Flexible Programming Systems and Eco-Friendly Contemporary Architectural Design

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ABSTRACT

This article discusses the role of flexible architectural systems in achieving eco-friendly buildings. The discussion argues energy consumption associated with this amount of space and how to optimize energy consumption in the Auditoriums. According to the issue of sustainable architecture, flexibility and adaptability of spaces might be helpful in realizing the goals of sustainable architecture. The main question in design of auditoriums in architectural design process is: What is the optimal size of these spaces? Flexible architectural systems open new horizons for achievement of eco-friendly buildings especially in buildings which used temporarily such as auditoriums. Flexible architectural systems make it easy to change the volume of space to meet energy efficiency requirements. The aim of the study is finding appropriate strategies to achieve the design patterns in order to achieve energy saving goals and objective in design of auditoriums. The main questions of the paper are: 1- Is there any relationship between the size of auditoriums and the rate of energy consumption? 2- Are there any differences between the optimal size and initial size of auditoriums in Tehran? And 3- how long the payback time of these flexible structures would be? Experimental and quasi-experimental research method is adopted and case studies have been chosen randomly among auditoriums of Tehran. The result shows that flexible architectural systems is a reliable technique of achieving eco-friendly buildings and considering payback time, applying flexible architectural systems in auditoriums is efficient.

Key words: **sustainable architecture, auditoriums, energy efficiency, volume of space, flexible walls**

1. Introduction

Today's global warming, limits of fossil based fuels, stance against nuclear energy, environmental protection, environmental pollution all make the sustainability issue and sustainable architecture a critical issue (Tafazzoli, 2011). Architectural design Process is one of the most important parts of efficient way of buildings construction (Mahdavinejad & Refalian, 2011). In this paper stability of multi-functional spaces is discussed. Regarding flexibility and conformability which are issues facing sustainable architecture, designing of an intelligent building which conform with different condition direct or indirectly is invoked. This article has investigated on the eight main amphitheaters in Tehran to find out an efficient way to reduce the energy consumption by using new manufacturing methods and also flexible structures. The literature review of the paper shows that passive techniques play a crucial role in efficient way of construction (Mahdavinejad et al., 2012a). First, we have studied the definition of the flexible and intelligent structures and multi-functional spaces and sustainable architecture. Then, we have studied four buildings with flexible structures and evaluate strategies for energy efficiency. In the next stage via a comparative analysis of eight random examples of Tehran, we suggested appropriate solutions to optimize energy consumption. Using parametric information determine the effects of these solutions. We have obtained the initial cost savings in energy consumption and payback time.

2. Terminology and Literature Review

2.1. Flexibility and Smartness

2.1.1. Flexibility: According to oxford dictionary it means: the ability to be easily modified (URL 07). It is very important to know that flexibility is one of the most important obstacles which architectural design process has to face (Mahdavinejad & Moradchelleh, 2011).

2.1.2. Flexible Spaces: physical flexibility refers to the adjustability of a space, such as meeting the special sensory and/or mobility needs of individuals. Movable furniture and walls, or reconfigurable buildings, rooms, and passageways all represent this type of physical flexibility (Monahan, 2010).

2.1.3. Smart Structure: A structure is an assembly that serves an engineering function. A smart structure is one that serves this function smartly i.e. by responding adaptively in a predesigned useful and efficient way of changing environmental conditions (Wadhawan, 2007). Intelligent or adaptive structures are generally two types of applications which include structural and functional (Teuffel, 2002). “Applying of desired structures in this project is functional and type of structural system is dynamic and intelligent, type of control of these structures is direct control. Multipurpose functional space, according to oxford dictionary it means: Having several purposes or functions. Multi-functional space is the opposite of single purpose space which is designated for a specific function (Mahdavinejad et al., 2011). Building activities is defined in a single space and it has standards to resolve the needs of different functions. In architecture multi-functional space can accommodates several activities. Also, multifunctional spaces can be transition spaces (Blakemore, 2006), but from another point of view, these spaces are used for exhibitions, lectures and special events (Mahdavinejad & Abedia, 2011, 337 – 344).

2.2. Sustainability in Architecture

2.2.1. Sustainable Architecture: Energy as serious challenge in the 70's and 80 decades aroused complicated problem as sustainable architecture in 1990's. Therefore, energy is not the only concern and other subjects such as environment and resources are included, which are the basis of sustainability in architecture. In sustainable architecture concepts like the latent energy (amount of energy which is used to produce material), flexibility, and change ability of performance are the common issues, which should be seen. Against the last hundred years of architectural styles and it is based on specific types. New technologies are the bases of modern construction especially in mega-structures and great-scale projects (Mahdavinejad, Hajian & Doroodgar, 2012). It is very important to mention that the efficiency of implementation of new technologies into every day building construction lies in strategies which adopted in industrial developments. Especially is in Great-scale projects. (Mahdavinejad et al., 2011).

Sustainable architecture is not refer to any particular style and just is thinking the way to design cleverly, forehanded and accurately (Luhan & Domer, 2005). Sustainability is one of the factors in the design process which is inevitable. Sustainability in architecture is not an option but a requirement for individual projects. Sustainable architecture is not a constant ideal solution and it is a changing concept. Therefore, in each project must be defined and assessed (Soroush & Pouiande, 2011). One important component in order to proving the stability of the structure is cost for all stages of design and Construction and maintenance until commissioning and demolishing of the building and comparison with the cost of a conventional building (Tafazzoli, 2011).

2.2.2. Sustainable Architecture in Iran: It seems sustainable architecture like contemporary architecture has been imported to Iran recently but there is no properly definition of it so far while stability has been discussed previously in Iranian architecture. One of the key topics is post occupancy studies that in Iran have been ignored.

