structure of the Gateshead Music Center has a complex amorphous shape. It was "sculpted" with parametric modeling. A series of arches meet tangentially and they create a torus geometry. The surface profile is modified by the designers with the help of the parametric model which can re-calculate the geometry easily.

Figure 3.14 The Gateshead Music Centre Roof [www.farm3.static.flickr.com]

A series of simple pre-formed steel elements were used in the structure and they can be assembled by conventional techniques. Therefore, it is more practical and economic. The structural hierarchy is clear. The overall surface forces are carried by a shell and flexural hybrid. The boundary support forces collected through a primary and secondary support system. There is a harmony when the detailing of the connections are analyzed between the two modes of structural behavior. This is necessary to create an aesthetic resolution of the roof concept. After many model studies connections were done by the alternative means of hierarchy.

It seems that by only using simple geometries and by integrating form and function, a complex and visible structure was designed very economically. Large scale repetitive elements were used in place very easily.

B. The British Museum Great Court Roof

At the British Museum Great Court, the roof does not have a simple geometry. None of the connection geometries or the length of any member are repeated. The only symmetry exists at the centre of the courtyard. A soap bubble inspired the form and the necessary mathematical principles to apply this basic form are used. Members act primarily in compression in order to give the form of this basic shape. Interconnecting geometric patterns create the form of a soap bubble.

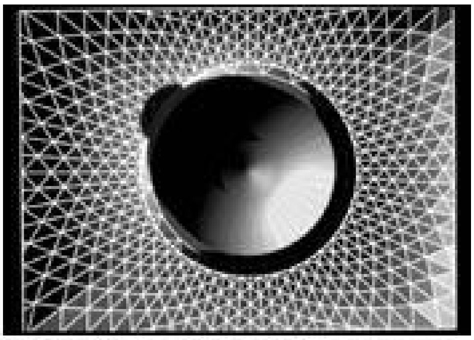


Figure 3.15 The British Museum Great Court Roof [www.steelconstruct.com]

There is a structural hierarchy that is followed in the above examples. Geometry can apply greater forces at the outer perimeter by using the structural hierarchy**.** In addition, through the span of the roof the members are changed too. In terms of design, the shape of the roof is inspired from natural forms. They also consider the same kind of force distribution of these natural forms along with their resistance. There is always a great harmony between the structural form and its function. They simply follow the nature and apply its rules in structural hierarchy. The projects prove the elegance and simplicity of forms found in nature and also show how economic it can be to apply them on the larger scale of construction at the same time. However, technological tools should not lead the process but they must be used as a great support.

In this thesis, while discussing hierarchy, the main principle in Serre has been taken into consideration. In fact, Serre is a similar system to the schemes that have already been displayed before in this chapter. According to this, the main building is treated as the major structure and SGSPCT is combined into this system. However, the most important issue is the hierarchic structure in SGSPCT. Different types of SGSPCT require different hierarchic order within themselves. (Atakara, 2000) In general, in this order, first the load is transferred into glass, cable and truss systems, then onto the main tubes and the main structure, and finally to the ground.

3.3 Geometry

Recent complexity of geometry can be studied under the headings of.

1-Geometry of the void,

2-A Tensegrity,

3-Deployable Structures,

4-Dematerialization,

5-In Between,

6-Nanotechnology and Architecture,

7-The Relation Between Design and Engineering.

8-Integration.

3.3.1 Geometry of the Void

There is a close relationship between geometry and architecture. In order to understand this relationship, geometry and geometric concepts must be defined to see the difference between the two. Geometry is part of mathematics that studies geometrical shapes. For instance, even the children use geometry to put up building blocks when playing with toys. On the other hand, geometric concepts are the ideas in geometry. For example, according to geometric concept, a dot is an infinitely small point. So what does geometry have to do with architecture?

Architecture embodies two main issues: design of a building is considered as art and construction is considered as science. But both parts have a sense from each other too. The aesthetic look of the building is as much important as how strongly it is build. In the aesthetic side, geometric shapes present a visually satisfying look. To make a building strong, architecture must use certain shapes over others in their design. For example, cones are stronger than cylinders against lateral loading. So, most architects build towers in the shape of a cone. Professional architects prefer to use the concept of symmetry in a very advanced manner instead of using simple shapes. In the field of architecture, the idea of symmetry is used in its geometric meaning. When divided into two equal parts, both sides of a building are exactly the same.

Most buildings adopt the concept of symmetry for two reasons: Firstly, it is visually pleasing because most things in nature are symmetrical. Secondly, they are easier to build, because one half of the design could be duplicated to create the other. They are stronger against earthquakes.

Complex geometries and forms have always been a part of the living world. As we moved ahead generation by generation, technology and its use in our lives grew stronger, from birth to death and even in design methods and techniques. The information age has taken over and brought along various challenges. From conceptualizing to modeling, and then developing and constructing them has its own levels of difficulty. But the breed of architecture of digitally driven processes and fabrication gives birth to highly dynamic transformations, geometries and structures.

New possibilities in computing technology are gradually advancing the architectural

> planning process. Computer programs are the tools to investigate the design through animations and the moving section, and to represent the project both in 2D and 3D. They help with architectural performance in the office on on the site. Boldly curving, graceful and futuristic buildings, such as Frank O. Gehry's Guggenheim Museum in Bilbao, Spain, or Bernhard Franken's BMW Bubble for the IAA 1999 were regarded until recently as unrealizable. The planning and the production process of these structures use a new approach which is completely different from the old-on-stone production method. [www.my.opera.com]

Experimental architecture is a future characteristic in architecture. Digital media allow for editing options and mutations in the evolution process itself. In this respect, where modernism is based on nature, digital technologies modify parameter to design more complex and accurate complex structures. Recent computer programs show the true complexity of a project's situation aesthetically and help create individual solutions for complex structures.

For example, complexity in geometry can be discovered in nature, human body as well as in architecture. Though it is assumed that complex architectural structures are a result of last century's technological evolution, complex manifolds have also been used formerly. Gaudi, was also forming complex geometry structures in Sagrada Familia in 1882.

Figure 3.16 The New Museum of Nuragic and Contemporary Art

[www.my.opera.com]

Nuragic and Contemporary Art Museum" is a building that displays a complex geometrical form. This was chosen as an example of this complex of buildings. Zaha Hadid's architecture is a museum designed as a coral. It is empty inside, but its surface is rough. It provides a cheerful and suitable environment for many cultural facilities.

Different parts of the building meet in a turbulence of visual continuity that vertical and indirect elements of circulation create.

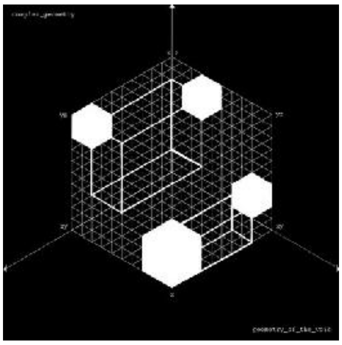


Figure 3.17 Geometry of the void [http://bp2.blogger.com/]

Everyone has a perspective and sees things from a different angle and physical structures can be formed using complex geometry as a good design tool.

Both mass and void can be described by using the same geometric system. We measure them, divide them and explore them. We do similar things with places that are arranged by matter.

Void helps to find out about new spaces with different type of geometry. For instance, void offers new spaces generated only by the sun and shadow, noise and silence, by different smells. Void can work in parallel with pure geometry in order to design buildings without physical boundaries.

Figure 3.18 Mobius House [www.shwetadeshmukh.in]

In 1993, Ben van Berkel designed "a house that would be acknowledged as a reference for the renovation of the architectural language" according to the client's desire. For six years, the architect put all his mind and effort to satisfy the wishes of his client. As a result, he created a house based on the studies of a German mathematician lived in the 19th Century.

With 'mobius house' (torus house) the use of complex terminology started.

> Theresearch discovered the logic between architecture and geometry. For some time after Venturi's Complexity & Contradiction in architecture, architects tried to establish an analogy between complexity in program and its manifestation into architectural form. Digital technologies (cad-cam) supported the process. Lots of conceptual models developed (blobs etc.) New terminologies evolved eventually like kinetics, supple, pliant etc.Some architects used this to produce functional concepts. A new aesthetic of digitally manufactured spaces can be seen today.[www.shwetadeshmukh.in]

Maybe we are in the middle of a process, but something is happening in the new proposals of architecture. There is a fight between architectural process and architectural aesthetic (form).The complexity of the shape is not new and the programs of the buildings are changing with the new needs of the people. Digital evolution introduces a new design method, which affects the whole architectural process, from concept to construction. Now, space can be highly plastic, flexible, and mutable in its dynamic evolution through motion and transformation. Form can be defined by its internal parameters and it can also be affected by a variety of other external, invisible forces and gradients (f.e. gravity, wind, turbulence, magnetism, moving particles) that are used as abstract analogies (pedestrian and automotive movement, environmental forces, intensities of use and occupation in time).

Figure 3.19 Gaudi: Nature Complexity .[http://iaac-digitalarchitecture.blogspot.com/2007/10/gaudi-nature-complexity.html]

Antoni Gaudi, an architect who might have been ahead of his time, looked at nature to find inspiration. He was able to create complex geometry without the technology that is available today. And he did it just by observing. We can see nature in his structures, colors and rhythms. The comparisons with animals and vegetables, the constant movement of its shapes, are present in his mature works. He looked how nature defies gravity, study its nature; the shapes of the cave or a mountain, how animals build their shelter and how they structured society. His perceptions about details made him produce unique pieces in the history of architecture.

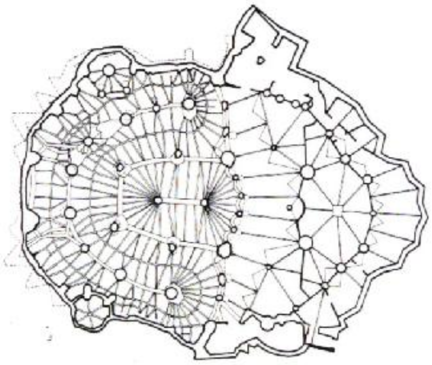


Figure 3.20 Colonia Guell Church

[http://www.gaudiclub.com/ingles/I_VIDA/fotobras/colonia/planta2.jpg, 2009].

In addition, Gaudi designed a method to analyze structures by a hanging model

(figure 3.11).He designed the Colonia Guell Church with this innovative technique. He integrated the parabolic arch and hyperboloid structures, nature's organic shapes, and the fluidity of water into his architecture. Gaudi designed many of his structures upside down by hanging various weights on interconnected strings or chains, using gravity to calculate catenaries for a natural curved arch or vault. Gaudi spent ten years working on studies for the design, and developing this new method of structural calculation. The outline of the church was traced on a wooden board (1:10 scale), which was then placed on the ceiling of a small house next to the worksite. [http://www.gaudiclub.com/ingles/I_VIDA/fotobras/colonia/planta2.jpg, 2009].

3.3.2 The Basics of Geometrical Construction Techniques

Basics of geometry helps to construct successfully the shapes, proportions and lines of Gothic architecture, also it is important to understand the bisection in the construction of angles.

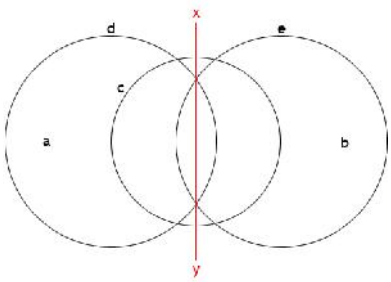


Figure 3.21 Perpendicular Bisection of A Straight Line

[www.stonecarvingcourses.com]

The perpendicular bisection of a straight line results in the creation of a 90° angle.

From thedrawing, a-b represents the line to bisected. A circle, c, is constructed with it's centre on the line a-b - the radius of the circle isn't important as it is the part of construction. The centre of circle c represents the point of bisection. At the two points where circle c cuts through line a-b, construct two further circles, d and e equal in diameter but larger than the diameter of c. At the point of intersection of d and e construct the perpendicular x-y as shown. The line x-y is now at 90° to a-b and bisects it at the centre of circle c. [www.stonecarvingcourses.com]

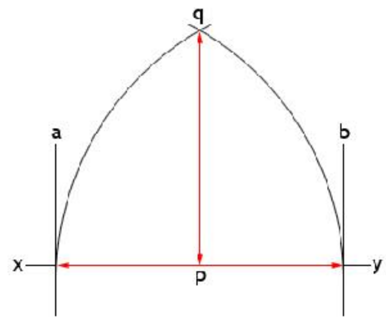


Figure 3.22 The Equilateral Arch [www.stonecarvingcourses.com]

Gothic architecture is special with the pointed arch. The basic Gothic arch is

equilateral in construction and forms the basis of many different elements. The compass is set to the span, a-b. With x-y as the springing line, the compass is positioned at the junction of a-x/y and a curve from x/y-q is drawn as shown. The procedure is repeated with the compass placed at the junction of b-x/y, with the point at which the curves join forming the rise p-q. Drawing straight lines from a-x/y to q and b-x/y to q it can be shown that the resulting triangle is equilateral in construction with all angles being 60°. [www.stonecarvingcourses.com]

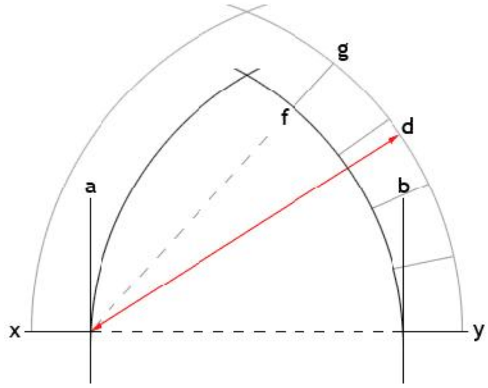


Figure 3.23 Setting out the Extrados & Joints

[www.stonecarvingcourses.com]

With the basic arch constructed and forming the intrados, the drawing can be further

developed to set out the extrados and joints of the arch stones.With the compass again positioned at the junction of a-x/y, extrados d is formed at the desired distance from the intrados set out in the previous drawing.Keeping the compasses at this length, the opposite side of the extrados is drawn from the point b-x/y. By scribing a straight line from the points a-x/y to the extrados d, the voussoir joints can be set out as shown at f-g. Using the point b-x/y, the voussoir joints on the opposite side of the arch can be set out in the same manner. [www.stonecarvingcourses.com]

3.3.3 Advances in Architectural Geometry

Geometry is the core of the architectural design process. It is important at all stages from the first step, searching to find the suitable form to the last which is actual construction. Modern constructive geometry provides many tools for the efficient design, analysis, and manufacture of complex shapes. Therefore, architecture is in constant search of new technics and technology to pass these challenges. However, new problems in geometry arise during the application. Architectural geometry differs from applied geometry and architecture in terms of the research. Modern architecture challenges can be met more effectively if we understand geometry.

3.3.3 A Tensegrity

Tension structures provide connection between earth and membrane, but it is not easy to maintain that strength. Therefore, tensegrity systems are needed to establish the necessary strength of the concrete. Such systems are self-anchored and self-stressed in a "closed" system.

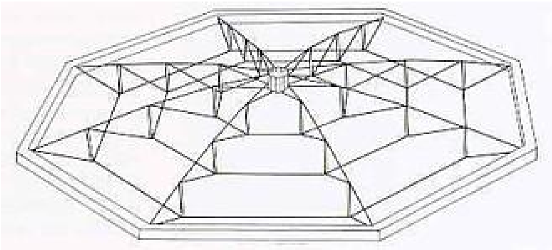


Figure 3.24 Cable Dome System by David Geiger. [Drawing: Geiger Engineers]

Figure 3.25 The Palau Saint Jordi in Barcelona, Spain. Architect: Arata Isozaki; Engineer: (Mamoru Kawaguchi)

3.3.3 B Deployable Structures

Designers have to avoid dangerous and temporary scaffolding as it has always been a problem. The excessive use of final material during construction is another problem.

Figure 3.26. World Memorial Hall in Kobe, Japan. Mitsumne, architect; Mamoru Kawaguchi, engineer. [Photo: Mamoru Kawaguchi]

Prefabrication and deployment are two important issues that need to be understood. Deployment concerns more or less complete pre-assembly of an entire structure.

Figure 3.27 The BP gas station on the Bern-Zurich Highway. Heinz Isler, engineer [Mamoru Kawaguchi]

3.3.3 C Dematerialization

Nowadays with the newly generated designs which join the internal and external spaces, with the minimization of the materials used, and the maximization of the use of glass as the main material gave way to maximum transparency. In order to make maximum transparency possible, the material used is minimized as much as possible and this is called dematerialization. When looking at the analyzed examples of structures in this thesis, it is clearly seen that all the buildings are dematerialized as if they are competing against one another. When Serre is studied closely, it can be seen that the main purpose of this special system is actually creating maximum transparency, in other words use dematerialization. The transparent form, which is a suspended glass system with prestress cable truss (SGSPCT) comes out of the main building. This building is a prism of rectangles, therefore it developed a geometry of SGSPCT.

3.3.3 D In Between

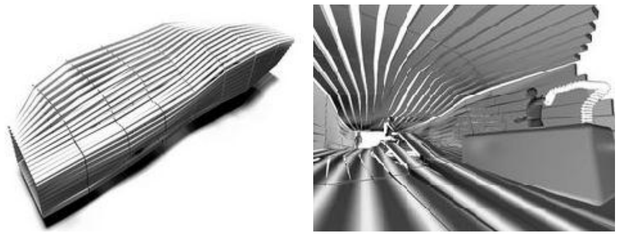


Figure 3.28 The E-Motive House [http://www.oosterhuis.nl/]

The E-Motive House figure 3.35 is a research project, experimenting on interacting spaces. Its form is a long movable space with two solid blocks on both ends. The space in between, changes its shape and content, depending on the weather and the movement of its inhabitants, therefore it changes the geometry and develops its own emotion. In its loom which is both hard and soft structure, there are wooden beams and long shaped inflatable chambers on the other. The interaction of these two structures is based on the game development program Virtools. As a result there is a complex space. At the end, the E-Motive House gives a feeling of a real time interaction. [http://www.oosterhuis.nl/]

In the age of new technologies, new materials and media there is a new digital architecture; it redefines space, function and form. Computer programs such as CAD

(Computer Aided Design) or CAM (Computer Aided Manufacture) make easier the process of producing an architectural project and set the foundations for new concepts, new forms and new architectural volumes.Mies van der Rohe, is a minimalist who eliminates interior walls and adopts an open plan structure, and reduces the structure to a strong, transparent skin. He believes that "less is more" and shows that digital architecture could actually produce the same aesthetics, using these new technologies.

3.3.3 E Nanotechnologies and Architecture

Nanotechnology industry has already begun to transform our world in ways that we cannot dream of, and on-going researches are still being done on it. Nanotechnology is the most transformative technology we have ever had and it will probably be used in every aspect of our social, economic, cultural, political, and spiritual lives. Moreover, its potential to transform our built environment is still unexplored. Nanotechnology has a distinctive ability to transform the whole world of construction into a more advanced environment as it uses matter at the scale of less than one billionth of a meter. Nowadays, some commonly used items such as cosmetics to clothing is already manufactured by using nanotechnology, and architecture is another field that uses this advanced technology, too. In the near future, it may take building enclosure materials (coatings, panels and insulation) to dramatic new levels of performance in terms of energy, light, security and intelligence. In architecture, the distinction between structure and skin, for example, could disappear as ultra light, super-strong materials functioning as both structural skeleton and enclosing skin are developed. This new science has brought to market three hundred nano-engineered products which are commercially available now. For instance, self-cleaning windows, smog eating concrete against the polluted environment and toxin-sniffing nano-sensors are all designed and manufactured by this amazingly advanced technology. In addition, scientists still carry out the researches on nano-composites which are as thin as glass. They are capable of supporting entire buildings, and photosynthetic coatings that can make any building surface a source of free energy.

3.3.3 F The Relationship between Design and Engineering

Digital Technology helps us process and store data and offers us a common platform where many issues can be related to each other and be resolved. With the use of digital technology, we have a common language and also many different views. All languages converts into 0s and 1s, into the digital language and this allows for such an interaction.

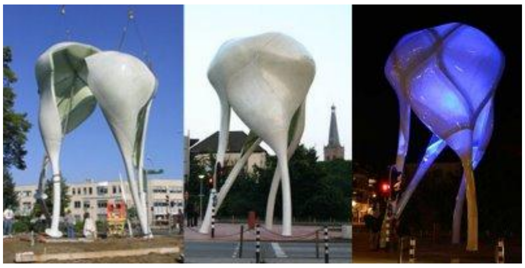


Figure 3.29 Digital Technology Forms [http://www.oosterhuis.nl/]

The Finite Element Method has been developed and the programs such as AnSys and Abaqus are software based on this (FEM). Their technologies that have been developed for the last 20 years and they are changing to meet the engineering needs of today. In this part, a research will look into FEM as well as how it is used with the Abaqus software suite.

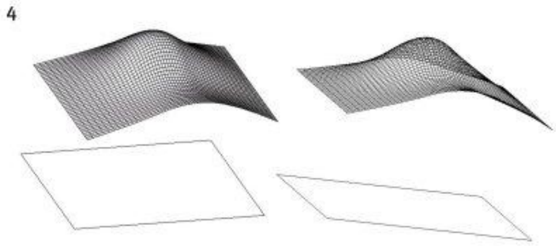


Figure 3.30 Digital Technology Forms [http://www.oosterhuis.nl/]

The suite consists of Abaqus/Standard, Abaqus/Explicit, and Abaqus/CAE. Abaqus

> Standard is applied to static, low-speed dynamic, or steady-state transport analysis; while Abaqus/Explicit may be applied to those portions of the analysis where high-speed, nonlinear, transient response dominates the solution. Using Abaqus CAE, one can create geometry, import CAD models for meshing or integrate geometry - based meshes that do not have associated CAD geometry. Abaqus/CAE also offers comprehensive visualization options which enable users to interpret and communicate the results of any Abaqus analysis.The software is used by engineers working in many different fields concerning design and production of many industrial goods and in the field of architecture and construction. The program is quite limitless in its scope. There is an advantage of using this technological device because it integrates different fields. One analysis of a field, such as industrial design, can raise questions in any number of other fields. With so many options of use the suite allows for an open dialogue between design fields, in a way becoming a tool of translation between the different domains of design and engineering. This exchange between different fields can create more efficient, safer and better overall designs in each of the involved fields.'[http://iaac-digitalarchitecture.blogspot.com]

3.4 Integration (Interconnected Systems)

There is always an order of construction which is parallel to a slow decrease in size of each element, and in the hierarchy of support. This type of integration enables the forming of a structure using less elements and leads to minimization.

Minimalism, along with economy and simplicity are important themes in modern architecture. The architectural expression is found in the simple quality of the materials used and presented with minimal detailing. These qualities are found historically in Japanese architecture.

In modern architecture, transparency is another important concept. The most famous Bauhaus transparent corner by Gropius is a classic example. Peter Rice proposed the use of the first cable trusses as wind bracing for glass to remove visually heavy bending structures from the facade plane. Specific articulated bolts were developed to adapt to the deflection movements of the cables. Other projects continued to develop the idea of cable structures using the articulated bolt system and amongst these the 50 Avenue Montaigne 24m high by 16m wide suspended glass plane in 1993 is a significant example. The technology of transparency involves exploiting the structural capacity of glass through tempering as well as inventive engineering for cable structures using non-linear analysis methods. Both designers and the industry are adapting themselves to these new techniques.

In the light of the analyzed examples in this thesis, it can easily be observed that there are two types of integration. In the first type of integration main building structure and the secondary building structure are integrated (see table 2). In some cases they even sustain each other in the support system. Visual integration can be clearly sensed, too. Second type of integration is the certain degree of integration: in this case, two separate structures can be visually identified; however support systems make use of one another (see table 6). Due to the extensive level of use of integration in complex structures, integration becomes the system itself.

In other words, when we mention ‘integration’ we refer to hybrid structures such as the Opera House in Sydney, when we mention ‘not integrated structures’ we refer to structural units added to each other.

3.5 Analysis of New Complex Structure and New Detail in Them

Details refer to;

1-Point details

2-System details

3-New member types.

Point detail analyses the smallest part of the system in the scale of 1/1. Likewise, when we analyse the system details, we refer to the whole system up to the scale of 1/20. When we refer to the new member type, it is the case which we analyse a detail that has never come across.

The analysis of new complex structures shows us the importance of the new detail.

New point details can include:

1-Opposite cable connection point, which is point detail,

2-Elongated Members, which is new member type,

Figure 3.32 shows us new point details and new organizations exist in all complex buildings except for the first degree complexity buildings such as “Serre”. So, if there is a new point detail and new organization, then complexity is high. So we can say all complex buildings have new point details and new organizations.

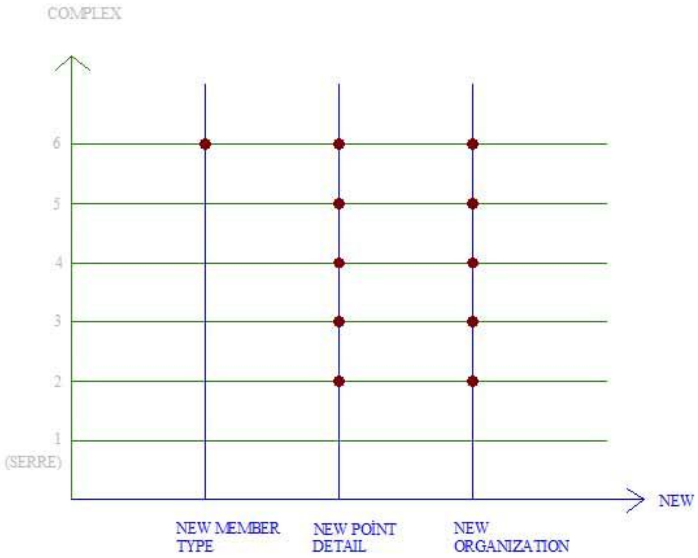


Figure 3.31 Complexity/New Detail

When the buildings which are used to form Figure 3.31 are studied it can said that:

If complexity is in the highest degree then there is a new member, new point detail and new organization. When the new point detail has an elongate member than the construction process of the system works as columns+branches+removable formwork steel shell formation+ removal of the formwork or the hierarchical order can be masonry+ removable partial formwork+ formation of steel shell+ movement of the formwork.

If new point detail is between cable and arch, and between cable and cable truss, then hierarchical order follows the main building structure+ horizontal cable trusses+pre-stressing+glasses at one level +cable are tensioned+ final balancing.

If the plan of the main building geometry is a circle or section of the secondary structure geometry is parabolic then there is a new point detail.

Chapter 4

MODEL OF COMPLEXITY

In this chapter, conceptual model were used. Figure 4.1 shows a typical conceptual model. Author did not reach any model which was directly interested about complexity. The different elements and relationships between the elements that are provided at each one of the detail levels are studied for each and every model. Some multidimensional models do not separate cube structure and contents. Only those concepts represented at the schema level are considered (relationships among instances are not taken into account [Abello, 2002].

There are 3 types of conceptual models:

A- To define type of process;

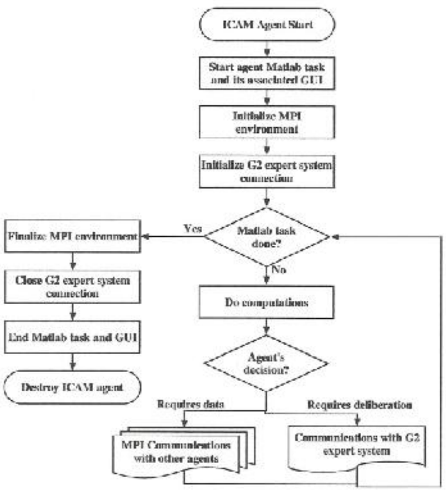


Figure 4.1 Conceptual Model for Reactive ICAM agent implementation [Sayda, 2008]

B- To define type of relationships;

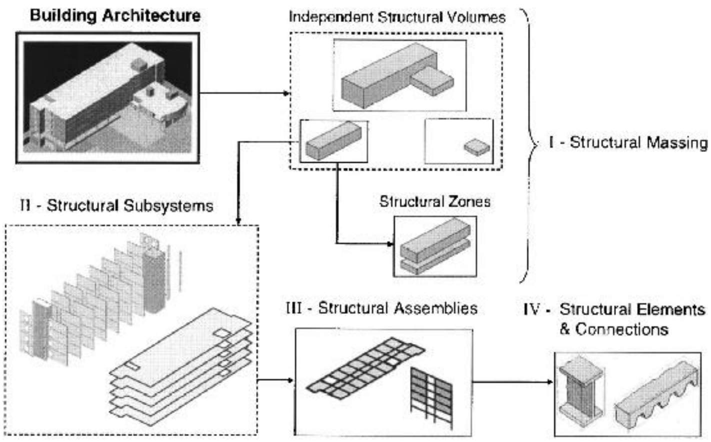


Figure 4.2 Computer Representation to Support Conceptual Structural Design within a Building Architectural Context, [Mora R.,Rivard H.,Bedard C.,2006]

C- To define the object itself ;

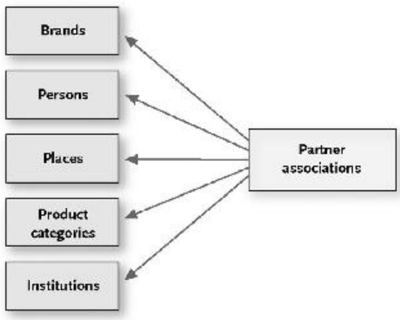


Figure 4.3 Conceptual Model Corporate partner associations [Uggla H. 2006]

Other examples of conceptual models:

Models are developed to represent objectives, requirements, options, or to establish relationships between the criteria used for the purpose of a tool and only with the fact that important elements of the offers. Number of parameters may contain a variety of models.[Sayın, E. 1985, Özkan, E. 1976]

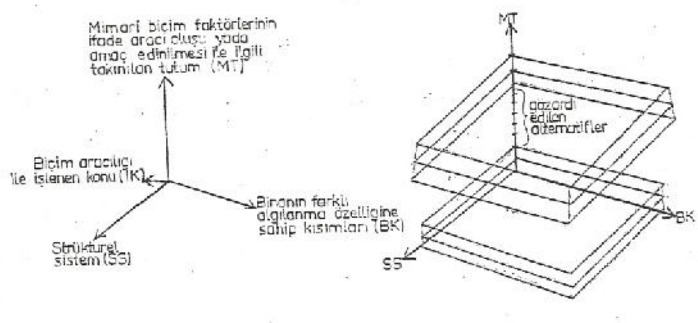


Figure 4.4 Conceptual Model for the form of skyscraper structural systems [Al, 1992]

Model of complexity

Determining factors of complexity in structure model must include below parameters.

1.Structural System,

2.Complexity,

3.Geometry,

4.New,

5.Process,

6.Hierarch,

7.Integration.

Author developed a type of conceptual model as shown figure 4.5. Sample buildings were analyzed in detail. Because the others have same in characteristics twenty cases are studied to classify types of the systems according to their structural characteristics and their geometry, which are listed in Appendix A. The model only includes ten cases because the others have same characteristics. The relation between these structures and integration to the main building structure, complexity, geometry, and construction process are discussed with this approach.

Structure system is divided into two parts as main buildings structure and the secondary structure and contains the following elements below.

Main building: arches forming a dome, masonry, triangulated steel sheel, frame

Second structure type: vertical struts which carry glass. Partially helps main building structure, simple, diagonal cable trusses, 3d organization of cable truss, horizontal simple cable truss, and triangulated steel shell.

Complexity made of six different ratings.

Geometry is divided into two parts as main buildings plan and the secondary structure plan and contains the following elements below.

Main Building Plan: circle, rectangular, circular+rectangular parts, parabolic, circular.

Secondary Plan: straight axe, circular, parabolic, rectangular, circular+rectangular parts.

New included new organization, new point detail and new member type.

Process and hierarch included ten different formations. Integration can be fully or not fully or not integrated.

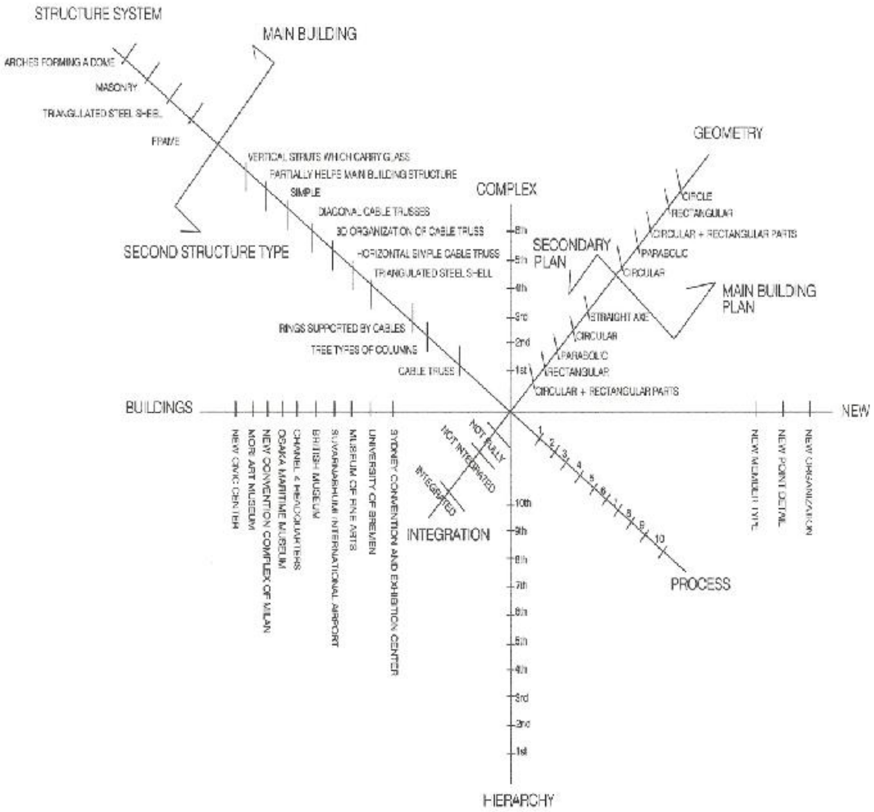


Figure 4.5 Model

This model can be used for all buildings in appendix c and it helps to form a model table. And with the help of model table graphs were drawn. From each categories one type is chosen and this categories mainly made of six different ratings (complexity).With the help of different examples, schematic drawings of structure for each category are drawn.

Models for these structures are also determined. The methodology of comparison is used for different cases in order to discuss the relation between structural and spatial characteristics by considering the rational and immeasurable properties.

GEOMETRY	SECONDARY	SECTION	CURVED	PARABOLIC	PARABOLIC	RECTANGULAR	RECTANGULAR	PARABOLIC	RECTANGULAR	RECTANGULAR	RECTANGULAR	TRIANGULAR
		PLAN	STRAIGHT AXE	CIRCULAR	PARABOLIC	RECTANGULAR	RECTANGULAR	CIRCULAR+RECTANGULAR PARTS	RECTANGULAR	RECTANGULAR	RECTANGULAR	RECTANGULAR
	MAIN BUILDING	SECTION	CIRCLE	PARABOLIC	PARABOLIC	CIRCULAR	RECTANGULAR	RECTANGULAR	RECTANGULAR	RECTANGULAR	RECTANGULAR	RECTANGULAR
		PLAN	CIRCLE	CIRCULAR	PARABOLIC	CIRCULAR	CIRCULAR	CIRCULAR+RECTANGULAR PARTS	RECTANGULAR	RECTANGULAR	RECTANGULAR	RECTANGULAR
STRUCTURE	SECOND STRUCTURE	SIZE	3600 CM	1200 CM	5000 CM	35000 CM	3000 CM	1500 CM	1200 CM	700 CM	500 CM	850 CM
		POSITION	BETWEEN ARCHES	BETWEEN TWO TENSION RINGS	WHOLE SYSTEM	CABLE TRUSS WITHIN STEEL SHELL	INFRONT OF MAIN BUILDING STRUCTURE	SPANNING THE DISTANCE BETWEEN TWO MASONRY PARTS	INFRONT OF FRAME	BETWEEN VERTICAL MEMBERS OF THE FRAME	IN FRONT OF M.B.S	IN FRONT OF FRAME
		TYPE	CABLE TRUSS	RINGS SUPPORTED BY CABLES WHICH ARE TENSED BETWEEN TENSION RINGS	TREE TYPE OF COLUMNS SUPPORTING FROM VARIOUS POINTS	SIMPLE	HORIZONTAL SIMPLE CABLE TRUSS	TRIANGULATED STEEL SHELL	VERTICAL AND HORIZONTAL (3D) ORGANIZATION OF CABLE TRUSS	DIAGONAL CABLE TRUSSES	VERTICAL STRUTS WHICH CARRY GLASS PIECES SOME OF THESE VERTICALS ARE SUPPORTED BY CABLES	PARTIALLY HELPS MAIN BUILDING STRUCTURE TO CARRY THE ROOF STRUTS SUPPORTED BY CABLES
	MAIN BUILDING	SYSTEM	ARCHES FORMING A DOME	FRAME	TRIANGULATED STEEL SHELL	SHELL	FRAME	MASONRY	FRAME	FRAME (MINIMAL)	FRAME	FRAME
		MATERIAL	STEEL	RC	STEEL	STEEL	RC	RC	STEEL	STEEL	STEEL	STEEL
INTEGRATED/NOT INTEGRATED			NOT	NOT	INTEGRATED	INTEGRATED	NOT	NOT	NOT INTEGRATED	INTEGRATED	CERTAIN DEGREE BUT NOT FULLY	NOT
PROCESS			1 TENSIONING HORIZONTAL CABLE TRUSS VERTICAL CABLE TRUSS	2 MAIN BUILDING STRUCTURE TENSION RINGS CABLES VERTICAL GLASSES GLASS SURFACE WITH SPIDERS	3 COLUMNS BRANCHES REMOVEABLE FORMWORK STEEL SHELL FORMATION REMOVAL OF THE FORMWORK	4 PARTIAL TEMPORARY FORMWORK STEEL SHELL CABLE TRUSSES GLASS	5 MAIN BUILDING STRUCTURE HORIZONTAL CABLE TRUSS PRESTRESSING GLASSES AT ONE LEVEL CABLE ARE TENSED FINAL BALANCING	6 MASONRY REMOVEABLE PARTIAL FORMWORK FORMATION OF STEEL SHELL MOVEMENT OF THE FORMWORK	7 MAIN BUILDING VERTICAL SUPPORTS 3D ORGANIZATION OF AND HORIZONTAL CABLE TRUSSES GLASS	8 MAIN FRAME DIAGONAL CABLE TRUSS PRETENSIONED ROOF CABLE TRUSSES PRETENSIONS GLASS	9 MAIN BUILDING STRUCTURE VERTICALS WHILE PUTTING GLASS LAYERS SOME VERTICALS ARE SUPPORTED BY CABLES PRETENSIONED	10 MAIN BUILDING STRUCTURE STRUTS SUPPORTED BY CABLES GLASS
HIERARCHY			ARCHES AND COMPRESSION RING CABLE TRUSS GLASS 1. group	MAIN BUILDING STRUCTURE TENSION RINGS RINGS AND CABLES GLASS 2. group	COLUMNS BRANCHES OF COLUMNS STEEL SHELL GLASS 3. group	(STEEL SHELL - CABLE TRUSSES)+GLASS 4. group	MAIN BUILDING CABLES CABLE TRUSS GLASS 5. group	MASONRY STEEL SHELL GLASS 6. group	MAIN BUILDING STRUCTURE VERTICAL STEEL SUPPORTS OF CABLE TRUSSES VERTICAL CABLE TRUSSES WHICH CORRESPOND TO VERTICAL STEEL SUPPORTS PRESTRESSING HORIZONTAL CABLE TRUSSES PRESTRESSING GLASS 7. group	(VERTICALS+CABLE TRUSSES)-GLASS 8. group	MAIN BUILDING STRUCTURE VERTICALS GLASS 9. group	MAIN BUILDING STRUCTURE VERTICALS GLASS 10. group
NEW	NEW ORGANIZATION		X	WHOLE SECONDARY STRUCTURE	EVERY MEMBER EQUAL IMPORTANCE	CABLE TRUSS SUPPORTING SHELL	CABLE BETWEEN CABLE TRUSS AND MAIN BUILDING STRUCTURE	EVERY MEMBER EQUAL IMPORTANCE	SIMILAR TO SERRE WHICH IS THE FIRST EXAMPLE	1- DIAGONAL CABLE TRUSSES 2- MINIMIZE MAIN BUILDING STRUCTURE	SECONDARY STRUCTURE PARTIALLY HELPING TO CARRY THE ROOF	SECONDARY STRUCTURE PARTIALLY HELPING TO CARRY THE ROOF
	NEW POINT DETAIL		X	OPPOSITE CABLE CONNECTION POINTS	ELONGATED MEMBERS	-	BETWEEN CABLE AND ARCH BETWEEN CABLE AND CABLE TRUSS	ELONGATED MEMBERS		-	YES	-
	NEW MEMBER TYPE		-	RINGS	-	-	-	-	-	-	YES	-
COMPLEX	6 TH		-	X	-	-	-	-	-	-	-	-
	5 TH		-	-	X	-	-	X	-	-	-	-
	4 TH		-	-	-	-	-	-	-	-	-	-
	3 RD		-	-	-	-	X	-	-	-	X	X
	2 ND		X	-	-	X	-	-	X	X	-	-
	1 ST DEGREE		-	-	-	-	-	-	-	-	-	-
BUILDING			NEW CIVIC CENTER	MCRI ART MUSEUM	NEW CONVENTION COMPLEX OF MILAN	OSAKA MARITIME MUSEUM	CHANEL 4 HEADQUARTERS	BRITISH MUSEUM	SUVARNABHUMI INTERNATIONAL AIRPORT	MUSEUM OF FINE ARTS	UNIVERSITY OF BREMEN	SYDNEY CONVENTION AND EXHIBITION CENTER

4.1 New Details

Analysis of ten examples, contains the following tables. by working in over twenty of the most characteristic example of the sample is reduced to ten.These are:

1-50 Avenue Montaigne..

2-Banque Popularie De L'Ouest Et De L'Armorıque.

3-Capitol Park Phase 1.

4-Census Bureau, Baltimore MD.

5-Channel 4 Headquarters.

6-Glass pavilion.

7-Long Term Credit Bank.

8-Maritime Museum,Nagasaki.

9-Mc Carren Airport, Las Vegas.

10-National Museum of Science,Technology and Industry.

11-New Entrance to the Cnıt-La Defense.

12-NYU Student Center.

13-One North Wacker Drive.

14-Rose Center for Earth and Space.

15-Sydney Opera House.

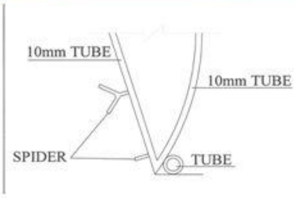
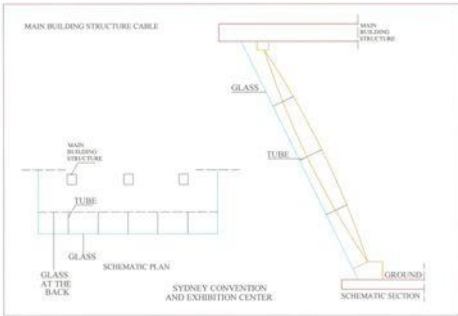
16-The Greenhoues of The Parc Citroen.

17-Tokyo Clup.

18-University of Connecticut, Stamford, CT.

19-Vanderbilt University Medical Library.

20-Yazaki North America, Canton, MI.

BUILDING	**STRUCTURE** MAIN SECONDARY	**GEOMETRY** MAIN BUILDING(1) SECONDARYSTRUC.(2)	**COMPLEXITY**	**INTEGRATION**	**STRUCTURAL HIERARCHY**	**PRODUCTION**
SYDNEY CONVENTION AND EXHIBITION CENTER	STEEL SGSPCT	(1) PLAN RECTANGULAR SECTION RECTANGULAR	1ST DEGREE	NOT INTEGRATED	10. GROUP (SEE TABLE 1 MODEL)	ONLY SGSPCT NEED SPECIAL DEVICES
		(2) PLAN RECTANGULAR SECTION TRIANGULAR				
  www.e-arvhitect.co.uk	**MAIN BUILDING STRUCTURAL SYSTEM IS FRAME. MAIN BUILDING MATERIAL IS STELL.** **SECONDARY STRUCTURE:** • **WHICH PARTIALLY HELPS THE MAIN BUILDING STRUCTURE TO CARRY THE ROOF.** • **TYPE-STRUCTS SUPPORTEDBY CABLES.** • **POSITION-INFRONT OF THE FRAME-VERTICAL**	NEW Organization: It forms a secondary structure partially helping to carry the roof. NOT INTEGRATED  **TABLE 1 : MODEL OF SYDNEY CONVENTION AND EXHIBITION CENTER**				

68

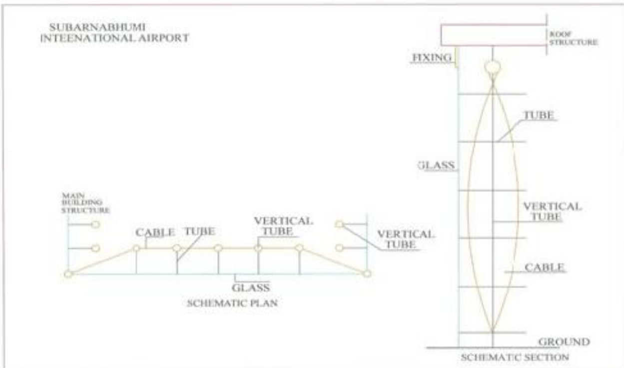
BUILDING	STRUCTURE MAIN / SECONDARY	GEOMETRY MAIN BUILDING(1) SECONDARYSTRUC(2)	COMPLEXITY	INTEGRATION	STRUCTURAL HIERARCHY	PRODUCTION
SUBARNABHUMI INTERNATIOMAL AIRPORT-BANGKOK	STELL FRAME / SGSPCT	(1) PLAN RECTANGULAR SECTION RECTANGULAR (2) PLAN RECTANGULAR SECTION RECTANGULAR	1ST DEGREE	NOT INTEGRATED	Only SGSPCT 7. GROUP	ONLY SGSPCT NEED SPECIAL DEVISES

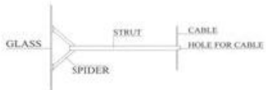
MAIN BUILDING STRUCTURAL SYSTEM IS FRAME,,
MAIN BUILDING MATERIAL IS REINFORCED CONCRETE.

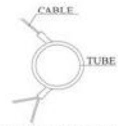
SECONDARY STRUCTURE:

- TYPE-VERTICAL AND HORIZONTAL(3D) ORGANIZATION OF CABLE TRUSSES.
- POSITION-IN FRONT OF THE FRAME

NEW DETAIL: NO NEW DETAIL.







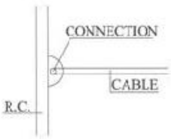
MAIN TUBE PLAN DETAIL

NOT INTEGRATED

TABLE 2: SUBARNABHUMI INTERNATIONAL AIRPORT-BANGKOK

69

BUILDING	STRUCTURE MAIN SECONDARY	GEOMETRY MAIN BUILDING(1) SECONDARY STRUC.(2)	COMPLEXITY	INTEGRATION	STRUCTURAL HIERARCHY	PRODUCTION
CHANEL 4 HEADQUARTES	RC FRAME SGSPCT	(1) PLAN CIRCULAR SECTION RECTANGULAR (2) PLAN CIRCULAR SECTION CIRCULAR	1st DEGREE SECONDARY SYSTEM INDEPENDENT OF THE MAIN BUILDING STR. COMPLEX ORGANIZATION OF SECONDARY SYSTEM	NOT INTEGRATED	5. GROUP	NEED SPECIAL MACHINES AND DEVICES



Ref:www.flickriver.com/photos

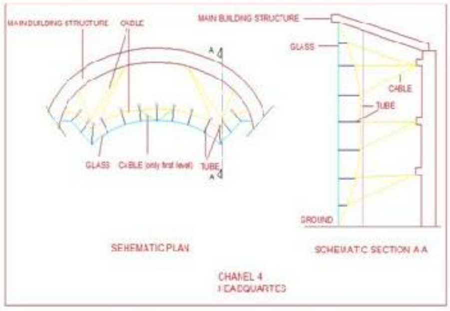
MAIN BUILDING STRUCTURAL SYSTEM IS FRAME.
MAIN BUILDING MATERIAL IS REINFORCED CONCRETE.

