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Attempt of numerical design recognition of space structure to use possession energy theory of space frame -shell and spatial structures-

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Abstract

In this 21st century, we are faced with the issue how we use materials of the earth ecologically. We, researchers, designers and engineers in architectural circles, always run after the possibilities of architectures that composed of limited materials of the earth. However, some architects are often put an emphasis on their artistic designs. That causes un-ecological structures.

In this report, I try to judge an artistic realization numerically by the method of potential structural energy which uses a function and a diagram.

This method can lead you to realize that structure is easy on the environment showed on a diagram given by analysing and reviewing a proper performance of a structure numerically based on “potential structural energy”.

Keywords: design epistemology, numerical design recognition, pentagon chart, structural design, space frame

1. Introduction

This report is a small experiment for the human to get the ecological life in the earth through an architectural design. In recent years, it began all of a sudden to be urged the "ecological life" on a global scale. Through it is not necessary to refer, this resulted from "consequent supremacy principle of market economy" that advanced nations developed in the 20th century. It made everything on the earth the prey of economic growth, because we recognized it as the only means to enrich the human's life, pushed acquired high quality IT technique out forward, and depended on it to live.

As a result, this supremacy principle of market economy damaged greatly the human's life in each several decades.

It also influences an architectural space that is one of the starting points of life. It might be the architectural design field that an aesthetic decision is put in question most under the influence of the market economy principle. When the architectural design is achieved, it is public to say nothing of this. Therefore, an aesthetic aspect is important as architectural decision.

However, the point where the architecture is quite different from the art is the life span of design. If the art is made substance at the moments, it consists as artistic production. But if the architecture is completed once, it is shared more and more by everyone. So architecture can be said to become a frame and a design after at least a century. Especially, huge architecture that becomes a landmark in the region is demanded by a long-life frame and a visual quality (aesthetic condition) including the effect of the market economy.

That is, three conditions that long life (more than a century), visual quality, and the effect of the market economy are indispensable that the public building is born in this world. The architecture and the architectural design with these conditions can be recognized to coexist with the global environment.

The main discourse introduces the simple numerical analysis and the comparison recognition using one function and one diagram about the above-mentioned longevity of architecture and a visual quality of architectural design. One function is the energy function of possession frame ($Ess[kN\cdot m]=\Sigma En[kN/m^2]\times Vn[m^3]$), and this can recognize the frame of the space as a workload of the material. One diagram is the radar chart of the Pentagon shape, and the values divided the energy of possession space flame by five peculiar amounts of shape (volume, area, maximum length, the highest height and total weight). This value can recognize the employed material and the peculiar amount of the potential energy on an architectural condition in the characteristic region.

2. Function of skeleton possessed energy and pentagon chart of numerical design recognition

2.1. Function of possession space flame energy (Ess)

Though it is a well-known fact, it is ruled by the peculiar condition of local ground that the architecture and the space frame (structure) have been completed. The structural design function (**Fed**, Tuboi Award 1999) is to put together design processes from sketch to construction in a function. This function can be written as :(Figure 1)

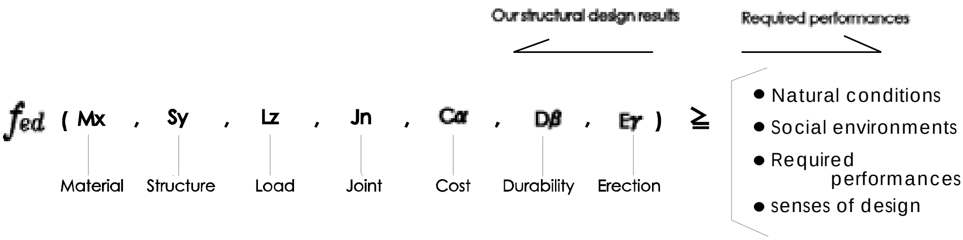


Figure 1: Structural design function

The right sides are the condition of local site, social environments, the condition of clients and design experiences of the past.

"≧" : "=" (equal) is the code of local site. ">" (more) is that the left side has better performance and quality of design than the right one.

This function can be used as follows.