2.3. Sustainability and Energy Saving

2.3.1. Space division: the appropriate division space allows the user to consume some energy enough to provide heating, cooling or ventilation for that space. Movable walls and hanging walls with the aim of increasing multipurpose spaces in amphitheaters were used to provide this condition. Most important features of these walls are:

- These are moved electrically and automated.
- There is no need to have rails on the floor so floor surface will be smooth and clearly.
- The audio and thermal insulation have more efficiency than before because of the two shell structure of these walls. There are also two telescoping rails on both sides that open when walls stop and stick to the side walls, such a way that the sound insulation reaches to its minimum (Spiridonoff et al., 2011).

2.3.2. The relation between Energy Consumption and Amount of Spaces

The amount of energy consumption including cooling, heating, electricity depends on volume, shape, direction, position, etc. of a building. It is assumed that all the 8 examples have similar conditions and only the size and capacity of users are different. Size and general form of a building have the most effect on the amount of heat loss. However the ratio of the outer shell of the building to its plan is lower, the building will be less heat transfer. According to the formula $Q=mc\,\Delta\partial$, the mass of amphitheater's air, which is the volume of space has a direct relation with energy. More the volume of a space is more energy will be consumed by it.

3. Research Backgrounds

3.1. Arena Zagreb

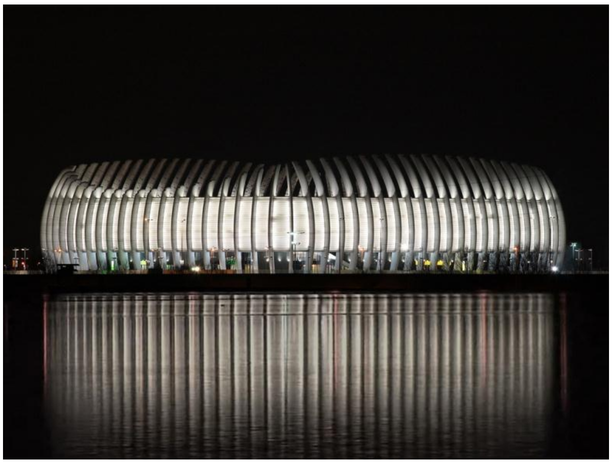

Fig.1. Stadium façade (URL 01)

Enclosed stadium Zagreb is located in Croatia in the southern part of Zagreb. In 2009, UPI-2M build 94340 square meters with a capacity of 15,000 and the area 94340 square meters and includes a basement floor and five floors on the ground. Combination of the structure and architecture creates its form. 86 large pre-stressed and prefabricated concrete curved columns shaped view of these oval bowls. Suspended ceiling is hung from the columns and in the required cases has the ability to open and light. It is not economical a stadium with a capacity that is made just for sports events, The building as a multi-functional space With functional features and space which create the greatest flexibility, is built. With multi-functional building elements the building can be separated into small spaces and can resolve a variety of needs based on users and user types. The ground floor of sport halls has all facilities for athletes and there is also an office space in this floor.

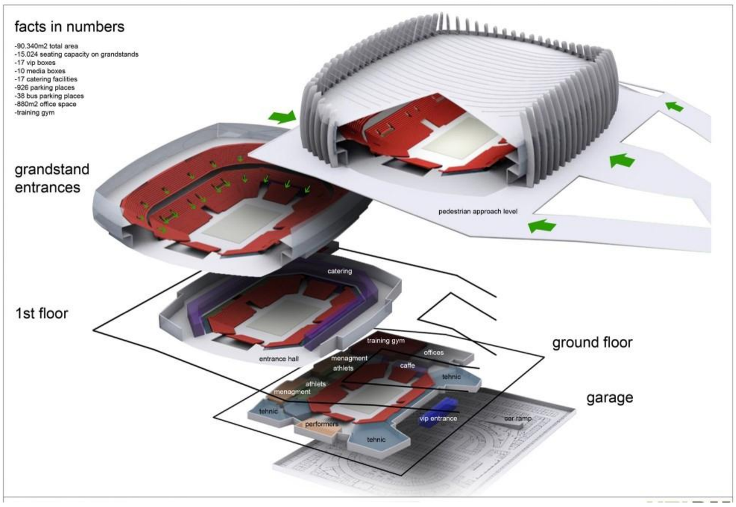

Fig.2. Organization scheme (URL 01)

Zagreb is designed for several sporting, cultural, recreational and commercial events. The main floor of the Central Stadium is easily transferable depends on the type of application, such as: Handball, Football, volleyball, hockey or other sports, as well as concerts, exhibitions and congresses. Smaller multi-functional spaces can be used in the second floor for small congress, workshops or lectures. Deformation of the audience' seats creates the flexibility in this stadium. The lowest part of audience' seats has 15 rows, as it is cumulative.


Fig.3. Multi-functionality diagrams (sports) (URL 01)

Moreover, it is possible to have additional seats on the competition ground for matches such as table tennis, badminton, gymnastics, boxing, wrestling, etc. The telescopic stands are designed to be cumulative. Cultural and recreational events such as concerts and exhibitions, moveable stations and equipment as linear are also added.

Moreover if less capacity was required for an event, upper part of the audiences' seats can be closed by using the hanging fabric partitions. In general, the main volume of the space with suspended ceiling structure solution, the performance requirements, can be less and less energy is consumed. HVAC systems for various scenarios are fully programmable and flexible. Whole building is operated by BMS that enables fine tuning of each element and presents a cost reduction element. Material of the original view that is located between the concrete columns is ventilated semi-translucent polycarbonate that reduces heat loss. In addition to the daylight, in a circular corridor around the place, brings security and it provides the space for the clarify individuals and facilities in the main façade.