SECONDARY STRUCTURE:
- TYPE-RINGS SUPPORTED BY CABLES WHICH ARE TENSED BETWEEN TENSION RINGS.
- POSITION-BETWEEN TWO TENSION RINGS WHICH ARE AT THE TOP AND DOTTOM.

NEWDETAIL

NEWDETAIL

NEW DETAIL: Horizontal prestress cable trusses supported by the extra cables which are prestress between main building structure and glass wall. New member:ring, new point detail;details which connect the opposite cables. Whole secondary structure is new organization.New point detail;1-Detail between cable and arch.2-Detail: between cable and cable truss. New organization;Cable between cable truss and main building structure.



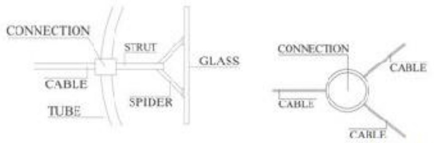


TABLE 3: MODEL OF CHANEL 4 HEADQUARTES

70

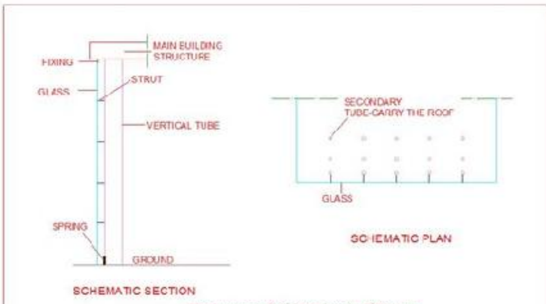
BUILDING	STRUCTURE MAIN / SECONDARY	GEOMETRY MAIN BUILDING(1) SECONDARYSTRUC.(2)	COMPLEXITY	INTEGRATION	STRUCTURAL HIERARCHY	PRODUCTION
UNIVERSITY OF BREMEN	STEEL FRAME / SGSPCT	(1) PLAN RECTANGULAR SECTION RECTANGULAR (2) PLAN RECTANGULAR SECTION RECTANGULAR	1ST AND 2ND (HALF SEPERATED) DEGREE	CERTAIN DEGREE OF INTEGRATION BUT NOT FULLY	9. GROUP (SEE TABLE 1 MODEL)	ONLY SGSPCT NEED SPECIAL DEVICES

MAIN BUILDING STRUCTURAL SYSTEM IS FRAME
MAIN BUILDING MATERIAL IS STELL.

SECONDARY STRUCTURE:

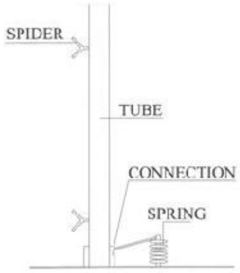
- TYPE-VERTICAL STRUCTURES WHICH CARRY GLASS PIECES.SOME OF THESE VERTICALS ARE SUPPORTED BYCABLES.
- POSITION-INFRONT OF THE MAIN BUILDING STRUCTURE.

NEW DETAIL: NO NEW MEMEER, There is new point detail. New organization is similar as Sydney Convention and Exhibition Center.



The Entrance hall of the University of Bremen

NOT INTEGRATED



http:// portrait.uni-bremen.de
http:// iaas.uni-bremen.de

TABLE 4: UNIVERSITY OF BREMEN

71

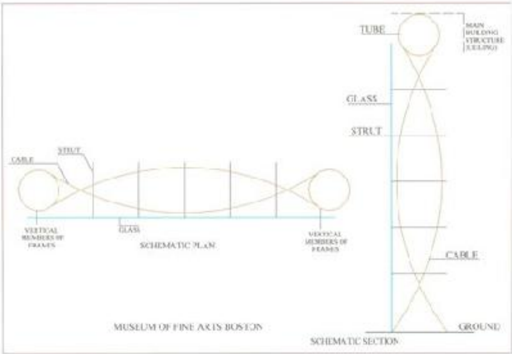
BUILDING	STRUCTURE MAIN SECONDARY	GEOMETRY	COMPLEXITY	INTEGRATION	STRUCTURAL HIERARCHY	PRODUCTION
MUSEUM OF FINE ARTS IN BOSTON	STELL FRAME SGSPCT	(1) PLAN RECTANGULAR SECTION RECTANGULAR (2) PLAN RECTANGULAR SECTION RECTANGULAR	2^{nd} DEGREE SECONDARY SYSTEM INFRONT OF THE MAIN BUILDING STR. COMPLEX ORGANIZATION OF SECONDARY SYSTEM	INTEGRATED	Only SGSPCT S.GROUP	NEED SPECIAL MACHINES AND DEVICES
 Rice P., Dutton H., 1995.	MAIN BUILDING STRUCTURAL SYSTEM IS FRAME(MINIMAL) MAIN BUILDING MATERIAL IS STEEL. SECONDARY STRUCTURE • TYPE-DIAGONAL CABLETRUSSES • POSITION-BETWEEN VERTICAL MEMBERS OF FRAME	NEW DETAIL: NO NEW DETAIL. NEW ORGANIZATION: 1 Diagonal Cable Trusses, 2 Minimized main building structure (because of the roof structure with cable trusses).  NOT INTEGRATED				

TABLE 5: MUSEUM OF FINE ARTS BOSTON

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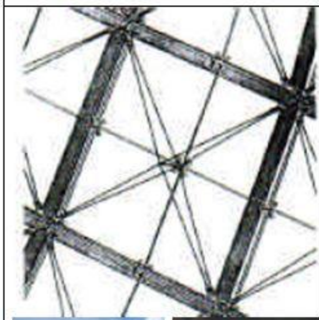
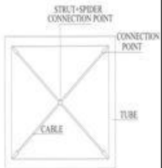
BUILDING	STRUCTURE MAIN (1) SECONDARY(2)	GEOMETRY MAIN BUILDING(1) SECONDARYSTRUC.(2)	COMPLEXITY	INTEGRATION	STRUCTURAL HIERARCH	PRODUCTION
OSAKA MARITIME MUSEUM	1-STEEL SHELL 2-CABLE TRUSS WITHIN STEEL SHELL	(1) PLAN CIRCULAR SECTION CIRCULAR (2) PLAN RECTANGULAR SECTION RECTANGULAR	2^{ND} DEGREE	INTEGRATED	4.GROUP (SEE TABLE 1 MODEL)	NEED SPECIAL MACHINES AND DEVICES-NEEDS TEMPORARY FORMWORK

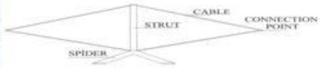


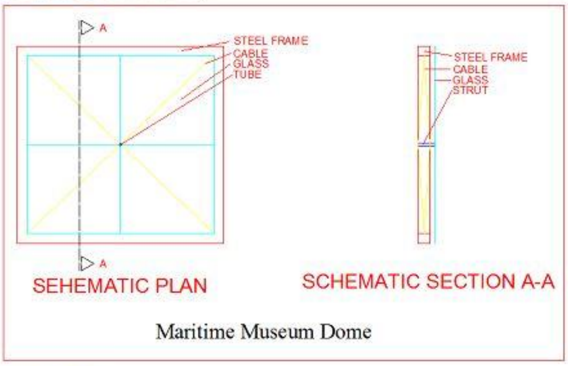
MAIN BUILDING STRUCTURAL SYSTEM IS STEEL SHELL.
MAIN BUILDING MATERIAL IS STEEL.

SECONDARY STRUCTURE:
- CABLE TRUSS WITH IN STEEL SHELL



NEW ORGANIZATION: CABLE TRUSS SUPPORTING RID.





NOT INTEGRATED

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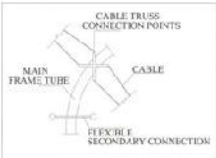
www.archspace.com

TABLE 6: OSAKA MARITIME MUSEUM

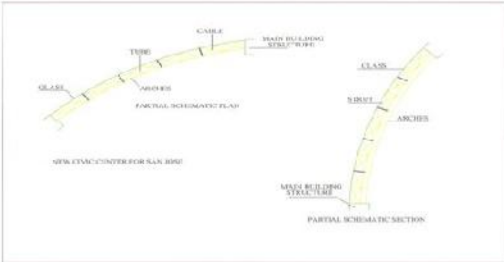
73

BUILDING	STRUCTURE MAIN (1) SECONDARY(2)	GEOMETRY MAIN BUILDING(1) SECONDARY STRUC.(2)	COMPLEXITY	INTEGRATED	STRUCTURAL HIERARCH	PRODUCTION
NEW CIVIC CENTER FOR SAN JOSE	1-ARCHES FORMING A DOME 2-TENSION RINGS SUPPORTED BY CABLES WHICH ARE TENSED BETWEEN TENSION RINGS. MAIN BUILDING STRUCTURAL SYSTEM IS ARCHES FORMING A DOME. MAIN BUILDING MATERIAL IS STEEL. SECONDARY STRUCTURE • CABLE TRUSS BETWEEN TWO TENSION RINGS.	(1) PLAN CIRCULAR SECTION PARABOLIC (2) PLAN CIRCULAR SECTION PARABOLIC	2ND DEGREE	NOT INTEGRATED	1.GROUP (SEE TABLE 1 MODEL)	NEED SPECIAL MACHINES AND DEVICES-NEEDS A TEMPORARY FORMWORK

NEW ORGANIZATION AND NEW POINT DETAILS AVAILABLE. CABLE TRUSSES USED AS CURVE FORM, AND SGSPCT SUPPORTED BY OUTHER MAIN BUILDING STRUCTURE. ALL CONNECTION POINTS BETWEEN GLASS AND STRUTS HAVE DIFFERENT ANGLE AND THERE IS FLEXIBLE MEMBERS BETWEEN THEM WHICH ARE NEW DETAILS.



www.engiebank.com



NOT INTEGRATED

TABLE 7: NEW CIVIC CENTER FOR SAN JOSE

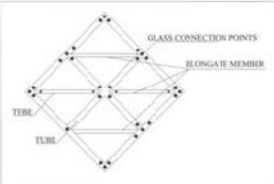
74

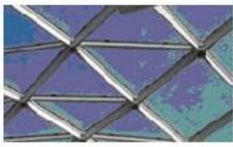
BUILDING	STRUCTURE MAIN / SECONDARY	GEOMETRY MAIN BUILDING(1) SECONDARYSTRUC.(2)	COMPLEXITY	INTEGRATED	STRUCTURAL HIERARCH	PRODUCTION
NEW CONVENTION COMPLEX OF MILAN	GRID SHELL / GRID SHELL	PLAN PARABOLOID (1) SECTION PARABOLOID (ONE SYSTEM) PLAN PARABOLOID (2) SECTION PARABOLOID	3rd DEGREE	INTEGRATED	3.GROUP (SEE TABLE 1 MODEL)	NEED SPECIAL DEVISES and DIGITAL TECHNOLOGY

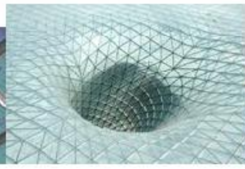
STRUCTURAL SYSTEM TRIANGULATED STEEL SHELL.

TREE TYPE OF COLUMNS SUPPORTING FROM VARIOUS POINTS.

NEW MEMBER TYPE: Either variety of the member in triangulation is very large or flexible members which can elongate.







NEW DETAIL: Every member has different measurements and angle so each connection points are different.

NEW ORGANIZATIONS: Every member has equal importance in the organization.

NOT INTEGRATED

TABLE 8: MODEL NEW CONVENTION COMPLEX OF MILAN

http://farm3.static.flickr.com
www.e-arvhitect.co.uk
http://designapplause.com

75

BUILDING	STRUCTURE MAIN SECONDARY	GEOMETRY MAIN BUILDING(1) SECONDARYSTRUC(2)	COMPLEXITY	INTEGRATION	STRUCTURAL HIERARCHY	PRODUCTION
BRITISHMUSEUM	STONE SGSPCT	PLAN CIRCULAR-RECTANGULAR PARTS (1) SECTION RECTANGULAR PLAN RECTANGULAR (2) SECTION PARABOLIC	3RD DEGREE	NOT INTEGRATED	6. GROUP (SEE TABLE 1 MODEL)	NEED SPECIAL DEVISES and DIGITAL TECHNOLOGY

www.london-architecture.info

MAIN BUILDING STRUCTURAL SYSTEM IS MASONRY.
MAIN BUILDING MATERIAL ISREINFORCED CONCRETE

SECONDARY STRUCTURE:

- TYPE- TRIANGULATED STEEL SHELL.
- POSITION- SPANINIG THE DISTANCE BETWEEN TWO MASONARY PARTS.

NEW DETAIL

NEW DETAIL: Either variety of the members in triangulation is very large or there are flexible members which can elongate.

NOT INTEGRATED

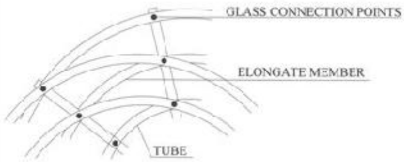


TABLE 9 :MODEL OF BRITISH MUSEUM

BUILDING	STRECTURE MAIN (1) SECONDARY(2)	GEOMETRY MAIN BUILDING(1) SECONDARY(2)	COMPLEXITY	INTEGRATION	STRUCTURAL HIERARCHY	PRODUCTION	
MORI ART MUSEUM-TOKYO	1-REINFORCED CONCRETE FRAME 2-RINGS SUPPORTED BY CABLES WHICH ARE TENSED BETWEEN TENSION RINGS.	(1) PLAN CIRCULAR SECTION PARABOLIC (2) PLAN CIRCULAR SECTION PARABOLIC	6^{TH} DEGREE	NOT INTEGRATED	2.GROUP (SEE TABLE 1 MODEL)	NEED SPECIAL MACHINES AND DEVICES-HIGH STANDARTS	

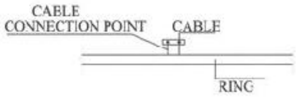
www.tokyo-hotel-booking.com
www.wayfarting.info

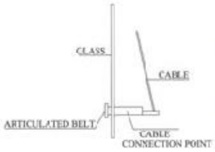
MAIN BUILDING STRUCTURAL SYSTEM IS FRAME.
MAIN BUILDING MATERIAL IS RC.

SECONDARY STRUCTURE:
- TYPE-RINGS SUPPORTED BY CABLES WHICH ARE TENSED BETWEEN TENSION RINGS
- POSITION-BETWEEN TWO TENSION RINGS

NEW DETAIL

NEW ORGANIZATION AND NEW POINT DETAILS AVAILABLE. WHOLE SECONDARY STRUCTURE ARE IN NEW ORGANIZATION. THERE IS A RING AS A NEW MEMBER. CABLE CONNECTION POINTS ARE NEW DETAILS.





The horizontal circular frame, which is tangled to diagonal webs with slender stainless steel cables, is attached to the edge of the concrete dome. The building is covered with glass shingly paired with transparent ceramic filters on top of each other.

NOT INTEGRATED

TABLE 10 : MODEL OF MORI ART MUSEUM-TOKYO

4.2 Complexity in Relation to Other Factors in the Model

The following statements are bounded directly to the examples.

If complexity is in the highest degree (6) then there is a new member, a new point detail and a new organization. If the complexity degree decreases, then the possibilities to have a new member also decrease. New point details and new organizations exist in all complex buildings except for the first degree complexity buildings such as “Serre”. So, if there is a new point detail and new organization, then complexity is high. All complex buildings have new point details and new organizations. (See fig 3.31)

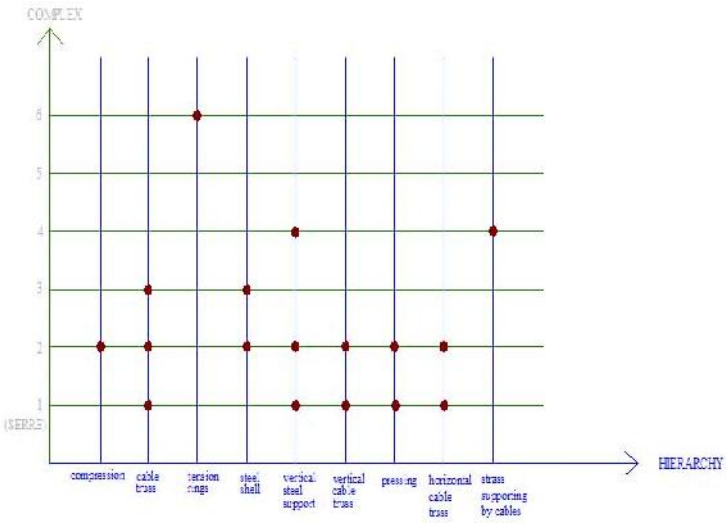
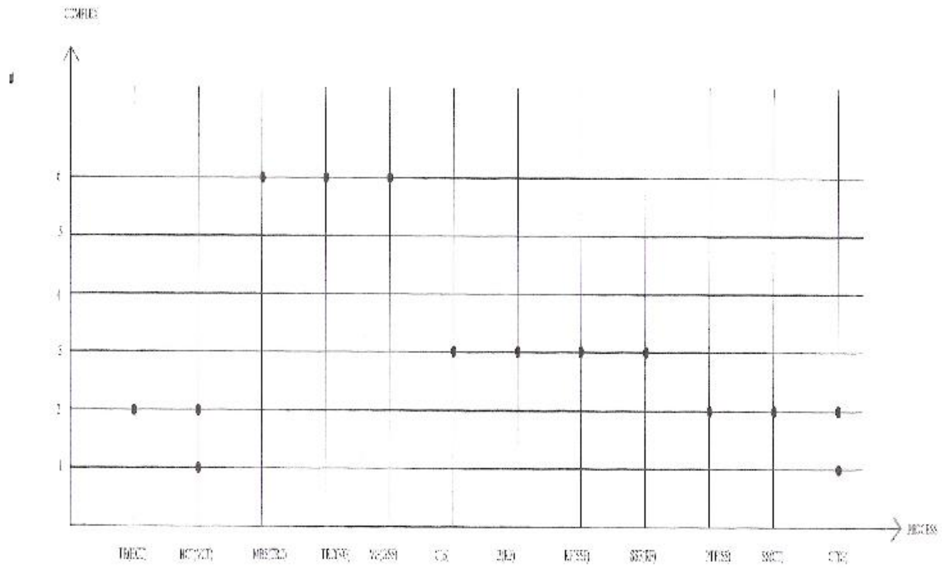
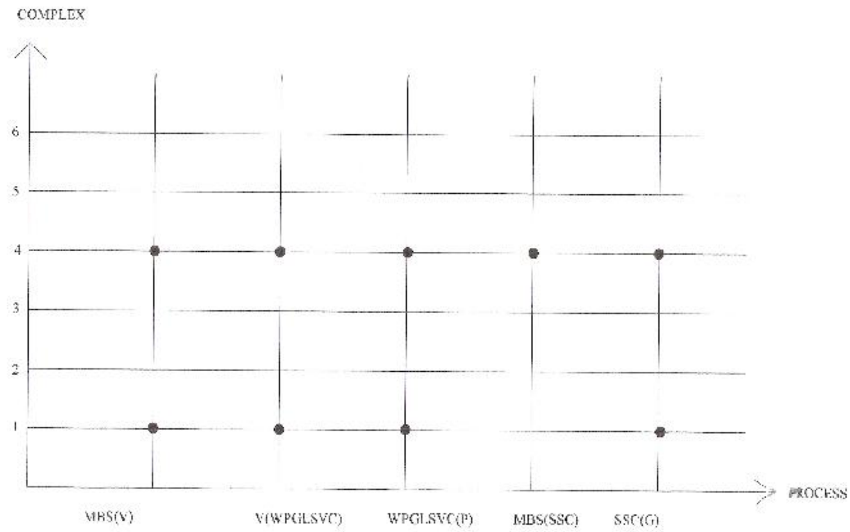


Figure 4.6 Complexity/Hierarchy

If complexity increases then there is no cable truss which is in compress, vertical cable truss, pre-stressing and horizontal cable truss. But there is a tension ring, steel shell, vertical steel supports, struts supported by cables.





COMPLEX
6
5
4
3
2
1
PROCESS
MBS(V)
V(WPGLSVC)
WPGLSVC(P)
MBS(SSC)
SSC(G)

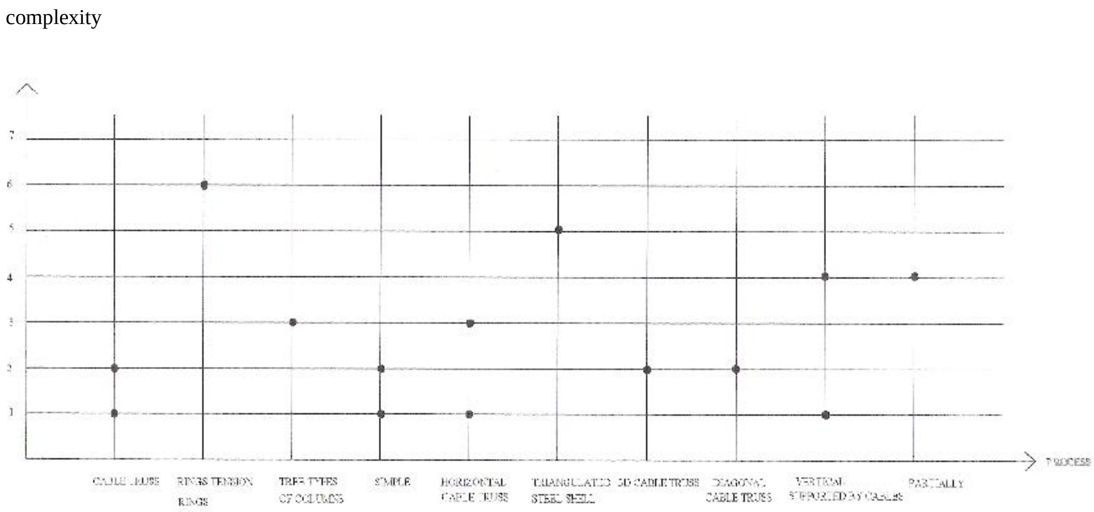


Figure 4.7 Complexity /Process

When complexity is high we need removable formwork after or before preparation for construction. For complex buildings, after building main building structure; tension ring cables, horizontal cable trusses and vertical cable trusses can be applied. But we can add glass surfaces after cable trusses for less complex buildings. We can use removable partial formwork after building the masonry part of complex buildings and then with the formation of steel shell we get rid of the temporary formwork.

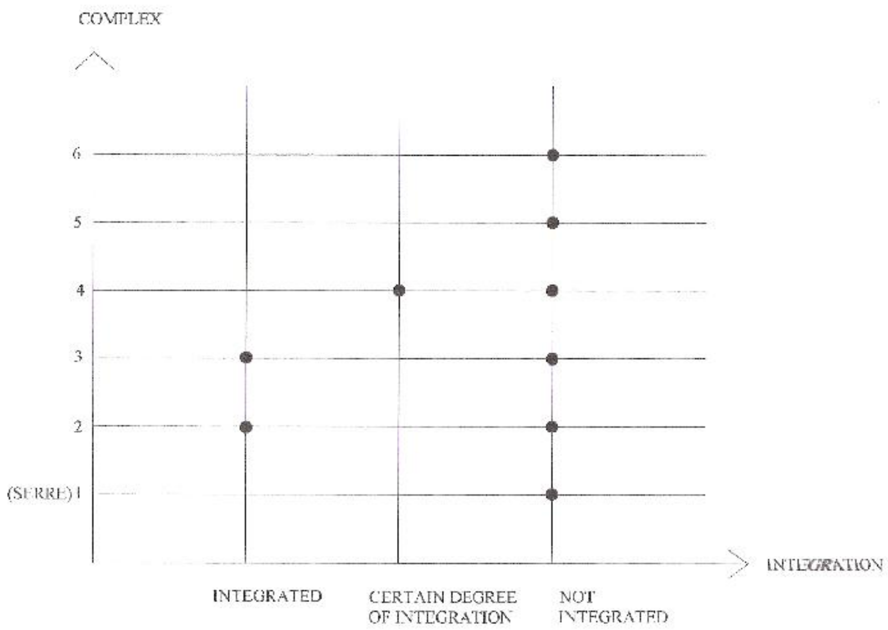


Figure 4.8 Complexity/Integration

For each level of complexity there are always conditions which end up with unit unintegrated parts of structure. Second and third degree complexity buildings are always integrated. Buildings with forth degree of complexity are integrated at a certain degree. Integration changes expect the first and the second degree complex buildings. Among all the buildings which are studied in this thesis, 5 of them are not integrated, 3 of them are integrated and one of the buildings is integrated to a certain degree.

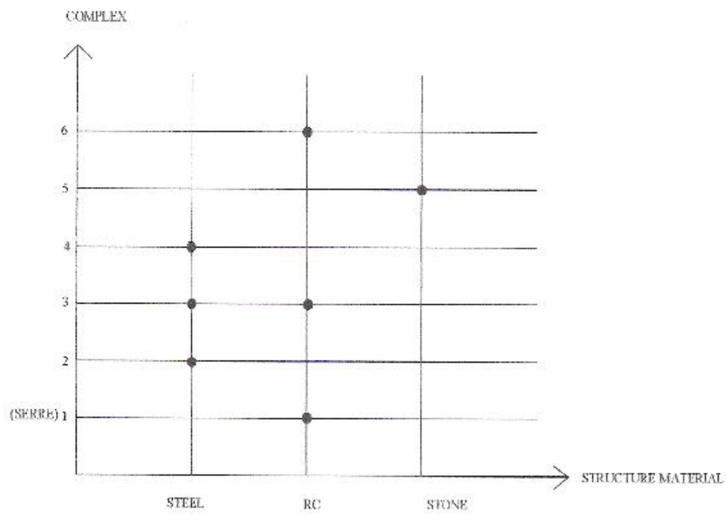


Figure 4.9 Complexity /Structural Material of the main building

Reinforced concrete is used in 1.-.3. and 6. degree of complexity buildings. Steel is used 2.-3. and 4. degree of complexity buildings. Both steel and reinforce concrete can be used in 3. degree of complexity buildings. But stone can be used in 5. degree of complexity buildings. **Result: So, material of the main building structure does not affect the complexity.**

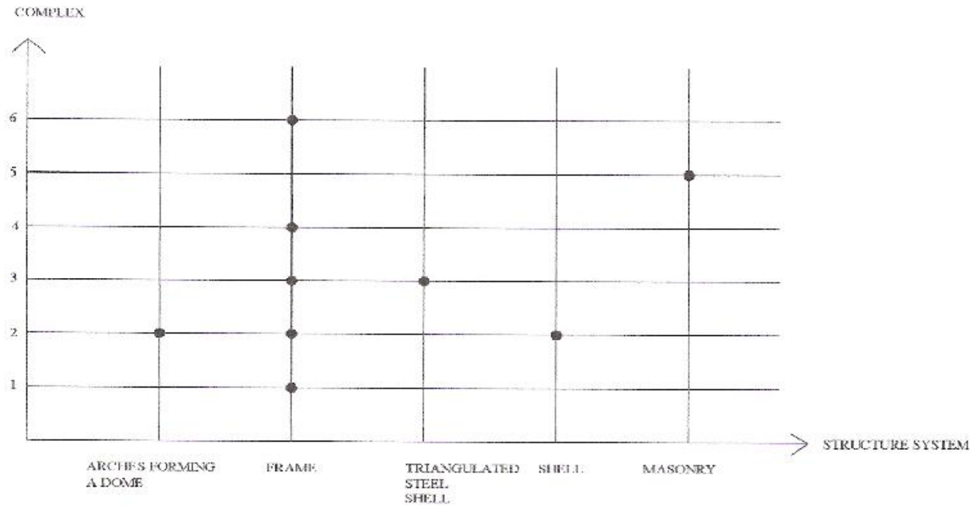


Figure 4.10 Complexity /Main Building Structural system

Arches form a dome frame shell and they can be used in 2. degree complexity buildings. The frame can be used in 1.-2.-3.-4. and 6. degree of complexity buildings. Triangulated steel shell can be used in the 3. degree of complexity buildings. We can see the masonry in 5. degree of complexity buildings. So, complexity is not affected by the main building structural system.

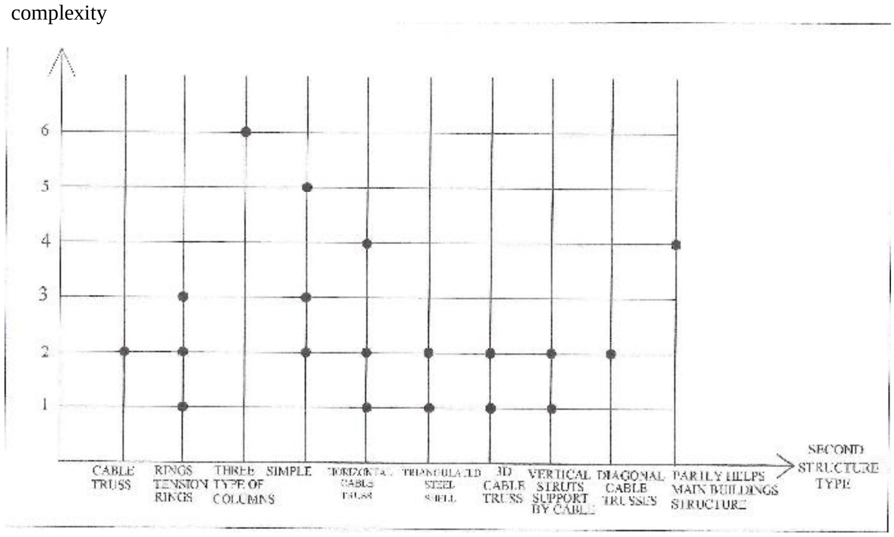


Figure 4.11 Complexity/Second structure type

Cable truss, horizontal cable truss, vertical strut supported by cables can be used in 1. degree complexity buildings as secondary structure. Cable truss, 3 D (horizontal / vertical) diagonal cable truss can be used in 2. degree of complexity buildings. Three types of columns, horizontal cable truss can be used in 3. degree of complexity buildings. Vertical struts supported by cables partially help the main building structure and it can be used in 4. degree of complexity buildings. Triangulated steel shell can be used in 5. degree of complexity buildings. Tension rings can be used as secondary structure in 6. degree of complex buildings.

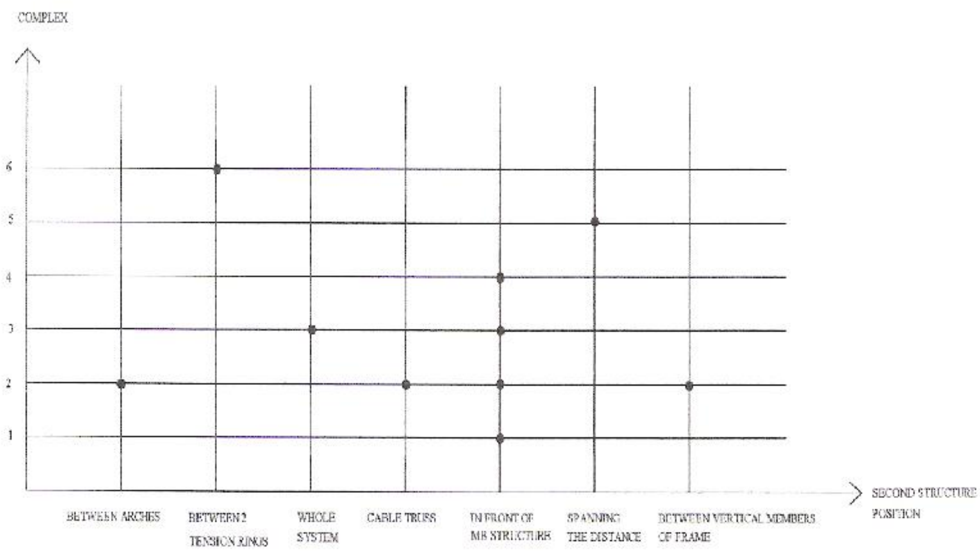


Figure 4.12 Complexity/Second structure’s position

Second structure’s position in front of the main building structure is used in 1. degree of complexity buildings. Second structure between arches, cable truss between the element of steel shell, cable truss in front of the main building structure or between vertical members of a frame can be used in 2. degree of complexity buildings. The position of the second structure is in the whole system or in front of the main building structure in 3. degree of complexity buildings. The position of the second structure always takes place in front of the main building structure in the 4. degree of complexity buildings. In 5. degree of complexity buildings the second structure is in spanning the distance between the two masonry parts. The position of the second structure in between the two tension rings can be seen in the 6th degree of complexity buildings. When the building is going to be more complex, then the position of the second structure changes in front of the main building structure.

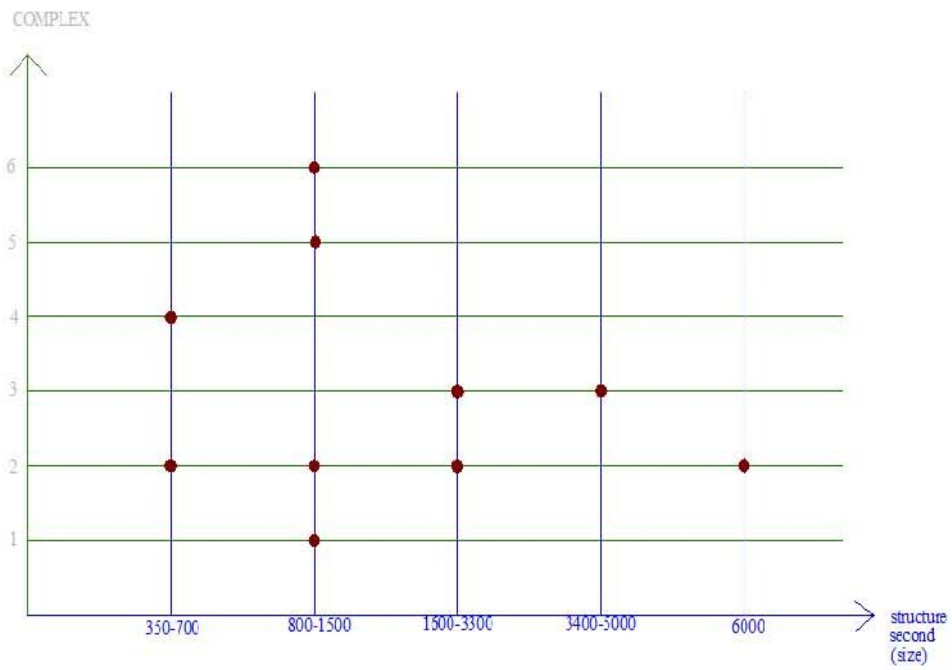


Figure 4.13 Complexity/Size

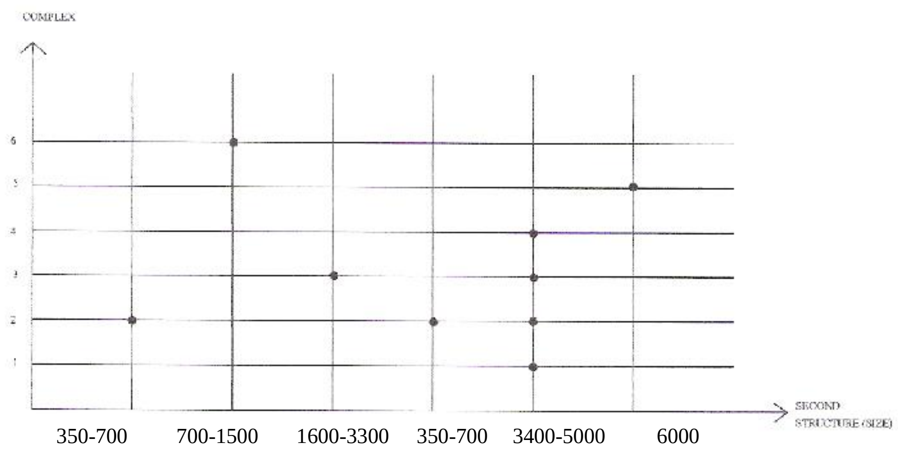


Figure 4.14 Complexity/Second structure size

The distance of systems ranges between 3.5m and 7m in the 4th degree of complexity buildings. We can see systems longer than 60m in 2nd degree of complexity buildings. In 3. degree of complexity building, the size of the second structure can be differed between 16m and 50m. In 5. and 6. degree of complexity buildings, the size of the second structure can be changed between 8m and 15m. **Result:So, system distances may be flexible and this has nothing to do with the increase or decrease of complexity**.

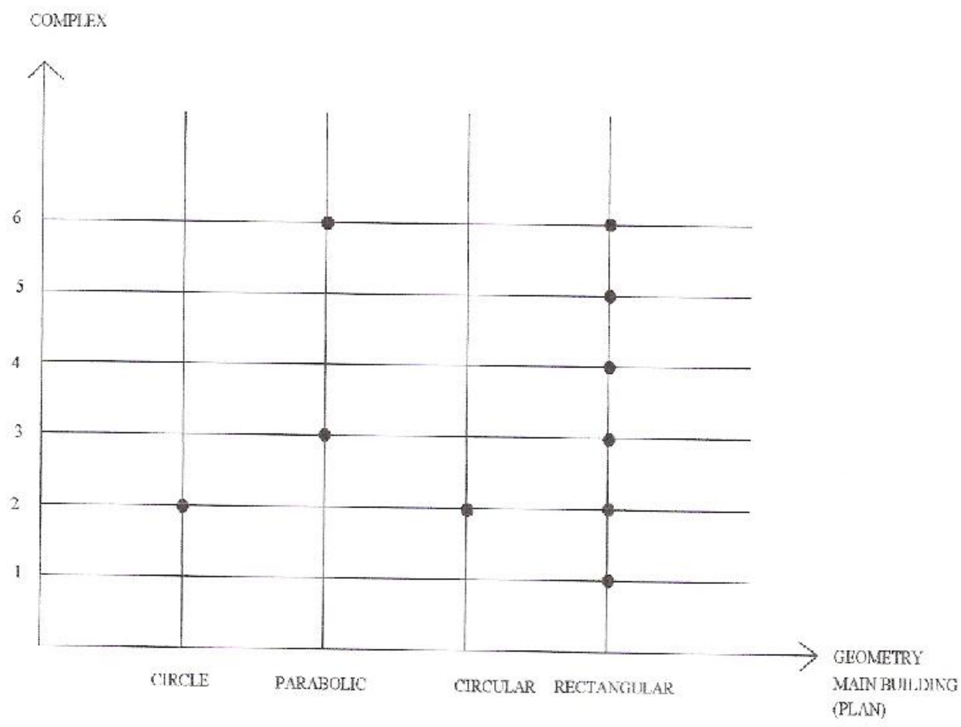


Figure 4.15 Complexity/ Geometry/The Geometry of the Main Building Plan

1st degree: main building structure plan geometry is rectangular.

2nd degree: main building structure plan geometry is circular or rectangular.

3rd degree: main building structure plan geometry is circular or parabolic.

4th degree: main building structure plan geometry is rectangular.

5th degree: main building structure plan geometry is circular or rectangular.

6th degree: main building structure plan geometry is circular.

complexity

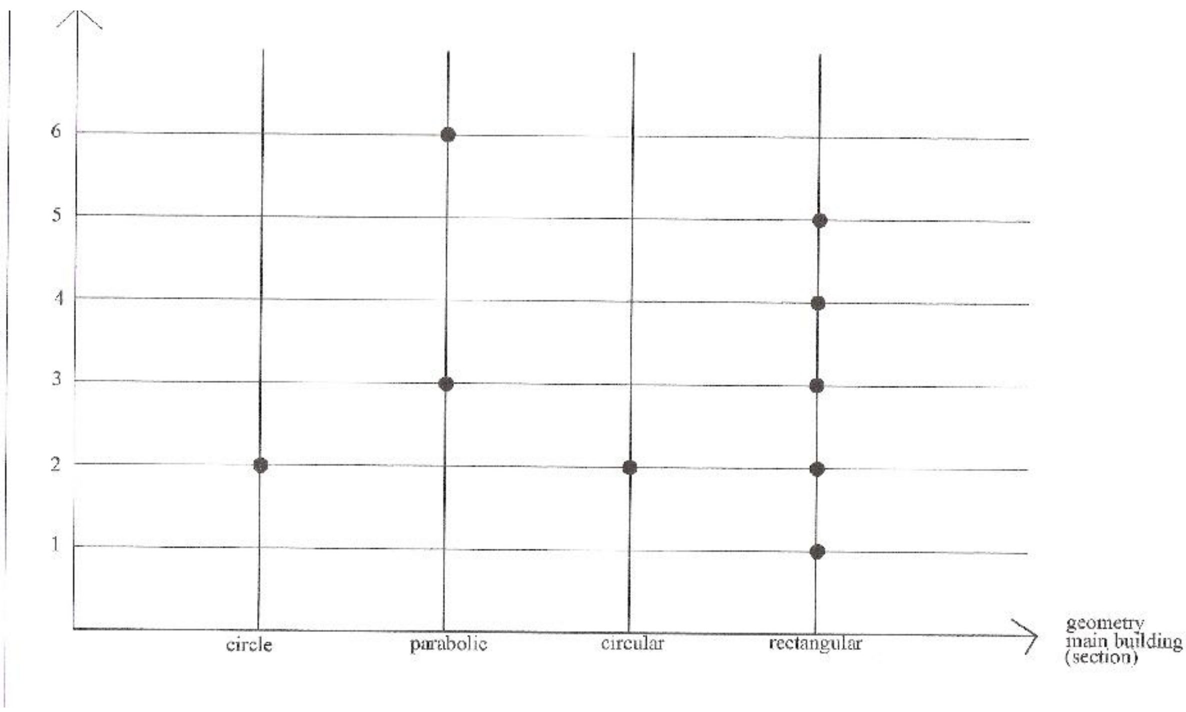


Figure 4.16 Complexity/Section geometry of main building

When building is complex the main building structure includes circular and rectangular parts together. In the 1st degree of complex buildings, the main building structure section geometry is rectangular like the main building structure plan geometry. In the 2nd degree complex building, the main building structure section geometry is circular or rectangular. In the 3. degree complex building, the main building structure section geometry is parabolic like the 6. degree. In the 4. and 5. degree complex building, the main building structure section geometry is rectangular.

Result:So, there is no direct relationship between complex structures and main building structure in terms of geometry.

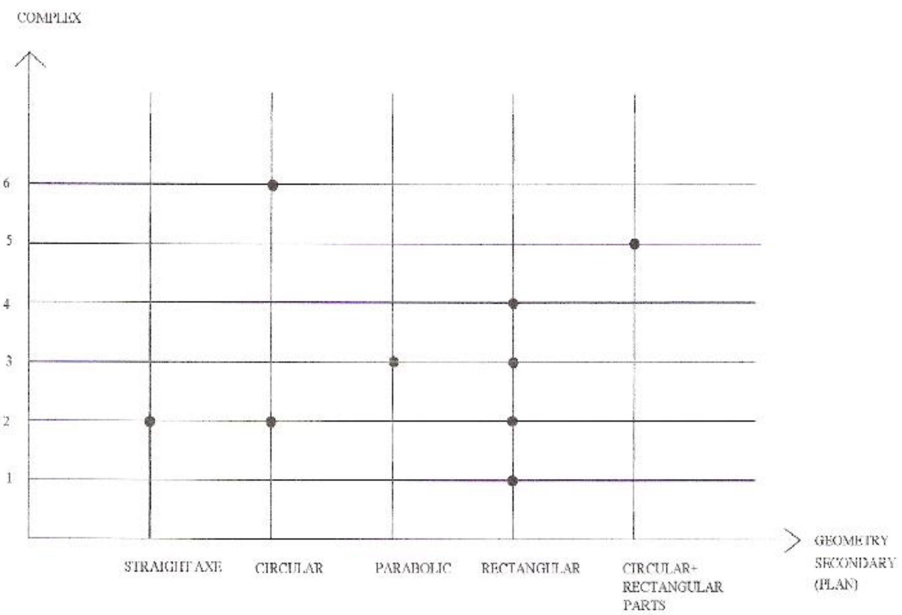


Figure 4.17 Complexity/Geometry of the plan of secondary structure

1st degree: secondary structure plan geometry is rectangular.

2nd degree: secondary structure plan geometry is based on straight axes, circular or rectangular forms.

3rd degree: secondary structure plan geometry is rectangular or parabolic.

4th degree: secondary structure plan geometry is rectangular.

5th degree: secondary structure plan geometry is circular or rectangular.

6th degree: secondary structure plan geometry is circular.

Result:When buildings are going to be complex then geometry of the secondary plan is not rectangular.

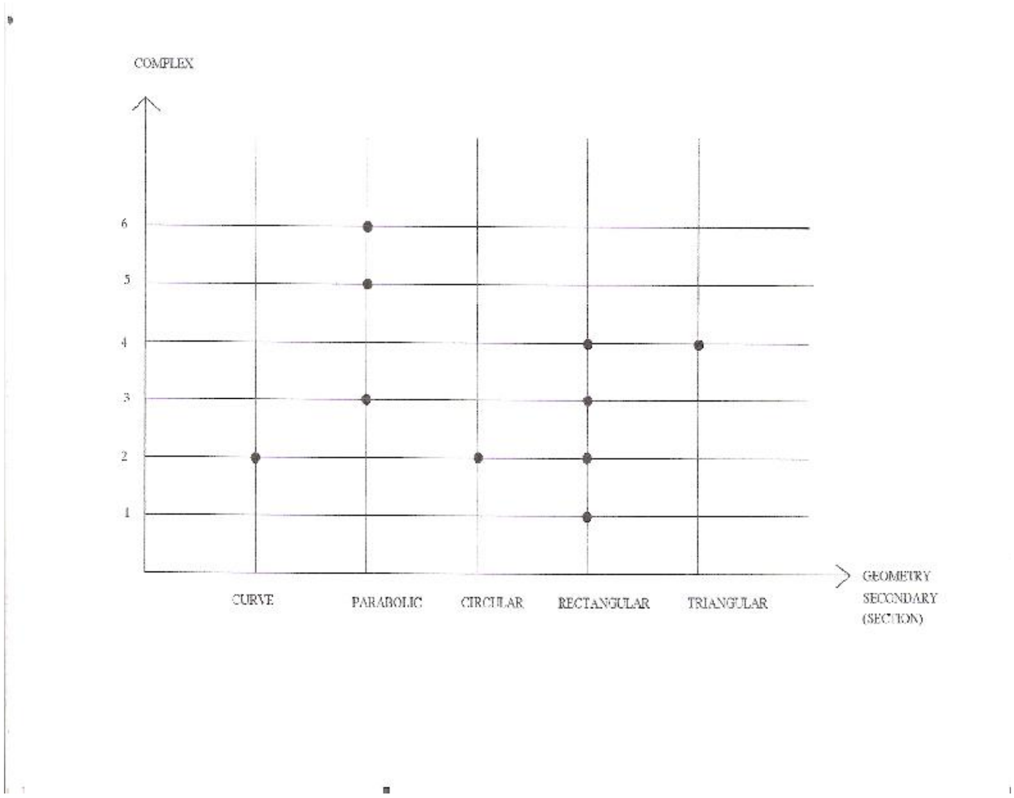


Figure 4.18 Complexity /Geometry of Section of Secondary Structure

1st degree: secondary structure section geometry is rectangular.