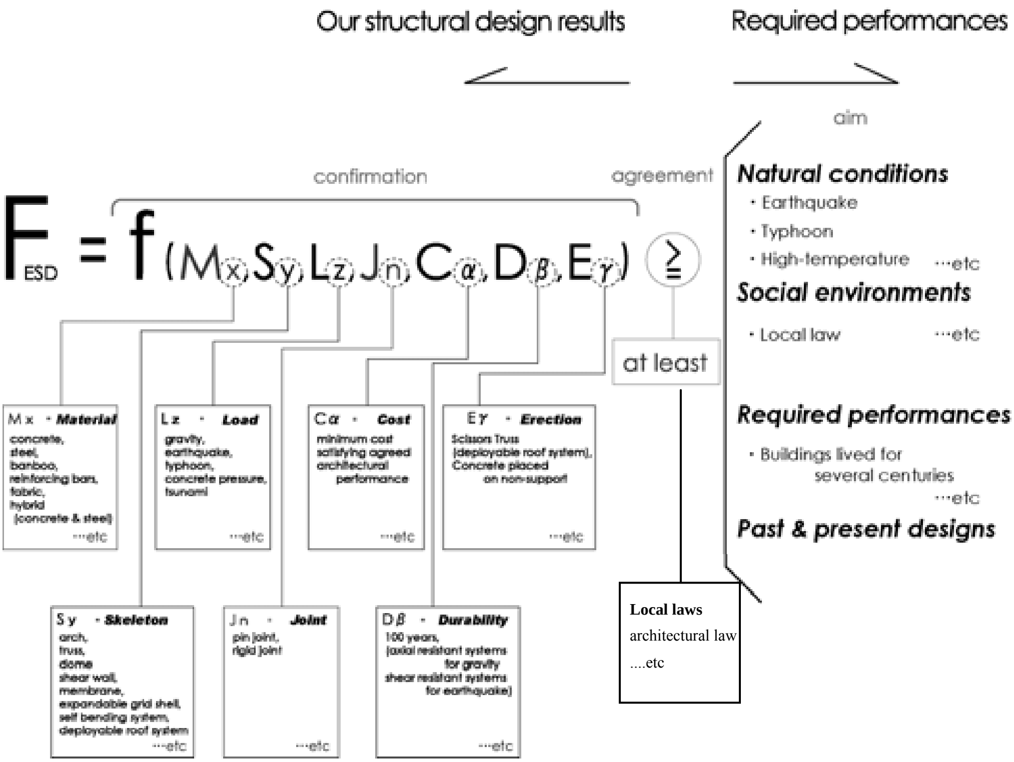


Figure 2: An example using the structural design function

Furthermore this function can be recognized the structural resistant system of space frame visually with the structural space cognitive diagram.

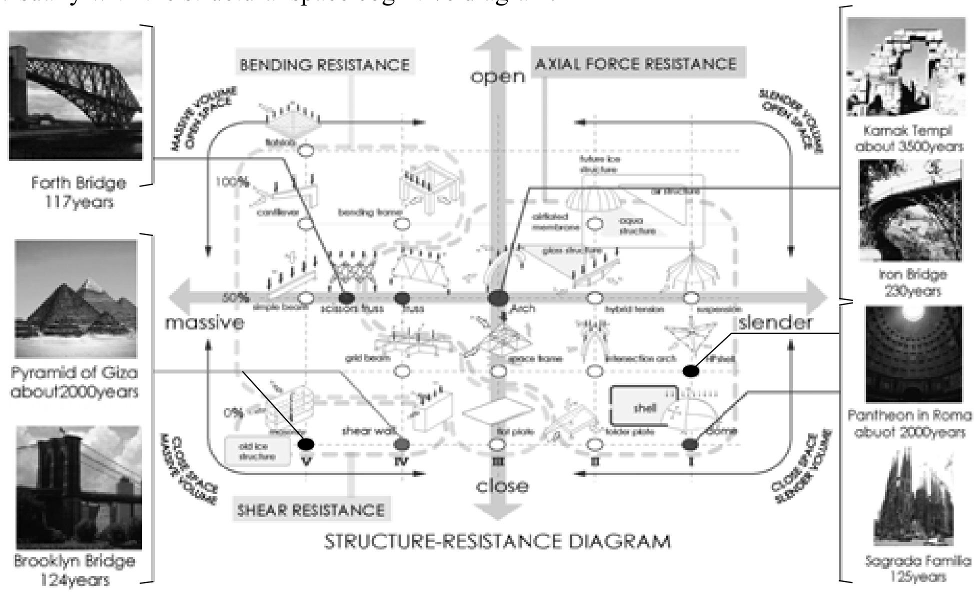


Figure 3: Structural space cognitive diagram

Due to analyze the theory of possession flame space energy in detail, it is necessary to consider all parameter of it. Now only the material (Mx) and the durability (Dβ) of this function are focused in this report.