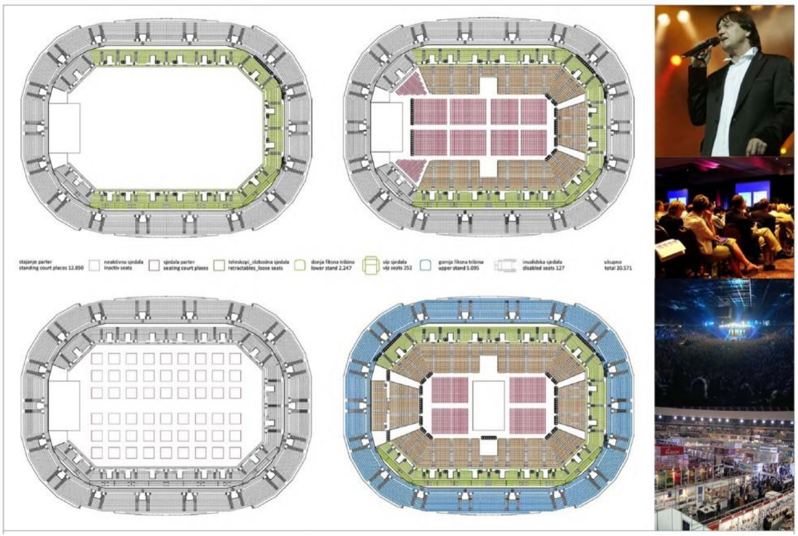

Fig.4. Multi-functionality diagrams (concerts) (URL 01)

Also the white pages will prevent over-heating because of its reflection characteristics. All other materials were used according to their quality, stability and durability of coating, repair and maintenance costs, and also environmentally friendly.

3.2. Erie Art Museum

Fig.5. Erie Art Museum main entry addition (URL 02)

The Museum of America, Pennsylvania, with an area of 57000 square feet, located in the reconstruction and EDGE studio conducted development in 2010. The development includes a new entrance and public spaces, new spaces for temporary and permanent exhibitions, a multi-functional space, café, outdoor, living spaces, an indoor sculpture garden and office spaces. Users can experience space and a new direction with the entry into the field and go to the lobby and the new Gallery to the old crossing, a plurality of spaces, different art media.

Fig.6. Ground, first, second floor plan (URL 03)

The Museum Gallery is an innovative design with an area of 1700 square feet that the three large panels with rotating hinges those employees can quickly form a space with minimal force. This was one of the reasons to design and build green buildings Kresge Foundation Grant. The panel has 26 feet wide, 16 feet high and 2 feet deep. The forms and creates are different positions for the gallery and includes different setting that is 64 degrees. Advantages of this design strategy are to add material that occur the construction will prevent and create a different space not to need to destroy the partition also be savings in staff time.

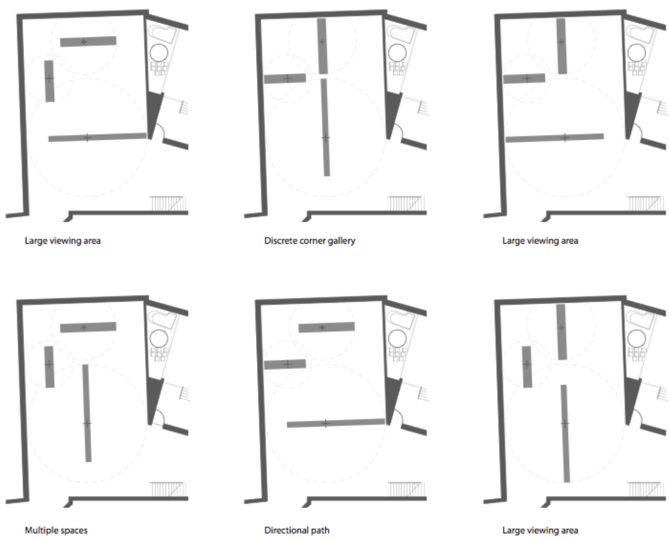

Fig.7. Wall configurations (URL 03)

During construction, they developed another system of movable panels on the second floor gallery. They can put the panel system in place and when they are not used, as are the surrounding walls of the exhibition. Green roofs, low water use plumbing fixtures, permeable paving, a permeable storm water removal system, a highly insulated building envelope, and an energy efficient mechanical system that delivers a Class in environment, set by the American Association of Museums, all contribute to a building designed to reduce operational expense and to limit environmental effect. In addition it has received LEED Gold certification.

3.3. Kyoto-Model: A House with 3 Walls

Fig.8. Kyoto-house façade (URL 04)

This home made in Japan, Kyoto City area is 121 square meters by Shigenori UOYA, Miwako Masaoka, and Takeshi IKEI. This proposal is to build a contemporary house in Kyoto. They designed this house based on study of the urban structure Kyoto**.**

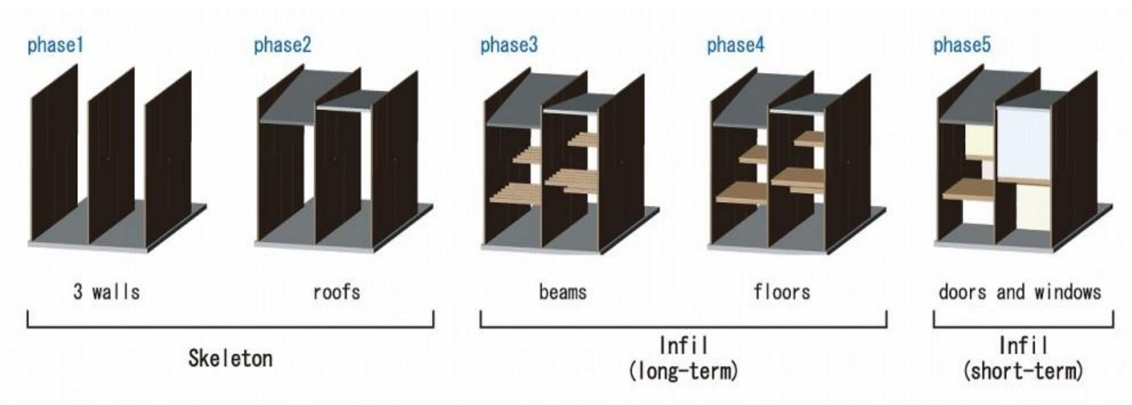

Fig.9. Composition (URL 04)

Bottom side of the facade and the facade are designed to fit the contemporary city Kyoto. Traditional Japanese architecture inspires the design and industry. One of the important factors in the design of this project is its flexibility. This house is flexible in three directional.