2nd degree: secondary structure section geometry is curved, circular or rectangular.

3rd degree: secondary structure section geometry is rectangular or parabolic.

4th degree: secondary structure section geometry is rectangular or triangular.

5th degree: secondary structure section geometry is parabolic.

6th degree: secondary structure section geometry is parabolic.

Result: When buildings are complex then the geometry of the section of the second structure is not rectangular but usually parabolic.

4.3 Result of The Model

For all buildings there are different processes and when complexity is high we need removable formwork after or before preparation. For complex buildings, after main building structure; tension ring cables, horizontal cable truss and vertical cable truss can be applied. But we can use glass after cable truss for less complex buildings. We can use removable partial formwork after masonry complex buildings and then with the formation of steel shell we get out of the temporary formwork. We use struts supported by cables just before the glass for the least complex buildings.

For each level of complexity there are always conditions which eliminate integration. Second and third degree complex buildings are always integrated. Forth degrees of complex buildings are integrated at a certain degree. Integration changes in between first and second degree complex buildings. Among the buildings which are studied in this thesis, 5 of them are not integrated, 3 of them are integrated and one of the buildings is integrated at a certain degree.

The reinforce concrete is used in 1.-.3. and 6. degree of complex buildings. Steel is used 2.3. And 4. degree of complex buildings. Both steel and reinforce concrete can be used in 3. degree of complex buildings. But stone can be used in 5. degree of complex buildings. So, main building structure does not affect the complexity.

Arches form a dome frame shell and they can be used in 2. degree complex buildings. The frame can be used in 1.-2.-3.-4. and 6. degree of complex buildings. Triangulated steel shell can be used in the 3. degree of complex buildings. We can see the masonry in 5. degree of complex buildings. So, complexity is not affected by the main building structural system.

Cable truss, simple, horizontal cable truss, and vertical strut supported by cables can be used in 1. degree complex buildings as secondary structure. Cable truss, simple, 3 D (horizontal / vertical) diagonal cable truss can be used in 2. degree of complex buildings. Three types of columns, horizontal cable truss can be used in 3. degree of complex buildings. Vertical struts supported by cables partially help the main building structure and it can be used in 4. degree of complex buildings. Triangulated steel shell can be used in 5. degree of complex buildings as a secondary structural system. Tension rings can be used as secondary structure in 6. degree of complex buildings. Second structure’s position in front of the main building structure is used in 1. degree of complex buildings. Second structure between arches, cable truss between steel shell, in front of the main building structure or between vertical members of frame can be used in second degree of complex buildings. The position of the second structure is in the whole system or in front of the main building structure in 3. degree of complex buildings. The position of the second structure always takes place in front of the main building structure in the 4. degree of complex buildings. In 5. degree of complex buildings the second structure is in spanning the distance between the two masonry parts. The position of the second structure in between the two tension rings can be seen in the 6th degree of complex buildings. When building is going to be more complex, the position of the second structure changes in front of the main building structure.

The distance of systems ranges between 3.5m and 7m in the 4th degree of complex buildings. We can see systems longer than 60m in 2nd degree of complex buildings. In 3rd degree of complex building, the size of the second structure can be differed between 16m and 50m. In 5. And 6. degree of complex buildings, the size of the second structure can be changed between 8m and 15m.

1st degree: main building structure plan geometry is rectangular.

2nd degree: main building structure plan geometry is circular or rectangular.

3rd degree: main building structure plan geometry is circular or parabolic.

4th degree: main building structure plan geometry is rectangular.

5th degree: main building structure plan geometry is circular or rectangular.

6th degree: main building structure plan geometry is circular.

When building is complex the main building structure includes circular and rectangular parts together. In the 1st degree of complex buildings, the main building structure section geometry is rectangular like the main building structure plan geometry. In the 2nd degree complex building, the main building structure section geometry is circular or rectangular. In the 3. degree complex building, the main building structure section geometry is parabolic like the 6. degree. In the 4. and 5. degree complex building, the main building structure section geometry is rectangular. Except the 2. degree complexity, the main building structure section geometry is rectangular.

1st degree: secondary structure plan geometry is rectangular.

2nd degree: secondary structure plan geometry is straight axe, circular or rectangular.

3rd degree: secondary structure plan geometry is rectangular or parabolic.

4th degree: secondary structure plan geometry is rectangular.

5th degree: secondary structure plan geometry is circular or rectangular.

6th degree: secondary structure plan geometry is circular.

When buildings are going to be complex then geometry of the secondary plan is not rectangular.

1st degree: secondary structure section geometry is rectangular.

2nd degree: secondary structure section geometry is curve, circular or rectangular.

3rd degree: secondary structure section geometry is rectangular or parabolic.

4th degree: secondary structure section geometry is rectangular or triangular.

5th degree: secondary structure section geometry is parabolic.

6th degree: secondary structure section geometry is parabolic.

When buildings are complex then the geometry of the section of second structure is not rectangular but usually parabolic.

When new member type is a ring, then after the main building structure tension rings, rings and cables and glass are used. If a new member is used, then after the main building structure comes verticals and glass. There is no relationship between hierarchy and the new member types.

If there is a new member the material is steel. If there is no new member, then the materials used can be either steel or reinforce concrete or can be stone.

In masonry structure, shell and triangulated steel shell there is no new member type. If structural system includes a frame, the new members can be both ring and no new member. If structural system consists of arches forming a dome, there can be new member types or not. Material generally steel for new complex structures.

If the main building plan geometry is circular then the new member type can be rings. If the main building plan geometry consists of parabolic or circular and triangular parts then there is no new member type.

If the section of the main building geometry is circle or circular, then there is no new member type. If the section of the main building geometry is parabolic, then there can possibly be a new member type as rings.

If the plan of the secondary structure geometry is straight axe, then there is no new member type. If the plan of the secondary structure geometry is circular, then there can possibly be rings as new member type. If the plan of the secondary structure geometry is rectangular, it can possibly be a new member type

If the section of the secondary building structure geometry is curve, circular, triangular, then there is no new member type. If the section of the secondary building structure geometry is parabolic, there can possibly be rings as new member type. If the section of the secondary building structure is rectangular then there can possibly be new member type.

If the section of secondary structure geometry is curve, then there is new organization in this system. If the section of the secondary structure geometry is parabolic, then we can say that the whole second structure as new organization or every member has an equal importance. If the section of the secondary structure geometry is circular, then the new organization is cable truss supporting the shell. If the section of the secondary structure geometry is triangular, then the secondary structure partially helps to carry the roof. So there are relationship between complexity and geometry. Especially, the British Museum is the best example to see this. There are two different geometry which are combining another five degree complex structure.

The final results are;

1-Main building structure does not affect the complexity.

2-System distances may be flexible and this has nothing to do with the increase or decrease of complexity.

3-There is no direct relationship between complex structures and main building structure in terms of geometry.

4-When buildings are going to be complex then geometry of the secondary plan is not rectangular.

5-When buildings are complex then the geometry of the section of the second structure is not rectangular but usually parabolic.

Chapter 5

CONCLUSION

Throughout the history of architecture, the application of system details has played a very important role in the design process of a building. Architecture has always been linked to society in a strong way since it is the only activity where users actually experience the product in three dimensions.

Earlier architecture and construction were based on practical experience, but several factors such as structural analysis and design, information, telecommunication, technology, etc, have improved building materials and design processes. Several of these affect the architectural appearance of buildings, although not all changes in architecture can be explained by technical progress.

Most of these releases are not available for most countries and the traditional materials are being processed, revised and reconsidered in order to make them more efficient, technology is giving way to benefit these processes. Are the new computer-based design techniques and the new designs leaning towards a complete new architecture that requires new materials for its development?

Parallel to the progress in materials sciences, the technology of construction and manufacturing of building materials have also developed. The different architectural styles have been developed by technical development and ideas of architects. With the requirements of the clients, architects have provoked technological developments as in terms of design as in detail for construction.

Frank Lloyd Wright defined modern architecture in an interview: “it was not architecture made in the modern period but rather "organic" architecture made with tensile strength.” He called the new principle "tenuity" and as it is tenuous, flexible but strong in connection. He associated it with a railway trestle bridge. Post and beam construction, in contrast, is stacked with neither tensile strength nor unity.

Today, the engineering offers possibilities for innovative design. Membrane structures redefine the meaning of inside and outside. Tensegrity systems of cables and rods elegantly balance the tension and compression in materials that hold up buildings. The rationality and efficiency of deployable structures, made at one location or at ground level on site and then erected in one operation, add a new dimension to the aesthetic appreciation of architecture. Architects have new choices like shells, hybrids, computer-driven morphology studies, and exotic new material.

As an outcome, the role of architects is changing, as it is leaving behind traditional notions based on a highly specialized, isolated discipline. Nowadays the role of the architect is similar to that of an orchestrator of unfixed data-driven processes. They use digital platforms where information is not fixed. Architecture now shares information and uses a multidisciplinary approach.

In the bright future the relation between the process of design and the interaction between the buildings will be achieved in just one step, this is a whole interaction which is able to lead to a design and a designed-interactive object. This may become in a reformulation of what is understood as architecture and maybe even the name will change to express the new-powerful condition of being an architect.

Research objective of this thesis is to find what the factors are which form the structural complexity in contemporary lightweight dematerialized architecture. The aim of the thesis, on the one hand, is to display the existence of the complex structures which are formed by the recently developed details used in construction; on the other hand, it questions the same structures according to their differences, geometry, and the methods used during the construction process. Twenty cases were analyzed and found that the details are the most effective factor on the complex structures. The major characteristics of these 20 cases are to be light weight and dematerialization. The analysis of the criterion which enables the existence of complex buildings are interpreted, and the hypothesis, which is: new detail which covers new members, new organizations and new point details is the major factor which determines complexity.

There are six different elements which might affect the complexity of these systems. These are;

1-Main Building Structure, Secondary Structure

2-New Detail,(new memebers,new organizations-system detail, new point details)

3-Complexity,

4-Hierarchy,

5-Construction Process,

6-Geometry

The cases which are investigated in this thesis show that, the idea of new detail covering and integrating the concepts of complexity depends on hierarchy and geometry as well.

The final results are;

1-Main building structure does not affect the complexity.

2-System distances may be flexible and this has nothing to do with the increase or decrease of complexity.

3-There is no direct relationship between complex structures and main building structure in terms of geometry.

4-When buildings are going to be complex then geometry of the secondary plan is not rectangular.

5-When buildings are complex then the geometry of the section of the second structure is not rectangular but usually parabolic.

If the complexity is in the highest degree (6) then there is a new member and a new point detail and a new organization. If the complexity degree decreases then the possibilities to be a new member also decrease. New point details and new organizations are in rather complex buildings. So, if there is a new point detail and new organization then complexity is high. All complex buildings have new point details and new organizations.

In order for the new complex structures to exist the major factor is to enable the possibility of new details is proved. In addition to this, the placement of these details in the whole system carries an importance. In this case, hierarchy is involved in the process, too. Although integration and geometry carry an importance for complex structures, their importance is not as inevitable as new details.

The aim of the new detail is to minimize the bracing structure in order to create a space where one is neither inside nor outside the building to create new types of structures.

The geometry of such structures is determined according to the perpendicular wind loads on the glazed plane and to the requirements of the main building structure to which these loads are transferred. The appropriate geometrical solutions serve to show how the whole system works, and how the problems of holding a vertical plane of glass with necessary wind bracing have been resolved.

In summary complex structures sometimes stand as an entity but sometimes they are in cooperation with some other structures. These buildings are the ones in which the structural material used at a minimum degree whereas the transparency is at the maximum degree. Formally improbable structures become possible by the details used in constructing these complex structures. Because of the new details used in complex structures, this type of buildings are lighter, more resistant with all load, and display more freedom as far as the geometry is concerned. Complexity is an important concept to learn because if an architect knows about complexity and important of new detail, this means he will be able to design more transparent and more minimal buildings.

Hypothesis is based on the fact that the detail is the major factor which determines complexity in architecture. Chapter 4 and above writings prove that this hypothesis is true. New architecture, new complex geometries and material evolution do not exclude the conventional materials that have been used forever in construction, such as concrete, timber and bricks. The research shows that there are additional new details; new processes that evolved the way in which all types of materials have been used in the last years.

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APPENDIX/APPENDICES

Appendix A: Buildings which are Investigated

1-50 Avenue Montaigne,Paris, architects: Epstein, Glialman and Vidal, [Rice, Dutton, 1995].

2-Banque Popularie De L'Ouest Et De L'Armorıque, Montgermont , architects: Odile Decq and Benoit Cornette, [Rice, Dutton, 1995].

3-Capitol Park Phase 1, [The window glass company limited,2002; Pilkington Planar,2002].

4-Census Bureau, Baltimore MD, [Sweet's Group, 2001].

5-Channel 4 Headquarters, London, architects: Richard Rogers Partnership, [Rice, Dutton, 1995].

6-Glass pavilion, [Pilkington Planar, 2002].

7-Long Term Credit Bank, Tokyo, [Pilkington Planar,2002].

8-Maritime Museum,Nagasaki, architect: Tetsuo Furuichi, [Rice, Dutton, 1995].

9-Mc Carren Airport, Las Vegas, Nevada, [Sweet's Group,2001 ; Pilkington Planar, 2002].

10-National Museum of Science,Technology and Industry ,Paris, [Rice, Dutton, 1995].

11-New Entrance to the Cnıt-La Defense,Paris, architec: Sari Ingénierie [Rice, Dutton, 1995].

12-NYU Student Center, New York, NY, [Pilkington Planar,2002].

13-One North Wacker Drive, Chicago IL, [Sweet's Group, 2001].

14-Rose Center for Earth and Space, New York, NY , [Pilkington Planar,2002].

15-Sydney Opera House, [The window glass company limited,2002].

16-The Greenhoues of The Parc Citroen,Paris architect: Patrick Berger, [Rice, Dutton, 1995].

17-Tokyo Clup, architect: Edvard Suzuki, [Rice, Dutton, 1995].

18-University of Connecticut, Stamford, CT, [Sweet’s Group, 2001; Pilkington Planar, 2002].

19-Vanderbilt University Medical Library, Nashville TN, [Sweet’s Group, 2001; Pilkington Planar, 2002].

20-Yazaki North America, Canton, MI, [Sweet’s Group, 2001; Pilkington Planar, 2002].

Appendix B: Other Graphic of the Model

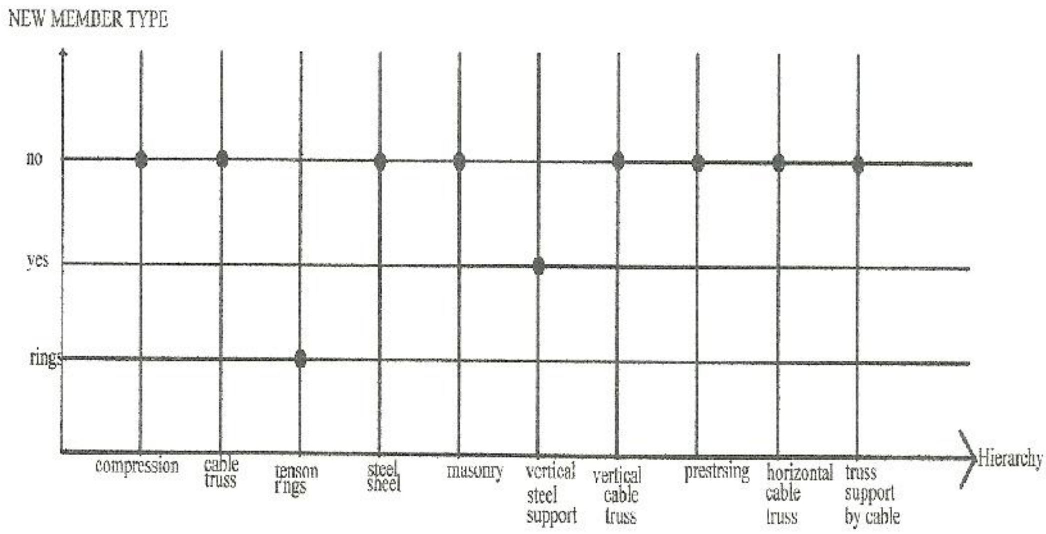


Figure 1 New Member Type/ Hierarchy

When new member type is a ring, then after the main building structure tension rings, rings and cables and then glass are used. If a new member is used, then after the main building structure comes verticals and glass. There is no relationship between hierarchy and the new member types.

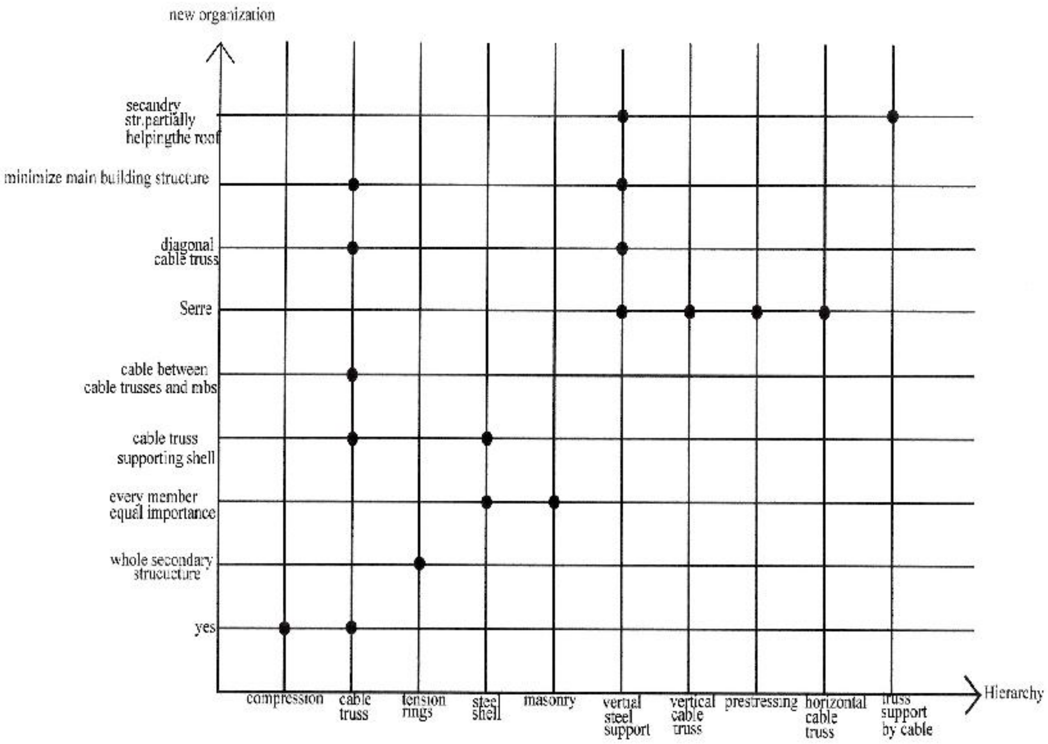


Figure 2 New organization/Hierarchy

If there is a new organization then;

1-in arches and compression ring-cable truss-glass are used,

2-if whole of the secondary structure is new to the organization, then the main building structure-tension rings-rings and cables and glass are used.

3-if every member carries an equal importance in columns-branches of columns-steel shell-glass or masonry-steel shell and glass are used.

4- If cable truss supports the shell in new organization, then hierarchical order is applied as steel shell, cable truss and glass.

5- If new organization is similar to ‘serre’ which is the first example; the main building structure, vertical steel supports of cable trusses, vertical cable trusses which correspond to vertical steel supports, pre-stressing, horizontal cable trusses, pre-stressing and glass is the hierarchical order.

6- If the new organization is the secondary structure, it partially helps to carry the roof;

a- the main building structure, verticals and glass,

b-the main building structure-struts supported by cables and glass is the hierarchical order.

7-if there is a new point detail, then the hierarchical order is as follows;

a-Tension ring+horizontal cable truss+vertical cable truss,

b-the main building structure+verticals+while applying glass layers some verticals are supported by cables+pre-tensioned.

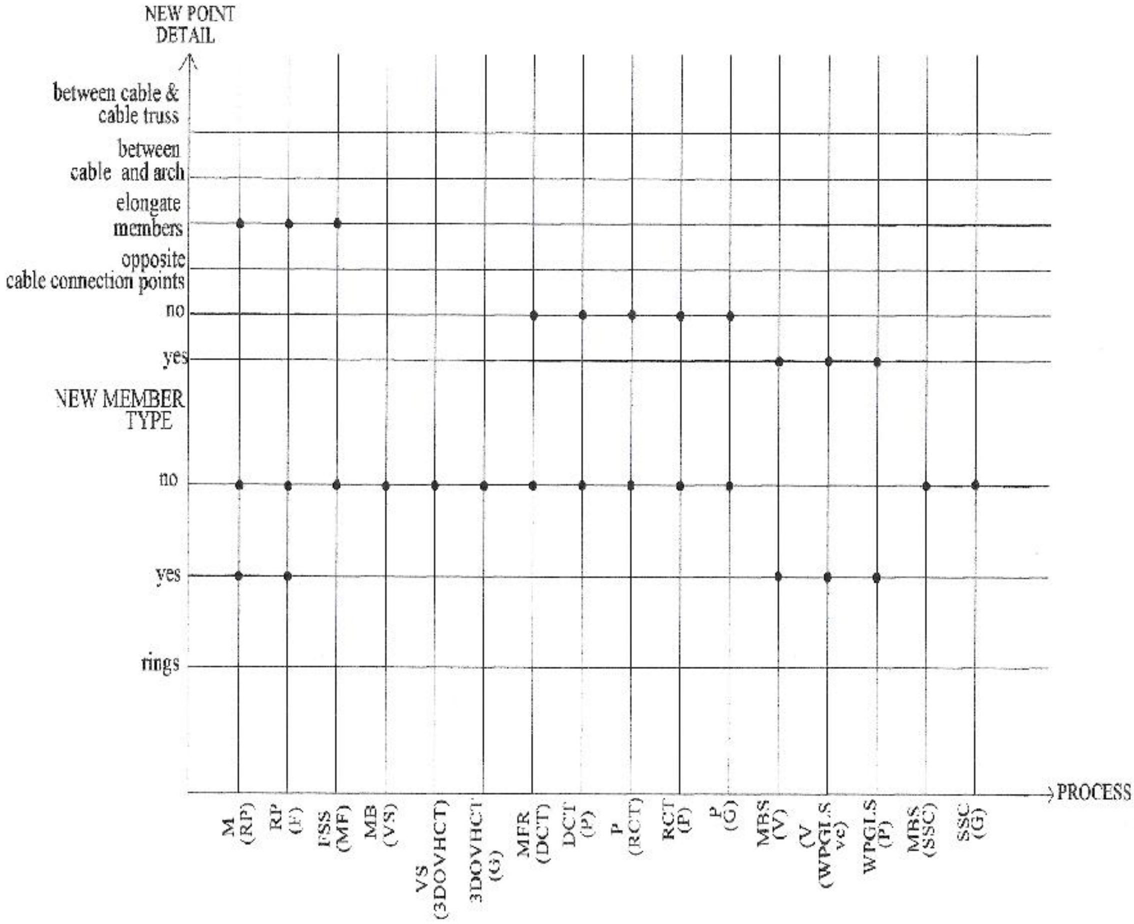


Figure 3 New Point Detail /Process

8- when the new point detail has an elongate member than the process of the system works as column+branches+removable formwork+steel shell formation+removal of the formwork or the hierachical order can be masonry+removable partial formwork+formation of steel shell+movement of the formwork.

9-if there is no new point details;

a-partial temporary formwork+steel shell+cable truss+glass,

b-main building structure+vertical supports+ 3d organisation of vertical and horizontal cable trusses+glass

c-main frame+diagonal cable trusses+pre-tensioned+roof cable trusses+pre-tensions+glass,

d-main building structure+struts supported by cables+glass.

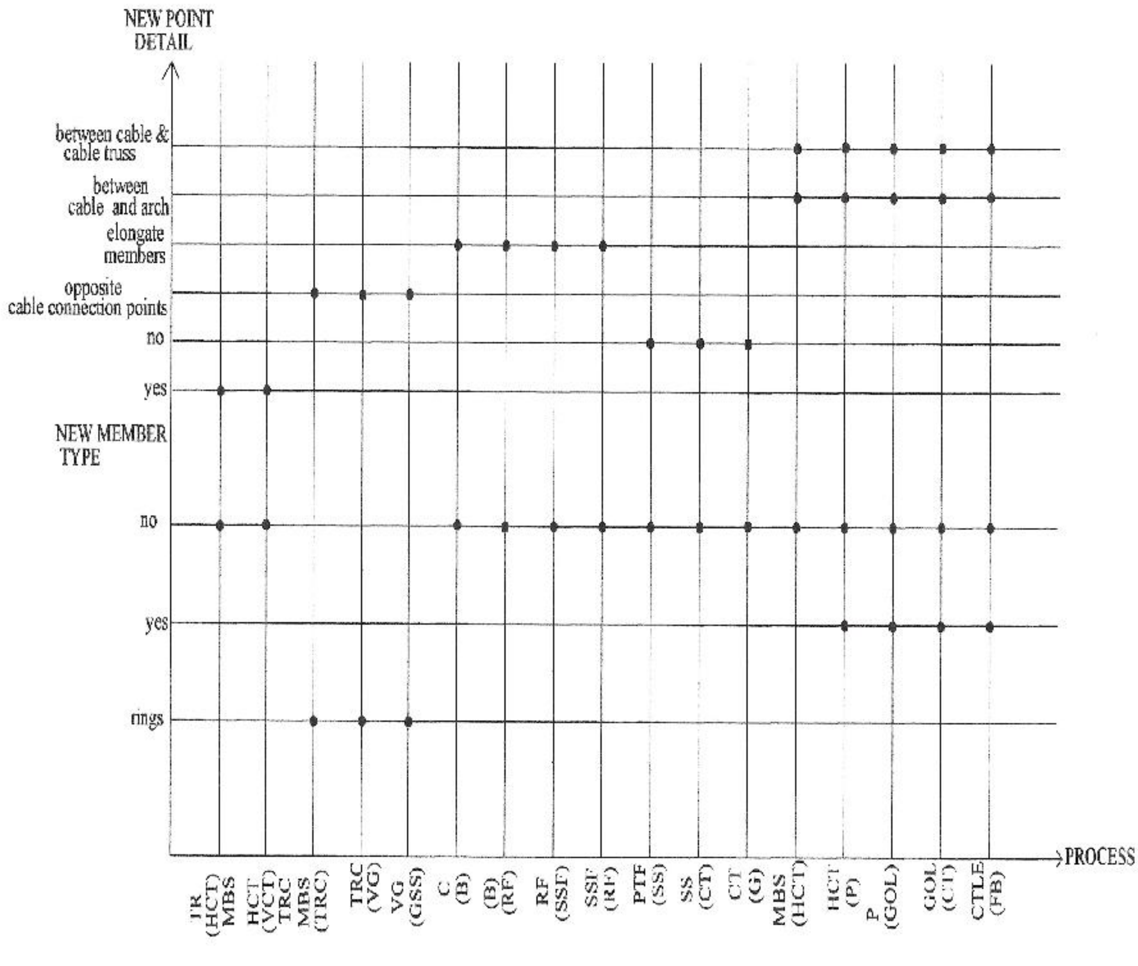


Figure 4 New Point Detail /Process

10-If new point detail is between cable and arch and between cable and cable truss then hierarchical order follows the main building structure+horizontal cable trusses+pre-stressing+glasses at one level+cable are tensioned+ final balancing.

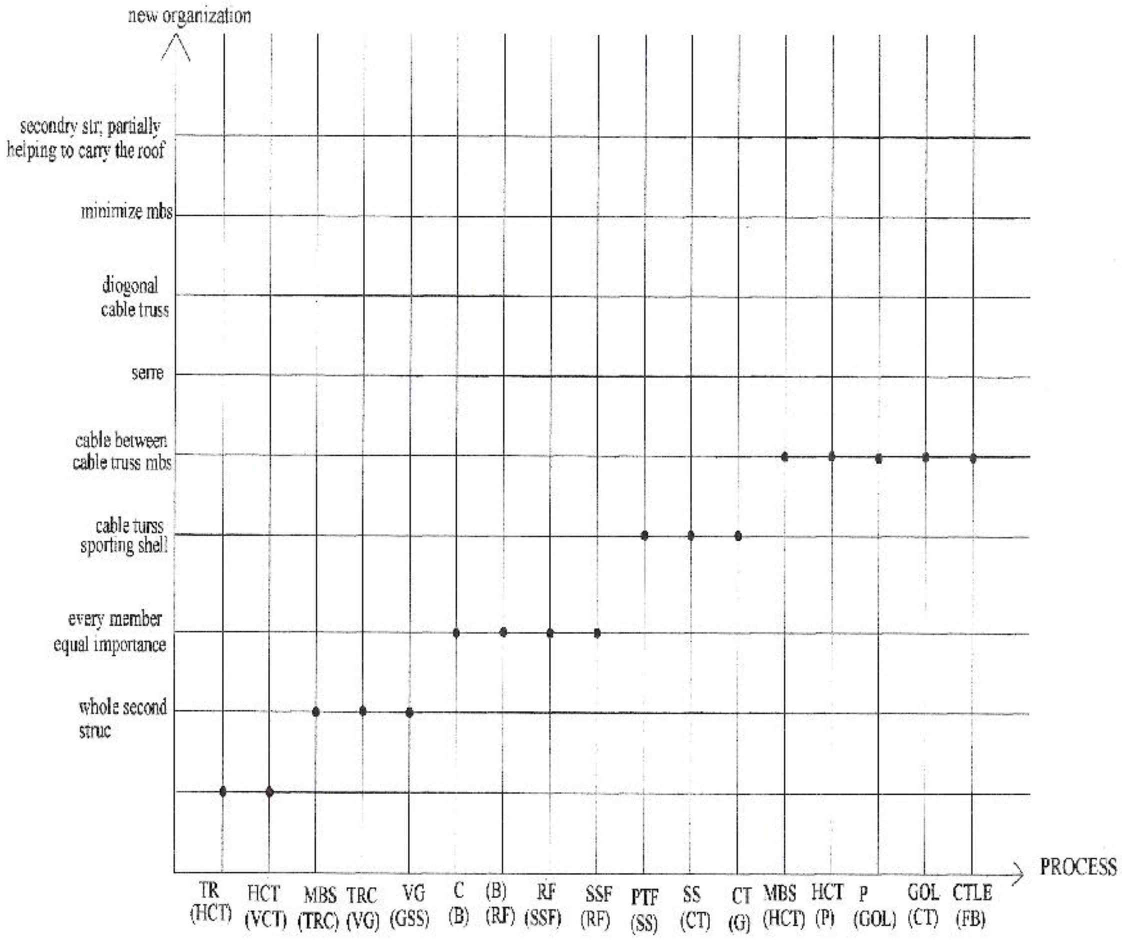


Figure 5 New Organizations /Process

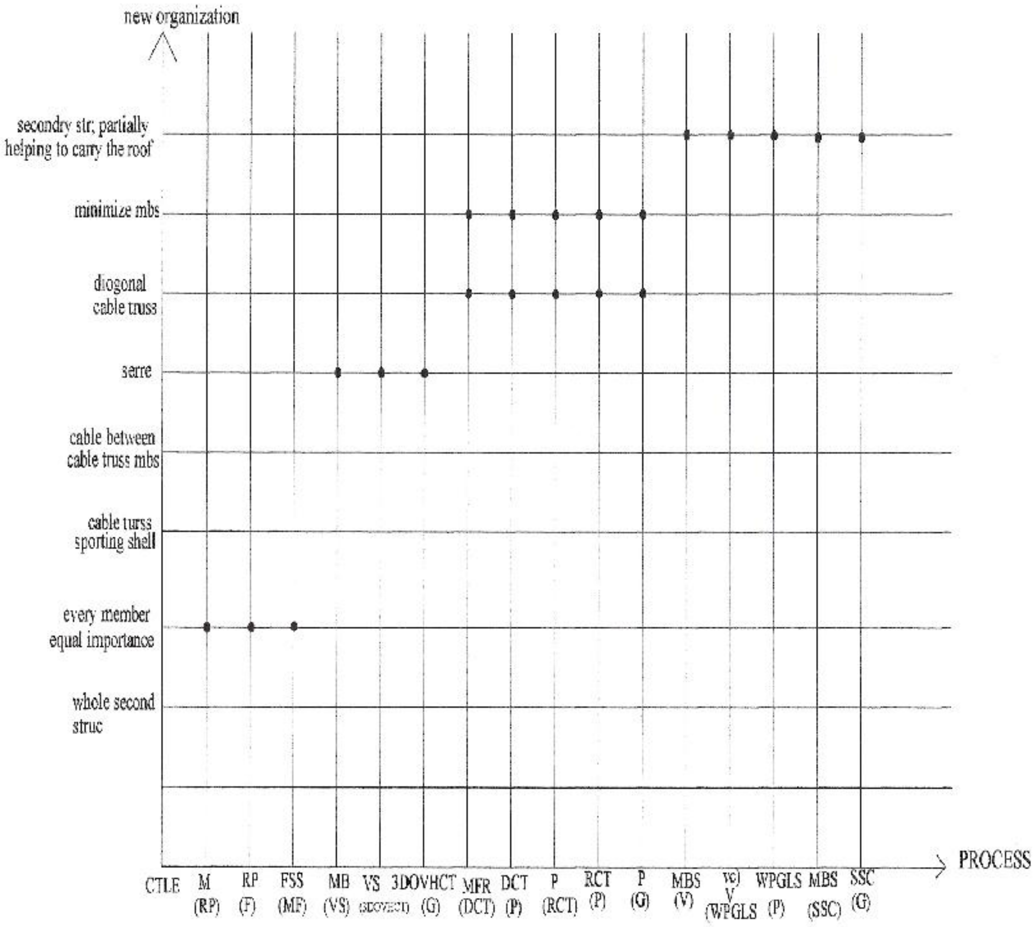


Figure 6 New Organizations /Process

If there is not new organization, then the process of the system is ordered as tension ring first, horizontal cable truss second and vertical cable truss the third. If the wall secondary structure is in a new organization, then the process of building goes as the main building structure first, tension rings second, cables third, vertical glasses forth, glass surface with spiders at last. If every member carries an equal importance for the new organization, then columns are first, branches are second, the removable formwork is third, steel shell formation is forth, removal of the formwork is the last.

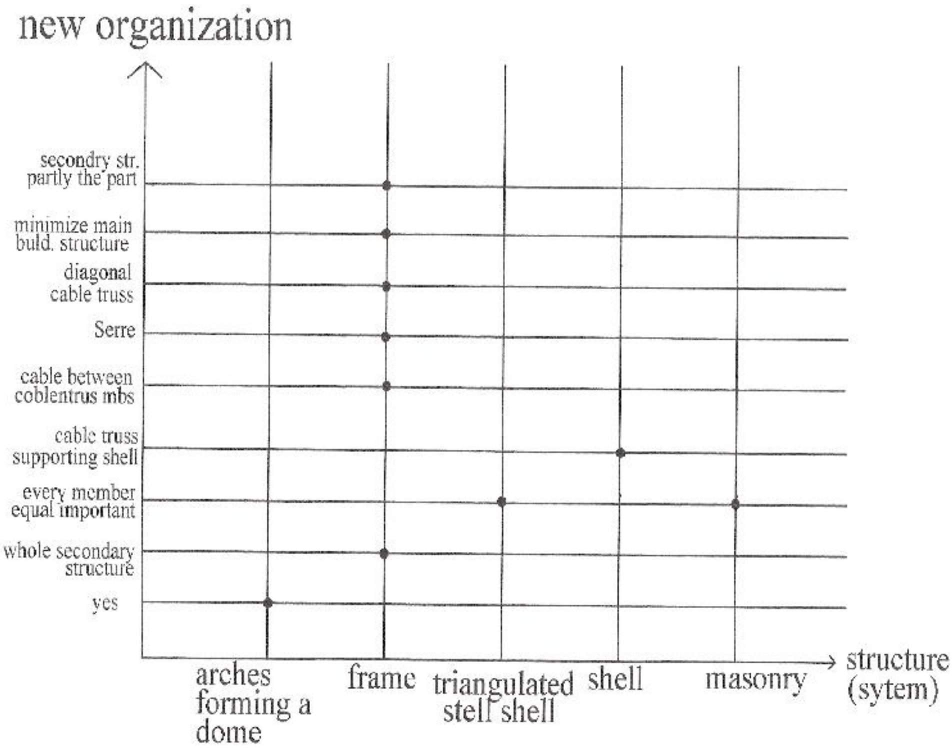


Figure 7 New Organizations/Structure

Or if the structure is masonry and every member has an equal importance, then the building process carries on after masonry removable, partial formwork then formation of steel shell and movement of the formwork at last. If the new organization is cable trusses, supporting shell, then the process follows the order of partial temporary formwork, steel shell, cable trusses and glass. If the new organization is cable between cable trusses, then main building are main building structure first, then after the building process is carried out as horizontal cable trusses first, prestressing, glasses at one level, cables are then set final balancing. If new organization is similar to “Serre” which is the first example, then the building process works as the main building structure first, vertical supports second, 3D organization of vertical and horizontal cable trusses third and glass forth. If the new organization includes diagonal cable trusses, the main building structure is minimized then building process starts after the main frame as;

1 Diagonal cable trusses

2 Pretentioning

3 Roof cable trusses

4 Pre tentioning

5 Glass

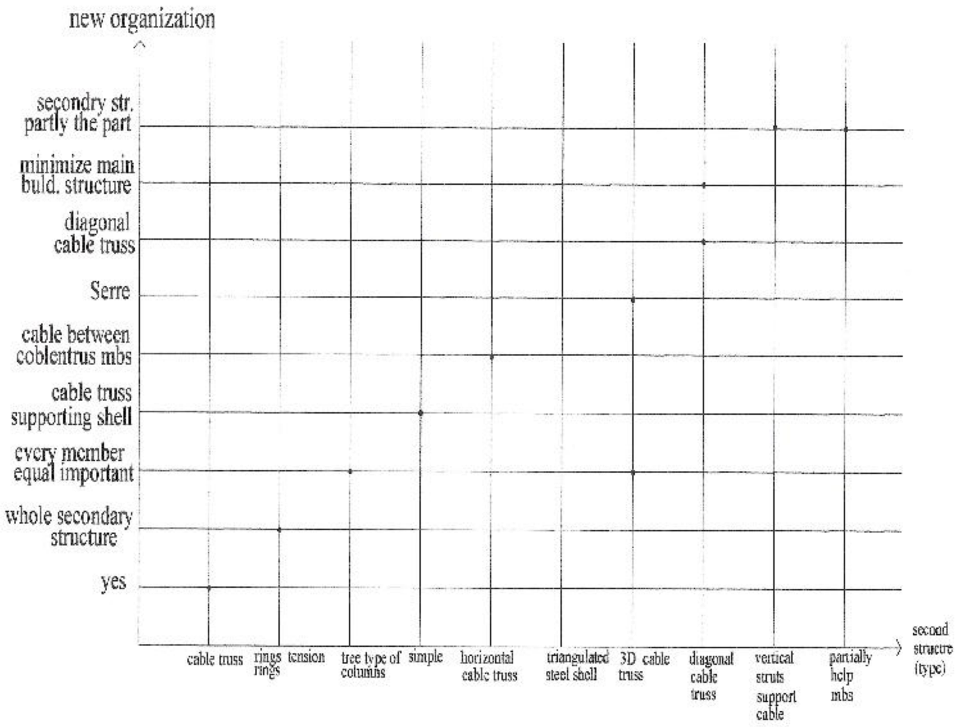


Figure 8 New Organizations /Type of Second Structure

If the new organization of the secondary structure partially helps to carry the roof, there are two alternatives for the building process. First alternative is after the main building structure verticals, while putting glass layers some verticals are supported by cables, then cables are pre-tensioned. Second alternative is after the main building structure 1- struts supported by cables 2- glass are placed.

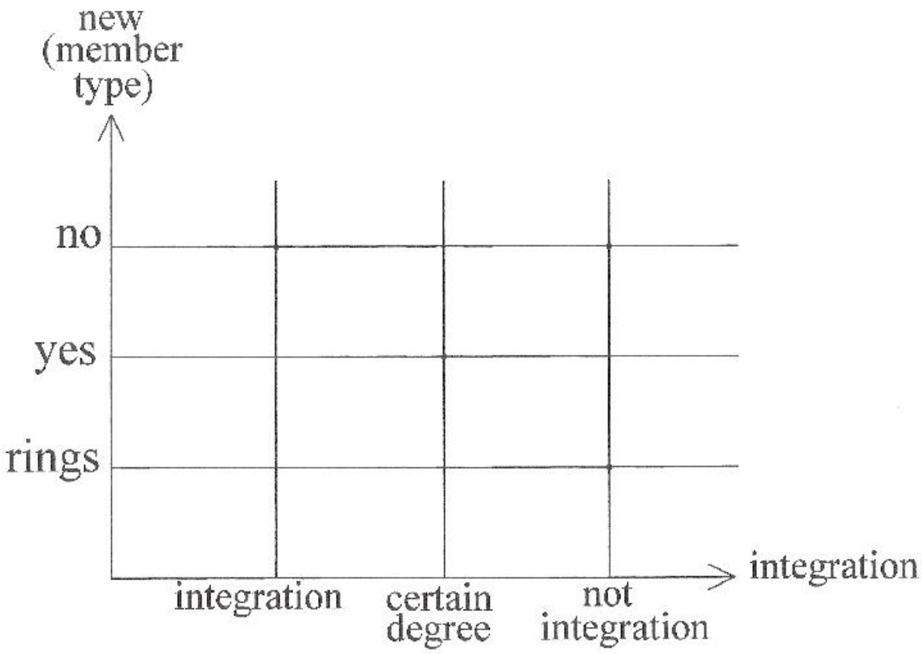


Figure 9 New member type/ integration

If there is no new member type in the structure, it can contain integrated parts or not. If the new member type is rings then the system is not integrated. If there is a new member type, the system is integrated at a certain degree, but not fully.

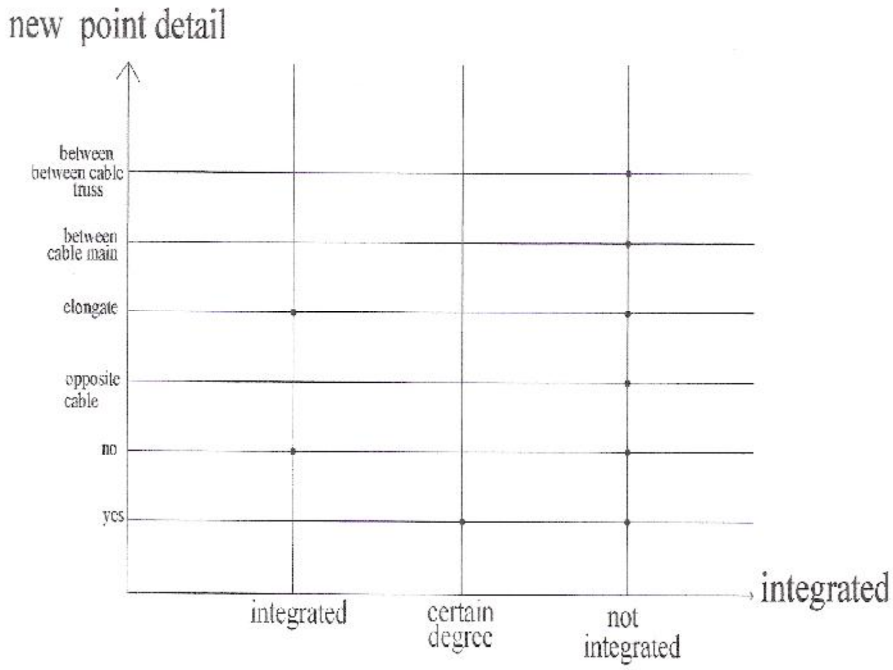


Figure 10 New Point Detail/ Integration

If there is an elongated member then the system is integrated. If there is a new detail, system is not integrated, or not fully integrated, but certain degree of it is integrated. If there is no new detail, the system can be integrated, or not integrated. If detail is an opposite cable system, it is not integrated. If a new detail between the cable and arch or between the cable and cable truss system exists, then system is not integrated.

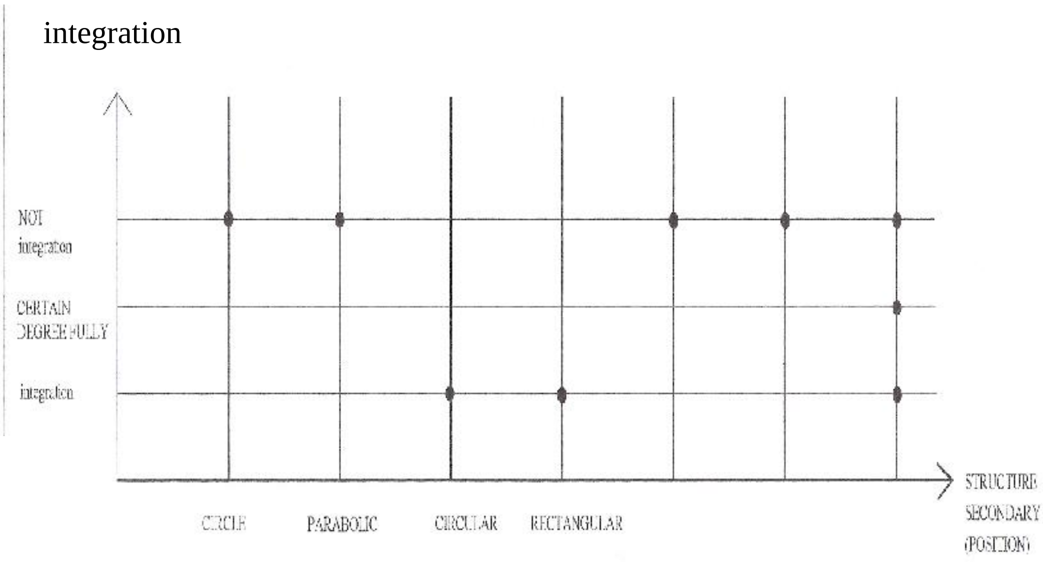


Figure 11 Second structure position/ Integration

If there is a new organization the system is not integrated. If whole of the secondary structure is the new organization, then the system is not integrated. If the new organization concerns every member as equality important, the system can be integrated, or not integrated. If new organization concerns cable between cable truss and main building structure then there is no integration. If there is a diagonal cable truss and main building structure is minimized, then system is integrated. If there is a secondary structure that partially carries the roof, there are two alternatives: they are not integrated, or they are integrated to a certain degree.

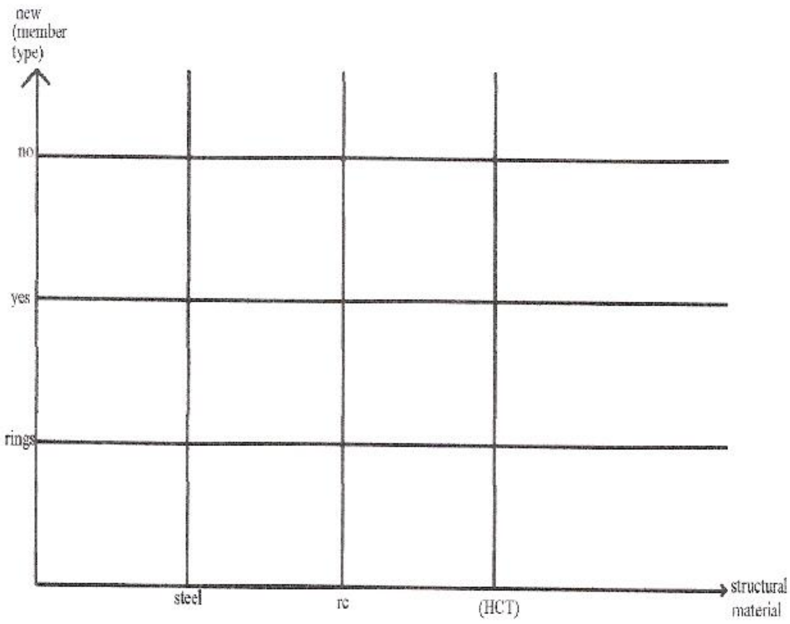


Figure 12 New Member Type/Structural Materials

If there are rings, the new member’s structural material is reinforced concrete. If there is a new member the material is steel. If there is no new member, then the materials used can be either steel, or reinforce concrete, or can be stone. In Masonry structures, shells and triangulated steel shell there is no new member type. If structural system includes a frame, the new members can consist of both rings or no new members exist. If structural system consists of arches forming a dome, there can be new member types, or not.