2.1.1. Composition of Ess

The energy of the possession space frame (Ess) is design condition at the right side of the function **Fed**. The energy possessed by a space frame or an existent one is described the total of natural potential energy, for example gravity, earthquake, typhoon and heavy snow, etc. In other words, the completed space frame has the workload when it maintains the own form for the natural outside power. This relation can be as follows :

$$[\mathrm{Power} \times \mathrm{Distance} = \mathrm{kN} \times \mathrm{M}] \tag{1}$$

The energy of a certain possession space frame is described to multiply Young modulus of the material (kN/m2) by the total quantity of the one for space frame. In other words, it is described about how each Young module works.

This relation can be as :

$$[\mathrm{kN/m^2} \times \mathrm{m^3} = \mathrm{kN} \cdot \mathrm{m}] \tag{2}$$

2.1.2. Advantages of Ess

The feature of the function of skeleton possessed energy defined here can be the mixed composition with two or more materials when architecture is designed in our daily life, because it is too difficult to design the architecture and the space frame with only one kind of material. Generally, it is also difficult to analyze and to confirm the longevity and the performance of the space frame using a different kind of materials.

However, if the function can be used, it is simple to interpret it with the Young modulus of the material（En）and the total quantity of the one（ΣVn） because the Young modulus is the international factor by consensus and the total quantity is made out from the environment of natural society and the local code. Therefore, if they have a different kind of materials, or if the quantity of materials is not same, it can be figured out with the integral amount (En×Vn). In other words, this has the possibility of numerical analysis and recognition about architectural design in using this theory that the architectural design has been analyzed with only the visual image.

2.2. The Pentagon chart of numerical design comparison

The diagram of QDCP(numerical design comparative pentagon) is completed to plot the values on it that the energy of possession frame space mentioned above is divided by five peculiar amounts of completed shape (volume, area, maximum length, the highest height and total weight).

2.2.1. Use of QDCP diagram

The diagram is used simply without complicated technique.

STEP 1

Five comparison values of the energy of possession space frame［Ess／sp・V, Ess／sp・S, Ess／H_{max}, Ess／L_{max}, Ess／W_E］(these values mentioned above) are plotted on the prescribed line in the diagram. (Figure 4)

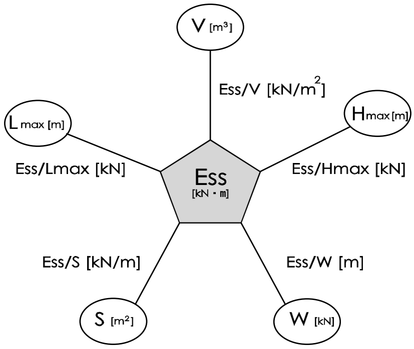


Figure 4: QDCP diagram

STEP 2

When these points that Ess is divided by each of five peculiar amounts of completed space (STEP 1) are joined, it determines pentagon shape. If the area of this pentagon is small, it can be represented the amount of the energy of space frame in this analysis of numerical design recognition.

3. Examples

When this theory is used, the possession frame energy per its volume (m^3) of three kinds of main materials is as follows.

Wood (Douglas fir and laminated wood):

Douglas Fir's elastic modulus $E=1.3\times 10^7$ kN/m^2

Possession frame energy Ess a volume[m^3] can be written as:

$$\mathrm{Ess(wood)} = 1.3\times 10^7 \times 1 = 1.3\times 10^7 \ \mathrm{kN}\cdot\mathrm{m} \tag{3}$$

Concrete:

Concrete elastic modulus $E=2.1\times 10^7$ kN/m^2

Possession frame energy Ess a volume[m^3] can be written as:

$$\mathrm{Ess(concrete)} = 2.1\times 10^7 \times 1 = 2.1\times 10^7 \ \mathrm{kN}\cdot\mathrm{m.} \tag{4}$$

Steel:

Steel elastic modulus $E=2.1\times 10^8$ kN/m^2

Possession frame energy Ess

$$\mathrm{Ess(steel)} = 2.1\times 10^8 \times 1 = 2.1\times 10^8 \ \mathrm{kN}\cdot\mathrm{m} \tag{5}$$

It can be understood that concrete has 1.6 times more workload than wood and that steel has 16 times more workload than wood. To put it the other way around, assuming the same amount of enegy, it is possible to compare how much materail are needed. To get the same amount of work, wood is needed 1/1.6 times more than concrete and steel is needed 1/16 times more than steel.