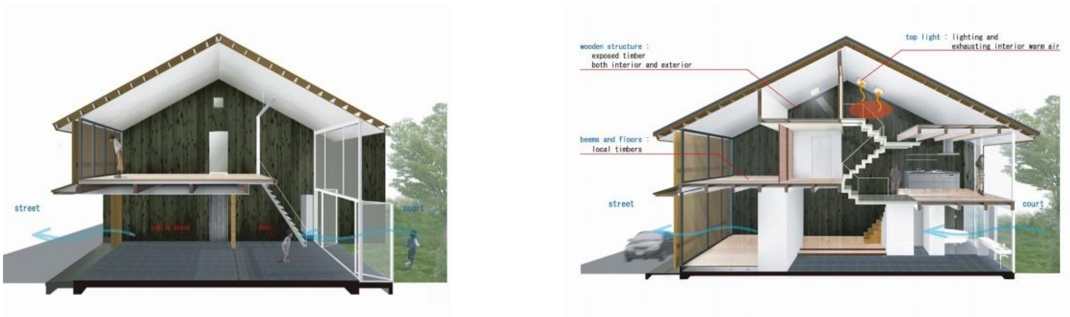

Fig.10. Passive design (URL 04)

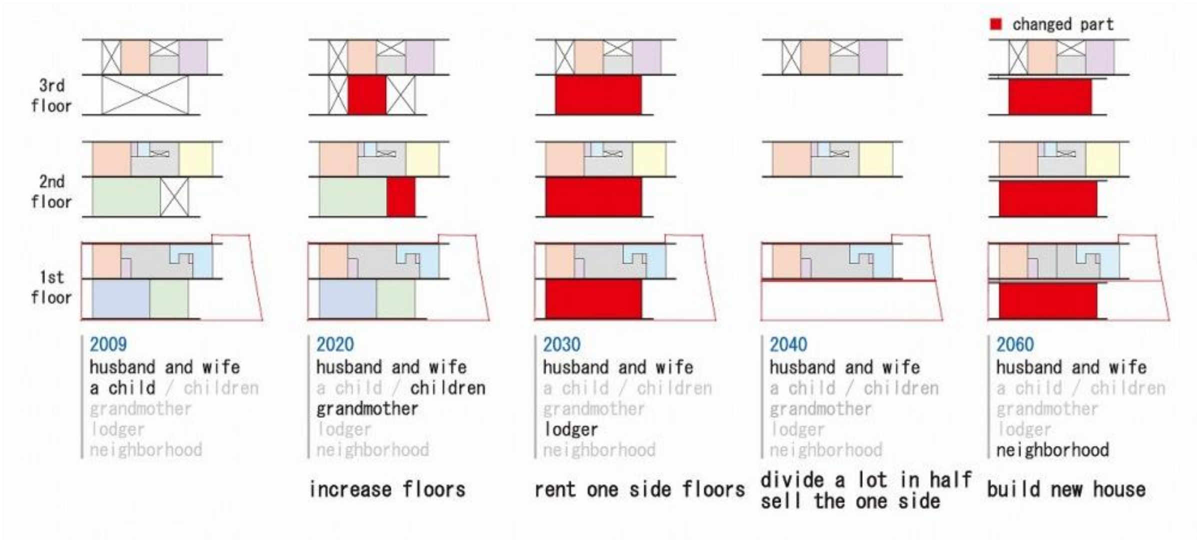

Fig.11. Flexible changing plan (URL 04)

Materials used in such doors are easily replaceable based on the characteristics of different seasons and periods to create a home- Home floor plan is designed as flexible. Another room can be made or removed based on the needs of users in space. - In future, the house can be divided to two parts. By halving the home becomes smaller. This means that internal walls can be used as external walls.

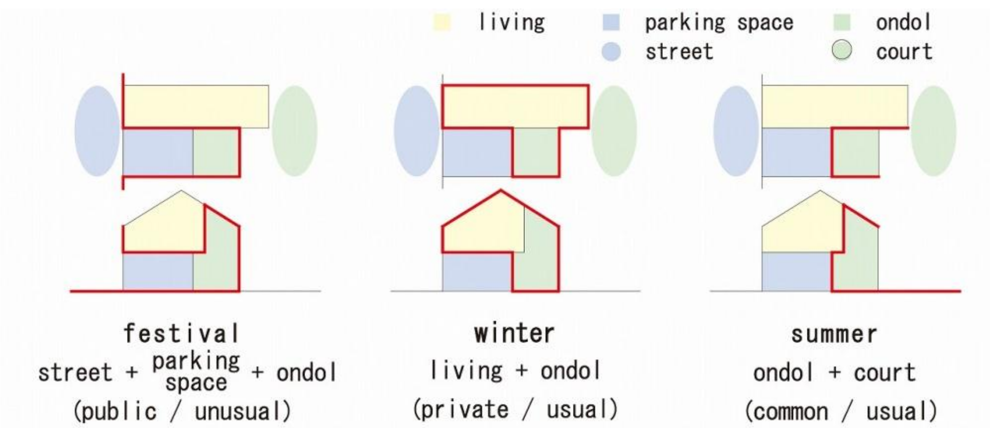

Fig.12. Flexible use (URL 04)

3.4. Saitama Super Arena

Fig.13. Saitama Super Arena, with sports and cultural user (URL 05).

The donor Saytama is the stadium in Japan. Its owner is Saitama Prefectural Government. Nikken Sekkei Ltd was team Manager of design and built in partnership with American architect Ellerbe Becket and Flack + Kurtz Consulting Engineers. Taisei Construction and Mitsubishi Heavy Industries and UDK were responsible for Construction and design and technical support team**.**

The stadium has sports and cultural facilities and based on the type of application can be a stadium with 30,000 capacity stadium for a football. For basketball its capacity is 20,000 and with 5,000-capacity for concert hall. This technology is a unique system for transferring a very large blocks with 9200 seats, with its walls, floors, and the place of spectators that has 5/41 meters high and weighs 15,000 tons and only in 20 minutes can be moved 70 meters.