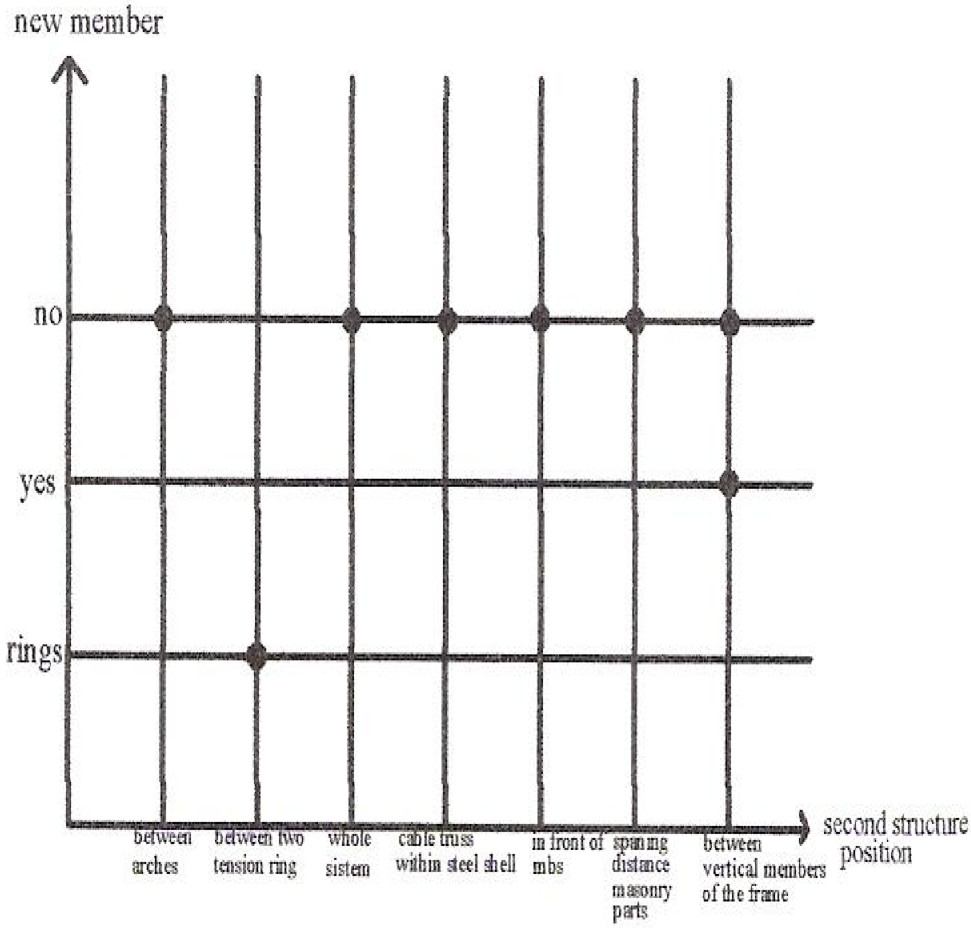


Figure 13 New member/Position of the second structure

If the type of the second structure consists of rings or tension rings then the new member is rings. If second structure type is vertical struts which carry glass pieces, some of these verticals are supported by cables then there is a new member.

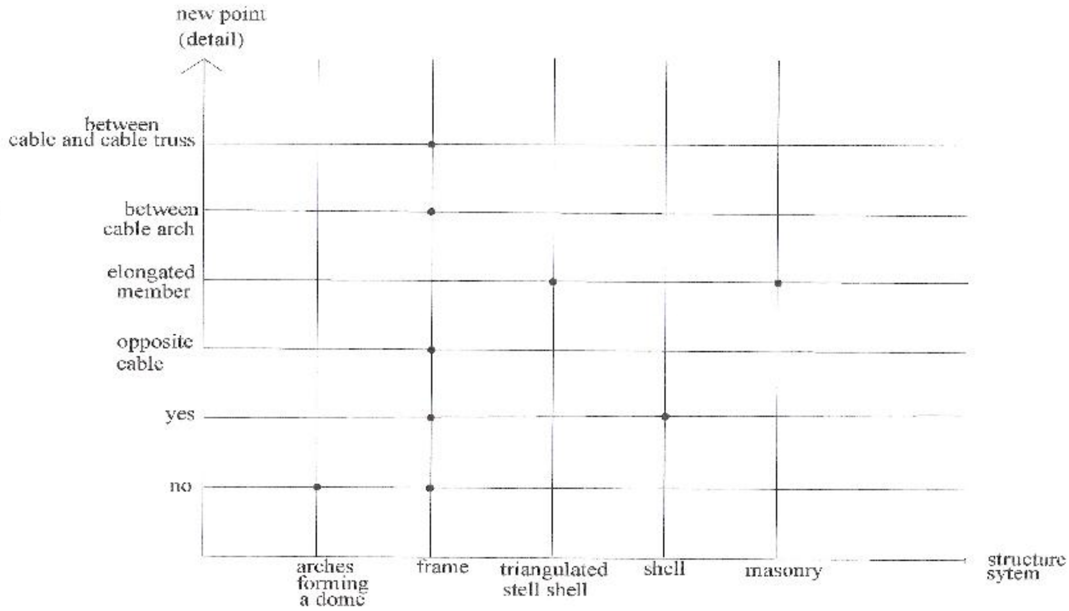


Figure 14 New Point Detail/Structural System

If the structural system consists of arches forming a dome, then there is a new point detail. If the structural system is based on a shell, there is no new point detail. If the structural system is masonry or triangulated steel shell, then there are elongated members. If the structural system is a frame, there is opposite cable connection points and there can be a new point detail.

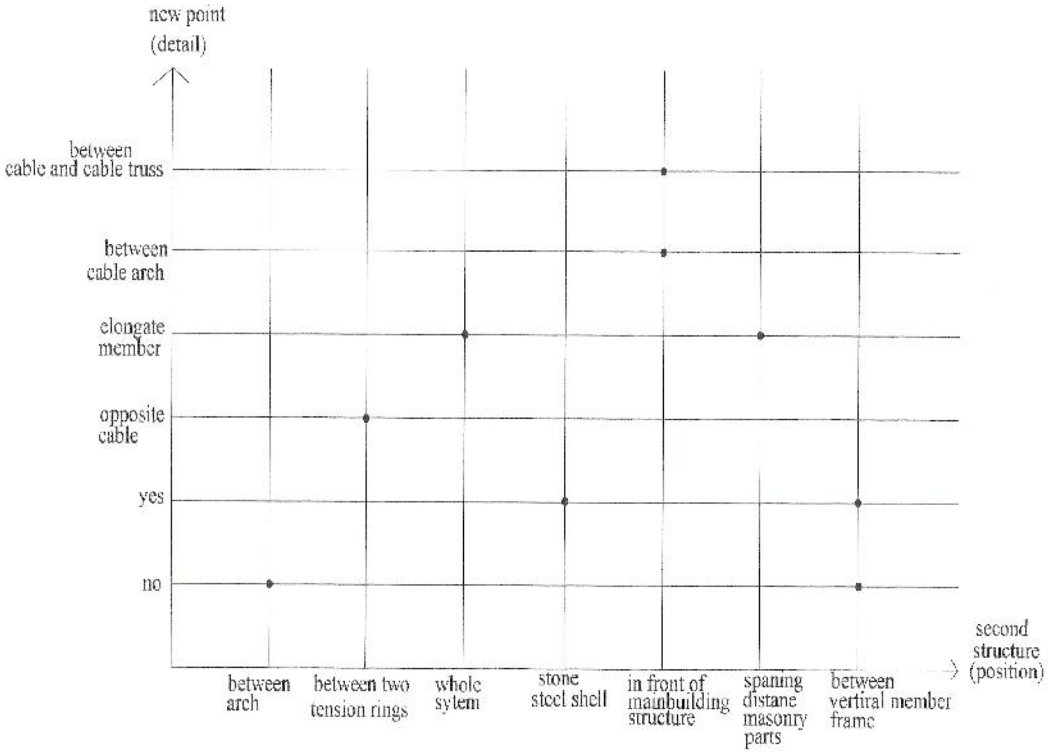


Figure 15 New Point Detail/ Position of the Second Structure

If the position of the second structure is between arches or between vertical members of frame, then there is a new point detail. If the position of second structure is between cable truss steel shell or between vertical members frame, then there is no new point detail. If the position of the second structure is between two tension rings then there is an opposite cable. If the position of the second structure concerns the whole system or spanning of the distance of masonry parts then there are elongate members. If the position of the second structure is in front of the main structure then there is a new point detail. If the position of the second structure between two tension rings then the new member is a ring. If the position of the second structure is in between the vertical members of the frame, there is a possible new member or not.

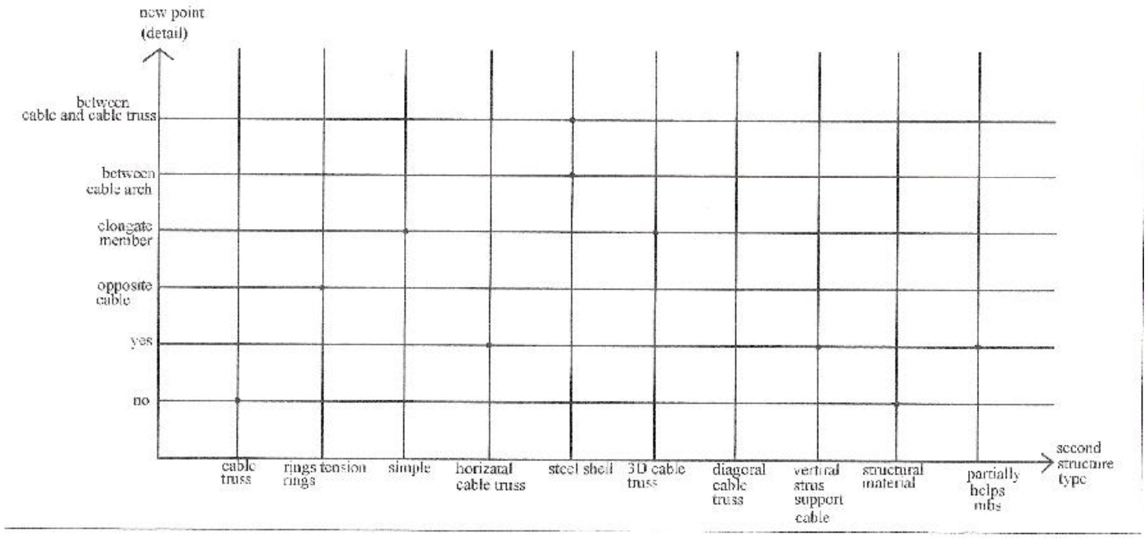


Figure 16 New Point Detail/ Second Structure type

If the second type of structure is cable truss or vertical struts carry the glass pieces, some of these verticals are supported by cables, and then there is a new point detail. If the type of the secondary structure consists of rings then there is an opposite cable. If the type of the second structure is tree type of columns supporting from various points or triangulated steel shell then there are elongated members. If the type of the second structure is simple, diagonal cable truss, partially struts support cables, and then there is no new point detail. If the second type of structure is horizontal cable truss, then there is a new point detail.

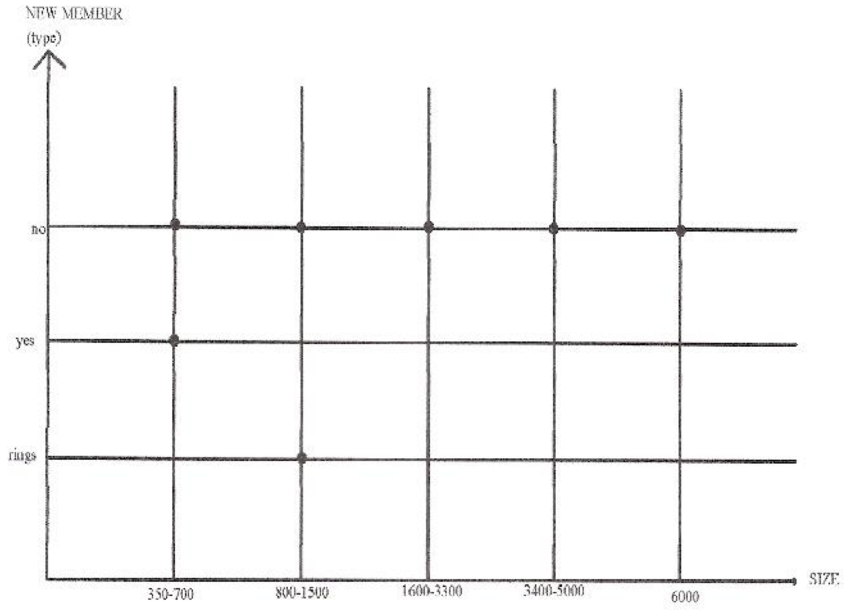


Figure 17 New Member Type/Second Structure Size

If the second structure size is measured more than 15 meters, then there is no new member. If the size of the second structures is measured from 8 meters to 15 meters, then there are rings or other new types of members.

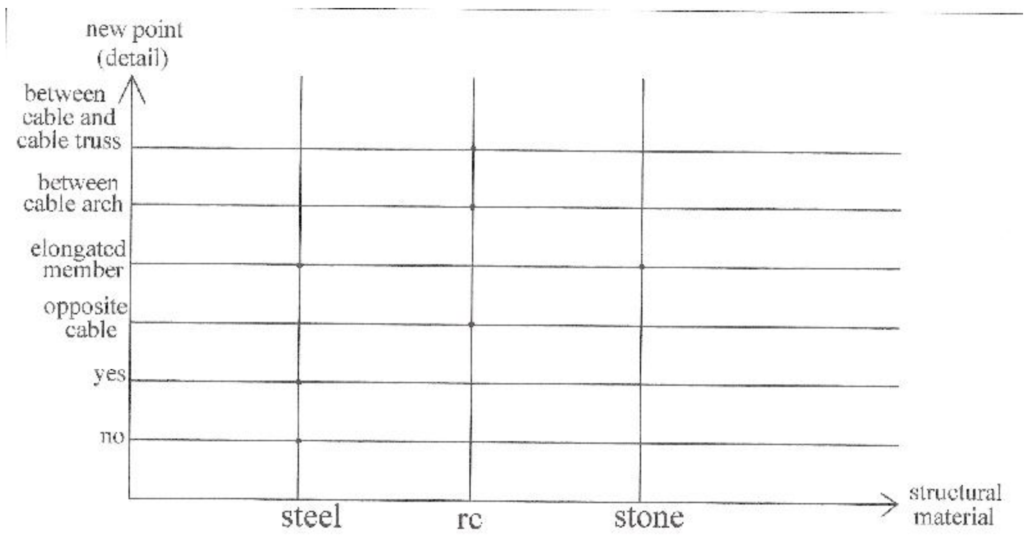


Figure 18 New point detail/Structural materials

If the structural material is steel or stone, then elongate members possibly exist. If the secondary structure's size is measured between 8-15 m, there are elongated members or opposite cables. If the size of secondary structure differs between 16-33 m, there is a new point detail between cable and cable truss or between cable and arch. If the size of the secondary structure differs between 34-50 m, there are elongated members. If the size of the secondary structure is measured more than 60 m, then there is no new point detail.

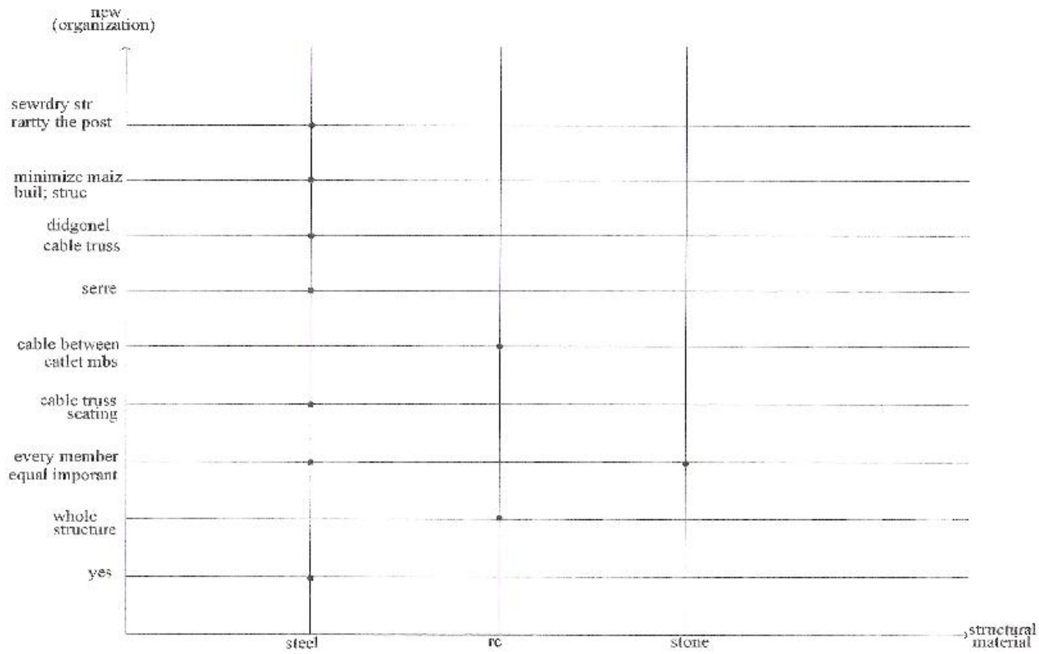


Figure 19 New organization/ Structural material

If the structural material is steel, the secondary structure partially helps to carry the roof, or there are diagonal cable trusses, or main building structure is minimized, or cable trusses support the shell, or every member has an equal importance. If the structural material is reinforced concrete then the whole secondary structure is subjected to a new organization. If the structural material is stone, then every member has an equal importance.

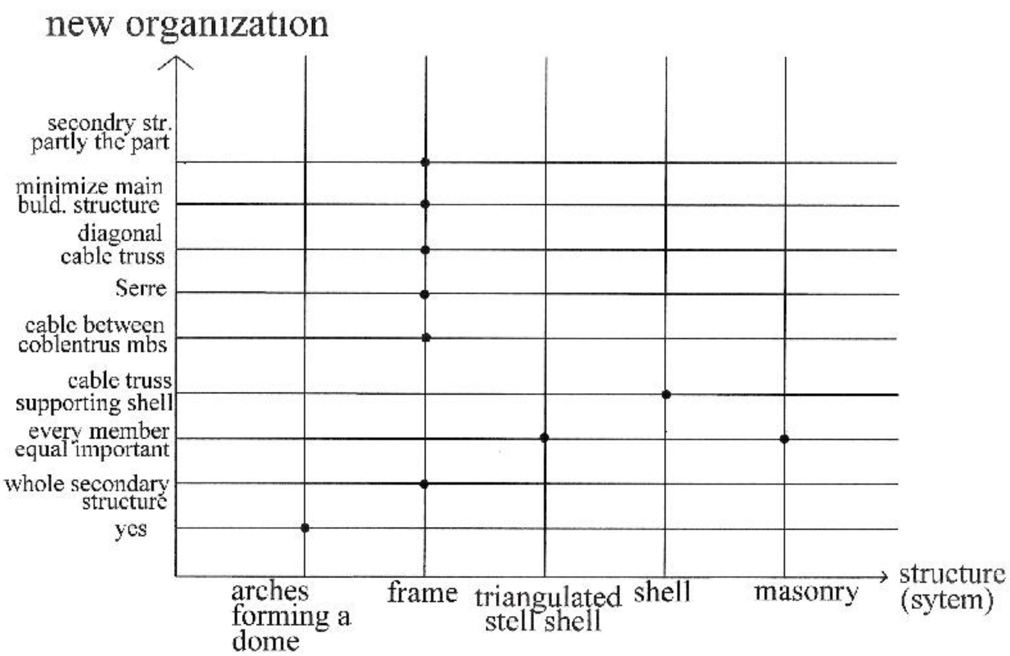


Figure 20 New Organizations/ Structural System

If the structural system is a frame, then whole structure is re-considered in terms of the new organization. Cables between cable trusses exhibit the features of diagonal cable trusses, or the main building structure or secondary structure partially helping to carry the roof is minimized.

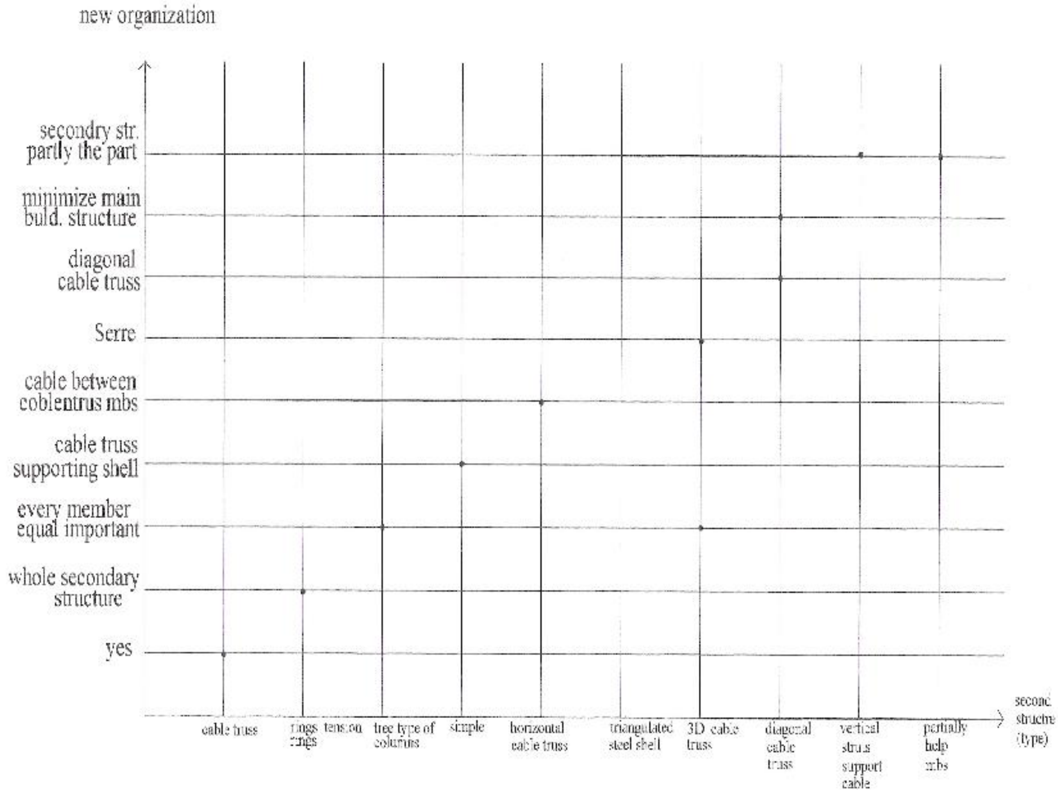


Figure 21 New Organization /Type of Second Structure

If the type of the secondary structure is based on tension rings then the whole secondary structure is included in a new organization. If the type of the new organization is tree type of columns support from various points, then every member has an equal importance. If the type of the secondary structure is simple, then there is a cable truss, supporting the grid shell, if the type of the secondary structure is horizontal simple cable truss then there is a new organization between cable, cable truss and the main building structure. If the type of the secondary building structure is triangulated steel shell, then every member has an equal importance. If the type of the second structure consists of 3D cable trusses it is “Serre” type. If the secondary structure’s type is diagonal cable truss, it is possible to minimize the main building structure. If the secondary structure’s type is vertical struts, which carry glass pieces, some of these verticals are supported by cables, or they partially help the main building structure to carry the roof struts, which are supported by cables.

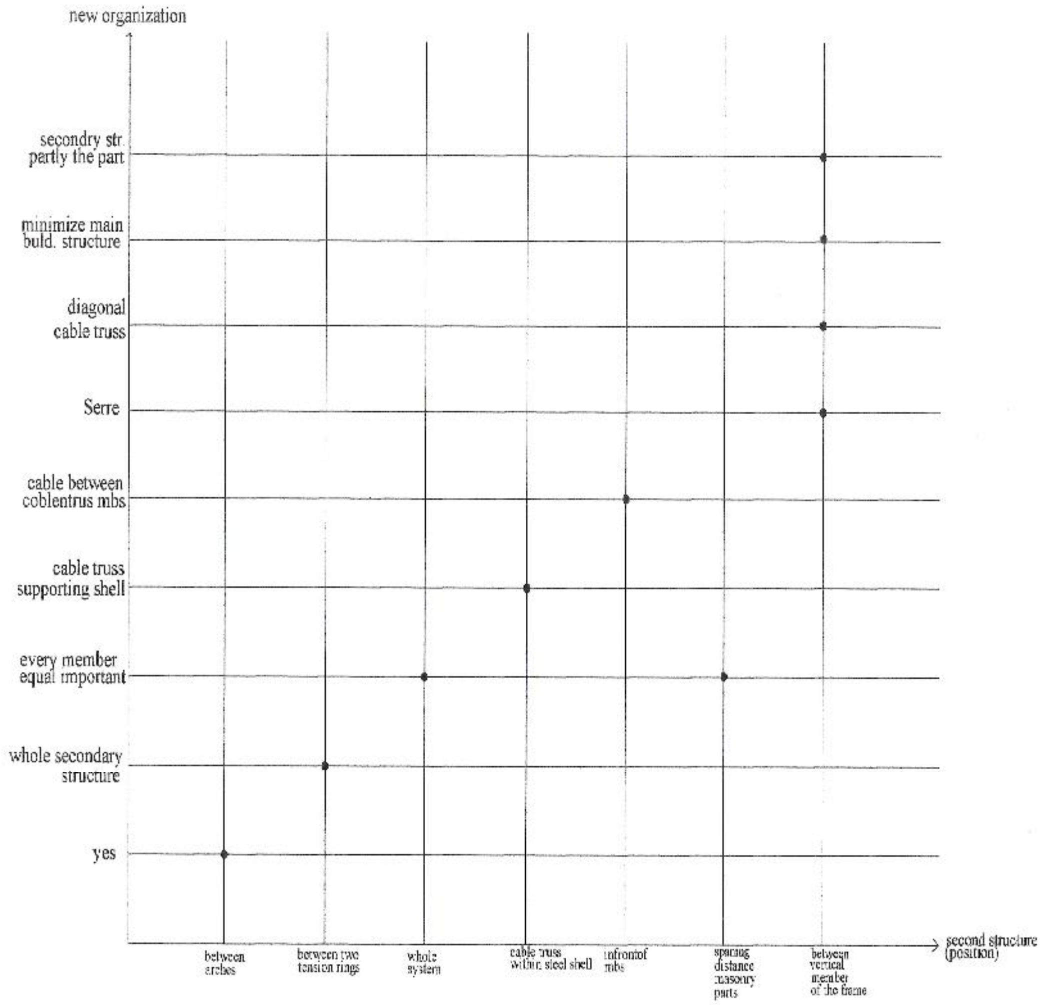


Figure 22 New Organization/Position of Second Structure

If the position of the secondary structure is between two tension rings then, the secondary wall structure is a new organization. If the position of the secondary structure is within the whole system, then every member has an equal importance. If the position of the secondary structure which is a cable truss, is within the steel shell, then the new organization is based on cable trusses supporting the steel shell. If the position of the secondary structure is in front of the main building structure, then the new organization is done between cable, cable truss and the main building structure. If the position of the secondary structure spans the distance between two masonry parts, then every member has an equal importance. If the position of the second structure is between the members of the frame, it is possible for it to look like "Serre" or to have diagonal cable trusses and the main building structure can be minimized, or the secondary structure can partially helps to carry the roof.

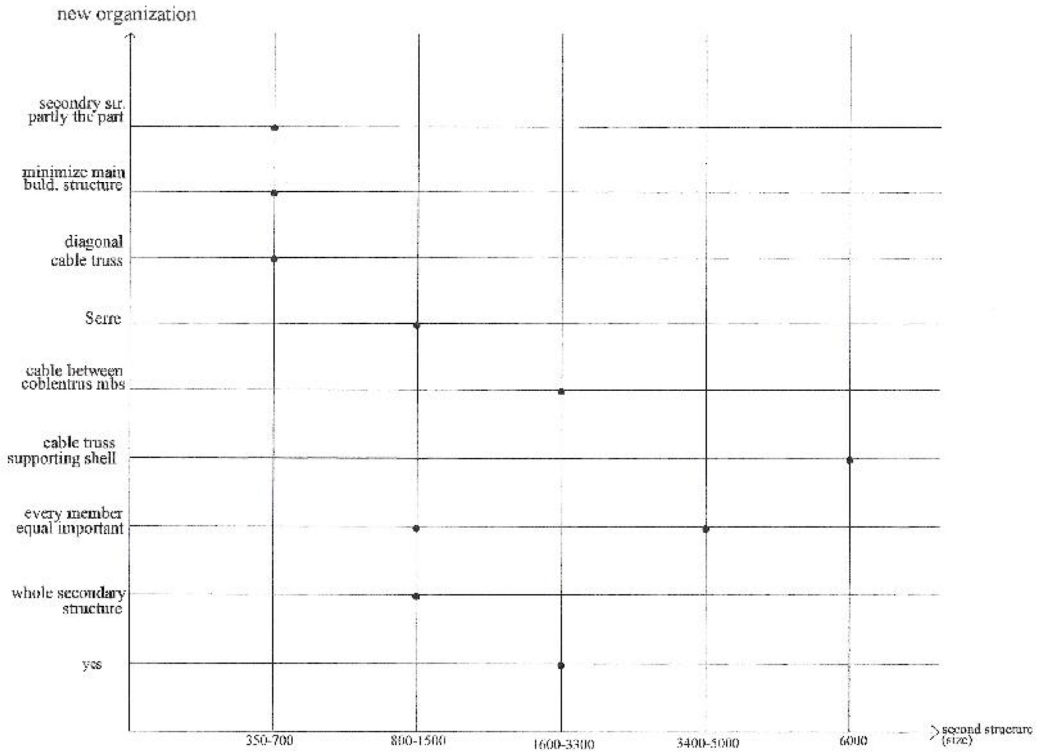


Figure 23 New Organizations/ Size of Secondary Structures

If the size of the secondary structure is between 3.5-7 m, there could be diagonal cable trusses, minimization of the main building structure is done, and the secondary structure partially helps the roof. If the size of the secondary structure is between 8-15 m, and it is like "Serre", every member has an equal importance, and the whole secondary structure is included in the new organization. If the size of the secondary structure is between 16-33m., there is a new organization. If the size of secondary structure is between 34-50 m. every member has an equal importance. If the size of the secondary structure is bigger than 60 m, then the cable truss supports the shell.

New member type

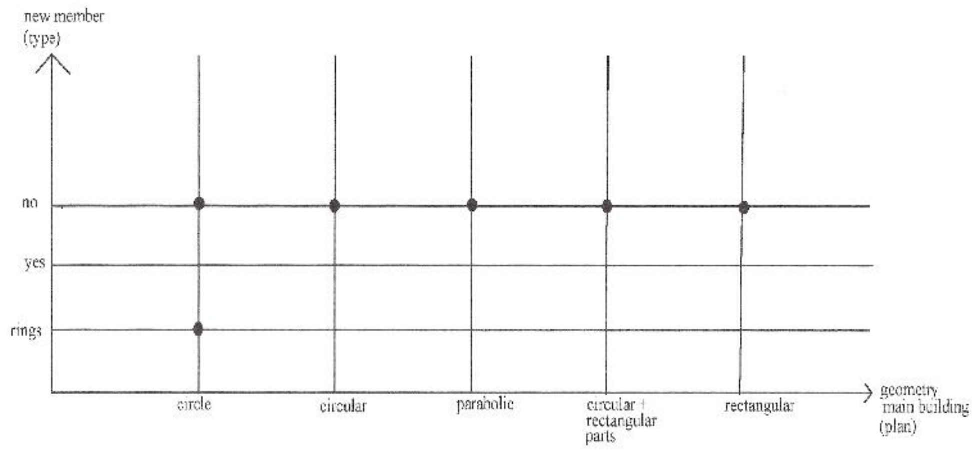


Figure 24 New Member Type/ Section Geometry of the Main Building

If the main building plan geometry is circular, then the new member type can be rings. If the main building plan geometry consists of parabolic or circular shapes which includes triangular parts, then there is no new member type.

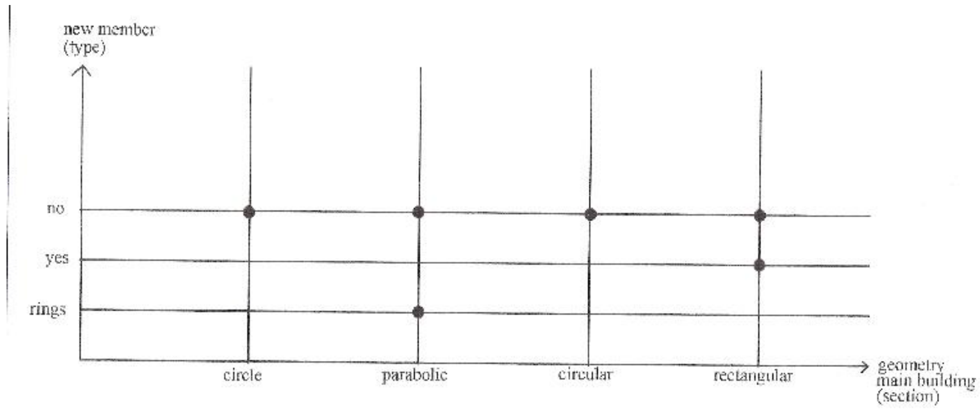


Figure 25 New Member Type/ Section Geometry of the Main Building

If the section geometry of the main building is a circle or circular, then there is no new member type. If the section geometry of the main building is parabolic, then there can possibly be a new member type as rings.

If the plan geometry of the secondary structure is based on straight axes, then there is no new member type. If the plan geometry of the secondary structure is circular, then there can possibly be rings as a new member type. If the plan of the secondary structure geometry is rectangular, it can possibly be a new member type.

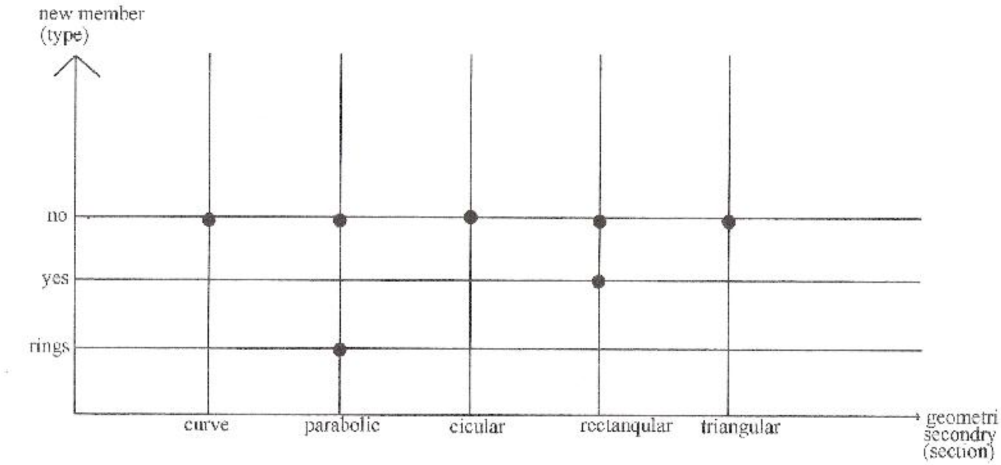


Figure 26 New Member Type/ Section Geometry of Second Structure

If the section geometry of the secondary building structure is curved, circular or triangular, then there is no new member type. If the section geometry of the secondary building structure is parabolic, there can possibly be rings as new member type. If the section geometry of the secondary building structure is rectangular, then there can possibly be a new member type.

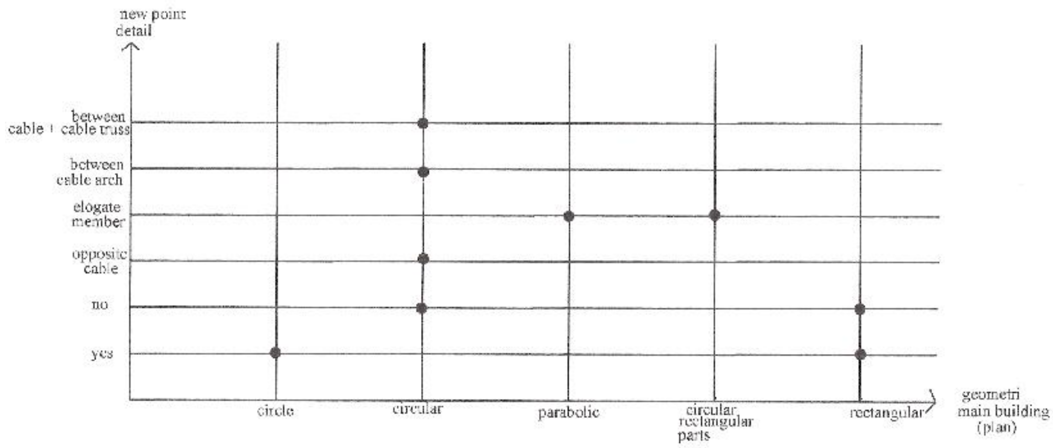


Figure 27 New Point Detail/ Plan Geometry of Main Building

If the plan geometry of the main building is a circle, then there is a new point detail. If the plan geometry of the main building is circular, then it is possible to have opposite cables, or a new point detail between cable and cable truss, or between cable and arch. If the plan geometry of the main building geometry is parabolic, or if it contains circular + rectangular parts, then there are elongate members as new point details. If the plan geometry of the main building is rectangular, there can possibly be a new point detail.

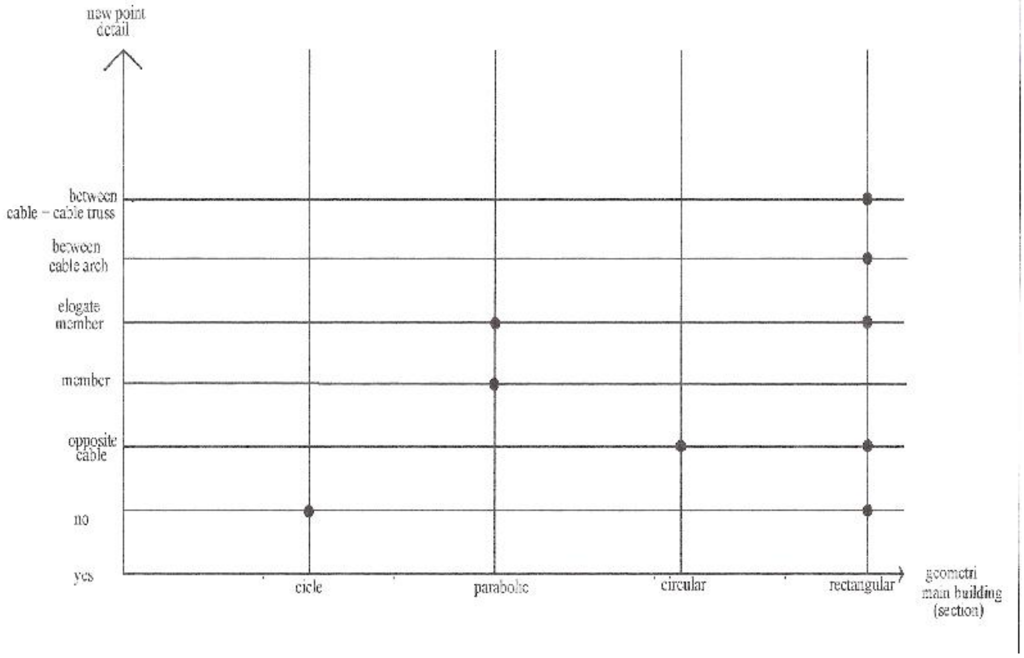


Figure 28 New Point Detail/ Section Geometry of Main Building

If the section geometry of the main building is a circle, then there is a new point detail. If the section geometry of the main building is parabolic, there is opposite cable or elongated members. If the section geometry of the main building is circular, then there is no new point detail. If the section geometry of the main building geometry is rectangular, then there can possibly be elongated members, or a new point detail between cable and cable truss or between cable and cable arches.

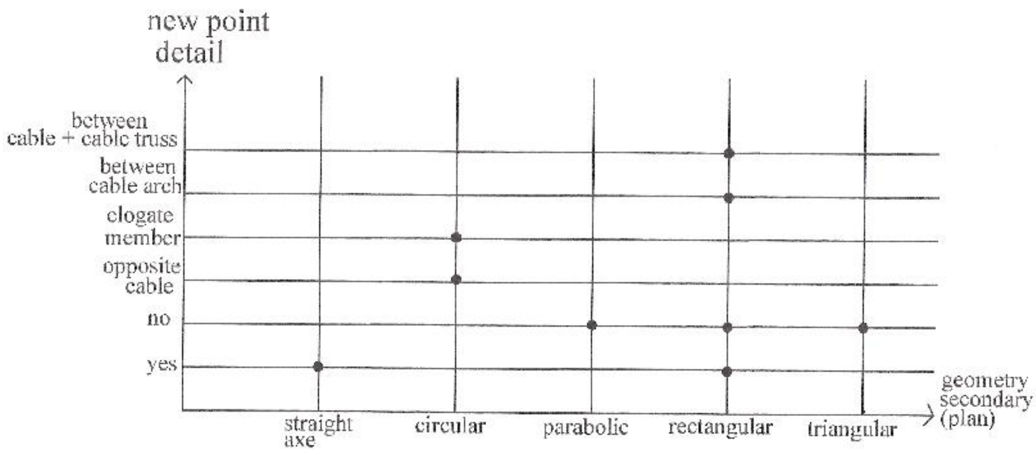


Figure 29 New Point Detail/ Secondary structure plan

If the plan geometry of the secondary structure's is based on straight axes, then there is a new point detail. If the plan geometry of the secondary geometry is circular, there can possibly be opposite cable. If the plan geometry of the secondary structure geometry is parabolic, or if it contains circular rectangular parts, then there are elongated members as a new point detail. If the plan geometry of the secondary structure geometry is rectangular, then there is a new point detail between cable and cable truss or between cable and cable arch.

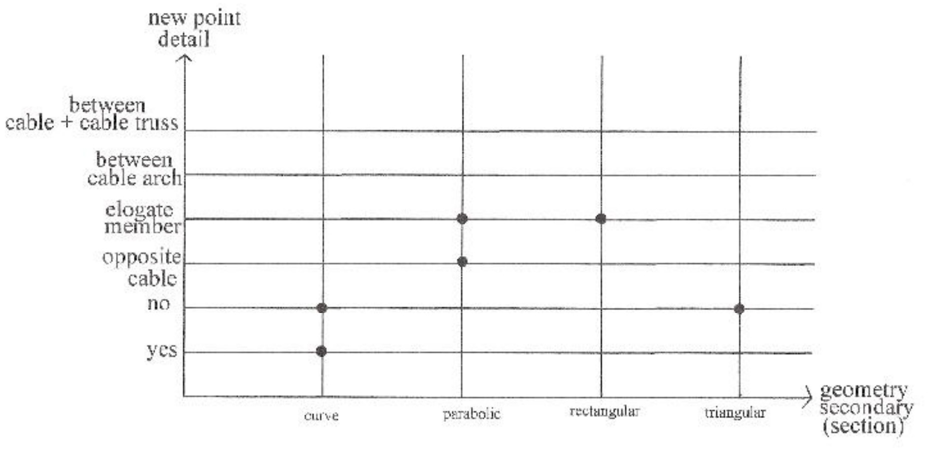


Figure 30 New Point Detail/ Section Geometry of Secondary Structure

If the section geometry of the secondary structure is curved then there is a new point detail. If the section geometry of the secondary structures is parabolic then it is possible to be elongated members, or opposite cables as a new point detail. If the section geometry of the secondary structure is circular or triangular, then there is no new point detail. If the section geometry of the secondary structure geometry is rectangular, it is possible to have a new point detail between cable and cable truss and between cable and cable arches.

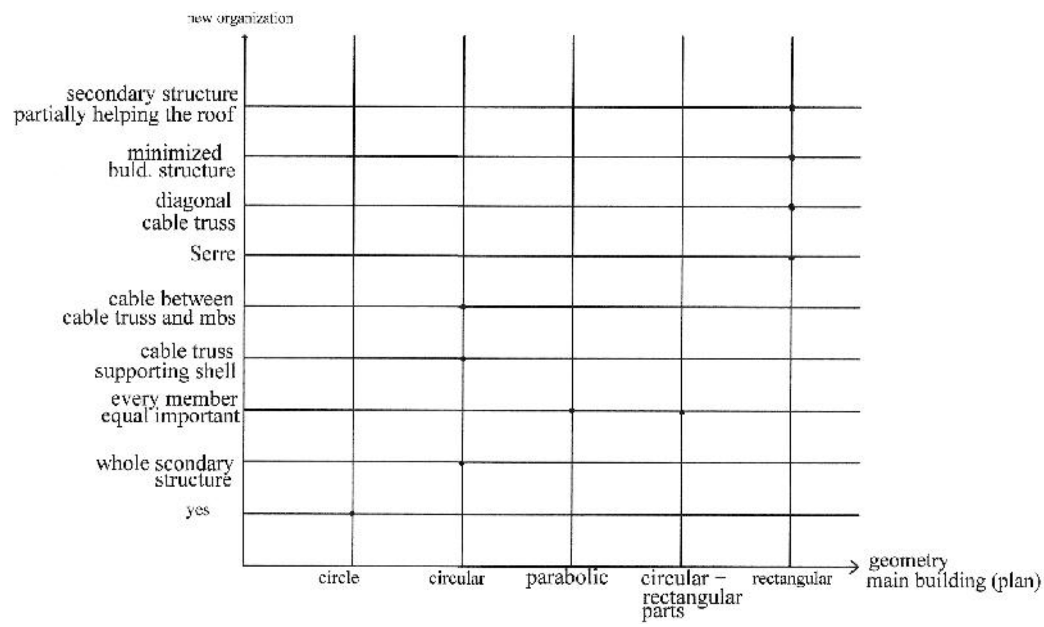


Figure 31 New organization/ Plan Geometry of Main Building

If the plan geometry of the main building is a circle, then there is a new organization. If the plan geometry of the main building is circular, then the whole secondary structure is included in the new organization, or cable trusses support the shell or there are cables between cable trusses and the main building structure. If the plan geometry of the main building is parabolic or circular, including rectangular parts, then each member has an equal importance in the system. If the plan geometry of the main building is rectangular, then it is “Serre” type or it has diagonal cable trusses, minimizing the main building structure, or secondary structure partially helps to carry the roof.