Next the enegy of space frame of a real project, for exmaple Dome project, is calculated and the analysis with five comparison values is practiced.(Figure 5,6)

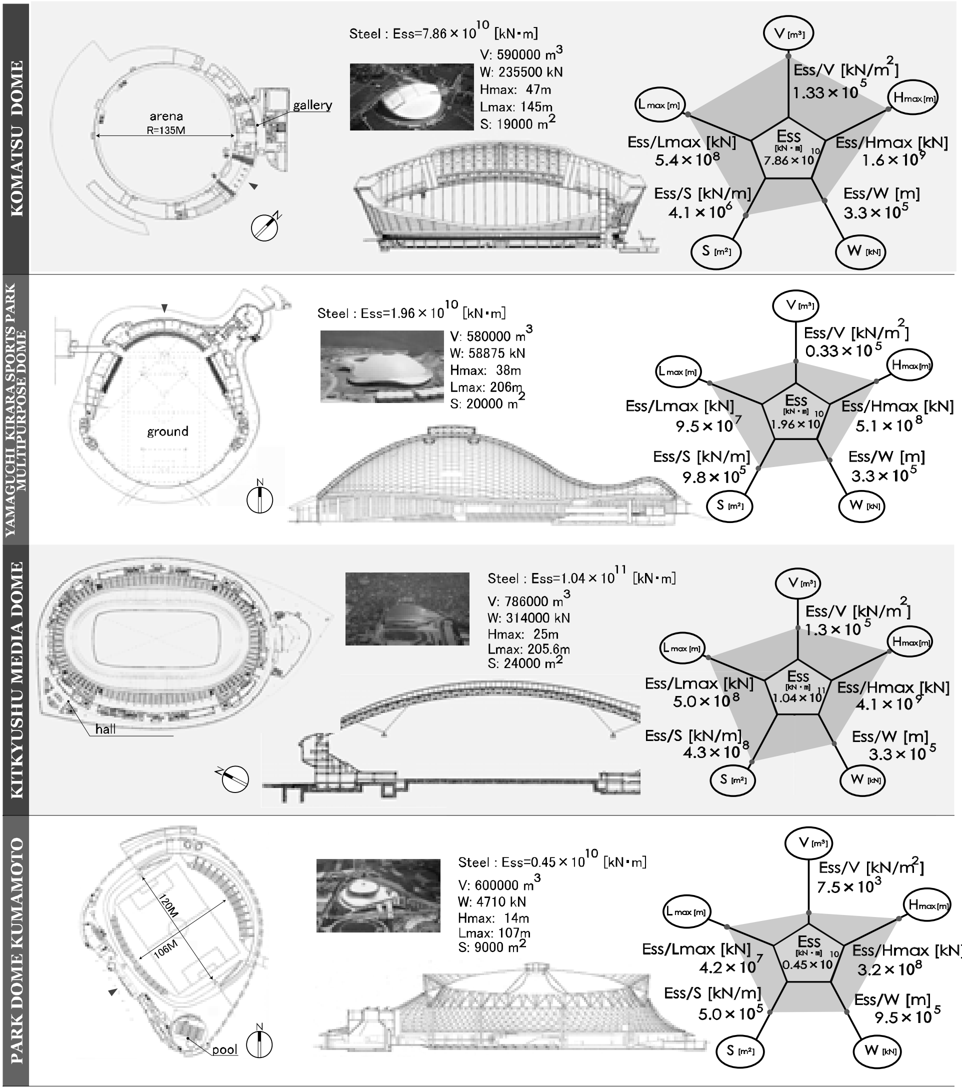


Figure 5: Dorm review sheet.1

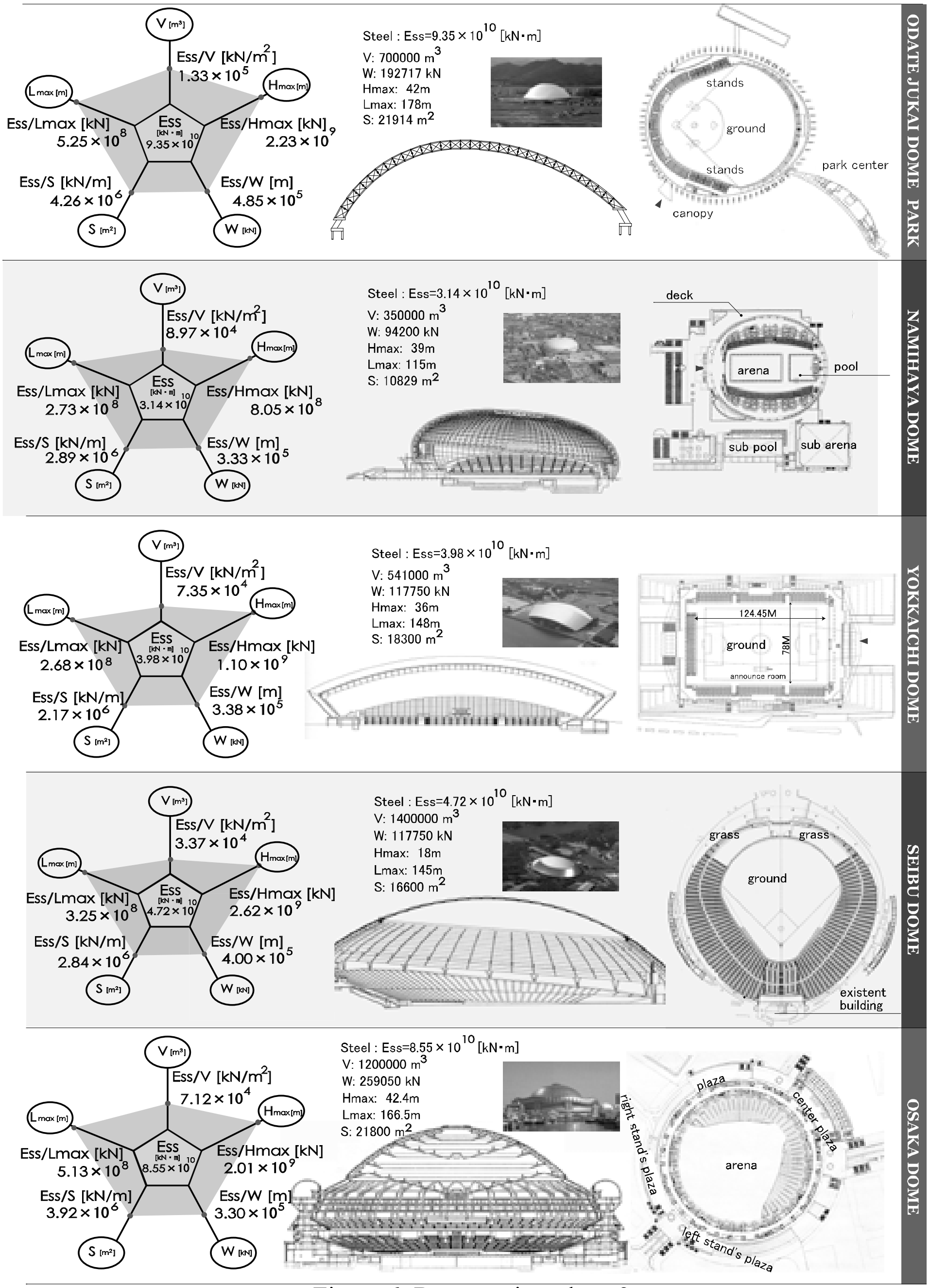


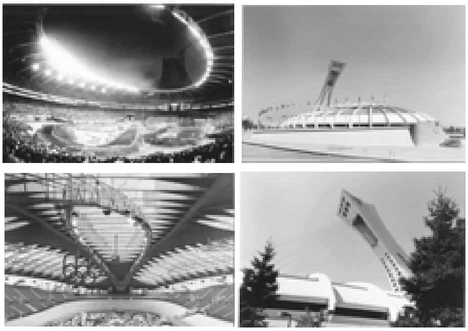
Figure 6: Dorm review sheet.2

3.1. Beijing bird's nest (Beijing Olympic stadium) and Montreal Olympic stadium

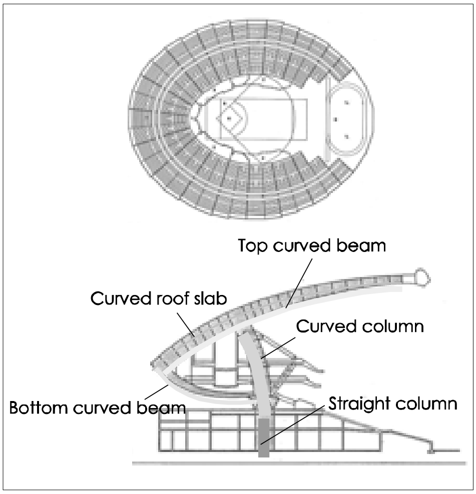
At the end the comparison with the Beijing Olympic Stadium(Bird's nest) and the Montreal Olympic Stadium is approximated with the reference literatures[2,3]. It is assumed that the Montreal Olympic Stadium has no roof.

