

Circular symmetric retractable structures and its implementation consideration and the urgency of reaching this technology

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Abstract

One of the subjects that keep many engineers and architects mind busy is the possibility of creating spaces with flexible and retractable ceilings that gives the better chance of fresh air and natural light of sun for the moments that there is no rain or a bad climate for its users.

Retractable ceiling have different kinds in the matter of material and structural system. This article displays methods for designing structures that can be retracted and are made of hard discs that are fixed together with joint fitting.

What is important in matching these together is providing the freedom of mobility when the structure closes or opens.

At first we talk about how these conformations are made with angled bars and then their covers with rigid plates are displayed. Finally we talk about performing consideration of these retractable structures and the need of using it in the country.

Key words: two dimensional structures, optimizing the shape of covering plates, performing consideration of retractable roofs, contemporary architecture of Iran

1. Introduction

In last two decades there have been many suggestions for retractable ceiling structures that are able to cover big gates, that some of them are used in tennis fields, swimming pools, and sport stadiums.

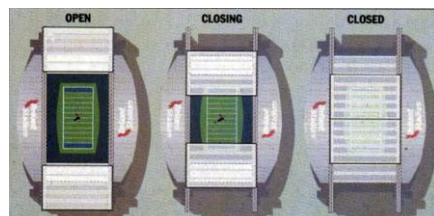


Figure 2: Rielant stadium retractable roof

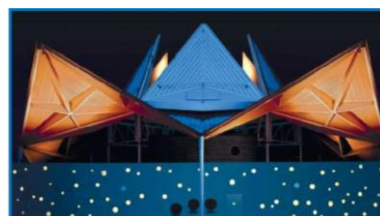


Figure 1: Starlight theater retractable roof

One of the topics that has been well studied is a flat structure that retracts radially. In this structures paired bars with scissor shaped angle are used as the main element, unlike general straight scissor shape bars, these bars do not have paralleled pivot. For real implementation of these bar structures it is needed that rigid covering plates and skeleton of lower structure be well matched that there will be no hole in the ceiling of a place.

First Kassabian et all suggested the use a combination of covering plates that replace half of angled bars. Fittings were located exactly at the same place as main bars. [1] Jenson & Pellegrino developed this method that leded to family of structures which was called radial retractable plate structures (RPS). Figure 3 (b) and (c) display an eight RPS symmetric model that is retracting. The bar that is fixed to it is shown in figure 3(a). When it is completely open one can see a circular open zone in the middle of it. [2]

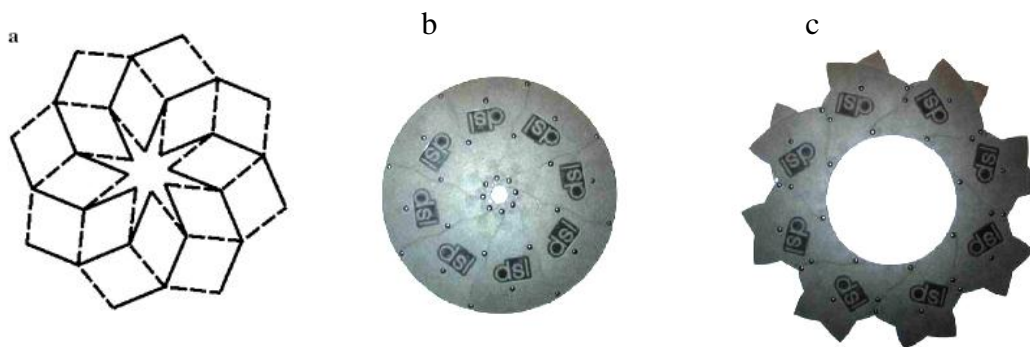


Figure 3: FBS formed by 16 bars & its RPS

This article talks about symmetric retractable structures that are made of these rigid plates and are fitted together using scissor shaped joints. These plates are only able to rotate over one pivot. What is important about these plates is how they should be layout and shaped to make a close circle that is able to retract. When closed these structures make a flat surface (without any hole) and when open there is a big circle in the middle the structure. From the point of beatification these structures are really attractive and will make a great deal for potential facilities available for engineers.

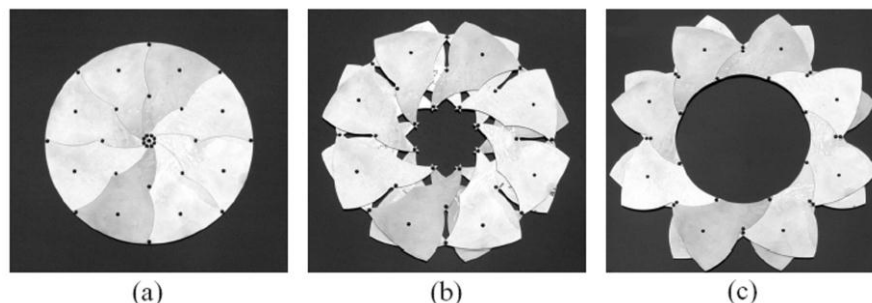


Figure 4: modeling of retractable symmetrical structures

Studied done on these structures are limited:

Verheyen has done a lot of research on transformable structures that are made of pair covering elements that are joint in the middle part to side elements using cylinder joints.

Wohlhart & You work on retractable structures that have rigid elements and are fitted together using joint fittings. [3]

The method of this article is studying on expandable, two dimension structures and it starts of angled bars and as it continues these bars are supported, exactly at the position of bars, with flat plates that have scissor joint8 fitting between them and a plate structure will be shaped that is able to retract, then shape and size of these plates are estimated to let the structure move.