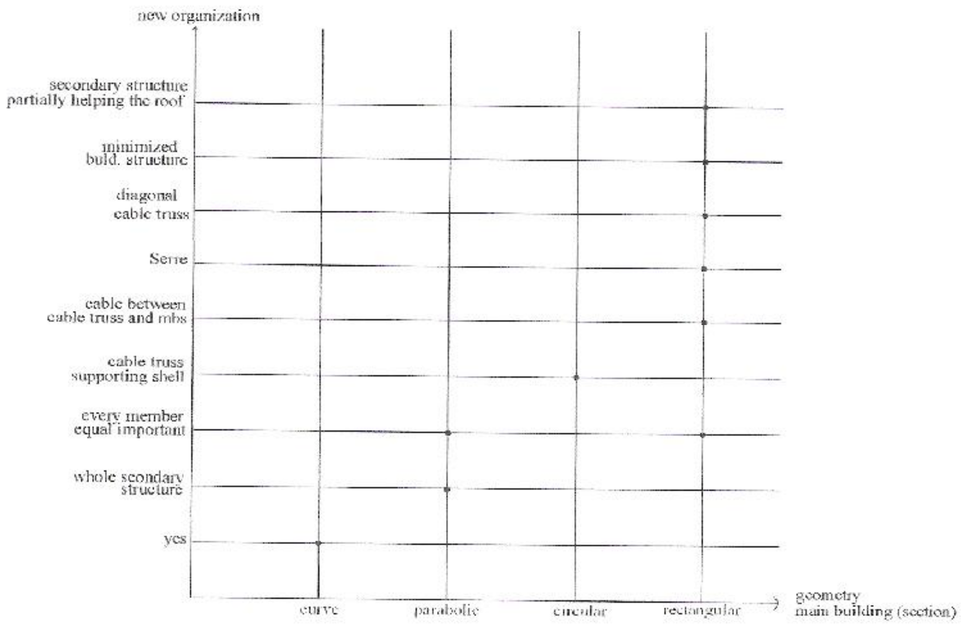


Figure 32 New Organization/ Section Geometry of Main Building

If the section geometry of the main building is circle, then there is new organization. If the section geometry of the main building is parabolic, then the whole second structure is included in the new organization and every member has an equal importance. If the section geometry of the main building is circular, then the new organization includes cable truss supporting the steel shell. If the section geometry of the main building is rectangular, then it can possibly be “Serre” or it is possible to have an equal importance for every member, it is possible to have diagonal cable truss, it is possible to minimize the main building structure or it is possible for the secondary structure to partially help carrying the roof.

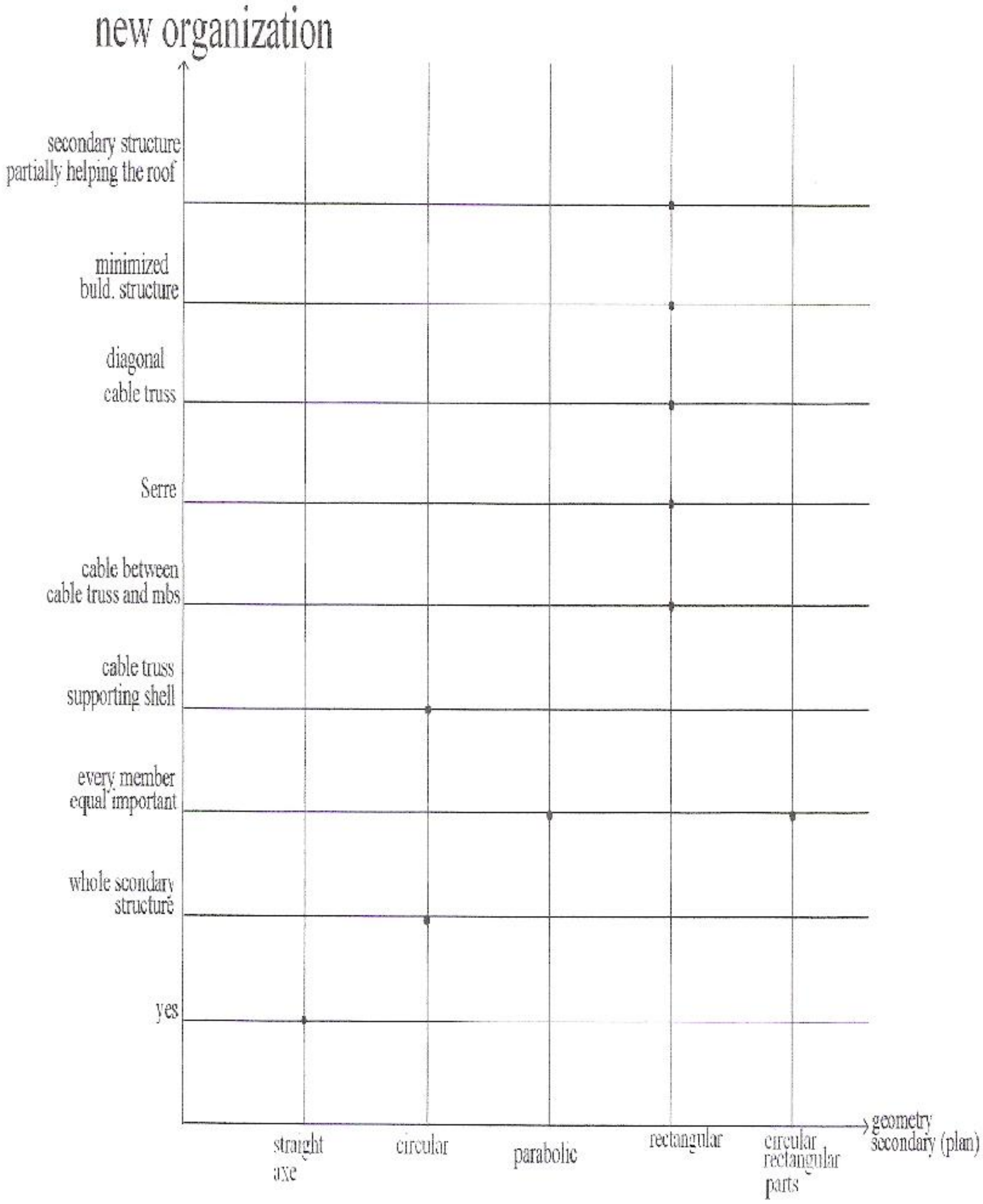
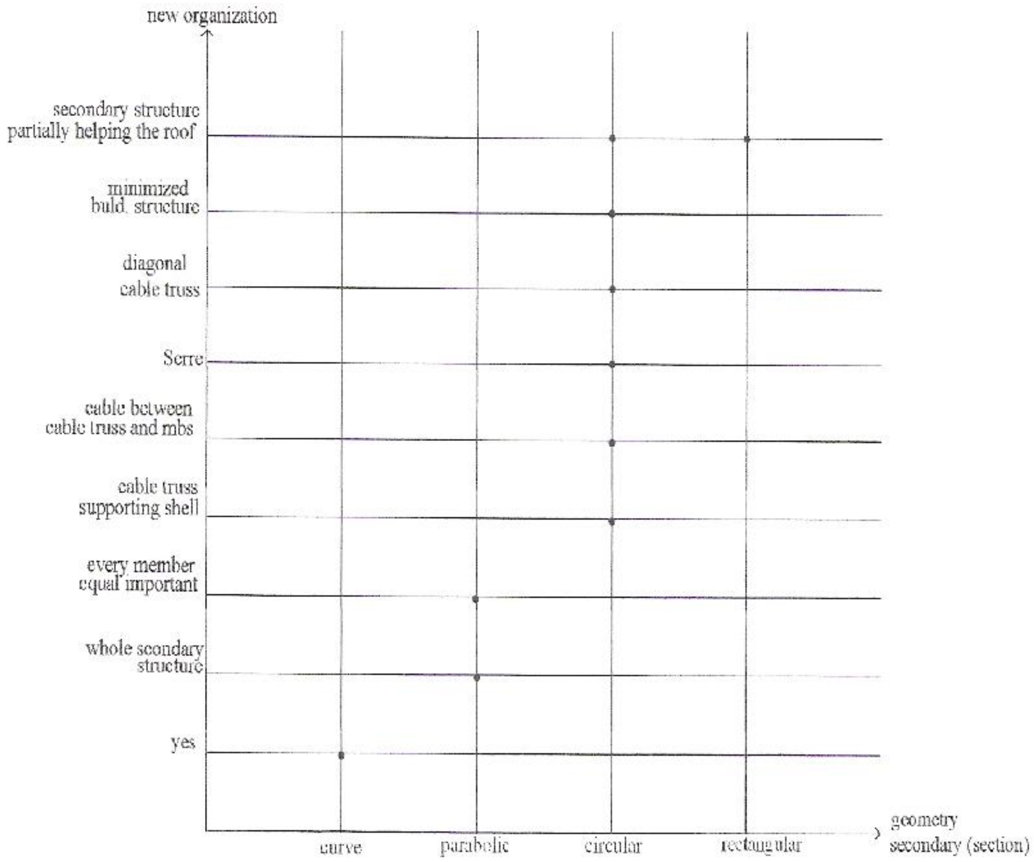


Figure 33 New Organization /Plan Geometry of Secondary Structure

If the plan and the section geometry of the secondary structure are based on straight axes, then there is a new organization in the system. If the plan geometry of the secondary structure geometry is circular, then the whole second structure is included in the new organization, or cable trusses support the shell. If the plan geometry of the secondary geometry is parabolic, circular including rectangular parts), then every member has an equal importance in this system. If the plan of the secondary structure geometry is rectangular, it can possibly be “Serre” type, it would possibly have diagonal cable trusses, and then it is possible to minimize the main building structure. There can possibly be cables between cable trusses and the building structure or the secondary structure can partially help to carry the roof.



Section

Figure 34 New organization/ Section geometry of secondary structure’s sectio geometry of the

If the section geometry of secondary structure is curved, then there is a new organization in this system. If the section geometry of the secondary structure’s is parabolic, then we can say that the whole secondary structure is a new organization, or every member has an equal importance. If the section geometry of the secondary structure geometry is circular, then the new organization is cable trusses supporting the shell. If the section geometry of the secondary structure geometry is triangular, then the secondary structure partially helps to carry the roof.

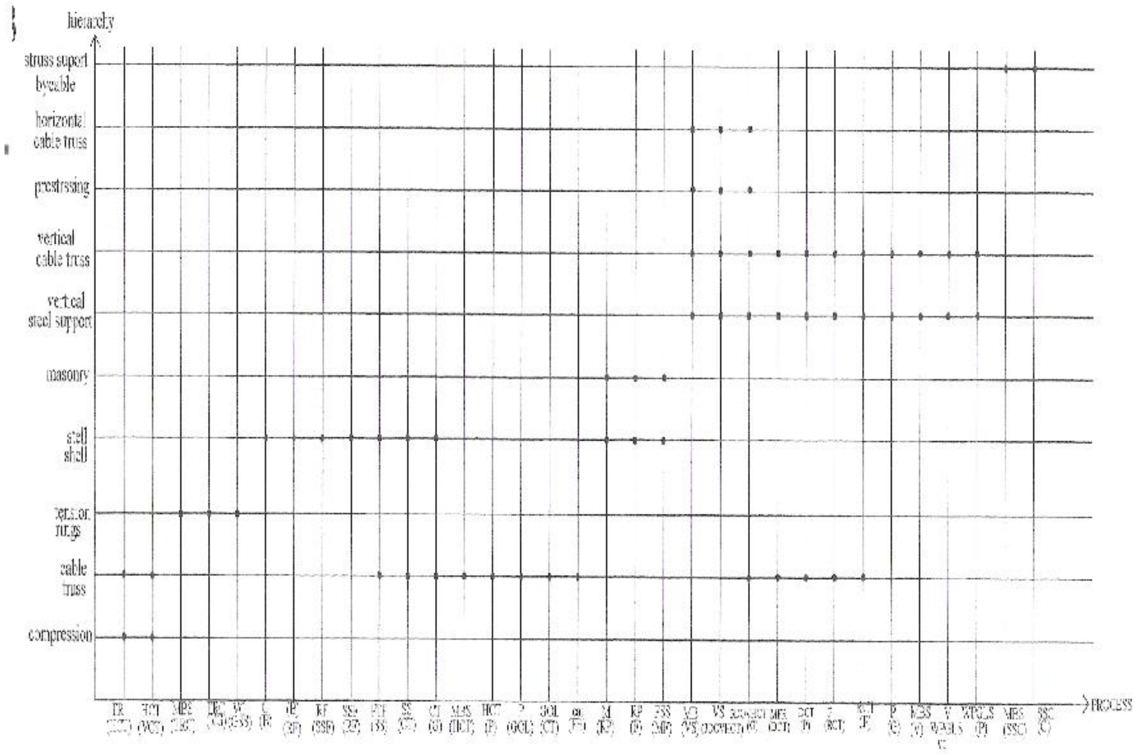


Figure 35 Hierarchies/ Construction Process

There are ten different group of hierarchy.

1- Arches and compression ring -cable truss-glass

2- Main building structure- tension rings-rings and cables-glass

3- Columns- branches of columns- steel shell-glass

4- Steel shell –cable trusses-glass

5- Main building –cables-cable truss-glass

6- Masonry – steel shell-glass

7- Main building structure- vertical steel supports of cable trusses- vertical cable trusses which correspond to vertical steel supports – prestressing – horizontal cable trusses- prestressing- glass

8- Verticals – cable trusses- glass

9- Main building structure – verticals- glass

10- Main building structure-struts- struts supported by tables- glass

And there are ten different construction processes;

Process 1: tension ring-horizontal cable truss-vertical cable truss.

Process 2: main building structure- tension ring cables- vertical pieces of glass-glass surface with spiders.

Process 3: columns-branches-removable formwork-steel shell formation-removal of the formwork.

Process 4: partial temporary formwork-steel shell-cable trusses-glass.

Process 5: main building structure- horizontal cable trusses-prestressing-glasses at one level- cables are tensed- final balancing.

Process 6: masonry-removable partial formwork- formation of stell shell- removal of the formwork.

Process 7: main building – vertical supports- 3D organization of vertical and horizontal cable trusses- glass.

Process 8: main frame-diagonal cable trusses- pretensioning- roof cable trusses-pretensioning-glass pieces.

Process 9: main building structure – verticals -while putting glass layers some verticals are supported by cables-pretensioning.

Process 10: main building structure – struts supported by cables- glass pieces.

There is a direct relationship between hierarchy and the construction process.

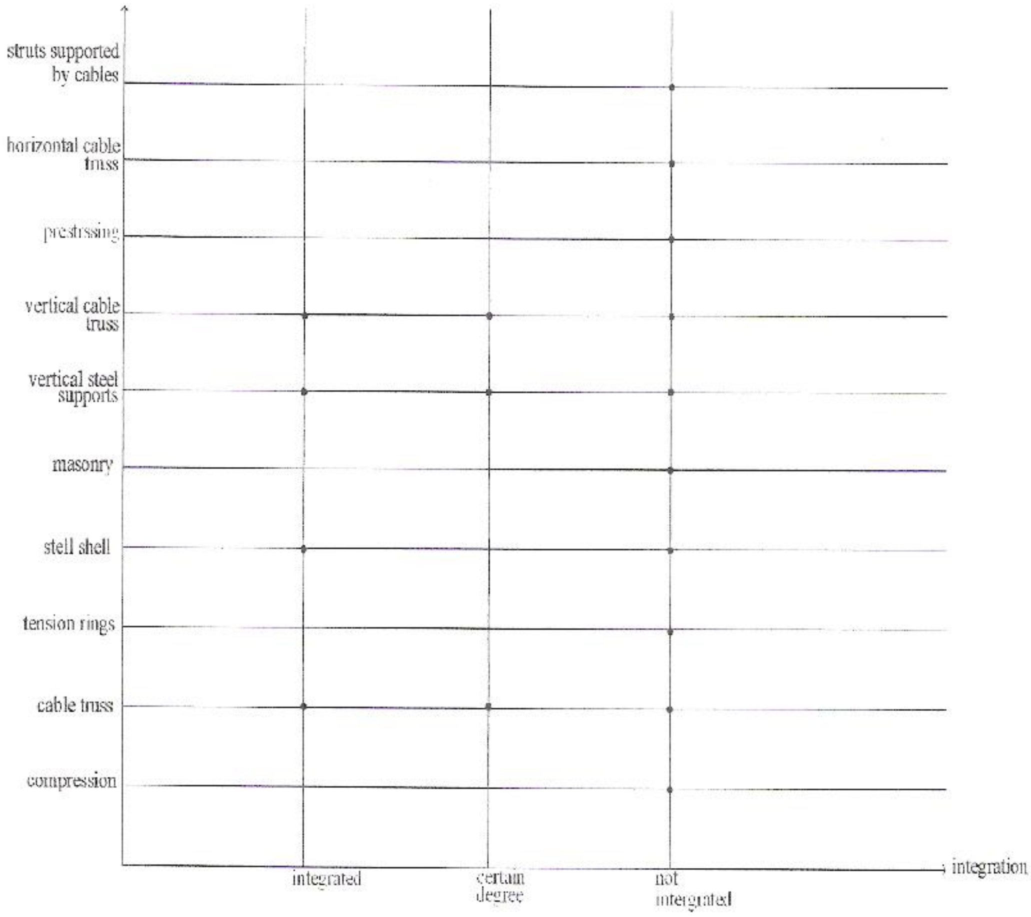


Figure 36 Hierarchy/ Integration

There is no integration in the 1-2-5-6-7 and 10. group of hierarchy.

There is integration in the 3-4 and 8. group of hierarchy.

There is a certain degree of integration in group 9 in hierarchy, but not fully.

In the first group of hierarchy, the system of the main building structure is arches forming a dome. In the 2- 5- 7- 8- 9- 10 of the hierarchy, the system of the main building structure is a frame. In the 3. Group of the hierarchy, the system of the main building structure is a triangulated steel shell.

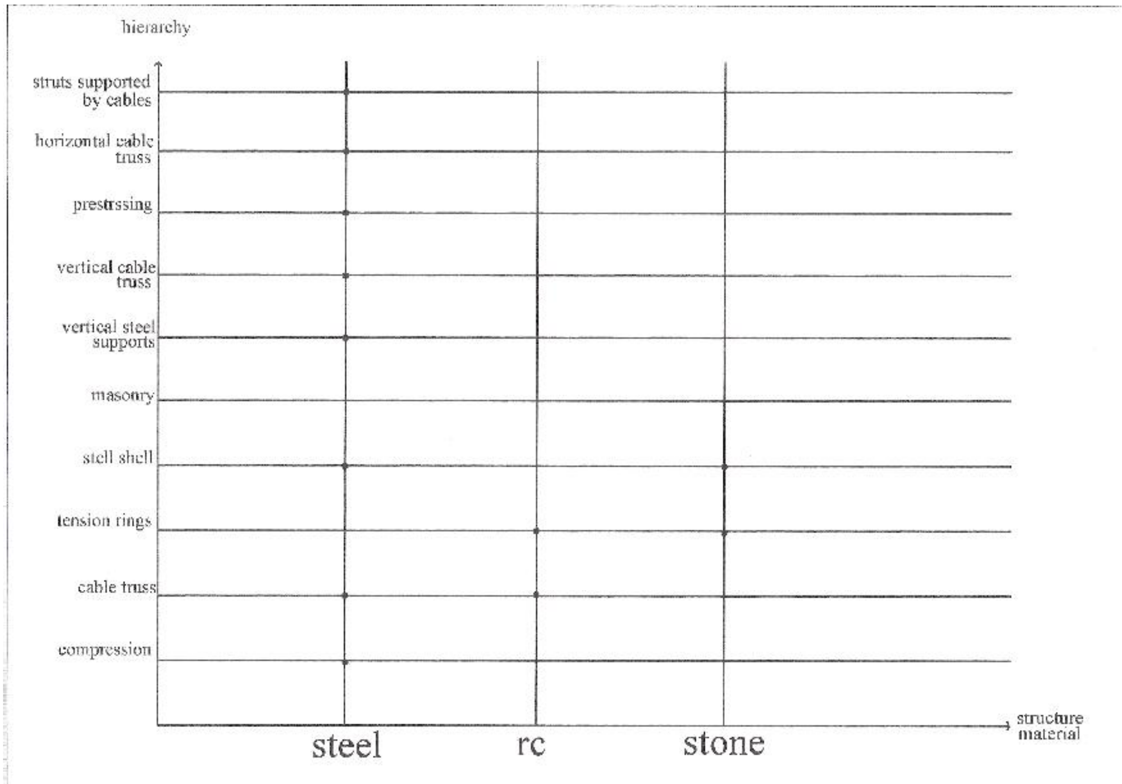


Figure 37 Hierarchy/Structural Materials

In 1-3-4-7-8-9-10. hierarchy, the structure of the main building material is steel.

In 2-5, the striations of the main building material is reinforced concrete.

In 6, material of the main building structure is stone.

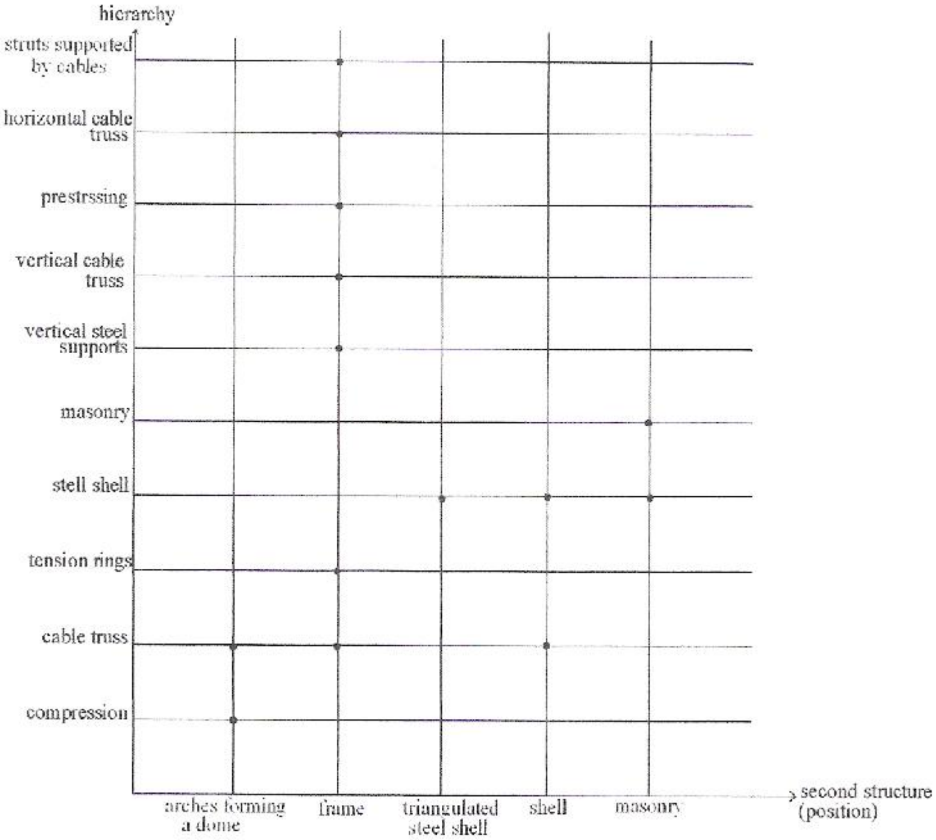


Figure 38 Hierarchy/Position of Second Structure

In the 1. Group of hierarchy, the position of the secondary structure is between arches.

In the 2. Group of hierarchy, the position of the secondary structure is between two tension rings.

In the 3. Group of hierarchy, the position of the secondary structure is within the whole system.

In the 4. Group of hierarchy, the position of the secondary structure is cable trusses within steel shell.

In the 5. Group of hierarchy, the position of the secondary structure is in front of the main building structure.

In the 6. Group of hierarchy, the position of the secondary structure is spanning the distance between two masonry parts.

In the 7. Group of hierarchy, the position of the secondary structure is in front of the frame.

In the 8. Group of hierarchy, the position of the secondary structure is between vertical members of the frame.

In the 9. Group of hierarchy, the position of the secondary structure is in front of the main building structure.

In the 10. Group of hierarchy, the position of the secondary structure is in front of the frame.

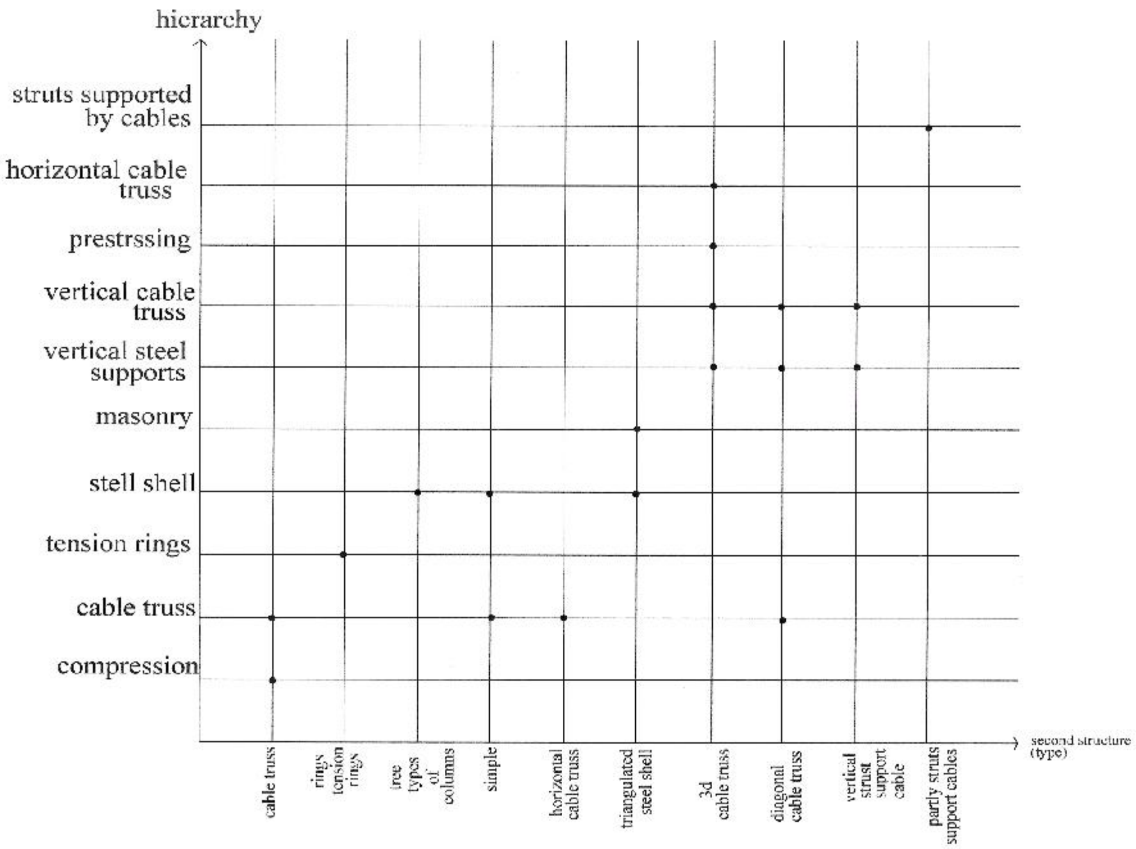


Figure 39 Hierarchy/Type of Second Structure

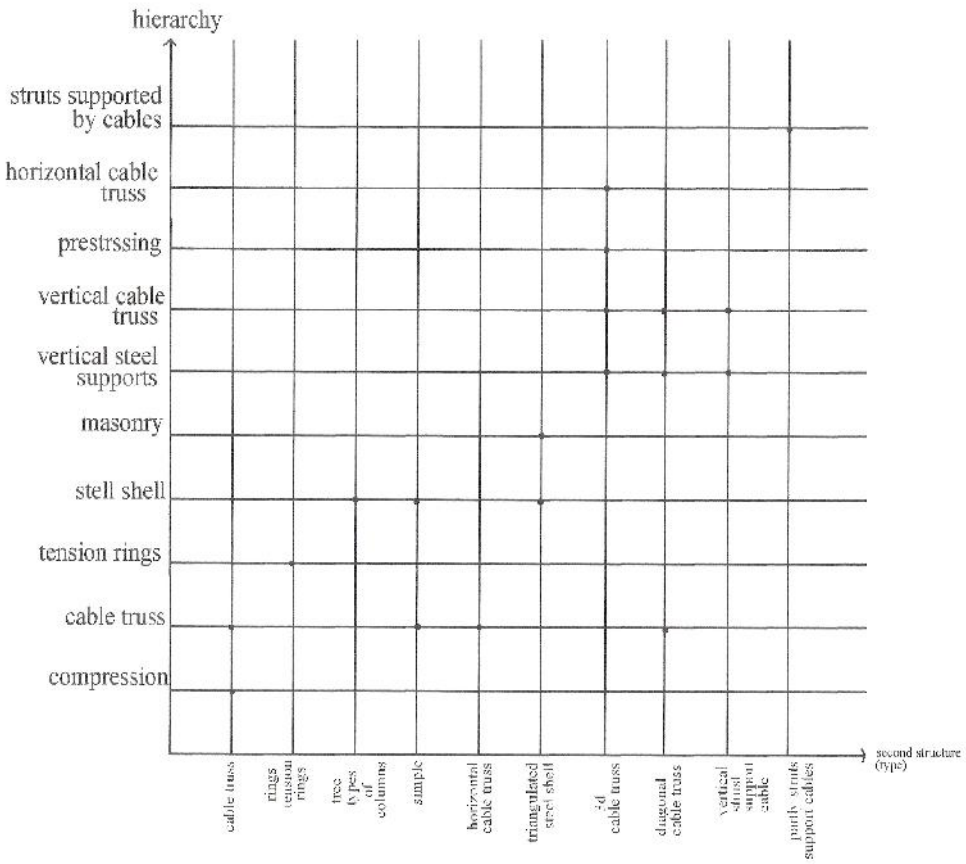


Figure 40 Hierarch/Type of Second Structure

In the first group of hierarchy, the type of the secondary structure is a cable truss.

In the second group of hierarchy, the type of the secondary structure is rings supported by cables which are tensed between tension rings.

In the third group of hierarchy, the type of the secondary structure is tree type of columns supporting from various points.

In the forth group of hierarchy, the type of the secondary structure is simple.

In the 5. Group of hierarchy, the type of the secondary structure is horizontal simple cable truss.

In the 6. Group of hierarchy, the type of the secondary structure is a triangulated steel shell.

In the 7. Group of hierarchy, the type of the secondary structure is vertically and horizontally organized cable trusses.

In the 8. Group of hierarchy, the type of the second structure is diagonally organized cable trusses.

In the 9. Group of hierarchy, the type of the second structure is vertical struts which carry the glass pieces and some of these verticals are supported by cables.

In the 10. Group of hierarchy, the type of second structure partially helps to the main building structure to carry the roof struts supported by cables.

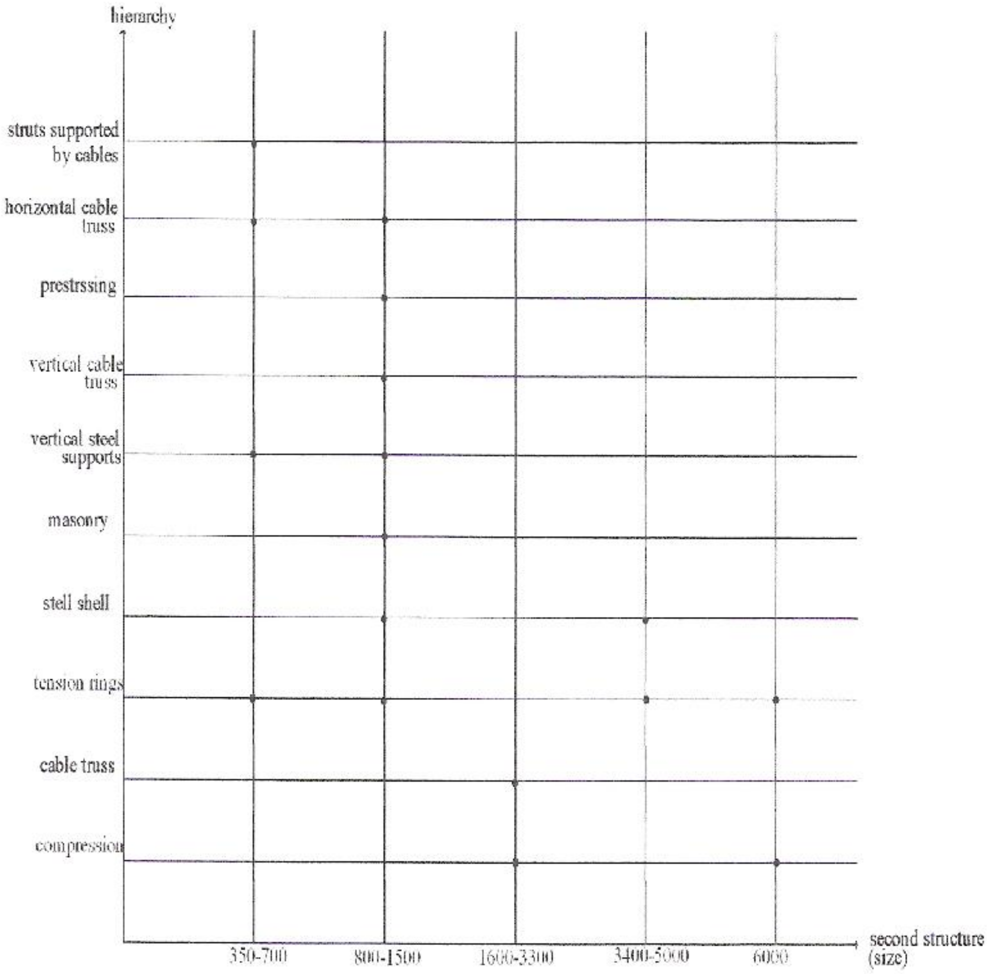


Figure 41 Hierarchy/ Secondary structure's size

In the 1. Group of hierarchy, the size of the secondary structure is 3300cm.

In the 2. Group of hierarchy, the size of the secondary structure is 1200 cm.

In the 3. Group of hierarchy, the size of the secondary structure is 5000 cm.

In the 4. Group of hierarchy, the size of the secondary structure is 35.000 cm

In the 5. Group of hierarchy, the size of the secondary structure is 3000 cm.

In the 6. Group of hierarchy, the size of the secondary structure is 1500 cm.

In the 7. Group of hierarchy, the size of the secondary structure is 1200 cm.

In the 8. Group of hierarchy, the size of the secondary structure is 700 cm vertical.

In the 9. Group of hierarchy, the size of the secondary structure is 600 cm vertical.

In the 10. Group of hierarchy, the size of the secondary structure is 350 cm vertical.

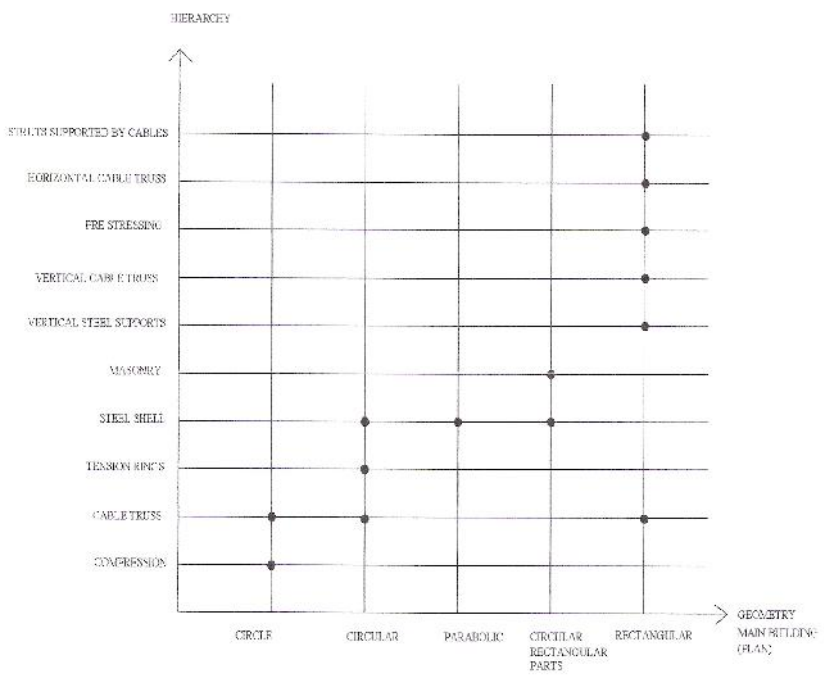


Figure 42 Hierarchy/Plan Geometry of Main Building

In the 1. group of hierarchy, the plan geometry of the main building' is a circle.

In the 2.-4.-5. group of hierarchy, the plan geometry of the main building's is circular.

In the 3. group of hierarchy, the plan geometry of the main building's is parabolic.

In the 6. group of hierarchy, the plan geometry of the main building's is circle (including rectangular parts).

In the 7.-8.-9.-10. group of hierarchy, the plan geometry of the main building is rectangular.

In the 1. group of hierarchy, the plan geometry of the main building's is a circle.

In the 2.-3. group of hierarchy, the plan geometry of the main building's is parabolic.

In the 4. group of hierarchy, the plan geometry of the main building's is circular.

In the 5.-6.-7.-8.-9.-10. group of hierarchy, the plan geometry of the main building's is rectangular. Types of

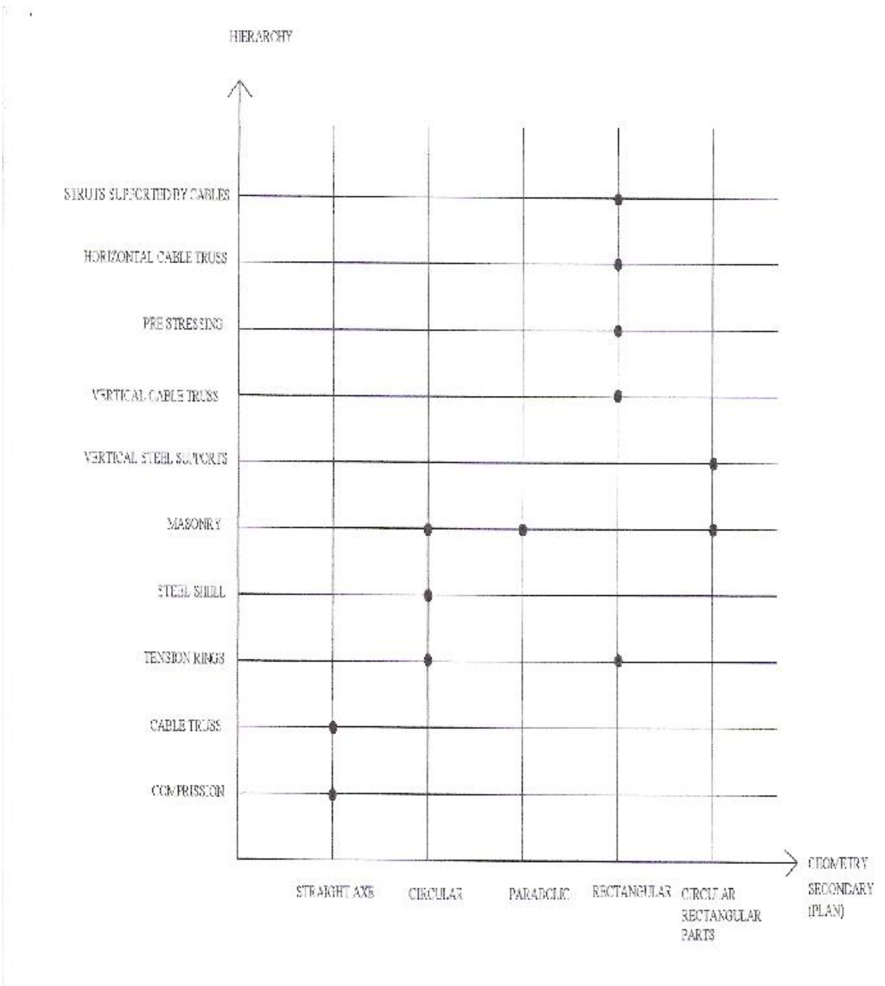


Figure 43 Hierarchy/Plan Geometry of Secondary Structure

In the first group of hierarchy, the plan geometry of the secondary structure is straight axe.

In the 2.-4. group of hierarchy, the plan geometry of the secondary structure's of is circular

In the 3. group of hierarchy, the plan geometry of the secondary structure's of is parabolic.

In the 6. group of hierarchy, the plan geometry of the secondary structure's of is circular (including rectangular parts).

In the 5.-7.-8.-9.-10. Group of hierarchy, the plan geometry of the secondary structure's of is re Types of

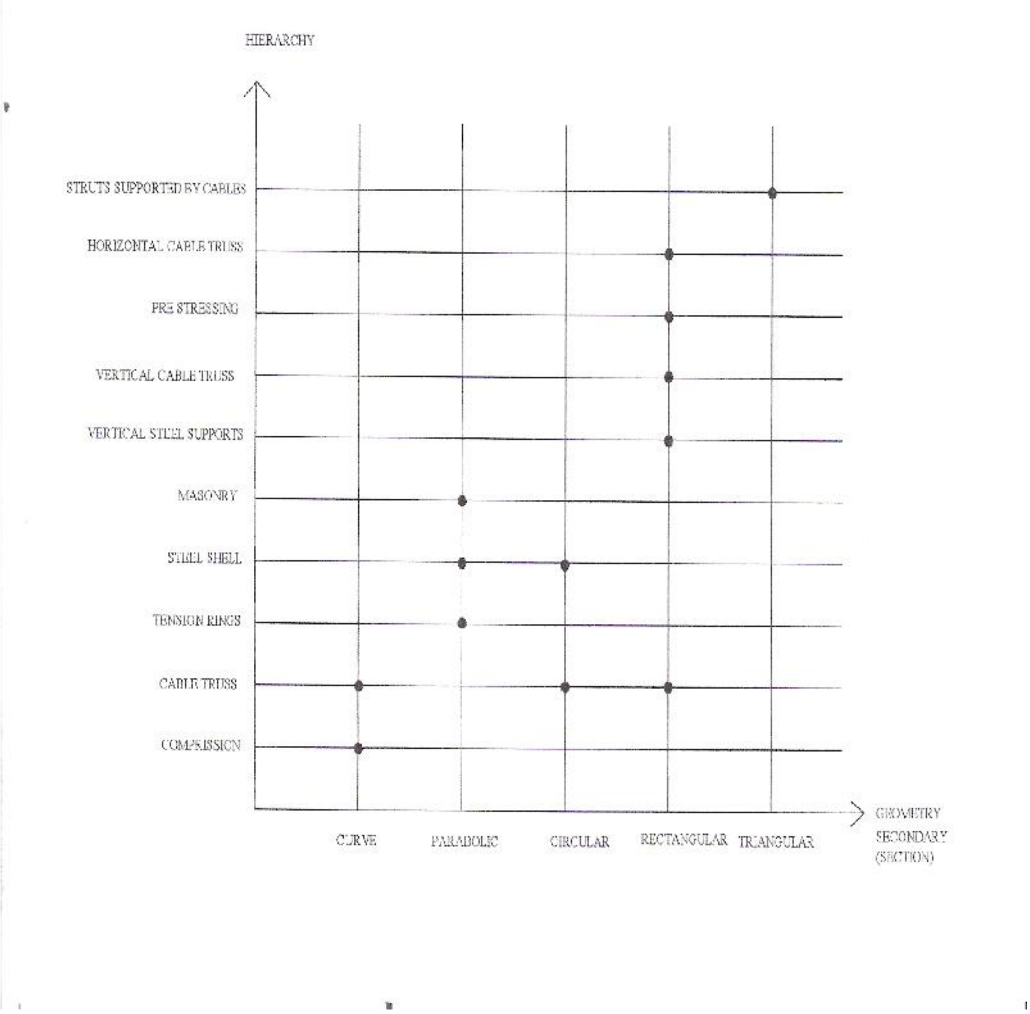


Figure 44 Hierarchy- Section Geometry of Secondary Structure

In the first group of hierarchy, the section geometry of the secondary structure is curved.

In the 2.-3.-6. group of hierarchy, the section geometry of the secondary structure is parabolic.

In the 4. group of hierarchy, the section geometry of the secondary structure is circular.

In the 5.-7.-8.-9. group of hierarchy, the section geometry of the secondary structure is rectangular.

In the 10. group of hierarchy, the section geometry of the secondary structure is triangular.

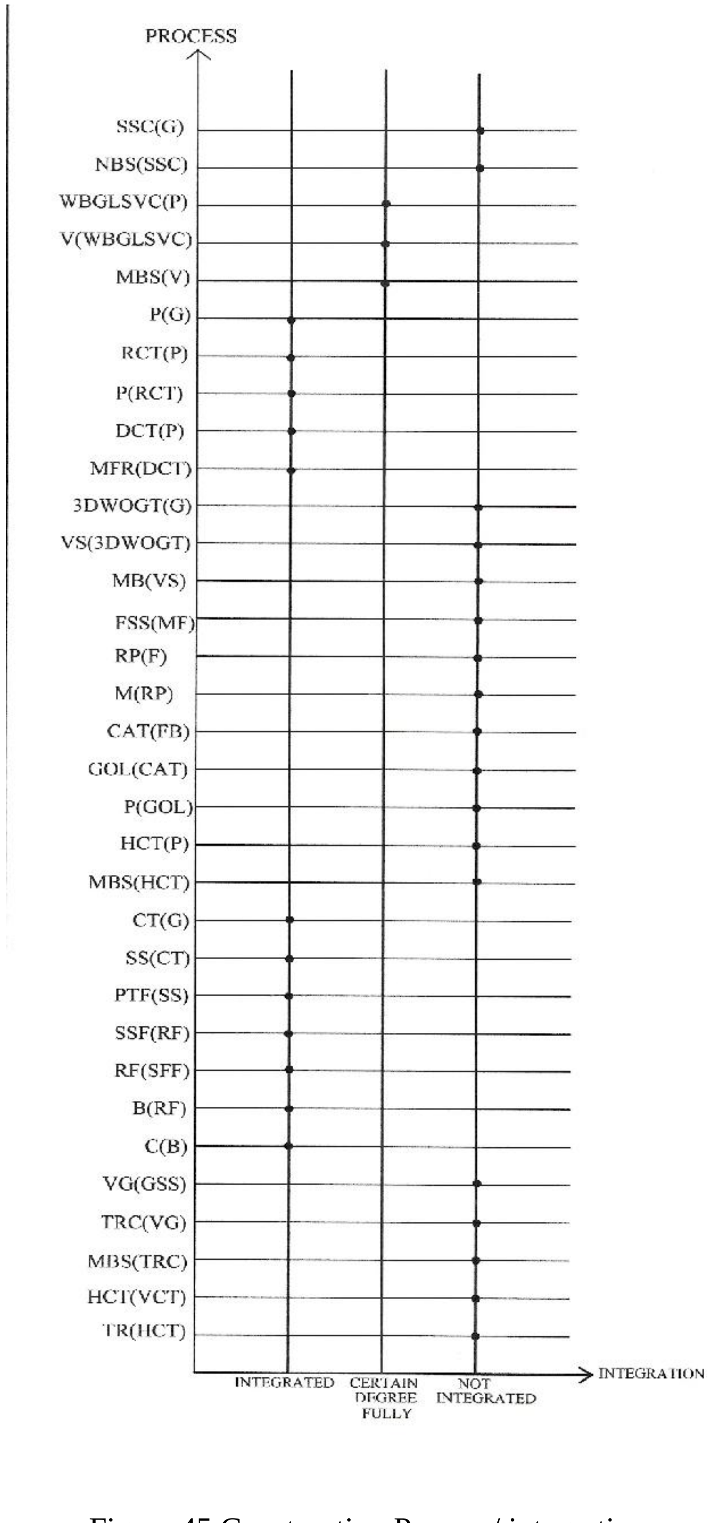


Figure 45 Construction Process/ integration

There is no integration in the 1-2-5-6-7 and 10. groups of process.