Ability of multi-functional buildings with a motion floor in the vertical direction of ceiling panels can be moved and move the partitions increases. Floor in the situation stadium with the lower capacity could rise to provide the desired location for a concert or sporting activities. Stadium becomes concert hall by a roller partitions. For appropriate acoustic matching, the roof panels can also be set based on user types. Its large glass facade allows natural light in and the path is clear. The roof structure can be placed 66 meters above ground level. The curved wall at the northern end of the stadium and two round towers at the southern end of which have vertical rotating elements keep the roof.

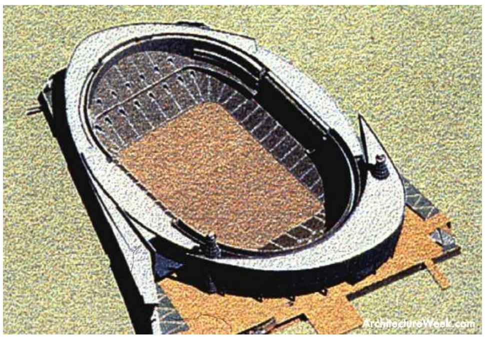

Fig.14. The 30,000-capacity stadium (URL 05)

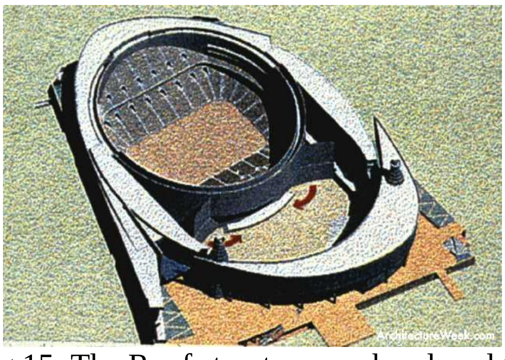

Fig.15. The Roof structure can be placed 66 meters above ground level (URL 05

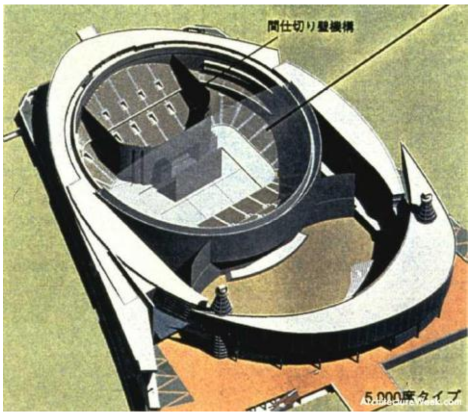

Fig.16. By Set partitions and ceilings it turns to the concert hall with capacity of 5,000 (URL 05)

Fig.17. The Roof structure can be placed 66 meters above ground level (URL 05)

Fig.18. In a large glass facade allows natural light to be used and the path is clear (URL 05).

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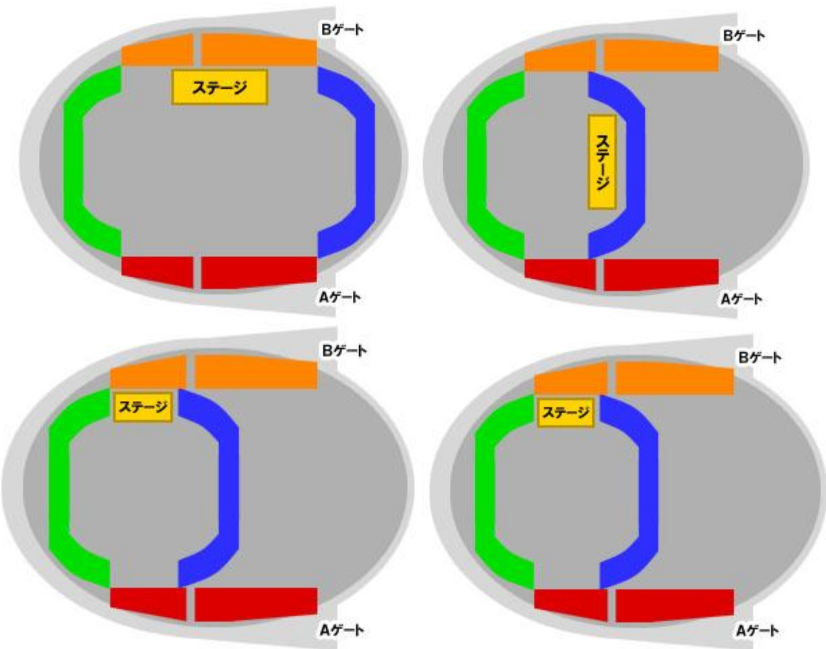


Fig.19. Different modes according to the type of stadium User (URL 06)

4. Research Questions and Methodology

These main questions of the paper are:

1- Is there any relationship between the size of auditoriums and the rate of energy consumption?

2- Are there any differences between the optimal size and initial size of auditoriums in Tehran?

3- How long the payback time of these flexible structures would be?

We chose empirical methods as the research method in this study and compared them through random selection. This article reviews the effect of flexible walls on the samples studied. To do this we accurate measurement of the dependent variables that is max, min number of users, cost overload, energy efficiency and handling Period, the effect of experimental procedures is specified.

In each of the samples, experimental procedures were performed in a single certain test that the capacity of salon has been tested.

Table 1: Summary of measures used in research methods, by authors

expected Sizes	The experimental procedure	Environment of study	Study
- Primary energy consumption in E1 - in the next step energy consumption E2 - Energy Efficiency - Cost Overload - Handling Period	- capacity (volume of salon) - Min, Max presence of individuals	Auditoriums salons	The use of separators and flexible walls

Performance of the proposed scheme is obtained by comparison of the existing building before and after of energy efficiency efforts. So that we have selected eight samples from the main salons of Tehran and maximum, minimum number of attendant is determined annually. Energy consumption at the beginning (E1) is calculated. In the next step energy consumption after using moveable walls (E2) is determined.