The possession frame energy of Montreal Olympic stadium and Beijing Olympic stadium is figured. The frames and the name of the main structures, expressions and diagrams are as follows (Figure 7)

Montreal Olympic stadium



Plan and section



The Volume(Vc1) of a concrete unit is as:

Top curved beam (Top C.B.):

$$B \times D \times l = (1.75 \times 4.5 \times 26) + (2.5 \times 3.5 \times 50) = 642.25 m^3 \quad (6)$$

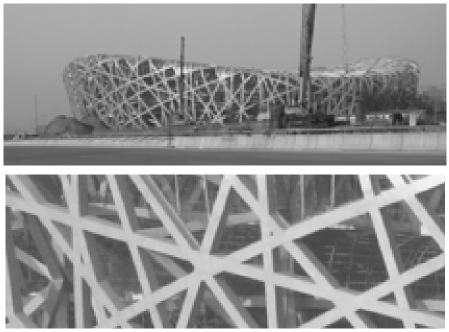
Bottom curved beam (Bottom C.B.):

$$B \times D \times l = 2.0 \times 2.0 \times 22 = 88 m^3 \quad (7)$$

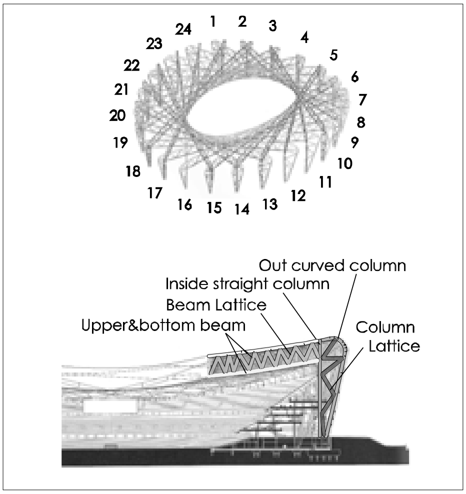
Curved column (C.C.):

$$B \times D \times H = 2.5 \times 5.0 \times 20 = 250 m^3 \quad (8)$$

Beijing bird's nest (Beijing Olympic stadium)



Frames



The Volume(Vc1) of a concrete unit is as:

Upper and bottom beam (U.B.B.):

$$t \times B \times 4 \times 2l = 343.2 m^3 \quad (17)$$

Straight column (S.C.):

$$B \times D \times H = 3.0 \times 6.0 \times 16 = 288\ \mathrm{m}^3 \quad (9)$$

Curved roof slab (C.R.slab):

$$B \times D \times l = 0.4 \times 70 \times 16 = 448\ \mathrm{m}^3 \quad (10)$$

Therefore

$$Vc1 = (\text{Top C.B.}) + (\text{Bottom C.B.}) + (\text{C.C.}) + (\text{S.C.}) + (\text{C.R.slab})$$
$$= 1716.25\mathrm{m}^3 \approx 1700\mathrm{m}^3 \quad (11)$$