There is integration in the 3-4 and 8. groups of process.

There is a certain degree of integration in group of 9. in process, but not fully.

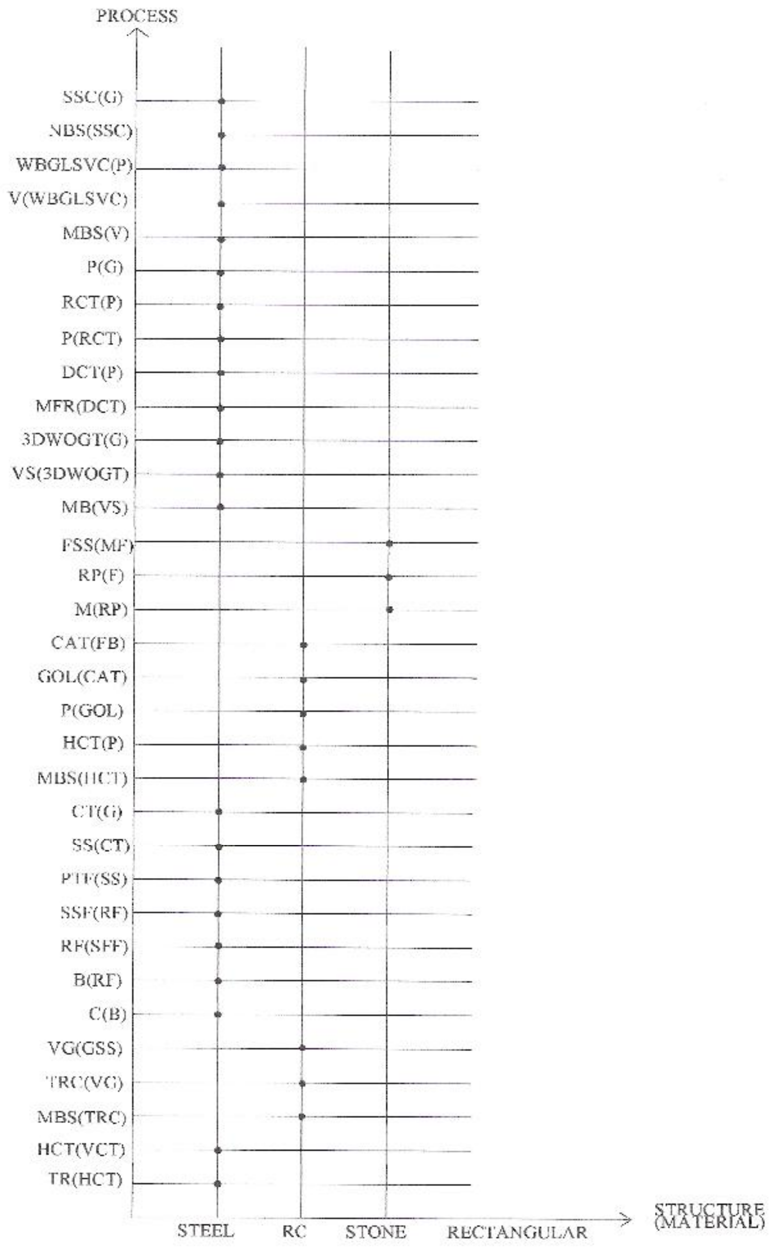


Figure 46 Process/Structural Materials

In 1-3-4-7-8-9-10. process, the structure of the main building material is steel.

In 2-5, material of the main building structure is reinforced concrete.

In 6, material of the main building structure is stone.

Constuction Process

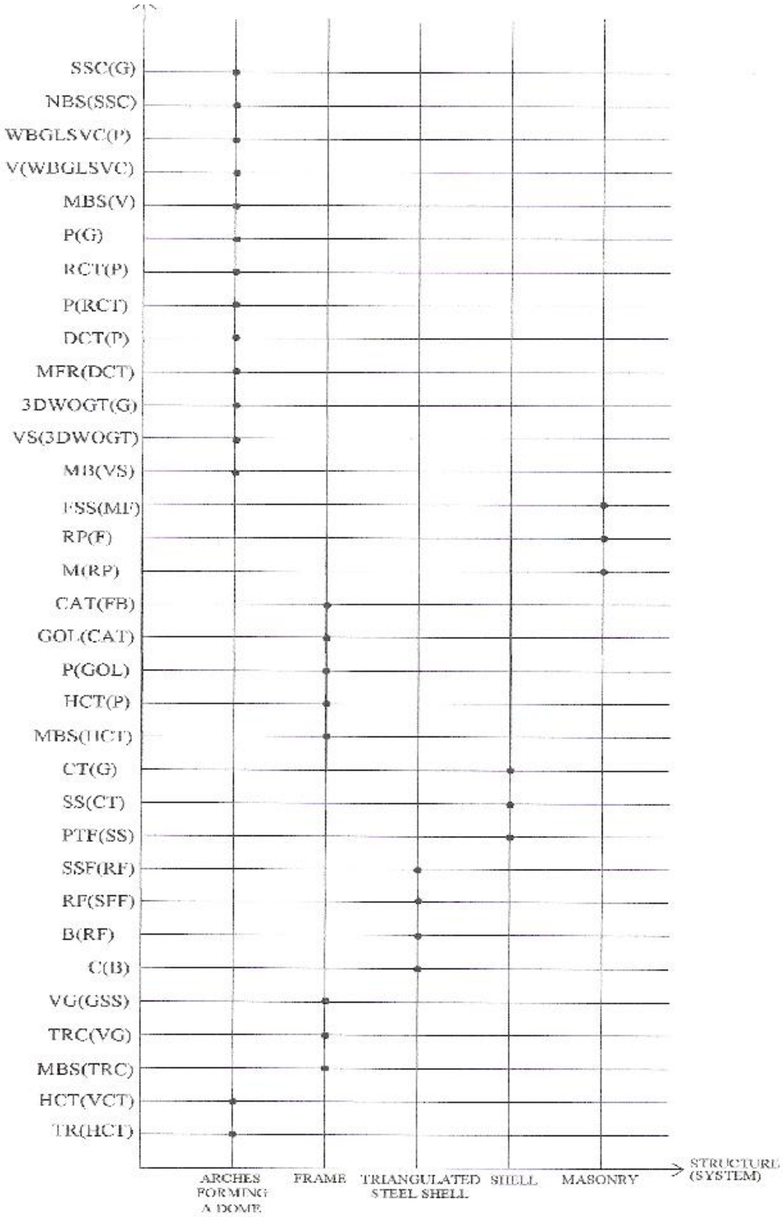


Figure 47 Process/Structural System of Main Building

In the first group of process, the system of the main building structure is arches forming a dome. In the 2- 5- 7- 8- 9- 10 of the process, the system of the main building structure is frame. In the 3. group of the process, the system of the main building structure is triangulated steel shell.

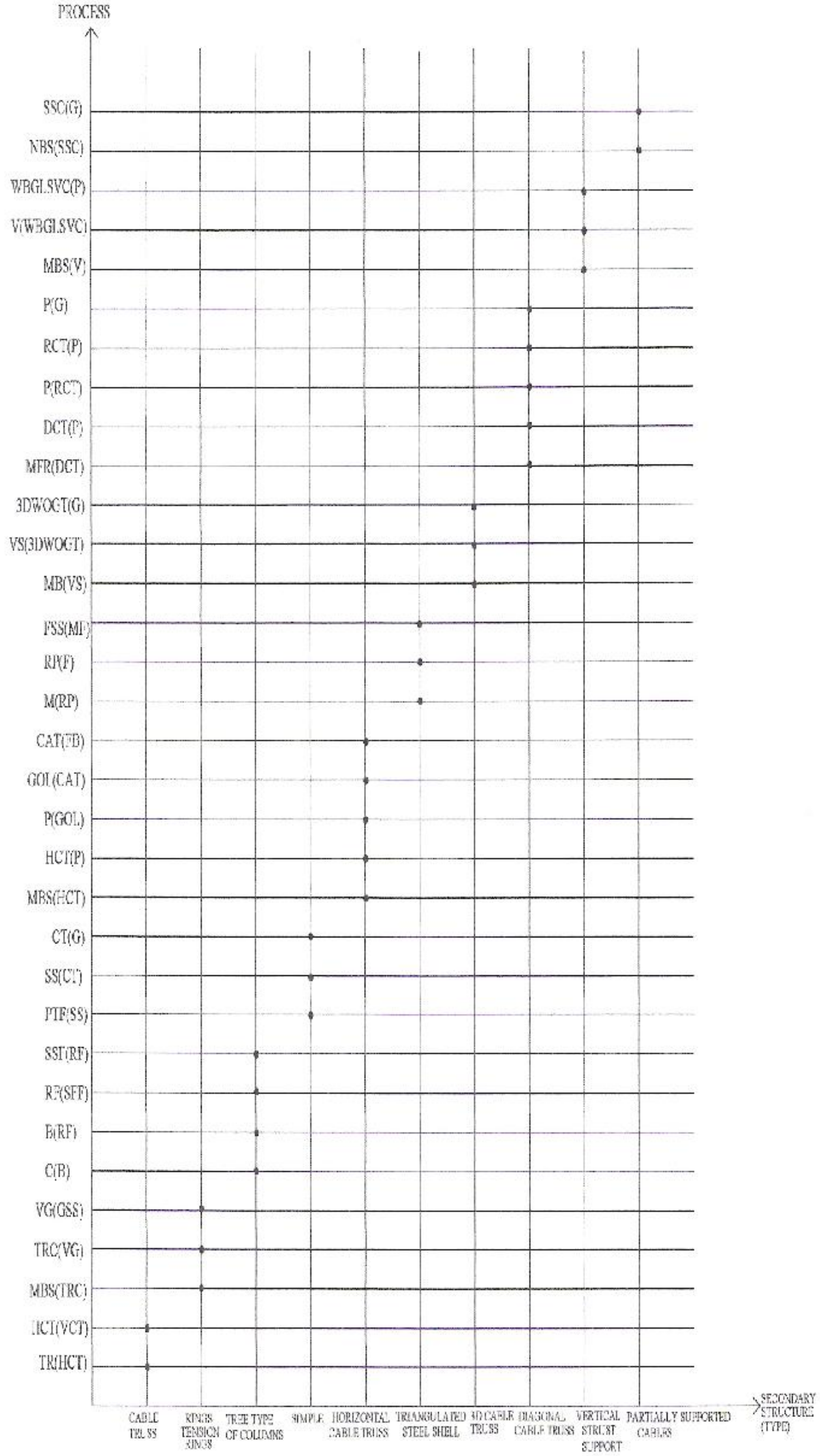


Figure 48 Construction Process/Secondary structure's type.

In the first group of process, the type of the secondary structure is cable trusses.

In the second group of process, the type of the secondary structure is rings supported by cables, which are tensed between tension rings.

In the third group of process, the type of the secondary structure is tree type of columns supporting from various points.

In the forth group of process, the type of the secondary structure is simple.

In the 5. group of process, the type of the secondary structure is horizontal simple cable trusses.

In the 6. group of process, the type of the secondary structure is a triangulated steel shell.

In the 7. group of process, the type of the secondary structure is vertical and horizontal organization of cable trusses.

In the 8. group of process, the type of the secondary structure is diagonal cable trusses.

In the 9. group of process, the type of the secondary structure is vertical struts which carry glass pieces. Some of these verticals are supported by cables.

In the 10. group of process, the type of the secondary structure partially helps the main building structure to carry the roof struts supported by cables.

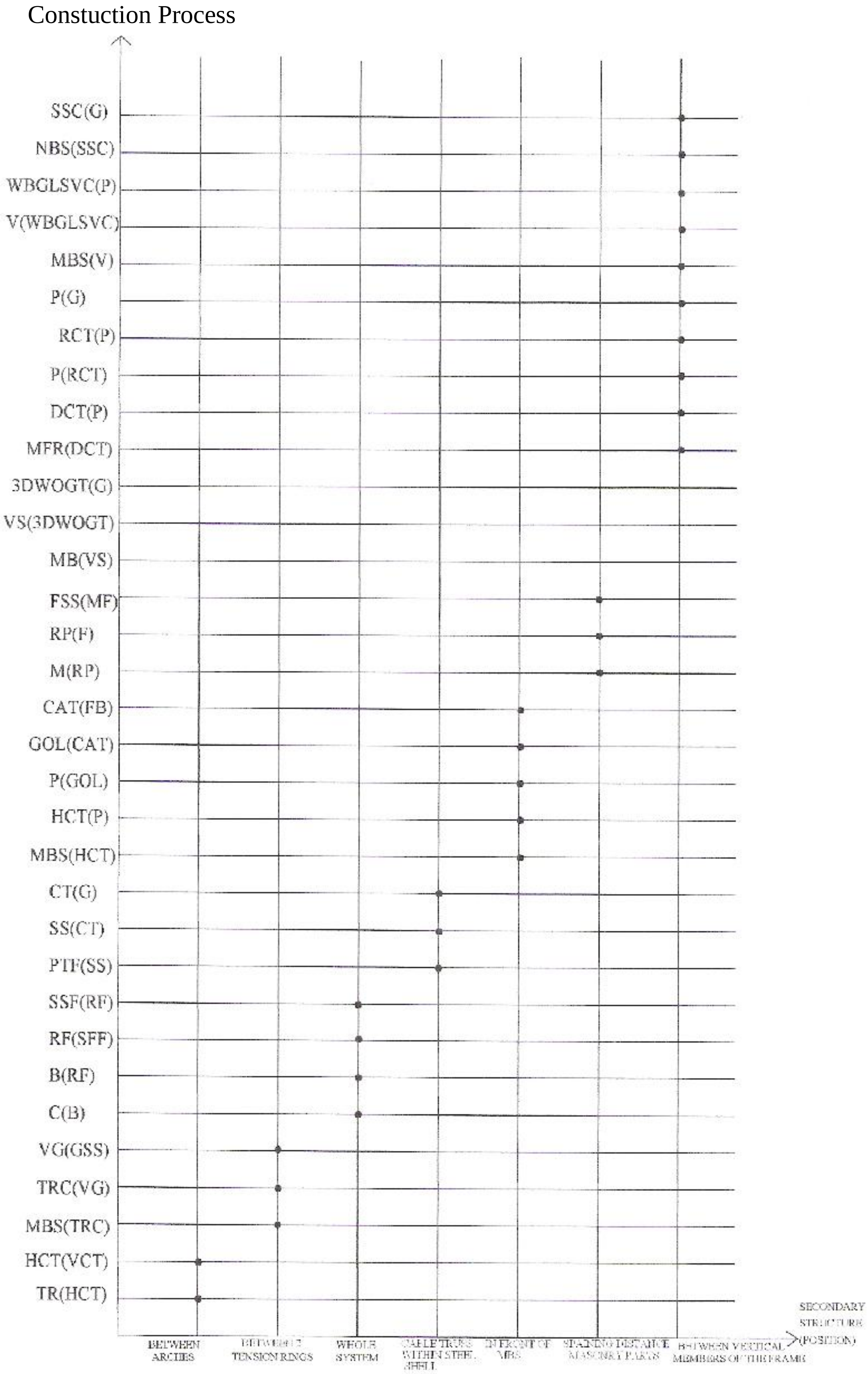


Figure 49 Construction Process/Secondary Structure's Position

Position of secondary

In the 1. group of process, the position of the secondary structure is between a

In the 2. group of process, the position of the secondary structure is between two tension rings.

In the 3. group of process, the position of the secondary structure is within the whole system.

In the 4. group of process, the position of the secondary structure is cable trusses within steel shell.

In the 5. group of process, the position of the secondary structure is in front of the main building structure.

In the 6. group of process, the position of the secondary structure is spanning the distance between two masonry parts.

In the 7. group of process, the position of the secondary structure is in front of the frame.

In the 8. group of process, the position of the secondary structure is between vertical members of the frame.

In the 9. group of process, the position of the secondary structure is in front of the main building structure.

In the 10. group of process, the position of the secondary structure is in front of the frame.

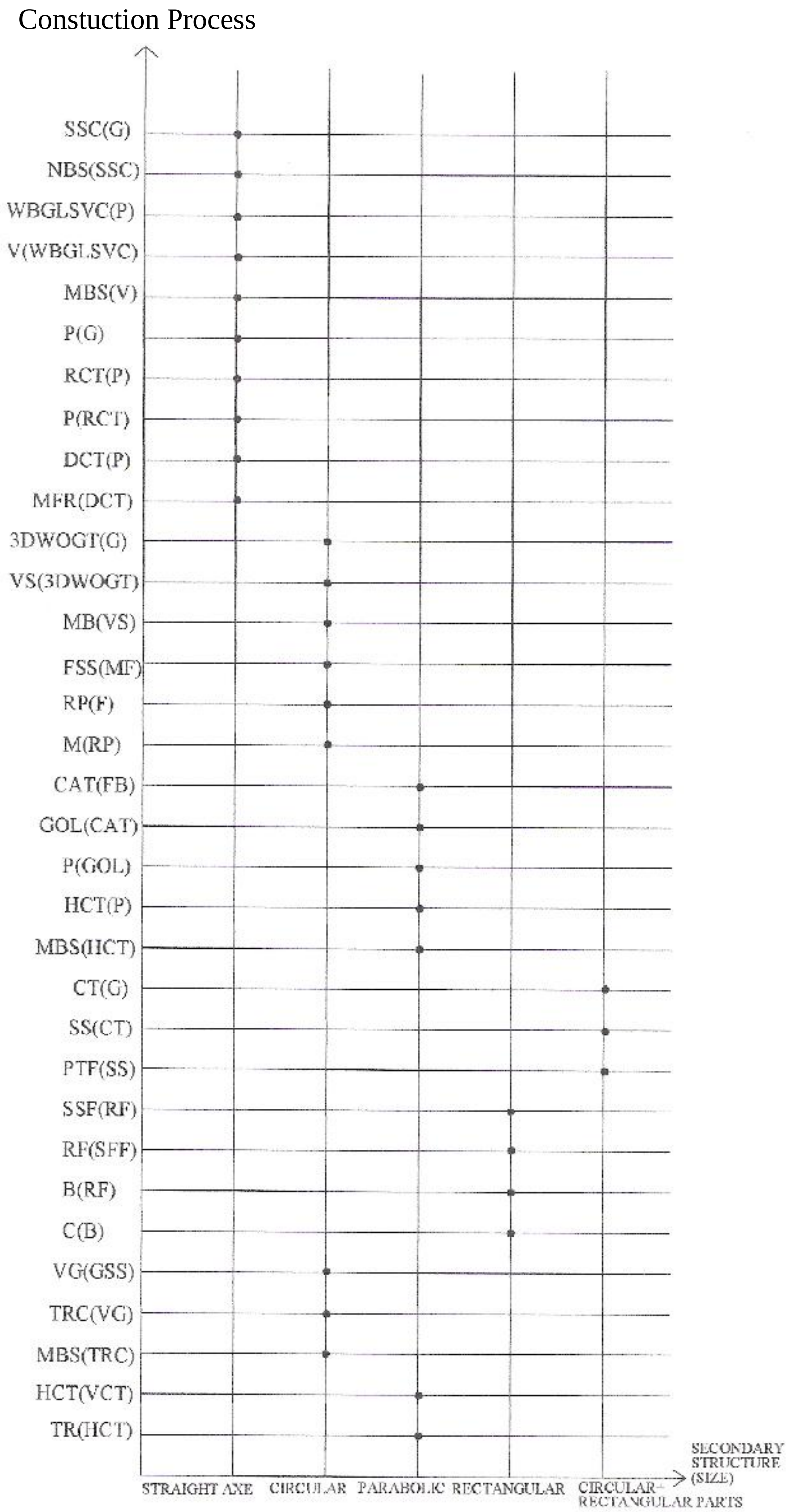


Figure 50 Construction Process/Second Structure’s Size

In the 1. group of process, the size of the secondary structure is 3300cm.

In the 2. group of process, the size of the secondary structure is 1200 cm.

In the 3. group of process, the size of the secondary structure is 5000 cm.

In the 4. group of process, the size of the secondary structure is 35.000 cm

In the 5. group of process, the size of the secondary structure is 3000 cm.

In the 6. group of process, the size of the secondary structure is 1500 cm.

In the 7. group of process, the size of the secondary structure is 1200 cm.

In the 8. group of process, the size of the secondary structure is 700 cm vertical.

In the 9. group of process, the size of the secondary structure is 600 cm vertical.

In the 10. group of process, the size of the secondary structure is 350 cm vertical.

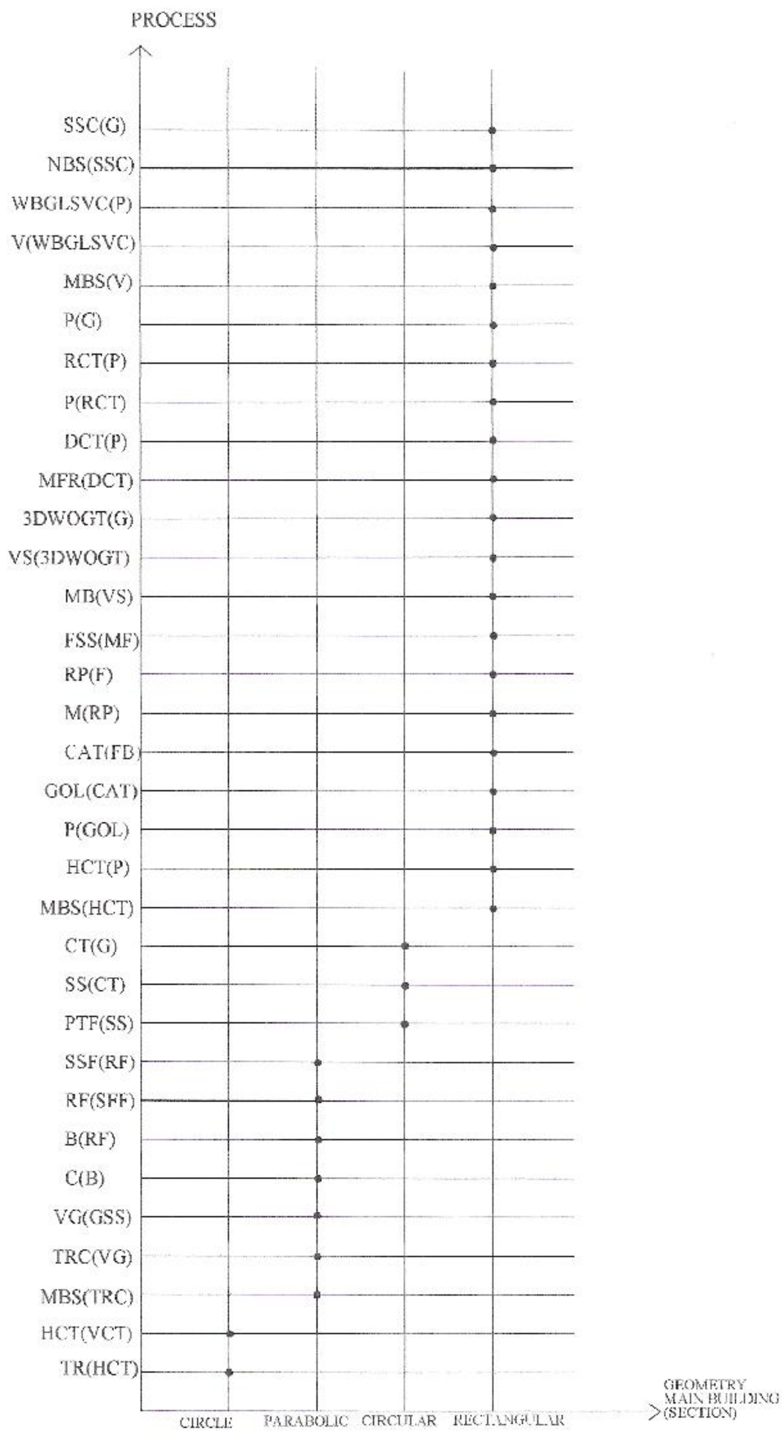


Figure 51 Construction Process / Main Building's Section Geometry

In the 1. group of process, the main building's section geometry is a circle.

In the 2.-3. group of process, the main building's section geometry is parabolic.

In the 4. group of process, the main building's section geometry is circular.

In the 5.-6.-7.-8.-9.-10. group of process, the main building's section geometry is rectangular.

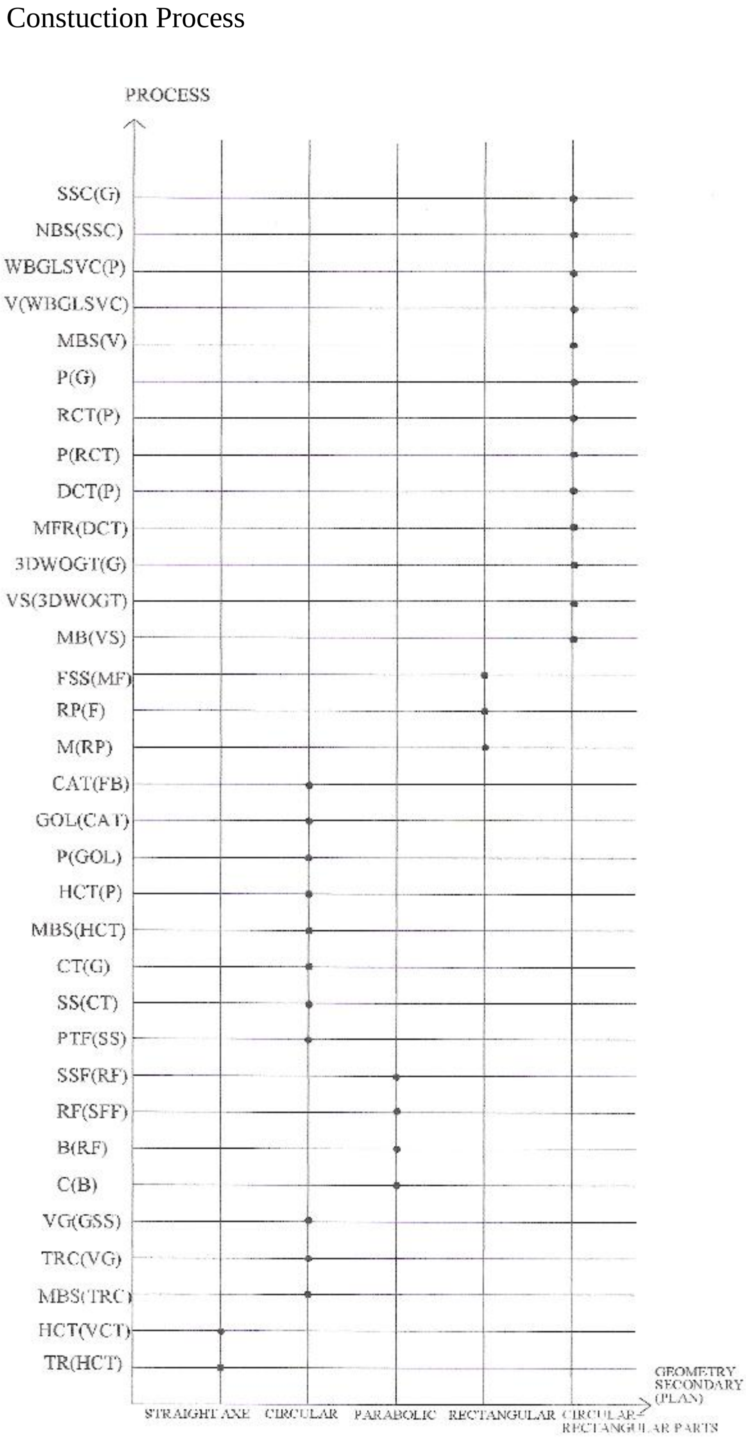


Figure 52 Construction Process / Geometry of Secondary Structure's Plan

In the first group of process, the secondary structure's plan geometry is based on straight axes.

In the 2.-4. group of process, the secondary structure's plan geometry is circular.

In the 3. group of process, the secondary structure's plan geometry is parabolic.

In the 6. group of process, the secondary structure's plan geometry is circular. (including rectangular parts).

In the 5.-7.-8.-9.-10. groups of process, the secondary structure's plan geometry is rectangular.

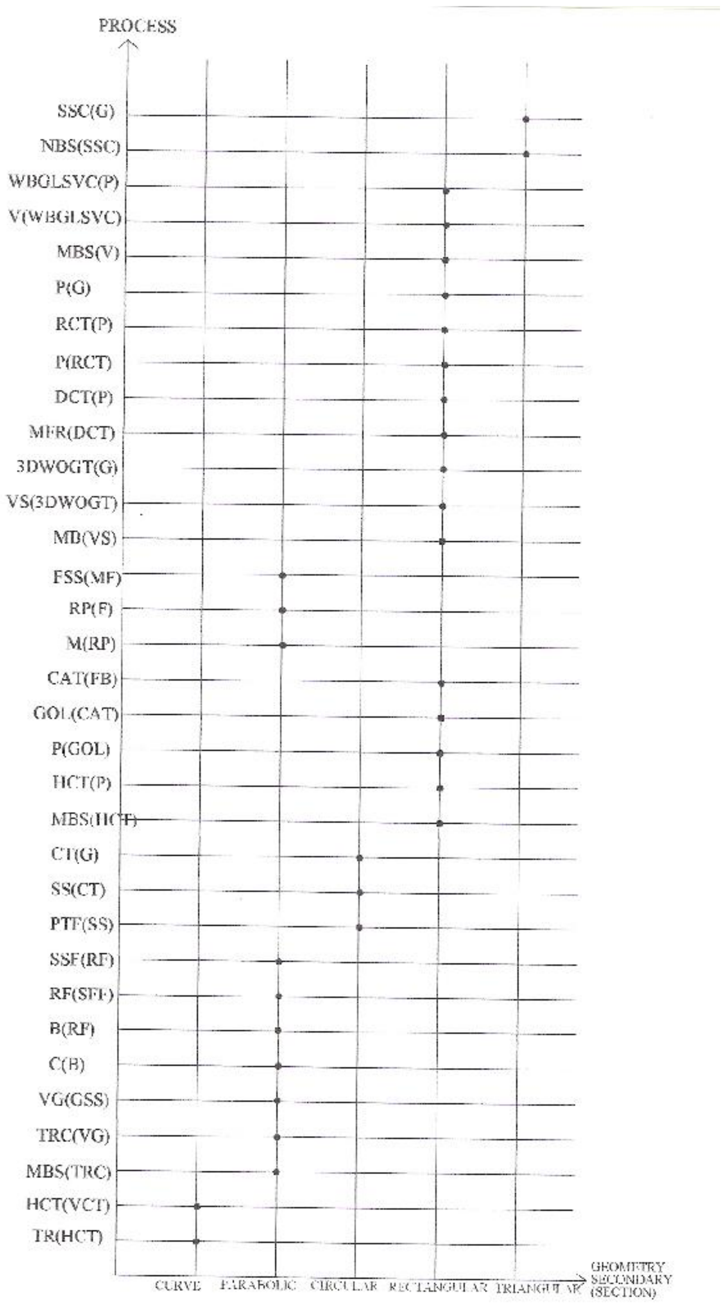


Figure 53 Construction Process / Geometry of Secondary Structure's Section

In the first group of process, the secondary structure's section geometry is a curve.

In the 2.-3.-6. group of process, the secondary structure's section geometry is parabolic.

In the 4. group of process, the secondary structure's section geometry is circular.

In the 5.-7.-8.-9. group of process, the secondary structure's section geometry is rectangular.

In the 10. group of process, the secondary structure's section geometry is triangular.

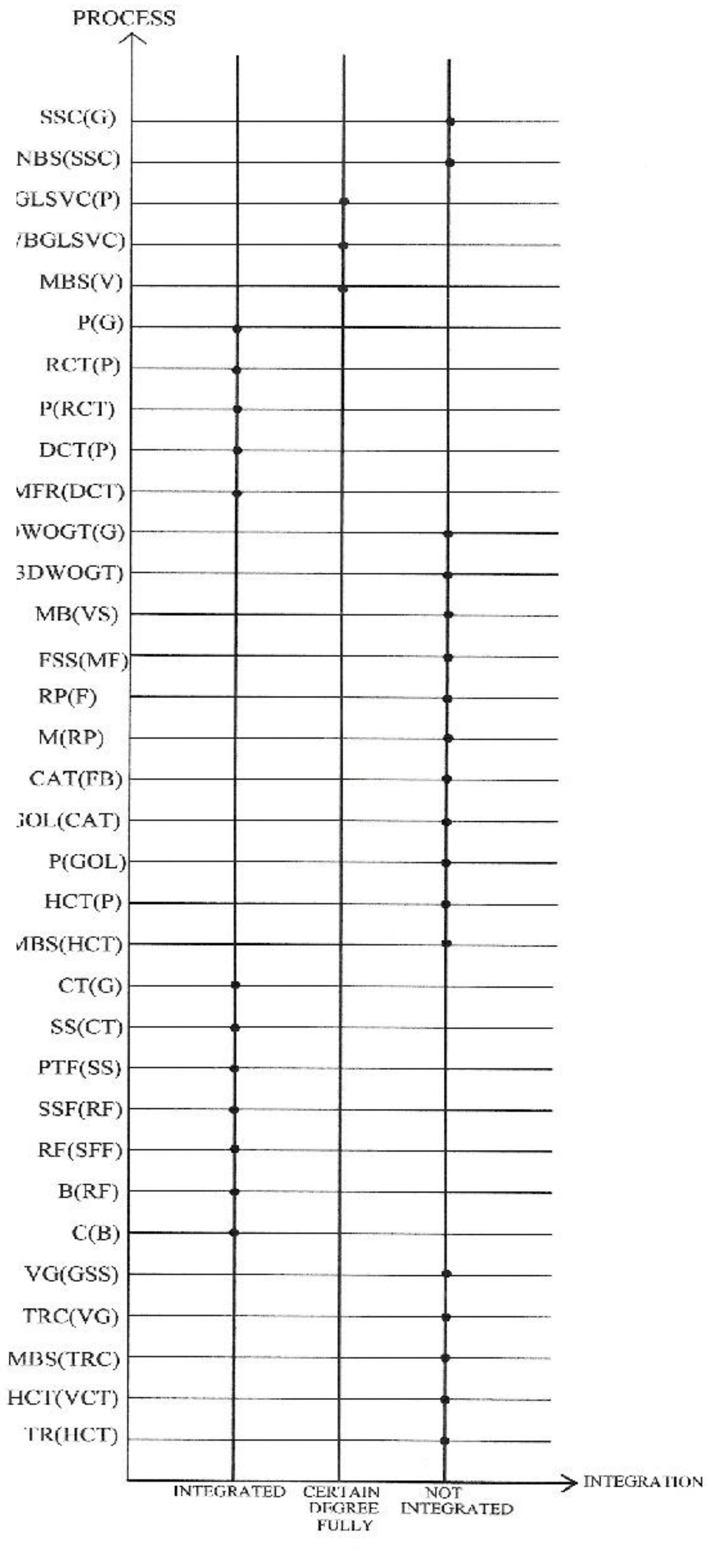


Figure 54 Construction Process/Integration

The process of the 1.-2.-5.-6.-7.-10. do not have integrated parts.

The process of the 3.-4.-8. have integrated parts.

The process of the 9. contain a certain degree integration, but not fully.

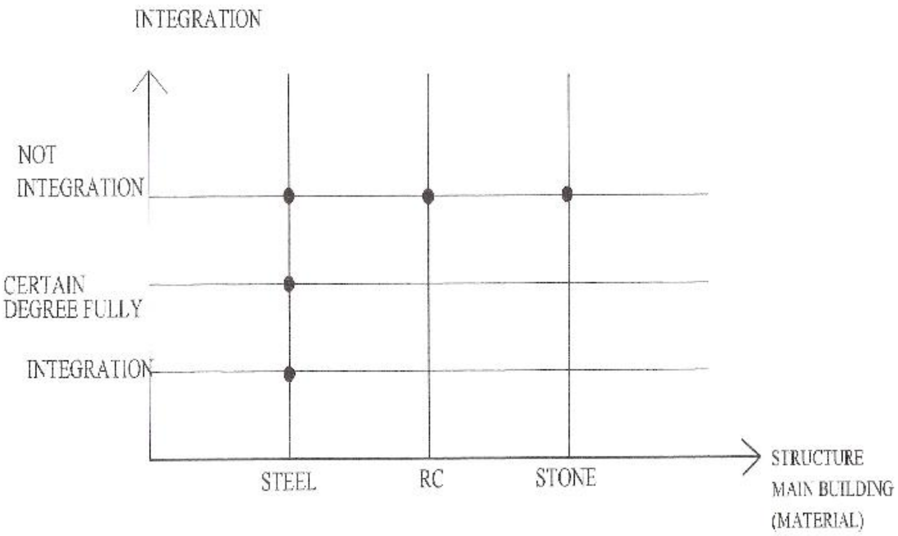


Figure 55 Integration/ structural material of the main

If the main building structure’s material is reinforced concrete or stone, then the system is not integrated.

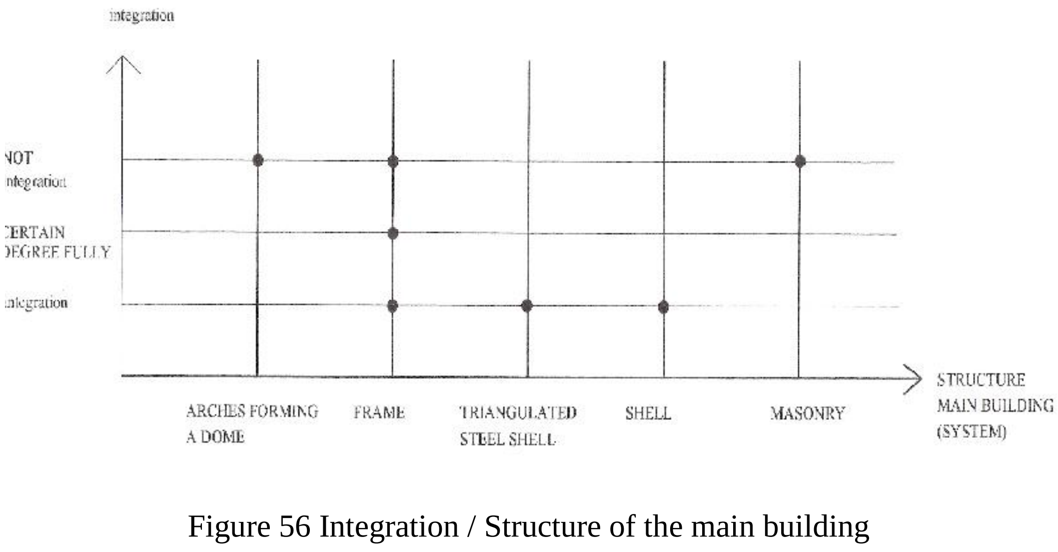


Figure 56 Integration / Structure of the main building

If the main building’s structural system is masonry or arches forming a dome, then the system is not integrated. If the main building’s structural system is steel shell or triangulated steel shell, then the system is integrated.

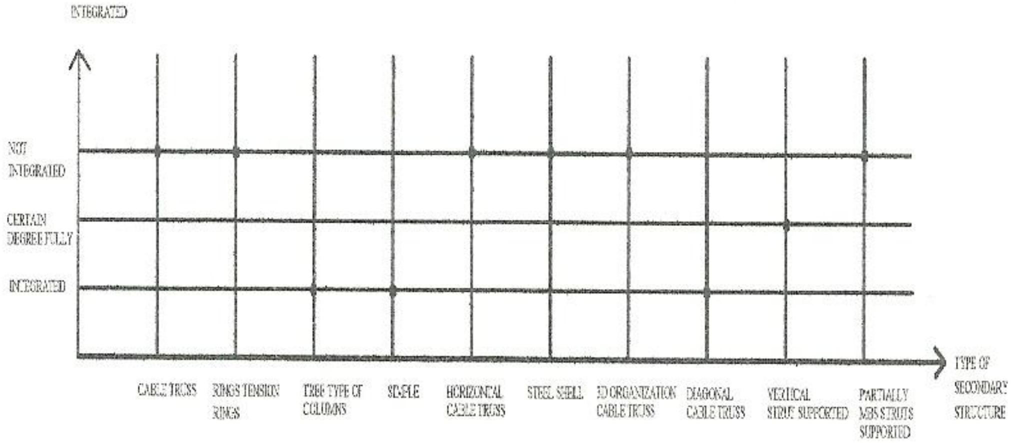


Figure 57 Integration / Type of secondary structure

If the secondary structure's type is cable truss, rings are tension rings, if there are horizontal cable trusses a triangulated steel shell, 3 D organization cable trusses that partially help the main building structure to carry the roof struts supported by cables, then the system is not integrated. If the type of the secondary structure is vertical struts, then the system has a certain degree of integration, but not fully integrated. If the type of the secondary structure is tree type of columns, or simple or diagonal

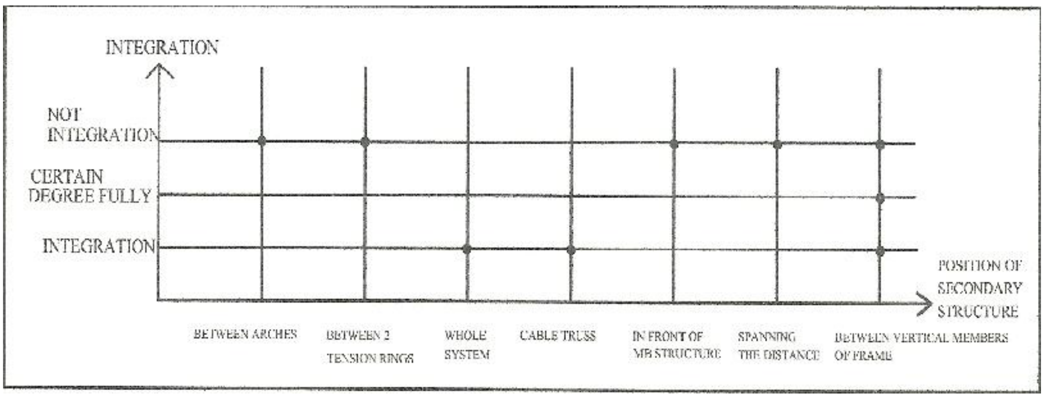


Figure 58 Integration / Position of the secondary structure

If the position of the secondary structure is between the arches or between the tension rings or in front of the main building structure or spanning the masonry parts, then the system is not integrated. If the position of the secondary structure includes the whole system or includes the shell system, it is integrated. If the position of the secondary structure is between the vertical members of the frame, then the system can have a certain degree of integration, integrated, or not integrated at all.

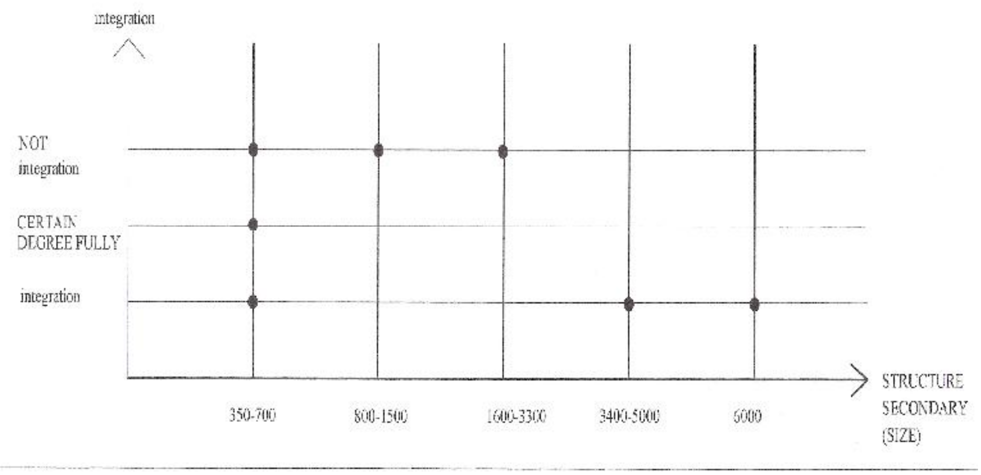


Figure 59 Integration / Size of secondary structure

If the size of the secondary structure is bigger than 3400 cm, the system is integrated. From 350 cm. to 3300 cm, the system can be integrated, integration to a certain degree, or not integrated.

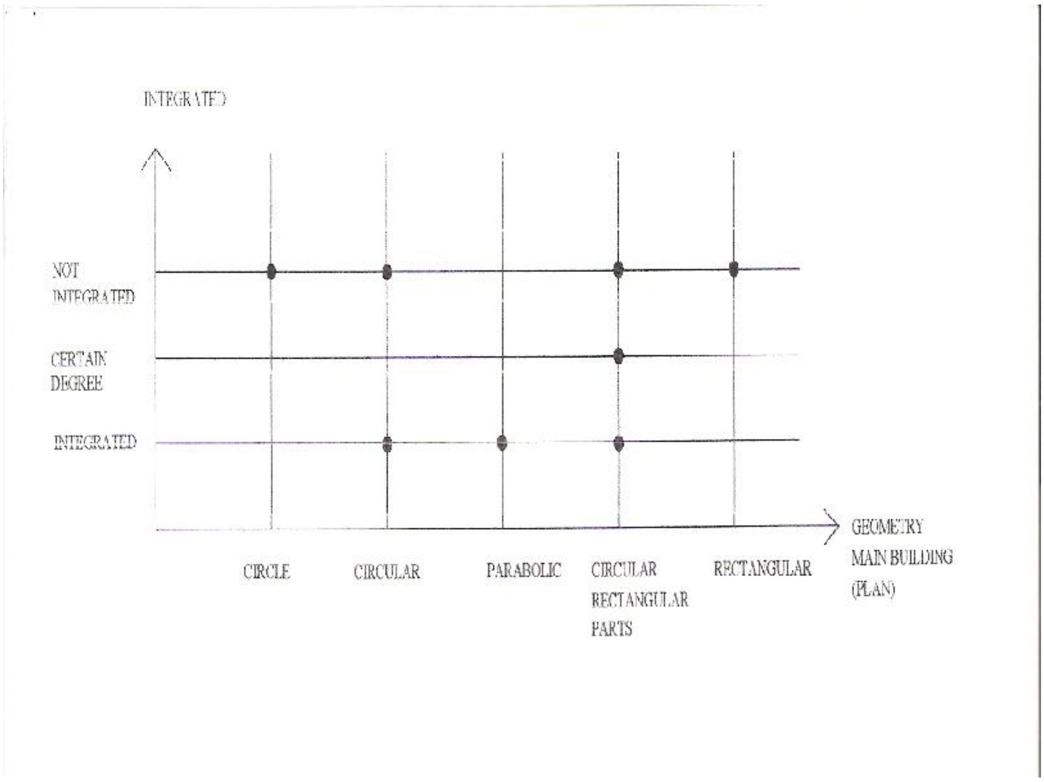


Figure 60 Integration / Plan Geometry of the Main Building

If the main building plan geometry is circle or circular (including the rectangular parts) then the system is not integrated. If the main building plan geometry is parabolic, then the system is integrated. If the main building plan geometry is rectangular, it gives a freedom to be integrated.