In the final step we calculate the amount of energy efficiency which based on the E1-E2 and is compared with overload cost of building a flexible sample for obtaining the necessary results. Economy is a very key role in the sustainability issues. By reviewing the costs added to the price of the building in the stability method, at what time during the life of the building it is compensated, thus the time required to recoup the costs of flexible walls and energy efficiency is compared to obtain cost dissipation time (Handling Period).

5. Test and Data Analysis

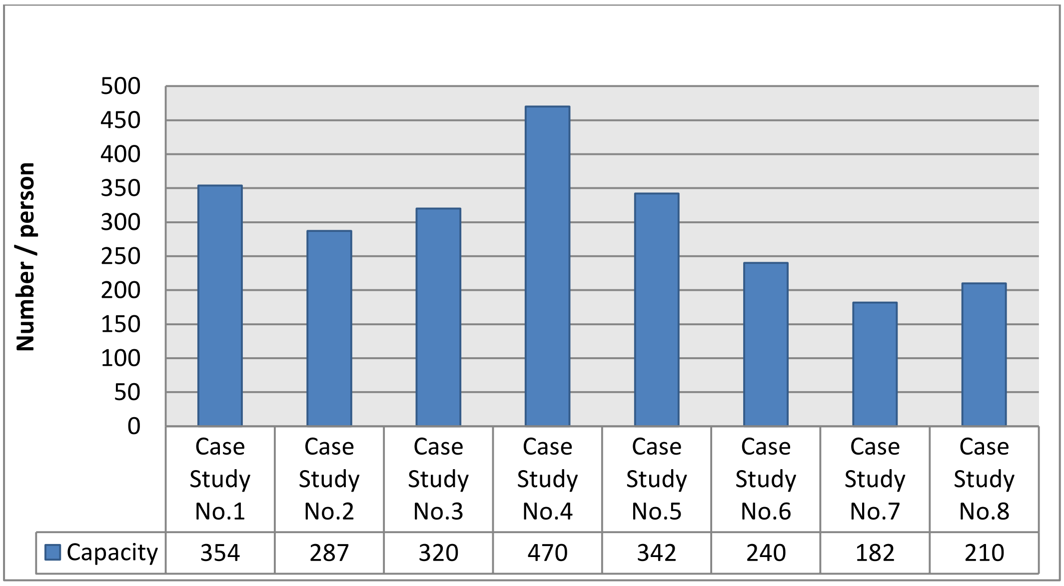


Fig.20. Capacity of Salons, by authors

In this chart the full capacity of each case has been shown with other cases. It is obvious the maximum capacity belongs to the sample No.4, and the minimum belongs to No.7. The average capacity is 300 persons for each case.

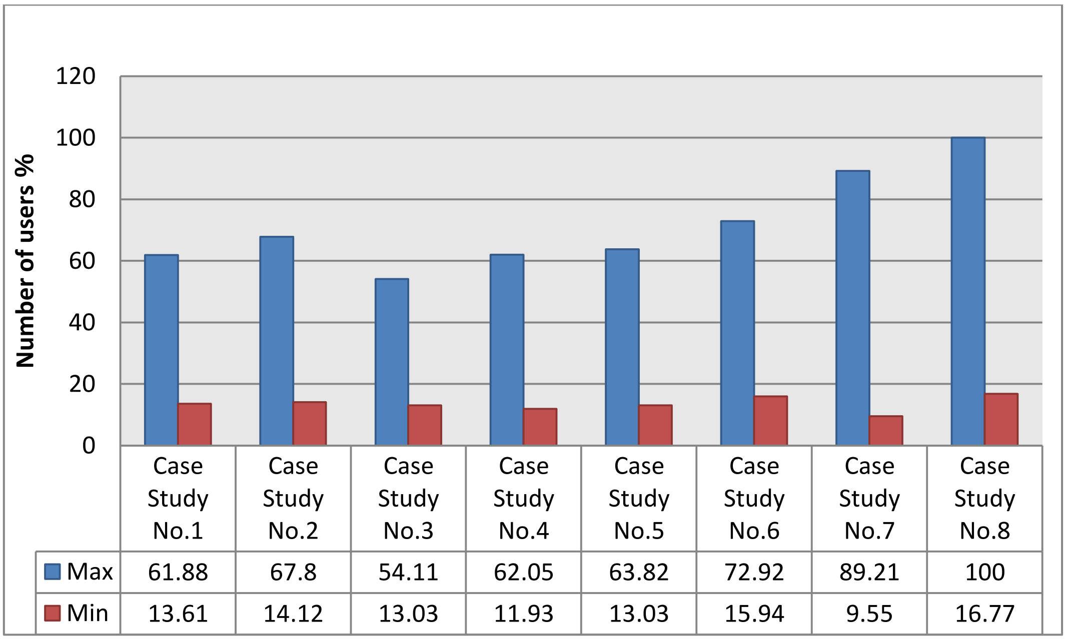
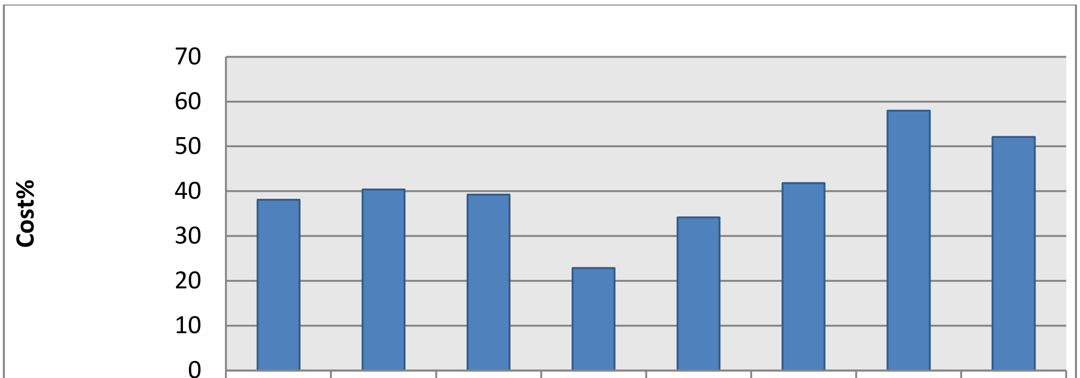