There are 38 units in this structure. The total volume (Vc) is as:

$$Vc = 1700 \times 38 \approx 65000\ \mathrm{m}^3 \quad (12)$$

The total volume is as follows because the weight of steel is about 0.1 t considering with the specific gravity.

$$Vs = 170/1.85 \times 38 \approx 850\ \mathrm{m}^3 \quad (13)$$

Then the possession frame energy of concrete Ess(c) is as:

$$Ess(c) = 2.05 \times 10^7 \times 65000 = 1.3325 \times 10^{12}\ \mathrm{kN \cdot m} \quad (14)$$

The possession frame energy of steel Ess(s) is as:

$$Ess(s) = 2.05 \times 10^8 \times 850 = 0.1742 \times 10^{12}\ \mathrm{kN \cdot m} \quad (15)$$

The possession frame energy of Montreal Olympic Stadium is as:

$$Ess = Ess(c) + Ess(s) = (1.3325 + 0.1742) \times 10^{12} \quad (16)$$
$$\approx 1.5 \times 10^{12}\ \mathrm{kN \cdot m}$$

The diagram is as follows

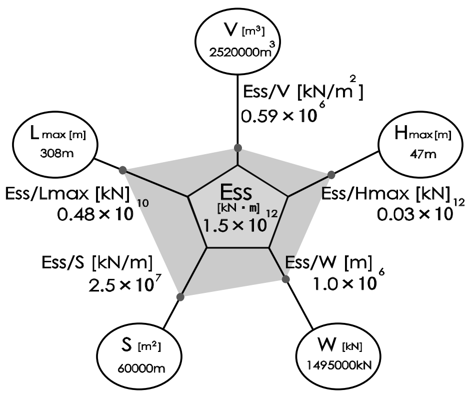


Diagram of Montreal Olympic

Where V≒2520000m3 , S≒6000m2 , W≒1495000kN , Lmax≒308m , Hmax≒47m

Beam Lattice (B.L.):

$$t \times l = 211.2\ \mathrm{m}^3 \quad (18)$$

Out curved column (O.C.C.):

$$t \times l \times b \times 4 = 63.5 \times 0.2 \times 1.0 \times 4 = 50.8\ \mathrm{m}^3 \quad (19)$$

Inside straight column (I.S.C.):

$$t \times l \times b \times 4 = 52.5 \times 0.2 \times 1.0 \times 4 = 42\ \mathrm{m}^3 \quad (20)$$

Column Lattice (C.L.):

$$t \times l \times b \times 4 = 79.2 \times 0.2 \times 1.0 \times 4 = 63.4\ \mathrm{m}^3 \quad (21)$$

Therefore

$$Vs1 = (\text{U.B.B}) + (\text{B.L}) + (\text{O.C.C}) + (\text{I.S.C}) + (\text{C.L})$$
$$= 710.56\ \mathrm{m}^3 \quad (22)$$

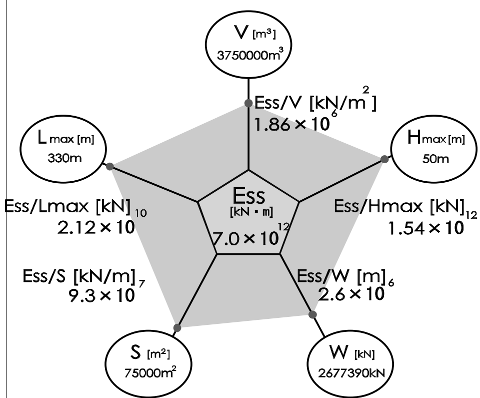
There are 48 units in this structure. The total volume (Vs) is as:

$$Vs = 710.56 \times 48 = 34106.88\ \mathrm{m}^3 \quad (23)$$

The possession frame energy of Beijing Olympic Stadium is as:.

$$Ess = 34106.88 \times 2.05 \times 10^8$$
$$= 6.9919 \times 10^{12}\ \mathrm{kN \cdot m} \approx 7.0 \times 10^{12}\ \mathrm{kN \cdot m} \quad (24)$$

The diagram is as follows



Where V≒3750000m3 , S≒75000m2 , W≒2677390kN , Lmax≒330m , Hmax≒50m

Montreal Olympic stadium | **Beijing bird's nest (Beijing Olympic stadium)**

Figure 7: Frames and the name of the main structures, expressions and diagrams

4. Result and Discussion

In comparison Beijing Olympic stadium with Montreal Olympic stadium, Beijing is 4.7 times as much as Montreal in possession frame energy.