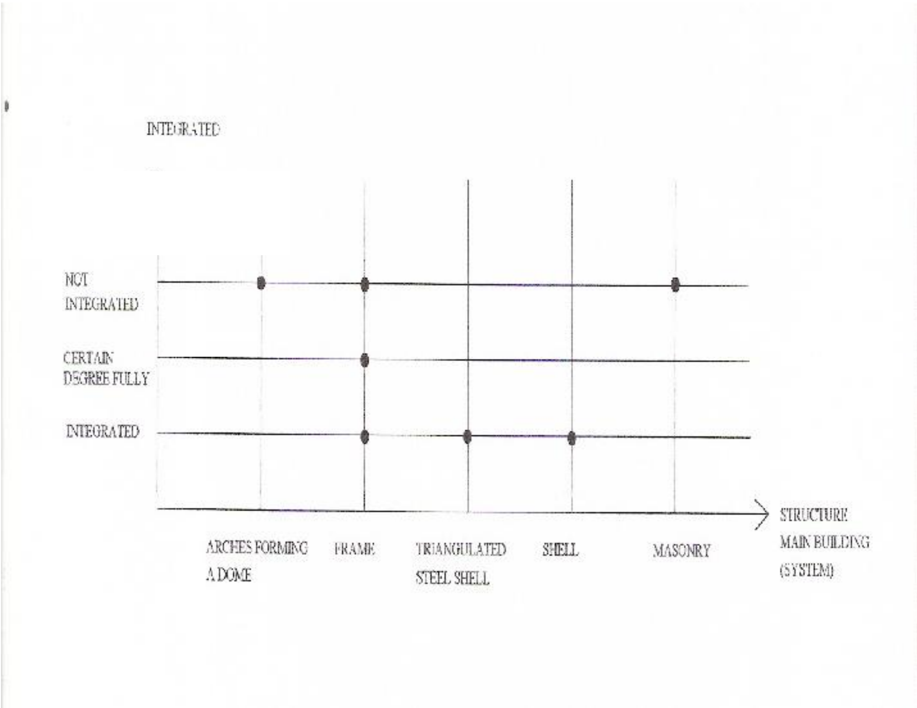


Figure 61 Integration / Structural System of the Main Building

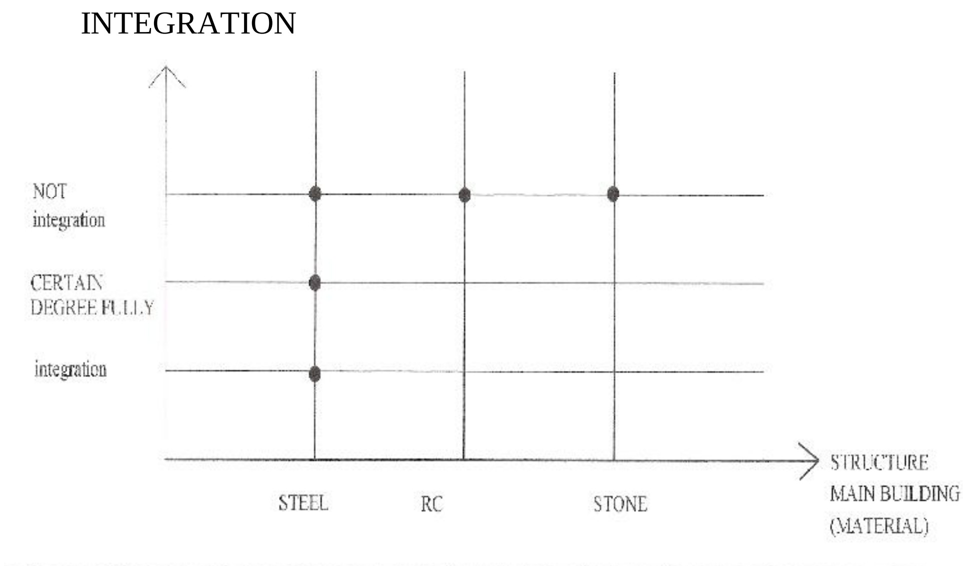


Figure 62 Integration / Structural Material of main building

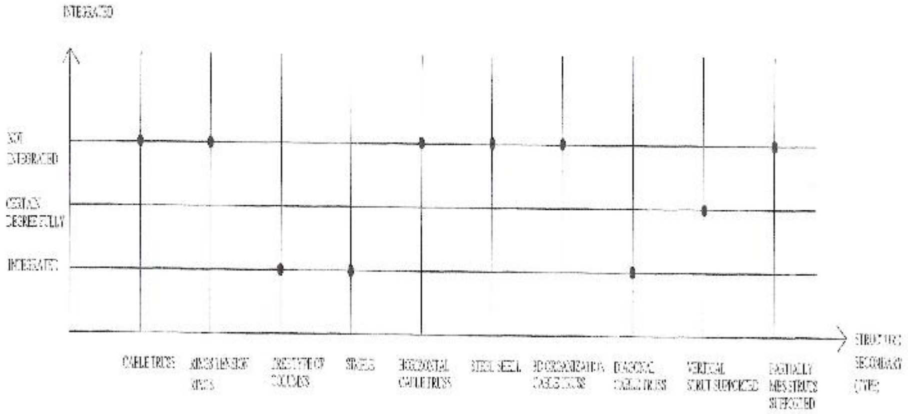


Figure 63 Integration / Type of Secondary Structure

If the type of secondary structure is tree type of columns or diagonal cable truss then the system is integrated.

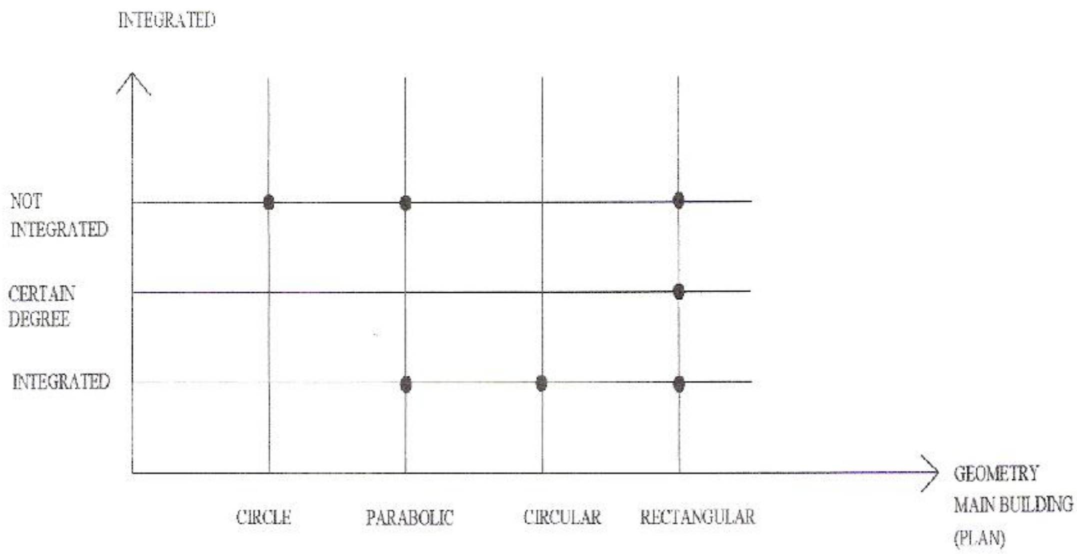


Figure 64   Integration / Plan Geometry of the Main Building

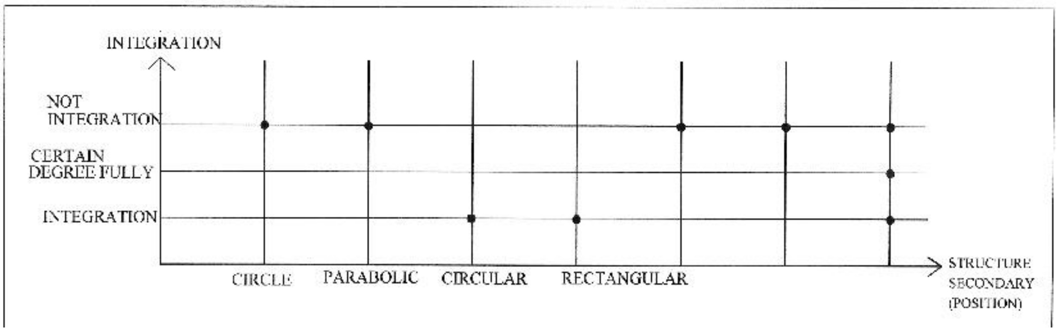


Figure 65 Integration / Plan geometry of main building

If the section geometry of the main building is a circle, then the system is not integrated. If the section geometry of the main building is circular, the system is integrated. Rectangular geometry gives freedom for integration.

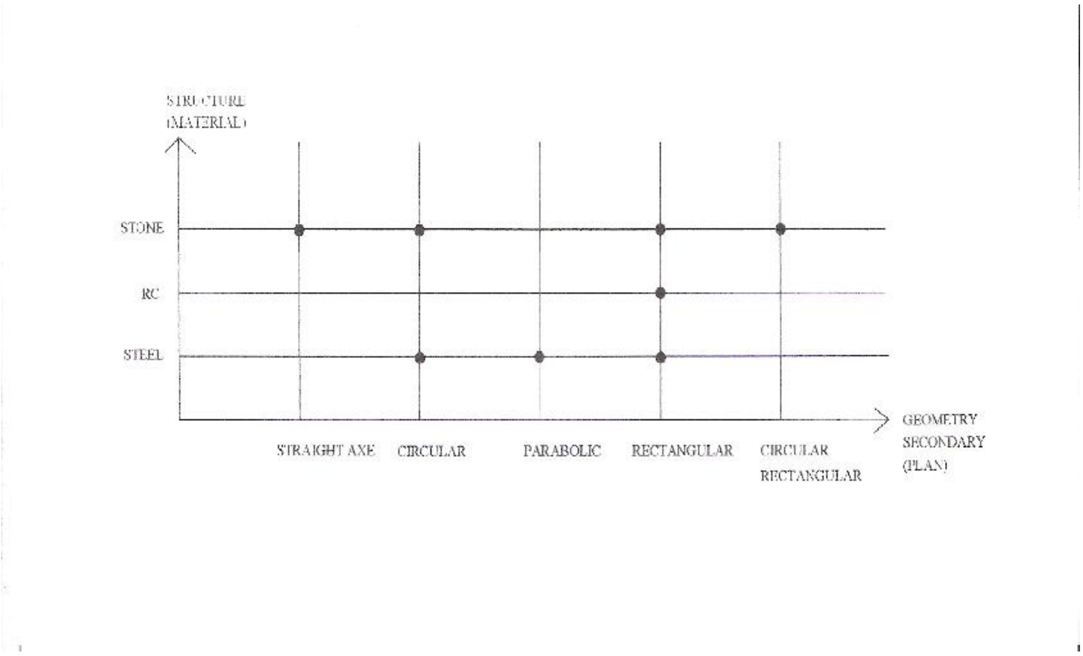


Figure 66 Structural Material / Plan Geometry of Secondary Structure

If the plan geometry of the secondary structure is based on straight axes or circular axes (including rectangular parts) then the system is integrated. If the plan geometry of the secondary structure is parabolic, then system is integrated. Rectangular geometry gives freedom for integration.

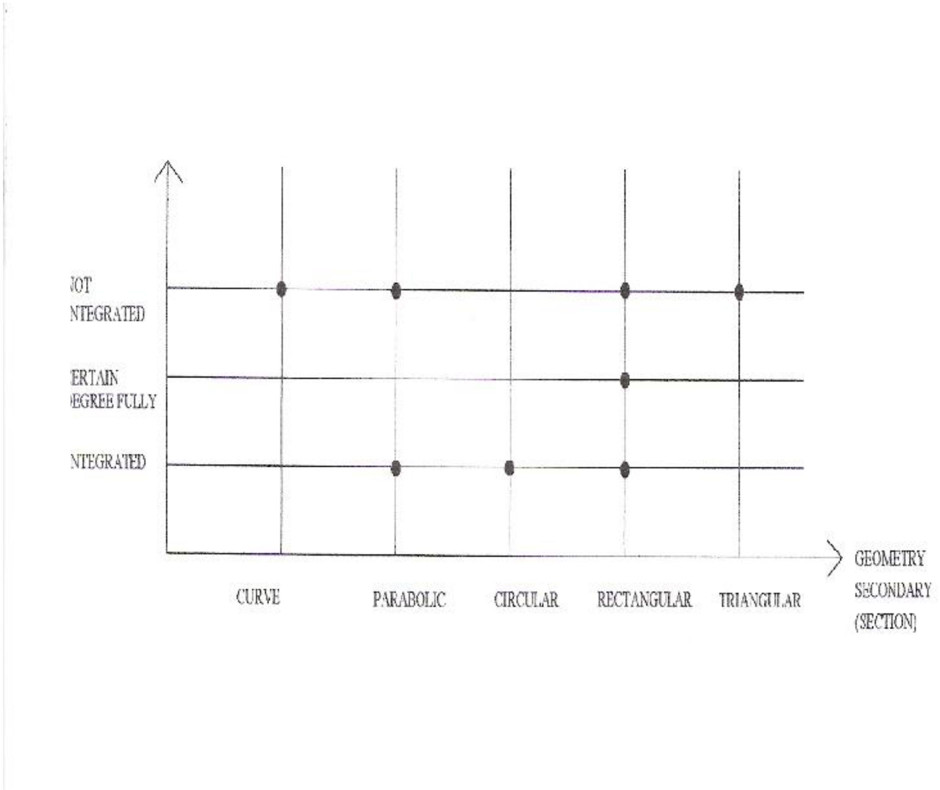


Figure 67 Integration / Section Geometry of Secondary Structure

If th eometry of the section of the secondary structure is curved or triangular, then the system is not integrated. If the geometry of the section of the secondary structure is circular, then the system is integrated. Rectangular section of the secondary structure geometry can be integrated, to a certain degree integrated, or not integrated at all.

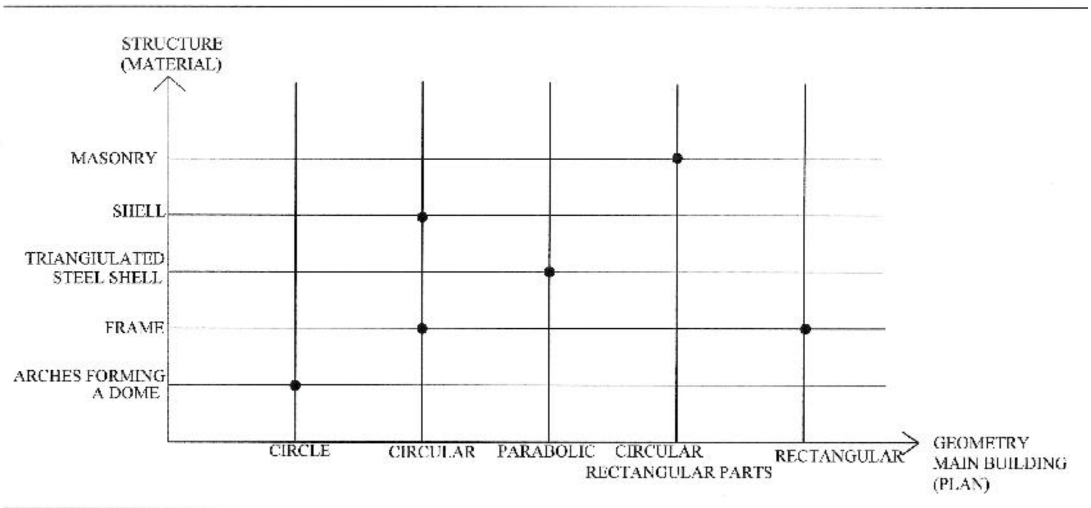


Figure 68 Structural Material / Plan Geometry of Main building

If the geometry of the main building plan is a circle, parabolic or rectangular, then the structural material is steel. If the geometry of the main building plan is circular (but including rectangular parts) the structural material is stone. If the geometry of the main building plan is circular, the materials can be steel or reinforced concrete.

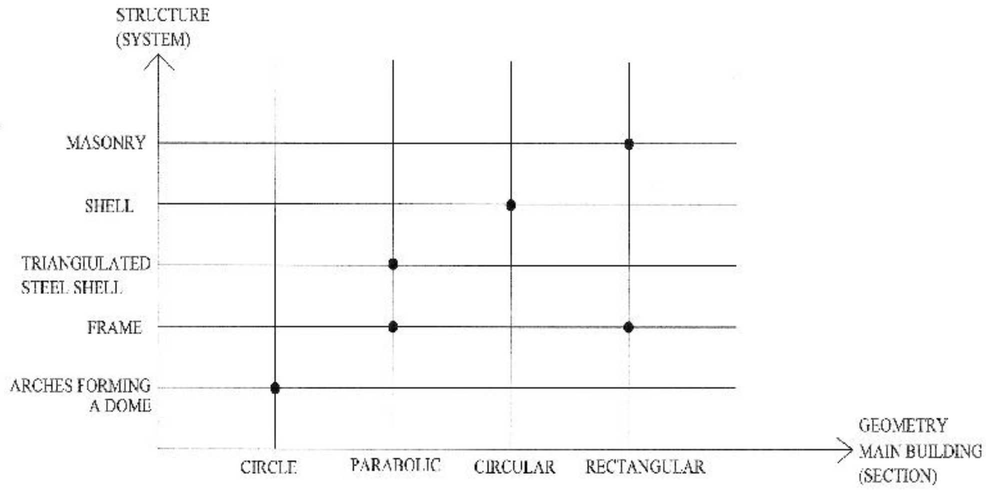


Figure 69 Structure / Section Geometry of Main building.

If the geometry of the section of the main building is a circle, the structural material is steel. If the geometry of the section of the main building is parabolic or circular, then the structural material can be reinforced concrete or steel. If the geometry of the section of the main building is rectangular, the structural material can be stone, reinforced concrete or steel.

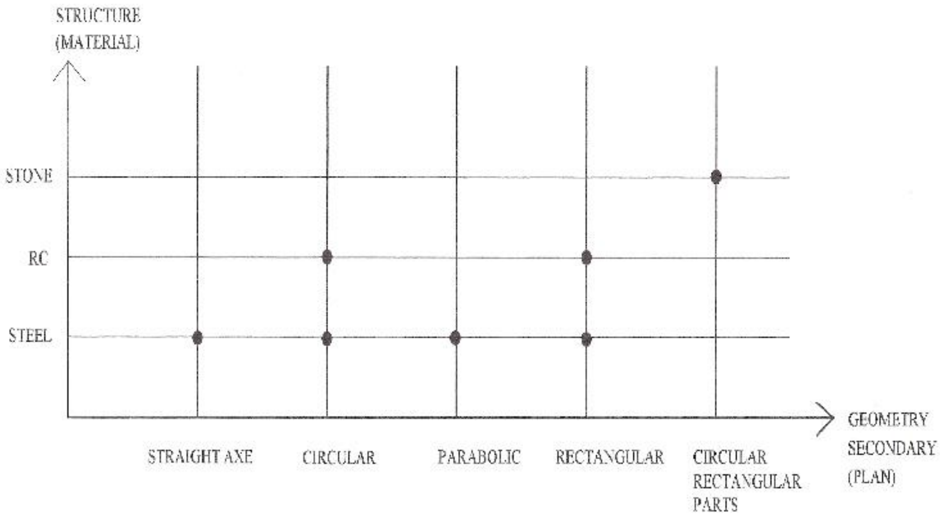


Figure 70 Structural Material /Plan Geometry of secondary structure

If the geometry of the plan of the secondary structure is based on straight axes or parabolic, then structural material is steel. If the geometry of the plan of the secondary structure is circular or rectangular, then the structural material can be reinforced concrete or steel. If the geometry of the plan of the secondary structure is circular (including rectangular parts) then the structural material is stone.

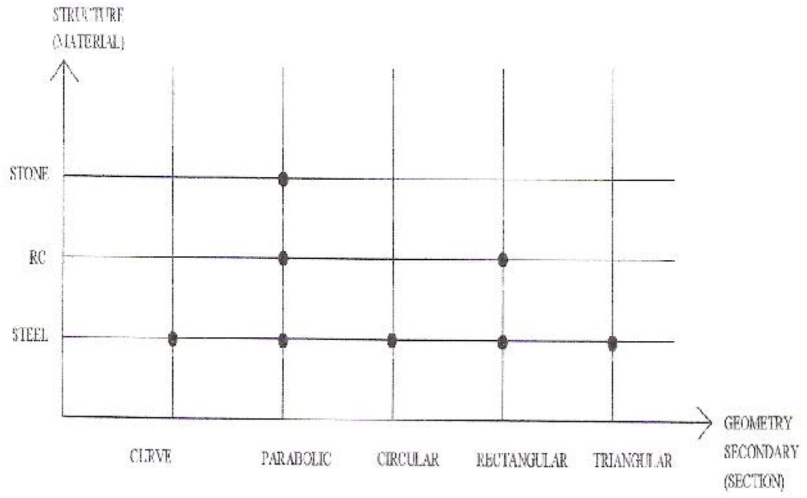


Figure 71 Structural Material/Section Geometry of Secondary Structure

If the geometry of the section of the secondary structure is a curve or circular or triangular, then the structural material is steel. The parabolic section of the second structure can be used together with stone, reinforced concrete or steel. The rectangular section of the secondary structure can be used together with reinforced concrete or steel.

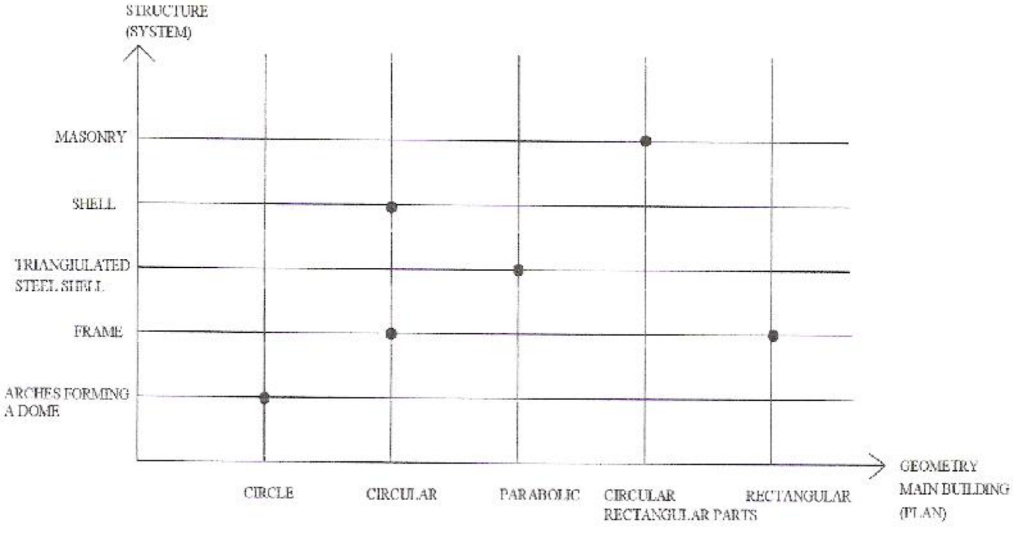


Figure 72 Structural System/Plan Geometry of Main Building

If plan geometry of main building structural system is a circle, then it is composed of arches forming a dome. If the geometry of the main building's plan is circular, then the structural system can be a frame or a steel shell. If the structural system is a triangulated steel shell, then the geometry of the main building's plan is parabolic. If the structural system is masonry, then the geometry of the main building's plan is circular which includes rectangular parts. If the structural system is a frame, then the geometry of the main building's plan is rectangular.

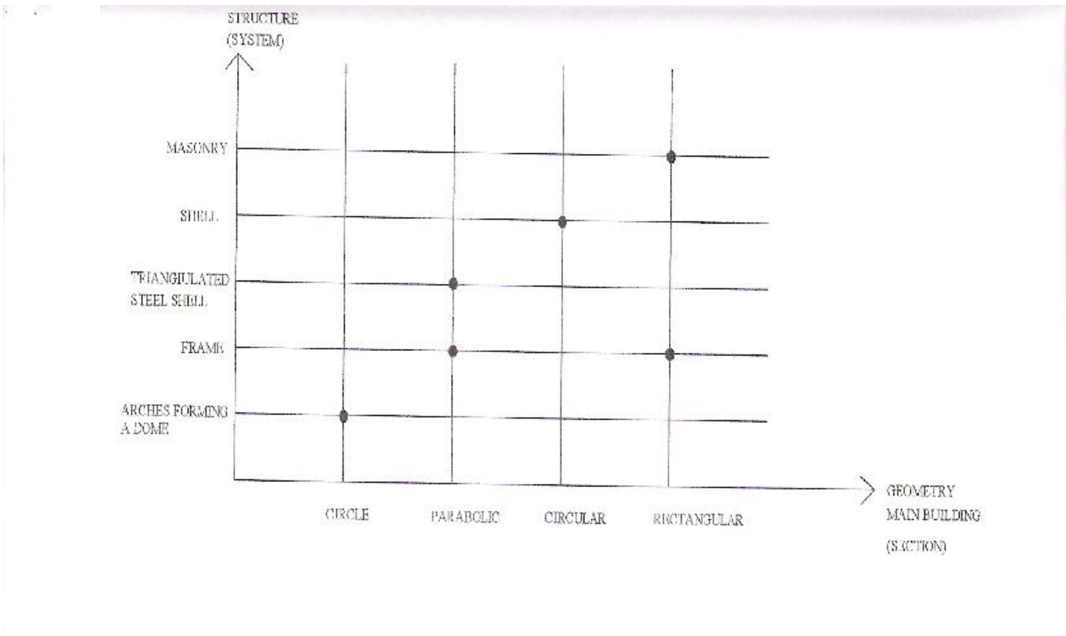


Figure 73 Structural System/Section Geometry of Main Building

If the structural system is composed of arches forming a dome, then the geometry of the main building's section is circle. If the geometry of the main building section is parabolic, then the structural system can be a frame or a triangulated steel shell. If the structural system is composed of shells, then the geometry of the main building section is circular. If the geometry of the main building's section is rectangular, the structural system can be masonry or frame.

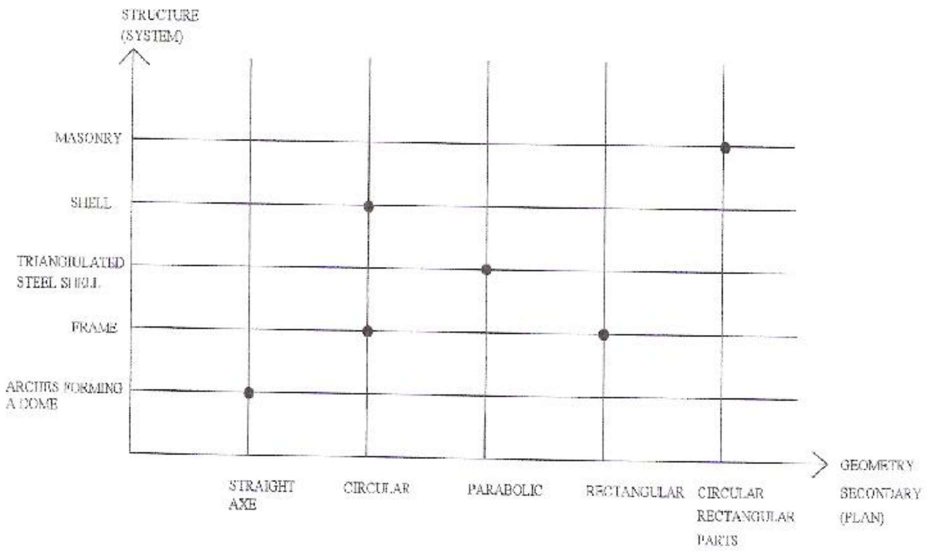


Figure 74 Structural System/ Plan Geometry of Secondary Structure

If the structural system is composed of arches forming a dome, then the geometry of the secondary structure's plan is based on straight axes. If the geometry of the secondary structure's plan is circular, then the structural system can be a frame or a shell. If the structural system is a triangulated steel shell, the geometry of the secondary structure's plan is parabolic. If the structural system is a frame, then the geometry of the secondary structure's plan is rectangular. If the structural system is masonry, then the geometry of the secondary structure's plan is circular, which includes rectangular parts.

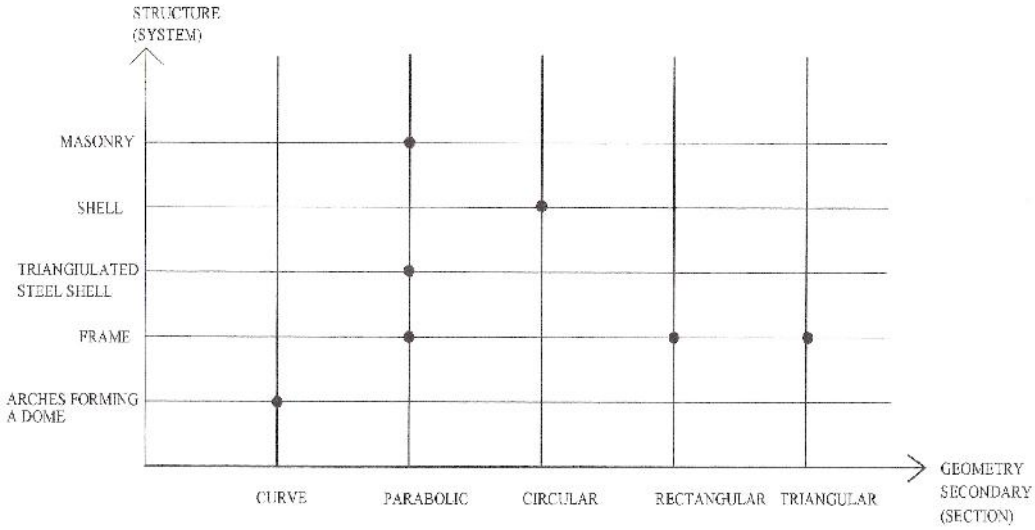


Figure 75 Structural System/Section Geometry of Secondary Structure

If the structural system is arches forming a dome, then the geometry of the secondary structure's section is curved. If the geometry of the secondary structure's section is parabolic, then the structural system can be a frame, a triangulated steel shell or masonry. If the structural system is shell, then the geometry of the secondary structure's section is circular. If the geometry of the secondary structure's section is rectangular and triangular, then structural system is a frame.

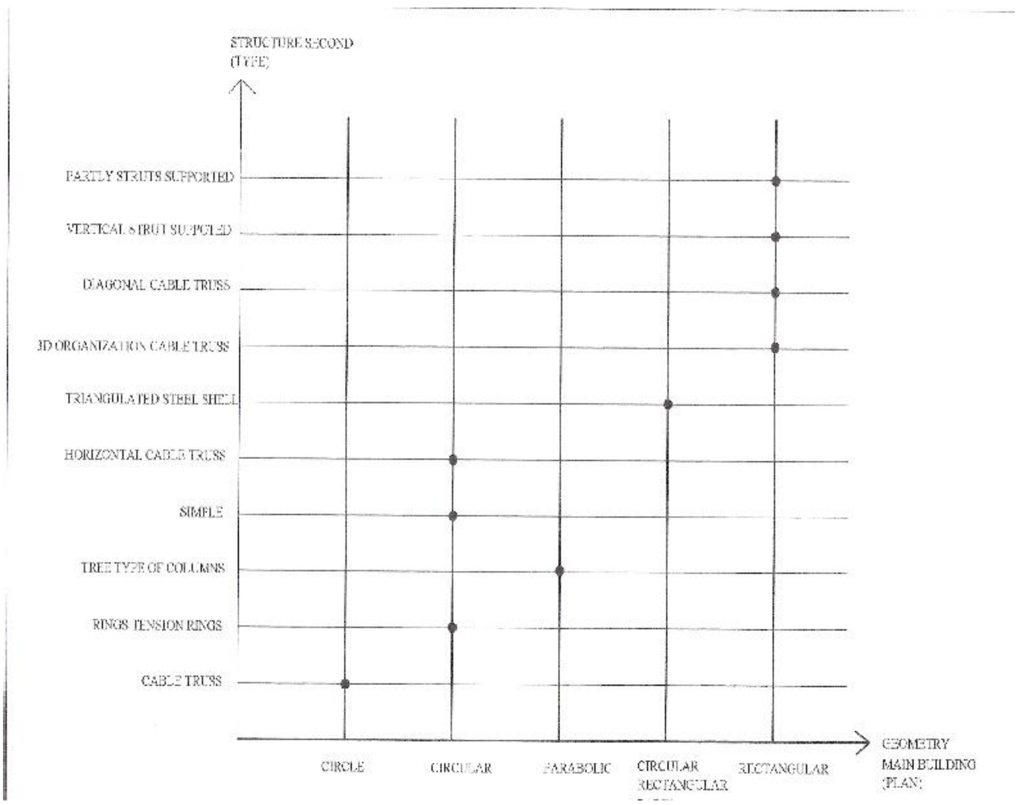


Figure 76 Structural System of Secondary structure /Plan Geometry of Main Building

When the type of the secondary structure partially helps the main building structure to carry the roof, or struts are supported by cables, or vertical struts which carry glass pieces, some of these verticals are supported by cables or diagonal cable trusses or vertical and horizontal (3 D) organization of cable trusses, then the geometry of the main building's geometry is rectangular. If the geometry of the main building's plan is circular (including rectangular parts), the type of the secondary structure is triangulated steel shell. If the type of the secondary structure is tree types of columns, then the geometry of the main building's plan is parabolic. If the type of the secondary structure is cable truss, then the geometry of the main building plan is a circle. If the geometry of the main building's plan is circular, then the type of the secondary structure can be horizontal cable truss, simple, rings or tension rings.

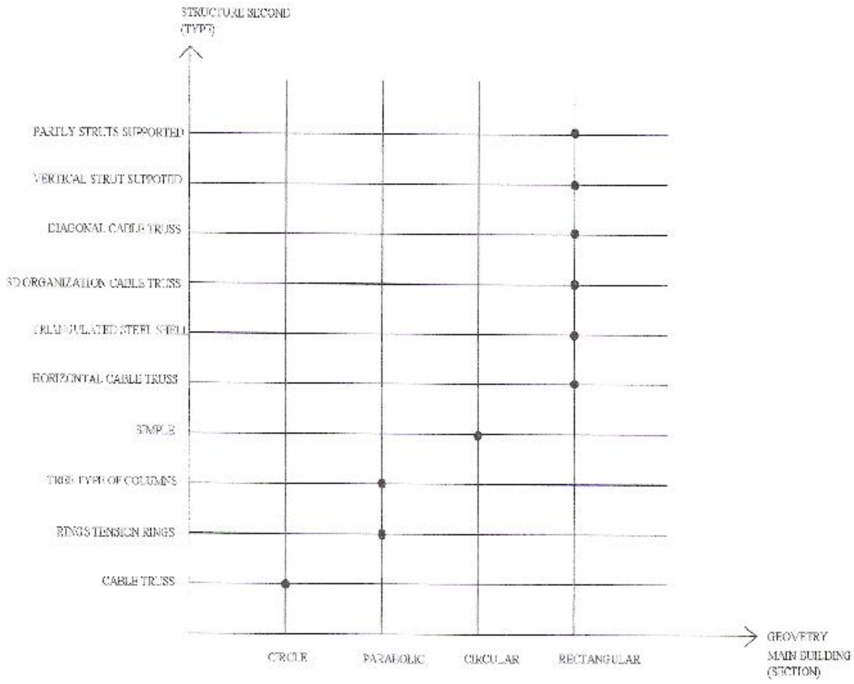


Figure 77 Structural System of Secondary Structure/Section Geometry of Main Building

When the type of the secondary structure partially helps the main building structure to carry the roof or struts supported by cables or vertical struts which carry glass pieces, some of these verticals are supported by cables or diagonal cable trusses or vertical and horizontal (3 D) organization of cable truss or triangulated steel shell and horizontal cable truss, then the geometry of the main building's section is rectangular. If the secondary structure type is simple, then the main building's section is circular. If the geometry of the main building section is parabolic, then the secondary structure type is tree types of columns or rings, tension rings. If the geometry of the main building section is circle, then type of secondary structure is cable truss.

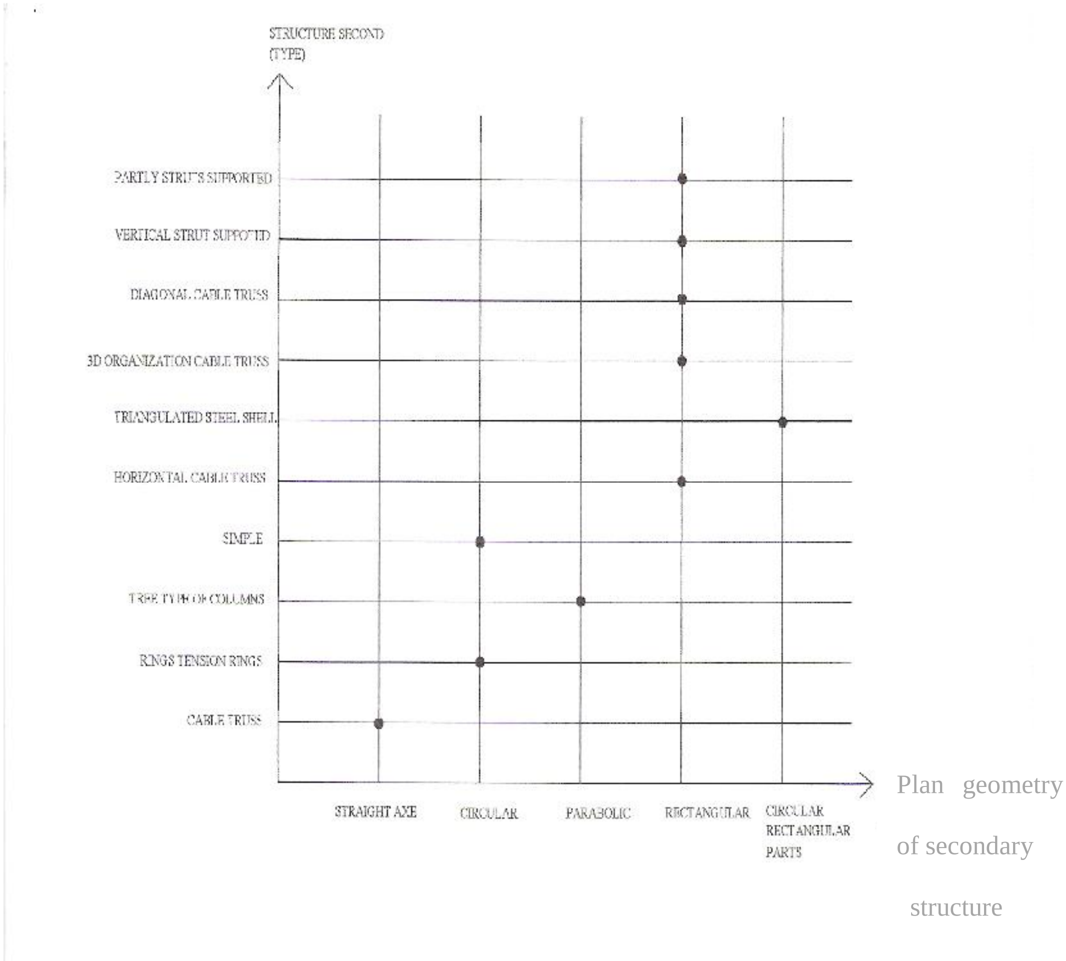


Figure 78 Type of Secondary Structure/Plan Geometry of Secondary Structure

When the type of the secondary structure partially helps main building structure to carry the roof or struts supported by cables or vertical struts which carry glass pieces, some of these verticals are supported by cables or diagonal cable trusses or vertical and horizontal (3 D) organization of cable truss, horizontal cable truss, then the geometry of the secondary structures plan is rectangular. If the secondary structural type is triangulated steel shell, then the geometry of the secondary structures plan is circular, but it includes rectangular parts. If the geometry of the secondary structure's plan is parabolic, then tree type of columns are the type of the secondary structure. If the geometry of the secondary structures plan is circular, then the type of the secondary structure can be simple or it can be tension rings. If the geometry of the secondary structures plan is based on straight axes, then the type of secondary structure is cable trusses.

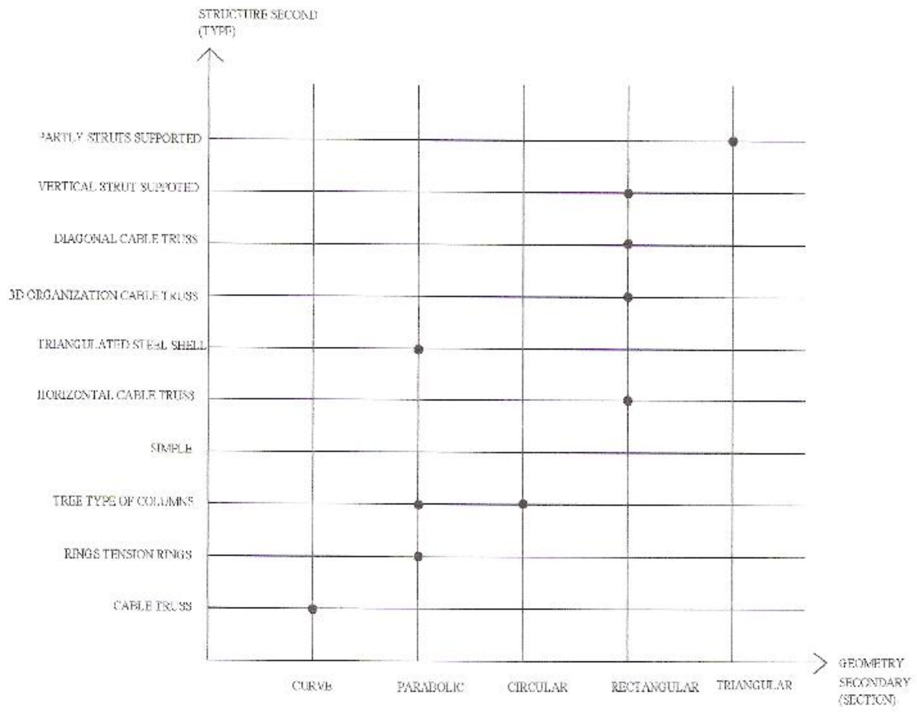


Figure 79 Type of Secondary Structure/Section of Secondary Structure

When the type of the secondary structure is vertical struts which carry glass pieces, some of these verticals are supported by cables or diagonal cable trusses or vertical and horizontal (3D) organization of cable truss, horizontal cable truss, then the geometry of the secondary structure’s section is rectangular. If the type of the secondary structure partially helps the main building structure to carry the roof or struts supported by cables, then the geometry of the secondary structure’s section is triangular. If the type of the secondary structure is simple, then the sectional geometry of secondary structure is circular. If the geometry of the secondary structure’s section is parabolic, then the type of the secondary structure can be triangulated steel shell, tree type of columns or tension rings. If the secondary structure type is cable truss, then the geometry of the secondary structure's section is curved.

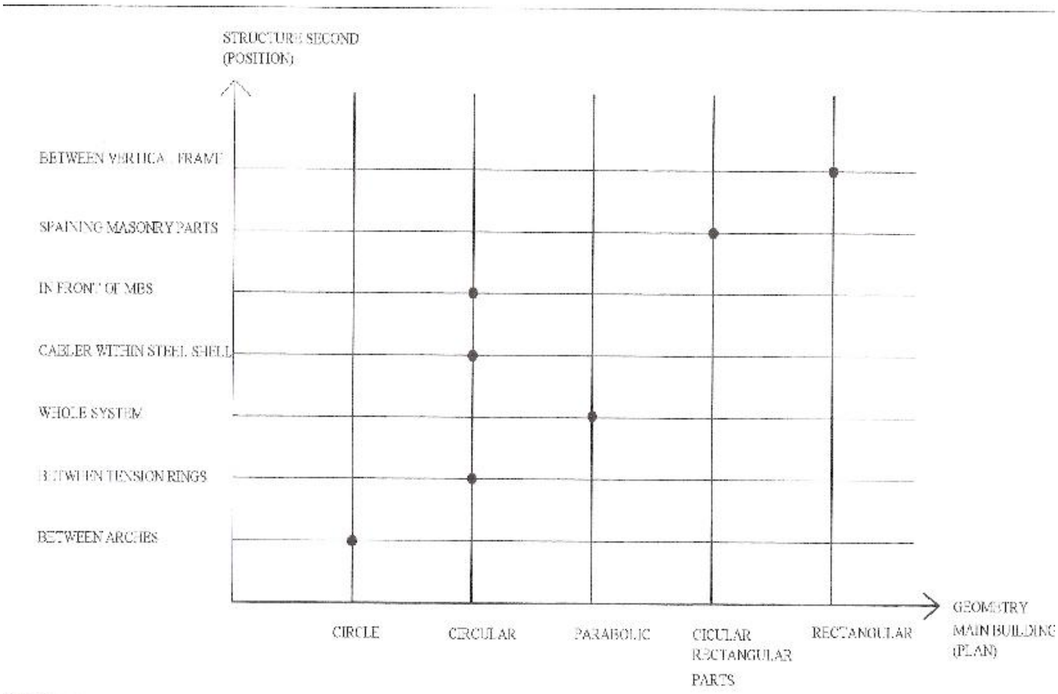


Figure 80 Position of Secondary Structure/Plan Geometry of Main Building

If the geometry of the main building's plan is rectangular, then the position of the second structure is between vertical frames. If the geometry of the main building's plan is circular (including rectangular parts) then the position of the secondary structure is spanning between masonry parts. If the geometry of the main building geometry is parabolic, then the secondary structure forms the whole system. If the geometry of the main building's plan is circle, then the position of the secondary structure is between arches. If the geometry of the main building's plan is circular, the position of the second structure can be in front of the main building structure, cables within steel shell or between tension rings.

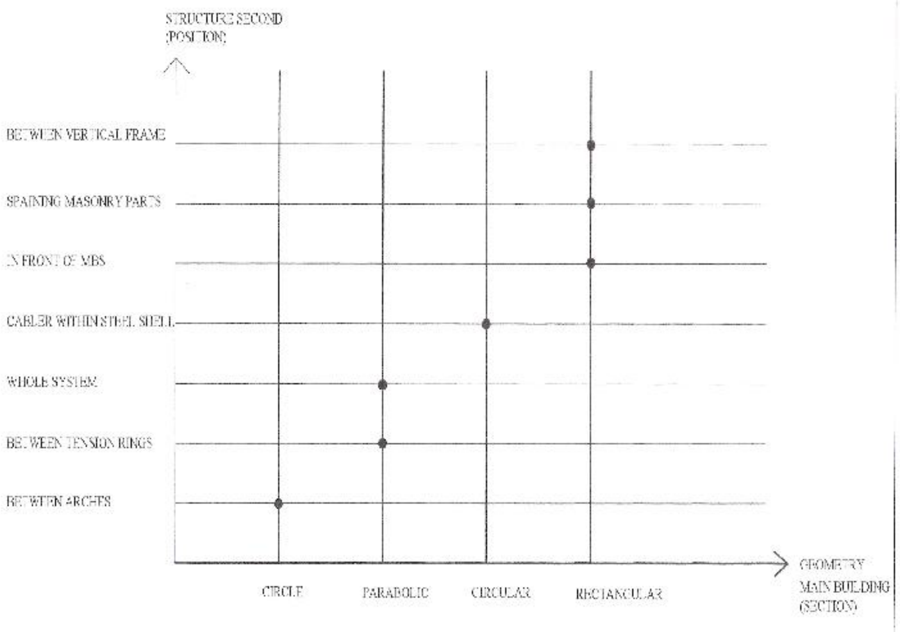


Figure 81 Position of the Secondary Structure/Section Geometry of the Main Building

If the position of the secondary structure is between arches, then the geometry of the main building's section is circle. If the position of the secondary structure is between the tension rings or within the whole system, then geometry of the main building's section is parabolic. If the position of the secondary structure is within the steel shell, then geometry of the main building's section is circular. If the position of the secondary structure is infront of the main building structure, or spanning masonry parts, or between vertical frames, then geometry of the main building's section is rectangular

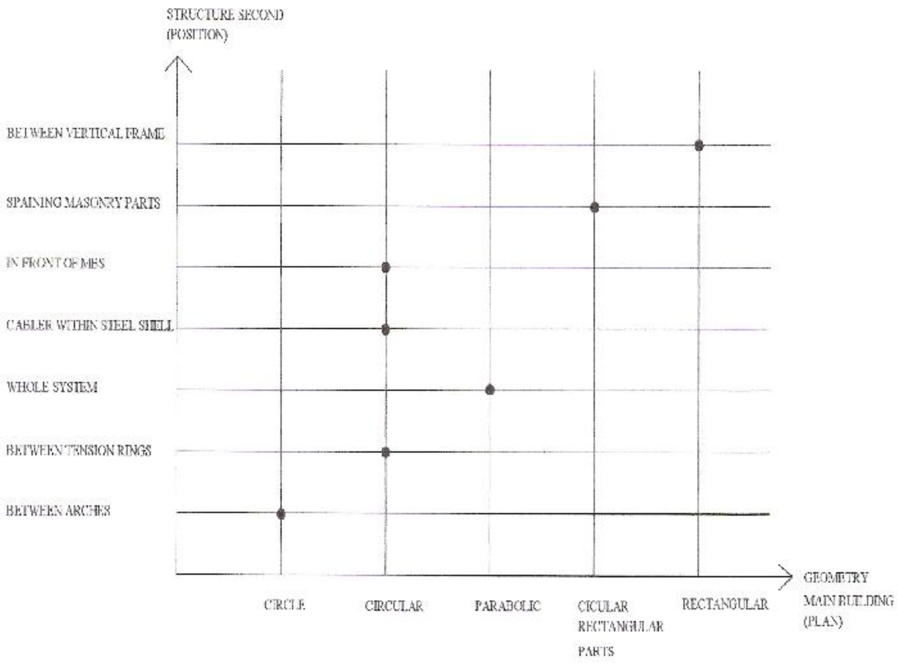


Figure 82 Position of Secondary Structure/Plan Geometry of Secondary Structure

When the position of the secondary structure is between arches, then the geometry of the secondary structure’s plan is based on straight axes. When the position of the secondary structure is between tension rings, or cables within a steel shell, then the geometry of the secondary structure’s plan is circular. When the position of the secondary structure is within the whole system, then the geometry of the secondary structure’s plan is parabolic. When the position of the secondary structure is between vertical frames or in front of the main building structure, then the geometry of the secondary structure’s plan is rectangular. When the position of the secondary structure is spanning between masonry parts, then the geometry of the secondary structure’s plan is circular (including rectangular parts).