Fig.21. Maximum and minimum number of users, by authors

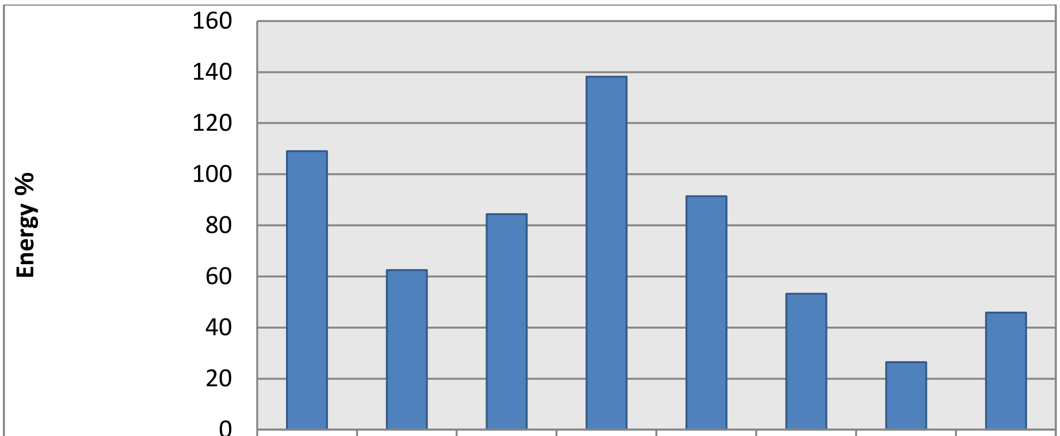
In chart 2 the extremum of participants in one year period in each case by surveying is determined respective to the capacity of each case by percent. Sample No.8 with 100% participate of attendant has the highest and No.7 with 9.55 participants has the lowest participation factor. The highest average attendance is 71.47 percent, in this survey and the lowest average attendance is 13.50 percent.



	Case Study No.1	Case Study No.2	Case Study No.3	Case Study No.4	Case Study No.5	Case Study No.6	Case Study No.7	Case Study No.8
Cost Overload	38.12	40.39	39.25	22.84	34.17	41.82	57.94	52.13

Fig.22. cost increase to build a prototype flexible, by authors

Cost increases for construction of a flexible prototype in each of the existing building have been calculated as percentage of the initial cost of each case. Maximum cost increase associated with the number 7 by 57.99 percent which has the minimum capacity and minimum cost increases belong to sample no 4 which have the maximum capacity. The average cost increases is 40.83.



	Case Study No.1	Case Study No.2	Case Study No.3	Case Study No.4	Case Study No.5	Case Study No.6	Case Study No.7	Case Study No.8
Energy Efficiency	109.09	62.51	84.43	138.24	91.37	53.18	26.52	45.86

Fig.23. The amount of savings in energy consumption, by authors

Energy consumption of existing buildings has been calculated (E1), Then we considered the movable walls for them and energy is again calculated (E2). Thereby the amount of savings in energy consumption E1-E2 obtained in this chart is expressed as the percentage of the energy savings and has been compared with each other. It can be seen most of the savings in the energy consumption related to the sample No. 4 which has the maximum capacity.

Lowest increased cost is 26.52%in the sample No. 7, which corresponds to the lowest capacity. Total average energy saving rate of 8 samples is 82.71%.

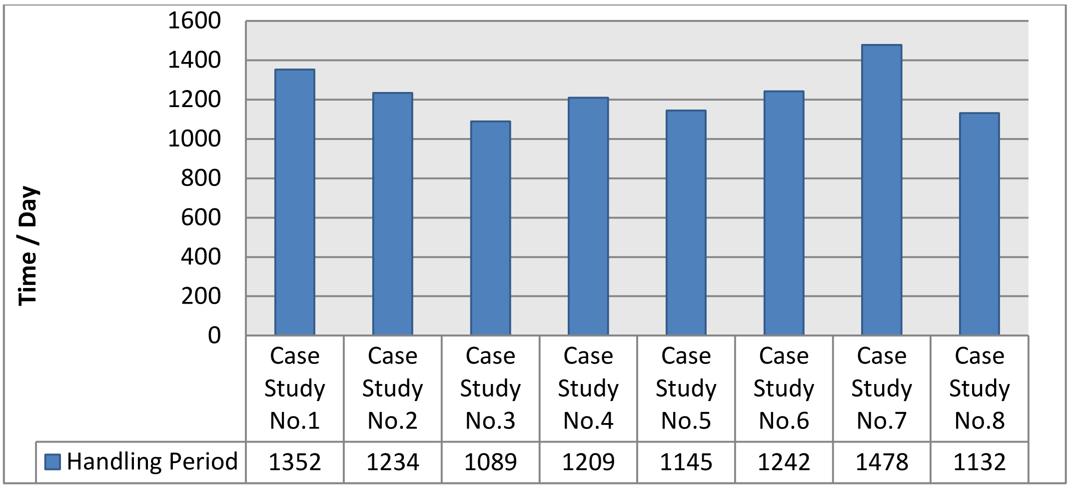


Fig.24. required time for compensation of building prototype flexible cost, by authors

In this chart the time for returning of investigation in the movable walls by energy saving has been showed. So cost return period is calculated in day unit. It can be seen the maximum duration is related to the sample No. 7 with 478 that has the least capacity, highest Cost Overload and lowest Energy Efficiency. The minimum duration belongs to No. 3 with 1089 days. The average time to return of the initial cost of each sample is 1235 days which is perfectly acceptable amount. It indicates this project is quite economical. Comparing and analyzing of graphs show that:

1. Energy efficiency and capacity have a direct relationship. It means whatever Capacity is more, Energy Efficiency is greater.
2. Cost overload and capacity have a reverse relationship. It means whatever Capacity is less, Cost Overload can be more. (Except in one case, 1 and 5)
3. There is a reverse relationship between cost overload and energy efficiency. It means whatever Cost Overload is less, Energy Efficiency will be higher. (Except in one case, 1 and 5)
4. There is not any determined relationship between capacity and Handling Period.