Beijing is about twice as much as Montreal in possession frame energy divided by Hmax, Lmax and W, furthermore, V is 3 times and S is 3.7 times as much as Montreal.

As a result, Montreal did efficient work load in construction. (See Fig.7) And then, comparing our new artistic project "the castle of Net for children" (See Fig.8 and 9), which is a wooden dorm designed without any hardware, with Beijing Olympic stadium and Montreal Olympic stadium, diagrams are showed as follows.(Figure 10)

Figure 8 and 9 : Facades of "the castle of net for children" at Hakone

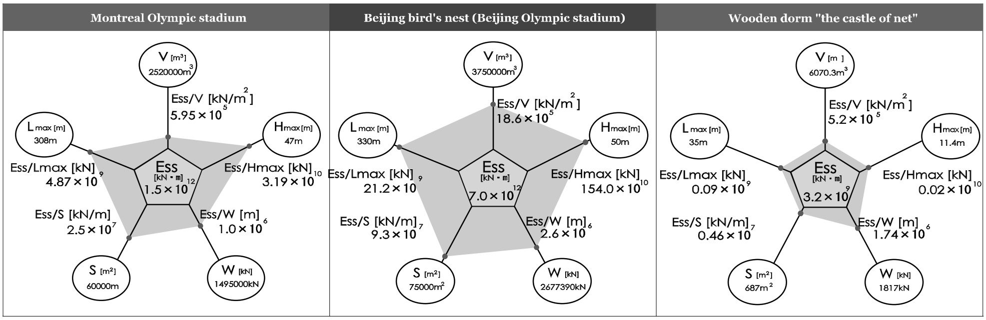


Figure 10 : Diagrams of Beijin , Montoreal and the castle of net for children

Komatsu dome air volume and Yamaguchi kirara sports park air volume are almost same value, however possession frame energy of komatsu is 4 times as much as Yamaguchi kirara sports park. (See. Fig.11)

This is because komatsu is an openable dome, in other words we need 4 times energy to make opneable dome in the same air volume.

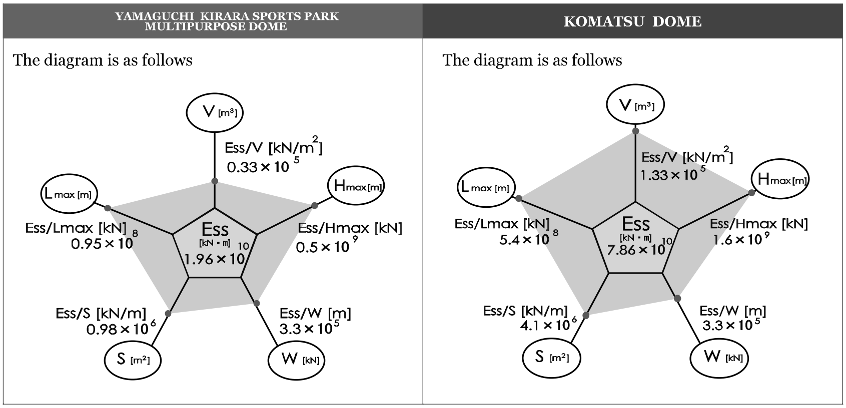


Figure 11 : comparison between Komatsu dome and Kirara sports park

A temporary work, construction cost, and structural resistance systems (arch and masonry construction, etc.) etc. have been excluded from this study. When the structural design function (Tsuboi award, 1999) previously described and the structural space cognitive diagram are reviewed at the same time, it will be able to be analyzed whether it is more ecological construction or not.

5. Conclusion and Possibility

It can be simple to compare between architectures which are used of different materials or are build at different sites according to use with two functions, structural design function and the function of possession frame space energy, and two diagrams, structural space cognitive diagram and QCPD diagram. For instance, it is possible to review and to figure the indispensable frame energy when Villa Savoye near Paris be built in Japan where the earthquake happens frequently. It is able to compare not only the space frame in Chapter 3 but also different kinds of materials and the economic background. This theory can be contributed to the ecological architectural design in the future.

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