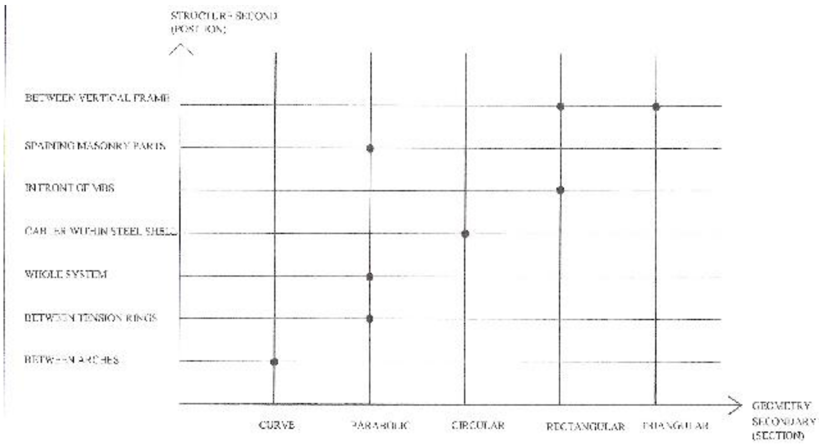


Figure 83 Position of the Secondary Structure/Section Geometry of Secondary Structure

If the position of the secondary structure is between arches, then the geometry of the secondary structure's section is curved. If the position of the secondary structure is between tension rings or within the whole system, or spanning between masonry parts, then the geometry of the secondary structure's section is parabolic. If the position of the secondary structure is in cable within a steel shell, then the geometry of the secondary structure's section is circular. If the position of secondary structure is in front of the main building structure or between vertical frames, then the geometry of the secondary structure's section is rectangular. If the position of the secondary structure is between the vertical frames then the geometry of the secondary structure's section is triangular.

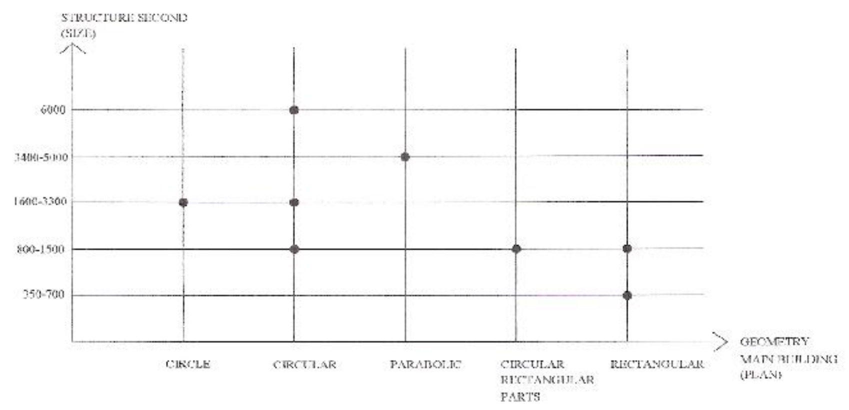
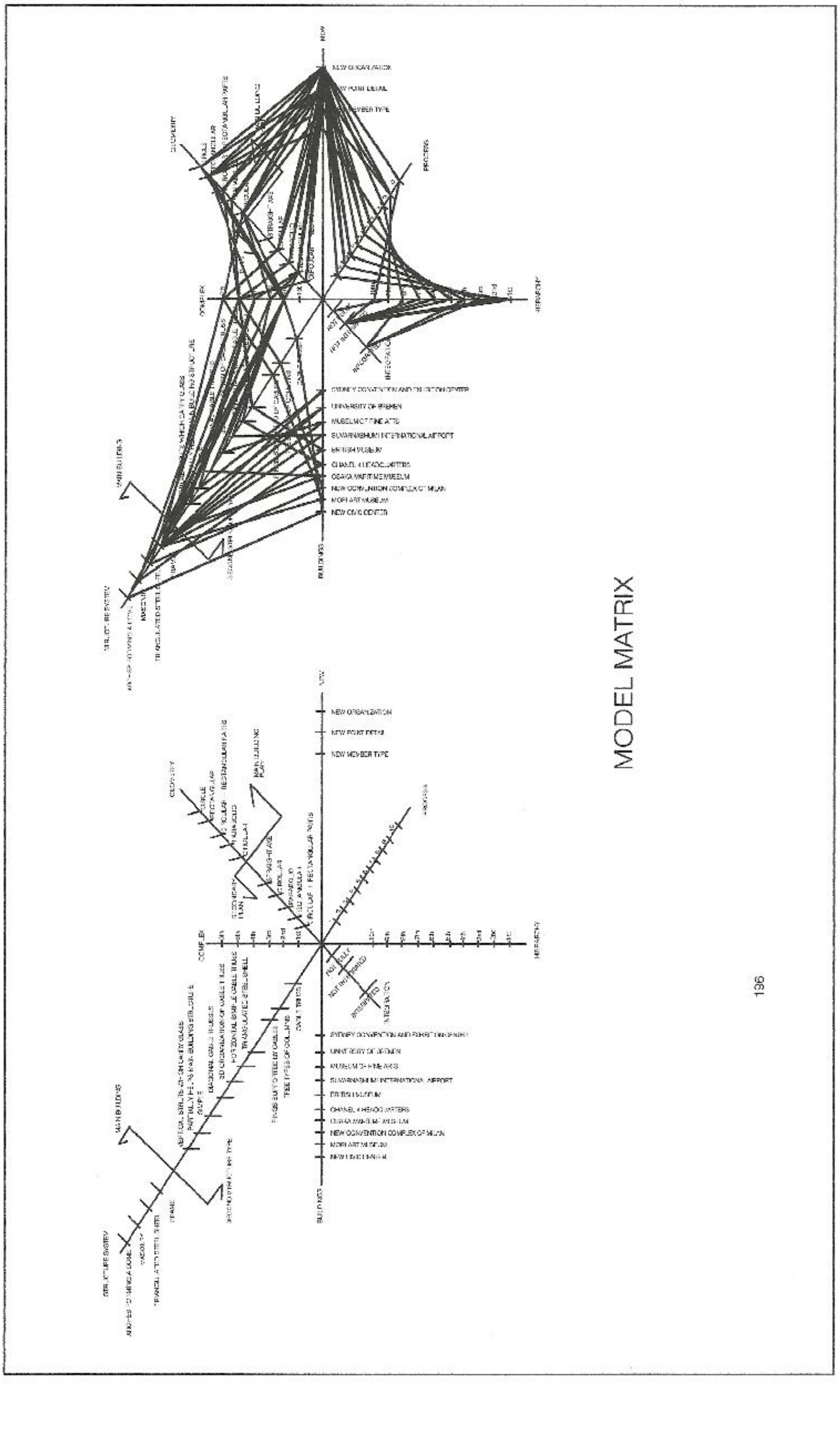
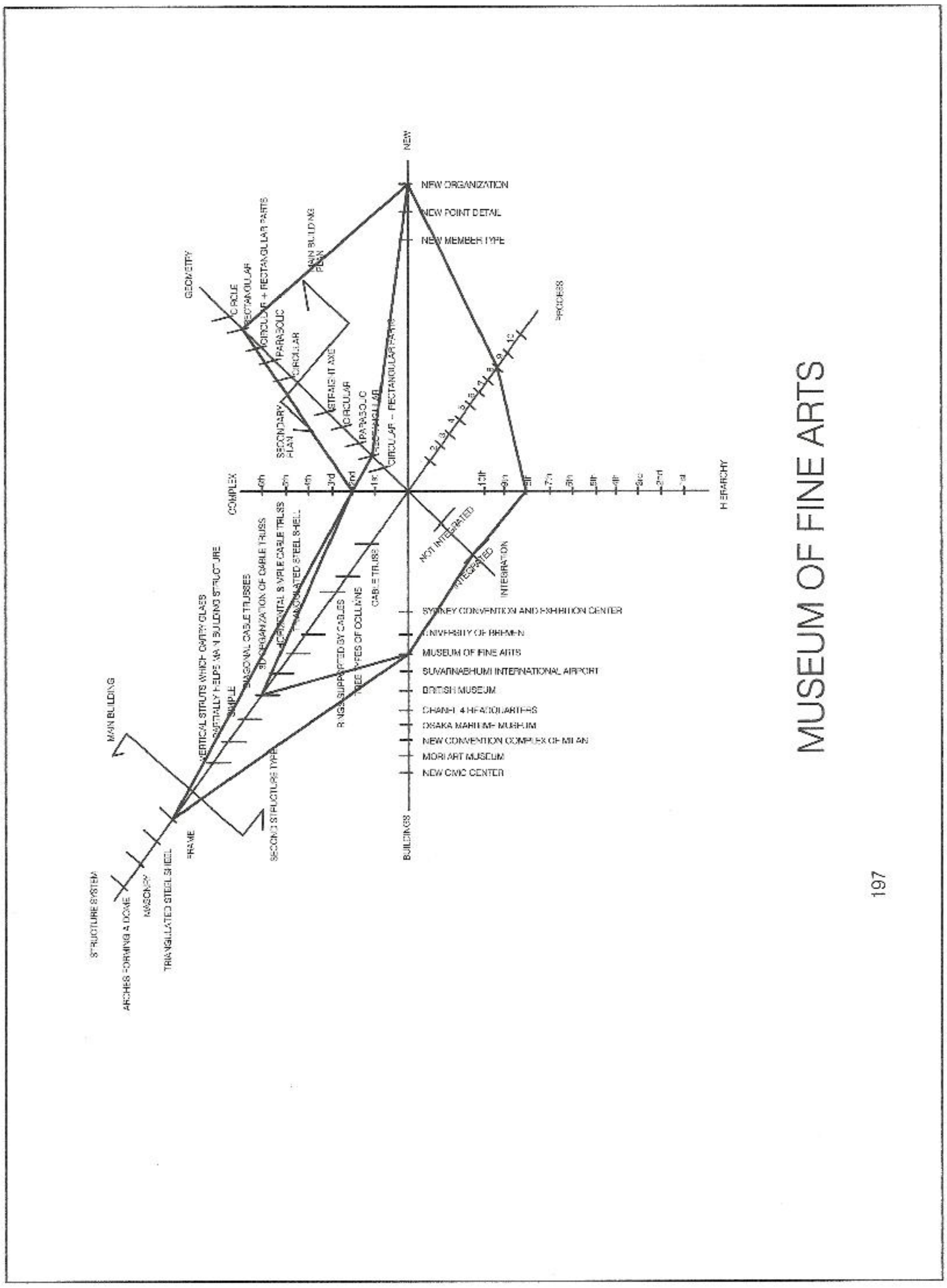


Figure 84 Size of the Secondary Structure/Plan Geometry of the Main Building

Between 8-60 m. the plan and section geometry of the main building can be a circle, circular, parabolic, circular (including rectangular parts) and rectangular. Between 8-60 m. the plan and section geometry of the secondary structure can be a circle, circular, parabolic, circular (including rectangular parts) and rectangular.

Appendix C: Other Matrices of the Model


MODEL MATRIX
196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197
NEW
NEW ORGANIZATION
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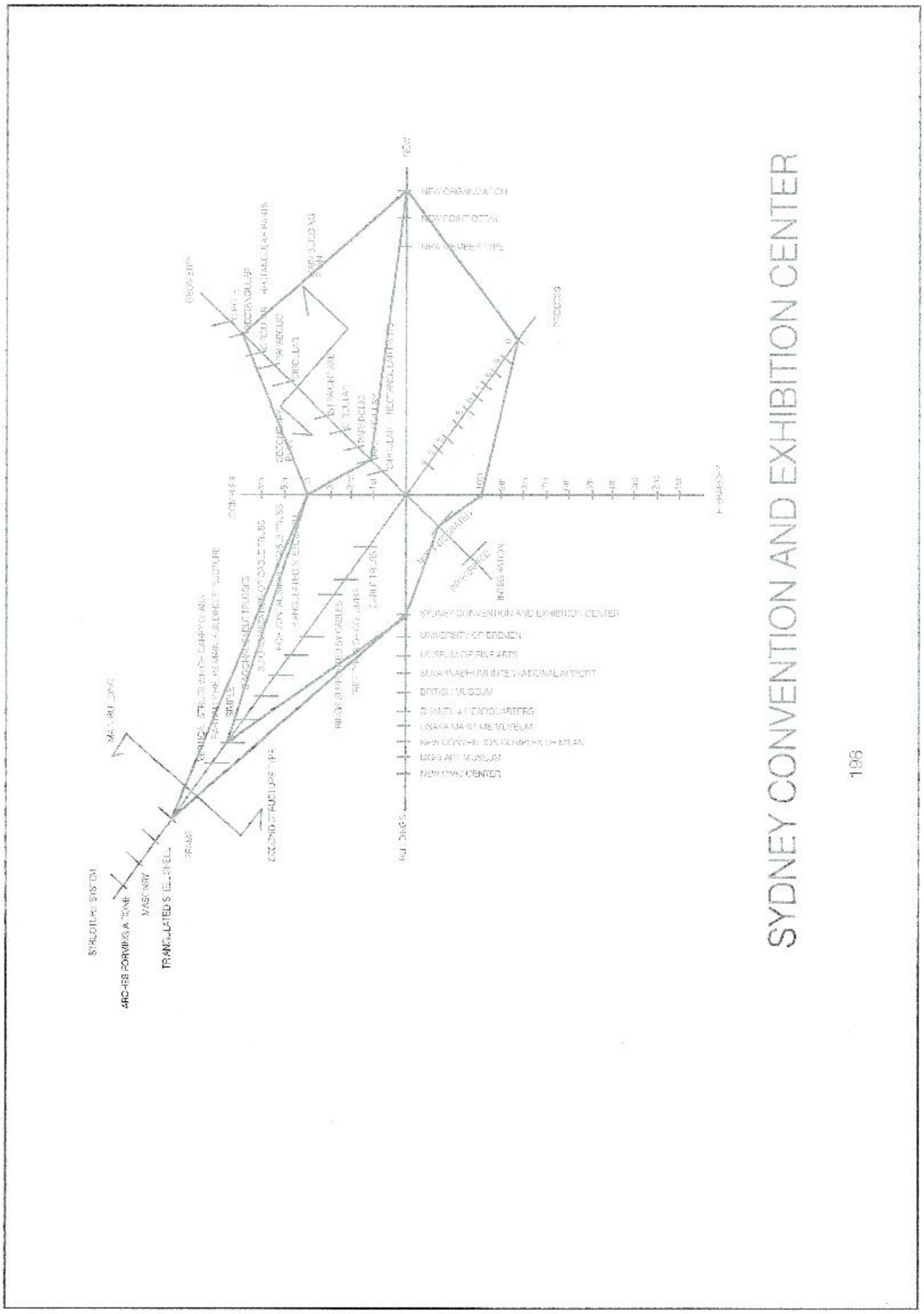
PROCESS
GEOMETRY
COMPLEX
HIERARCHY
BUILDINGS
NOT INTEGRATED
INTEGRATED
INTEGRATION
SYDNEY CONVENTION AND EXHIBITION CENTER
UNIVERSITY OF BREMEN
MUSEUM OF FINE ARTS
SUVARNABHUMI INTERNATIONAL AIRPORT
BRITISH MUSEUM
CHANEL 4 HEADQUARTERS
OSAKA MARITIME MUSEUM
NEW CONVENTION COMPLEX OF MILAN
MORI ART MUSEUM
NEW CIVIC CENTER
STRUCTURE SYSTEM
ARCHES FORMING A DOME
MASONRY
TRIANGULATED STEEL SHELL
FRAME
MAIN BUILDING
SECOND STRUCTURE TYPE
CABLE TRUSS
CIRCULAR + RECTANGULAR PARTS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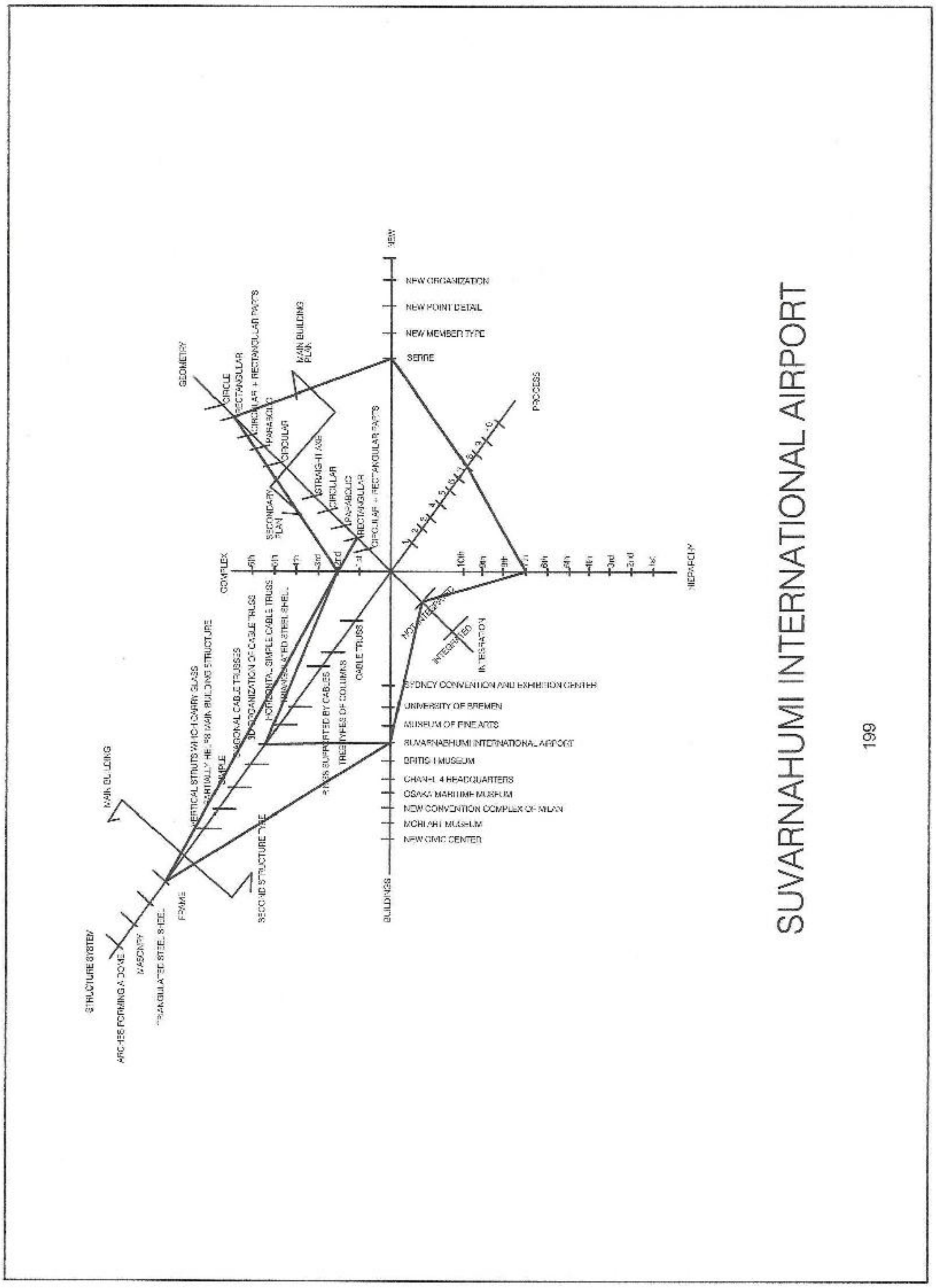
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UNIVERSITY OF BREMEN
MUSEUM OF FINE ARTS
SUVARNABHUMI INTERNATIONAL AIRPORT
BRITISH MUSEUM
CHANEL 4 HEADQUARTERS
OSAKA MARITIME MUSEUM
NEW CONVENTION COMPLEX OF MILAN
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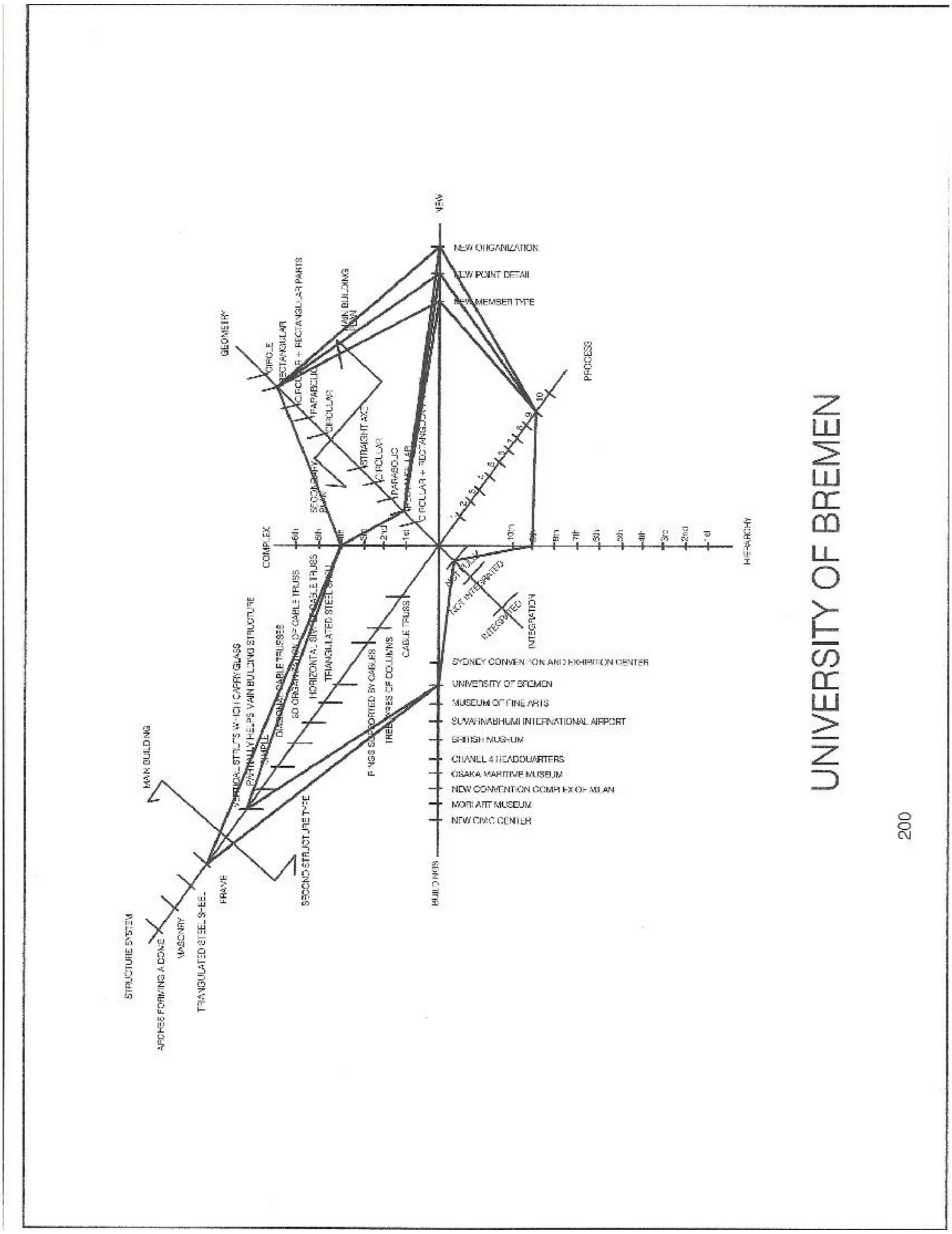
CABLE TRUSS


UNIVERSITY OF BREMEN
200
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INTEGRATED
NOT INTEGRATED
BUILDINGS
SYDNEY CONVENTION AND EXHIBITION CENTER
UNIVERSITY OF BREMEN
MUSEUM OF FINE ARTS
SUVARNABHUMI INTERNATIONAL AIRPORT
BRITISH MUSEUM
CHANEL 4 HEADQUARTERS
OSAKA MARITIME MUSEUM
NEW CONVENTION COMPLEX OF MILAN
MORI ART MUSEUM
NEW CIVIC CENTER
STRUCTURE SYSTEM
ARCHES FORMING A DOME
MASONRY
TRIANGULATED STEEL SHEEL
FRAME
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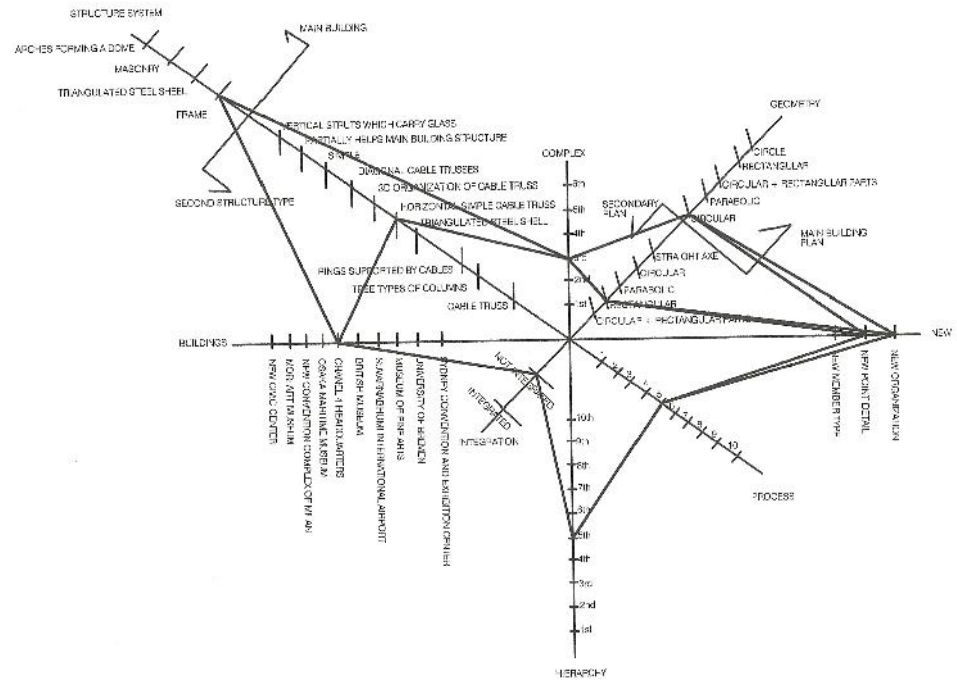
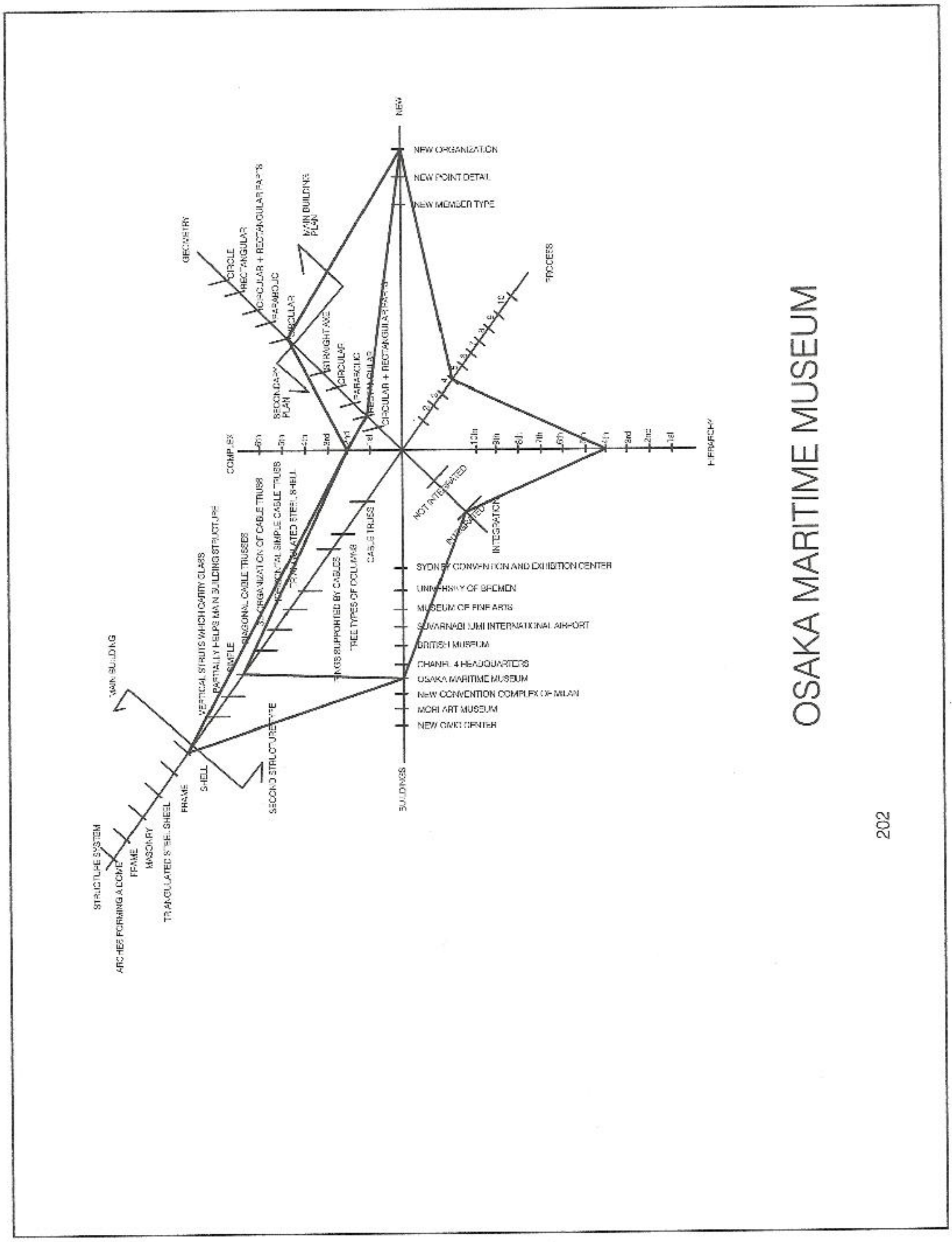
MAIN BUILDING
CABLE TRUSS
TREE TYPES OF COLUMNS
RINGS SUPPORTED BY CABLES
TRIANGULATED STEEL SHELL



CHANEL 4 HEADQUARTERS

201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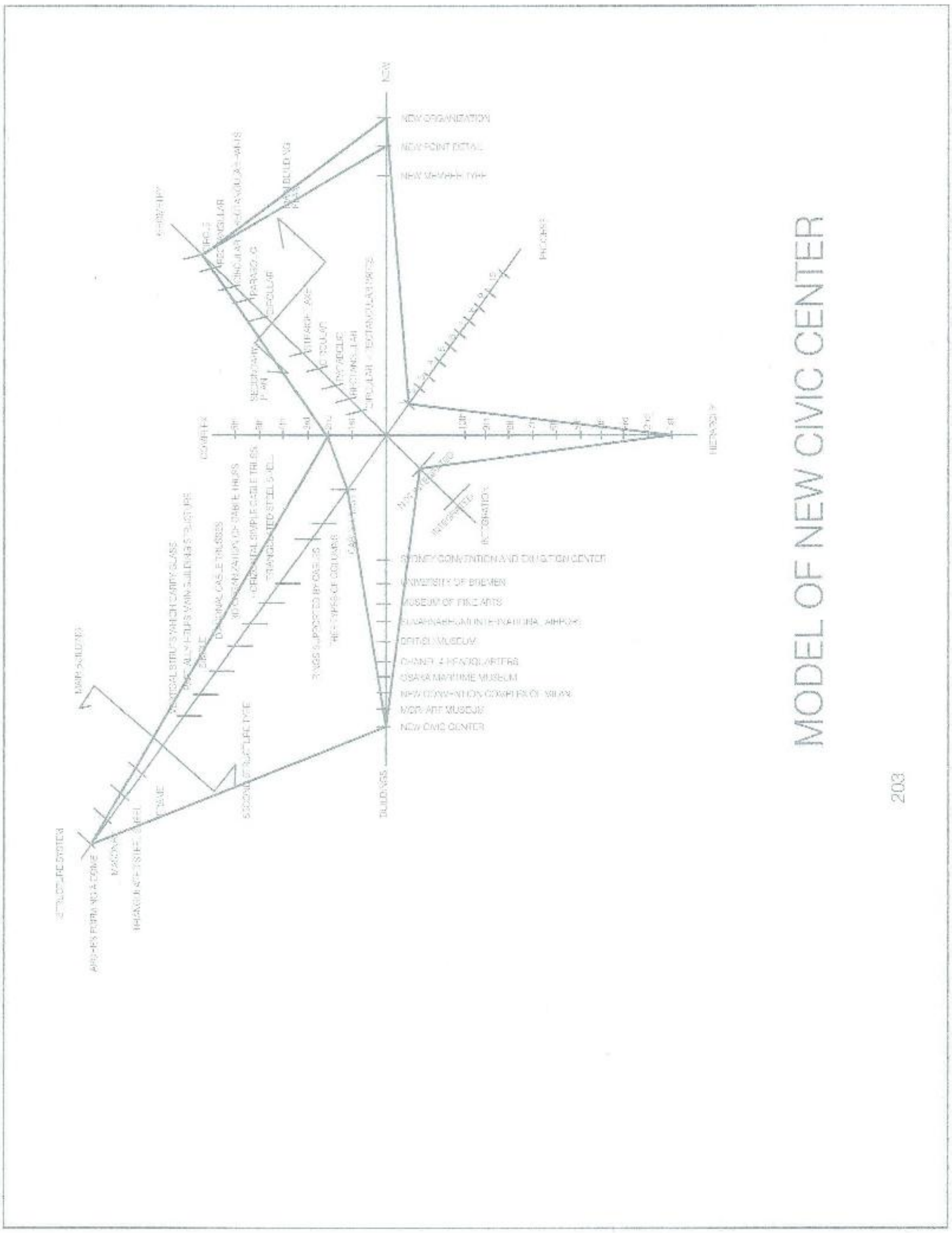
202


MODEL OF NEW CIVIC CENTER
203
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UNIVERSITY OF BREMEN
MUSEUM OF FINE ARTS
CHANNEL 4 HEADQUARTERS
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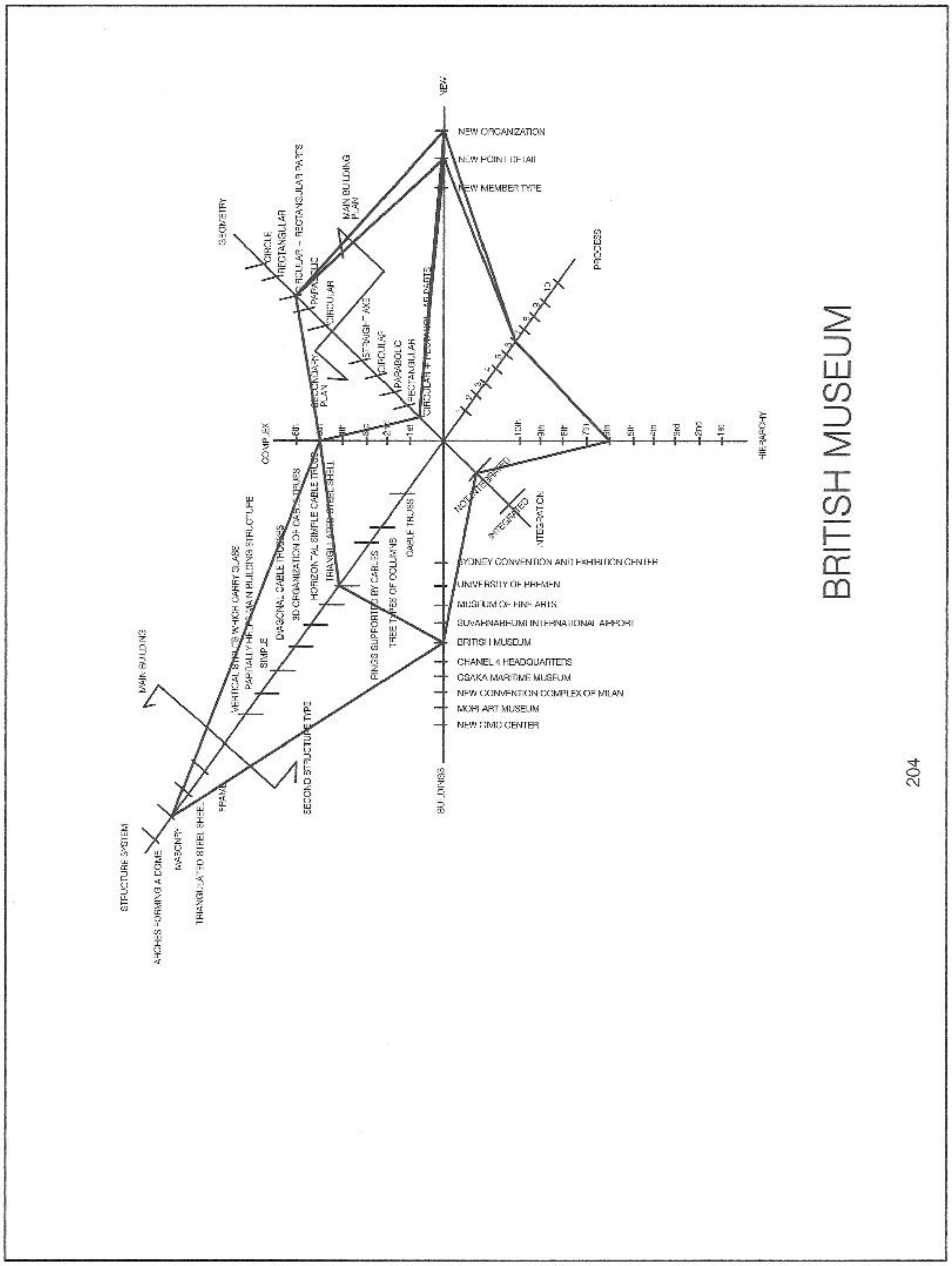
BUILDINGS
HIERARCHY
INTEGRATION
STRUCTURE SYSTEM
MAIN BUILDING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NOT INTEGRATED
GEOMETRY
CIRCLE
RECTANGULAR
CIRCULAR – RECTANGULAR PARTS
PARABOLIC
CIRCULAR
MAIN BUILDING PLAN
SECONDARY PLAN
STRAIGHT AXE
RECTANGULAR
CABLE TRUSS
TREE TYPES OF COLUMNS
RINGS SUPPORTED BY CABLES
TRIANGULATED STEEL SHELL
HORIZONTAL SIMPLE CABLE TRUSS
3D ORGANIZATION OF CABLE TRUSS
DIAGONAL CABLE TRUSSES
SIMPLE
VERTICAL STRUTS WHICH CARRY GLASS
SECOND STRUCTURE TYPE
MAIN BUILDING
FRAME
TRIANGULATED STEEL SHELL
MASONRY
ARCHES FORMING A DOME
STRUCTURE SYSTEM
BUILDINGS
SYDNEY CONVENTION AND EXHIBITION CENTER
UNIVERSITY OF BREMEN
MUSEUM OF FINE ARTS
SUVARNABHUMI INTERNATIONAL AIRPORT
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NEW CONVENTION COMPLEX OF MILAN
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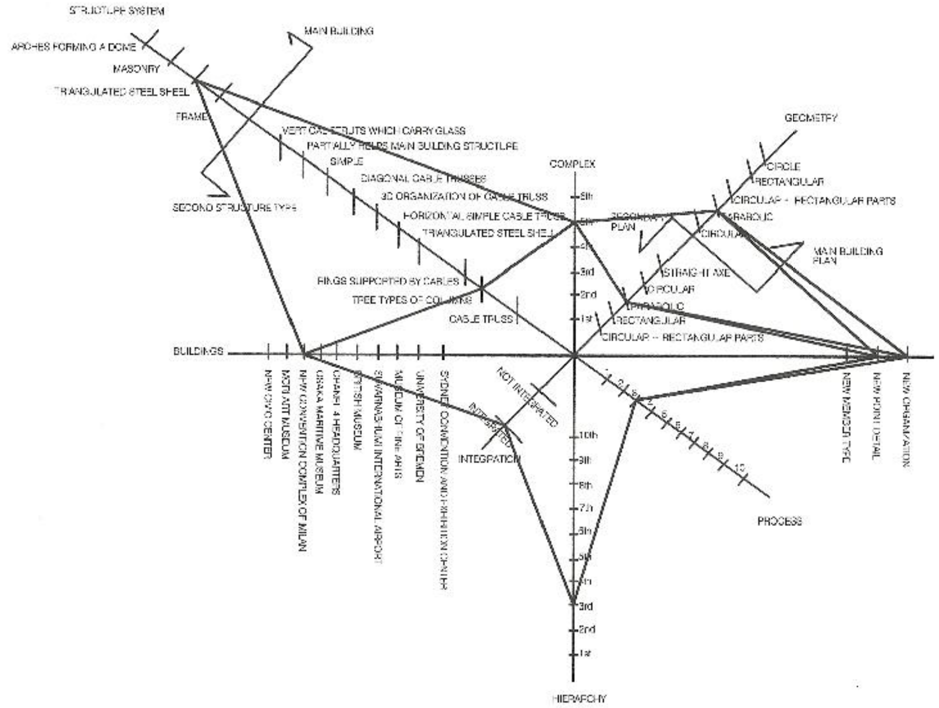
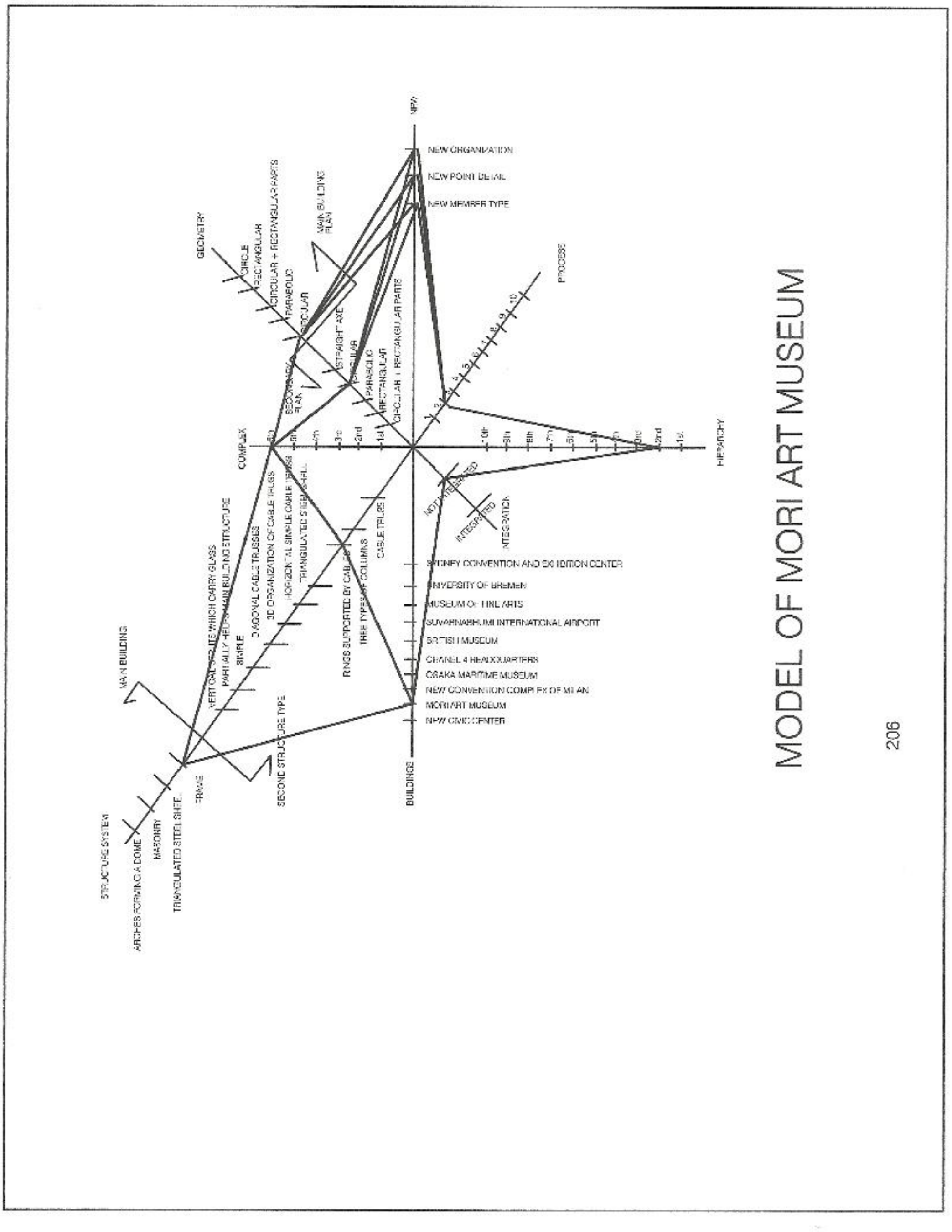
NEW CIVIC CENTER



MODEL OF NEW CONVENTION COMPLEX OF MILAN

205


MODEL OF MORI ART MUSEUM
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NOT INTEGRATED
SYDNEY CONVENTION AND EXHIBITION CENTER
UNIVERSITY OF BREMEN
SUVARNABHUMI INTERNATIONAL AIRPORT
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MORI ART MUSEUM
NEW CIVIC CENTER
BUILDINGS
MAIN BUILDING
SECOND STRUCTURE TYPE
FRAME
MASONRY
STRUCTURE SYSTEM
ARCHES FORMING A DOME
TRIANGULATED STEEL SHELL
CABLE TRUSS
SIMPLE
DIAGONAL CABLE TRUSSES
3D ORGANIZATION OF CABLE TRUSS
TRIANGULATED STEEL SHELL
CIRCULAR + RECTANGULAR PARTS