6. Conclusion

Regarding huge consumption of energy in auditoriums due to their large volume, while its capacity is not used regularly, multi-functionality of these buildings has a significant impact on improving energy consumption. The space be used for other functions such as fairs or space for small gatherings or large, and congress. Therefore, this research has studied a way to improve the performance of these building. For this purpose, by examining the different sources and researches, using of intelligent flexible structures as the most effective approach in such constructions, is recommended.

It is very important to pay a meaningful attention to the form and size of an auditorium in design stage, so flexible structures can be used to control the volume regarding capacity and using type. Reduction of energy consumption shows it is beneficially to employ flexible structures. Furthermore discussion of the energy economy is an important subject. The general opinion is the costs associated with the sustainability return within 5 to 10 years; in this case it is perfectly acceptable. As can be seen in samples, maximum return time is 4 years, so this project is purely economic.

Using flexible structure in amphitheater, a multi-functional space can be achieved with different functional characteristics. According to the query and position, the amphitheater has a capacity that can be placed at maximum volume, in the ceremony that less capacity is required, using movable walls, folding or rotating and suspended ceilings in a short time a different mode of multi-functional structure is achieved which reduces the volume and energy consumption. Thereby according to the type and number of user, saving in the time and energy can be achieved which totally means sustainability in the structure.

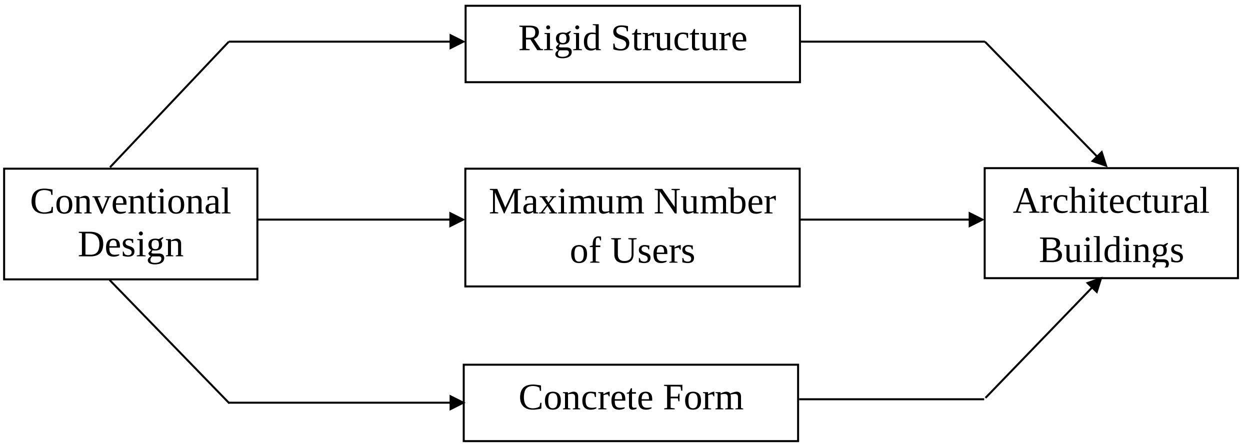


Fig.25. Conventional Design and Energy Consumption, by authors

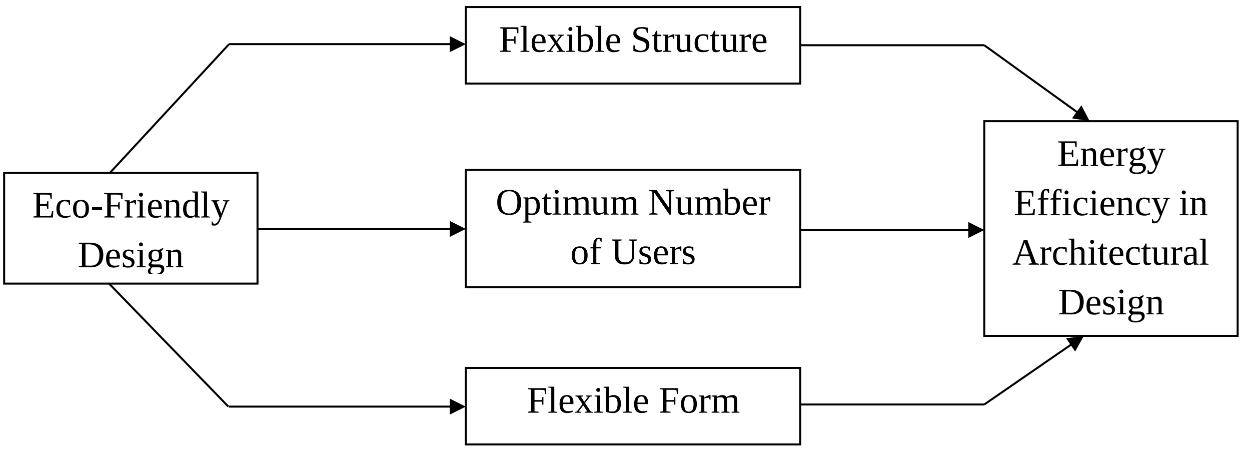


Fig.26. The Role of Flexible Architectural Systems in Eco-Friendly Design, by authors

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