General pattern of this article is like this:

Structure of retractable bars and their history is surveyed briefly at the first part. In second part cover elements for bar structure and special shape elements that will have no effects on the mobility of structure will be studied. In the third part we deal with implementation consideration of these retractable structures and finally the reason why it is important for our country to have this technology is discussed.

2. Background of expandable bar structures

Expandable bar structures that are fitted together with scissor joint fittings, are known for a long time. These structures were first just known as hooked bar structures that follow the Lazy tongue rule and use to open in a linear and two dimensional way.

A little later curved structure that could retract in three dimensions were invited by Spanish engineer called Pinero that these were developed by Escrig & Zeigler. An advantage of these structures in comparison with other retractable ones is the simplicity in their fittings. [4]

The considerable development of these structures was with simple angulated element by Hoberman. This element in its simplest shape in shown in figure 5, two angulated bars are the same that are located to one another with α angle these are fixed together in the center with a joint.

This angulated element has a special feature and that is the lines which pass the ends of the bars A,B,C and D have a permanent contact angle (α) that when the angulated element retracts this alpha angle stays fixed. [5].

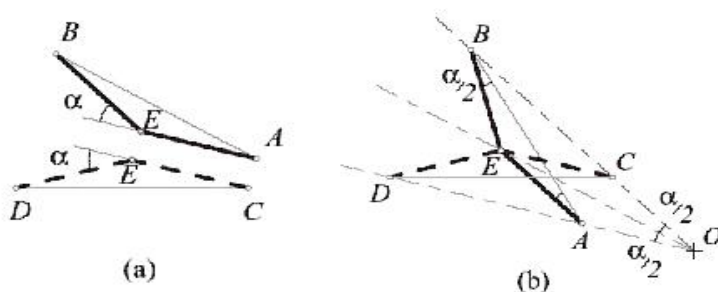
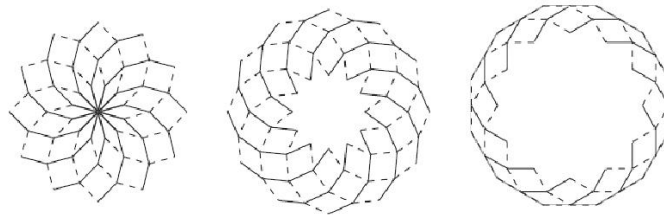


Figure 5: two angulated bars are the same that are located to one another with α angle these are fixed together in the center with a joint.

For this feature that we said about angulated elements, simple two dimensional structures can make one or two concentric rings (O in figure 5) with angulated elements. For example a retractable structure that is shown in figure 6 can be made with fixing two concentric rings with scissor shaped joints that are each made of 12 parts.

Three dimension expandable structures like Hoberman sphere is also made of closed rings that have the same angle.

Figure 6: retractable structure formed by angulated elements



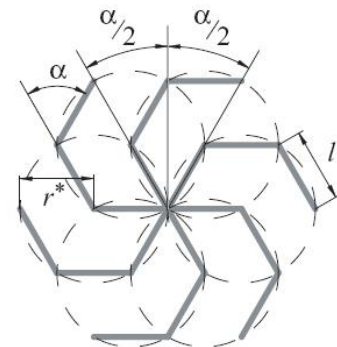
The continuation of expanding retractable structures You & Pellegrino showed that consecutive angulated bars that are shown in figure 6 are of the same α angle, and when structure retracts this α angle is fixed and does not change. So that this angulated elements can be replaced with a multiple angulated element. And also the displayed structure of figure 6 can be made of a set of twenty four bars that each has four elements with screwed equal angles. [6]

A retractable bar structure is defined with the number of segments in each angulated elements: k ,The number of angulated elements in each layer: n ,and segment length. So apart from measuring factor, this structure is completely defined with $n;k$ parameters.

For example in figure 7 $n;k$ are 6;3 so that;

$$\alpha = \frac{2\pi}{n}$$

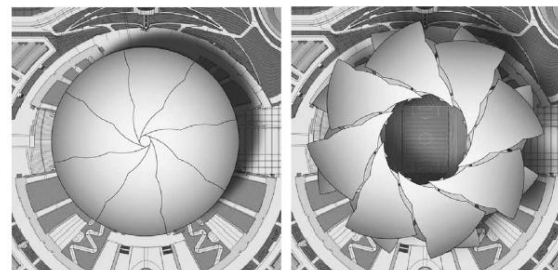
Figure 7: The structure with 6;3



3. Cover elements for bar structure

First we say that in the movement of an element in the bar structure, what limitation can be encountered after connection of covering plates?!

Figure 8: The stadium covered by rigid plates



Pay attention to a pair of paralleled bars $A_i A_{i+1}$ and $B_{i+1} B_{i+2}$ displayed in Figure 9. If $B_{i+1} B_{i+2}$ bar is fixed and has no movement a mechanism will occur that will let $A_i A_{i+1}$ bar to move. Now if there is a plate attached to this bars, this rigid surface omits parallelogram mechanism, to keep parallelogram mechanism feature a vertical cut with the inclination angle of θ should be made, cut line is called inclination line. So now we have two rigid plates that are fixed to joints and cannot overlap each other.

β angle can be increased or decreased based on inclination angle of θ . And based on total combination of inner angles at A, B and C we have:
$$\theta = \frac{\pi - \beta_1 - \beta_2}{2}$$

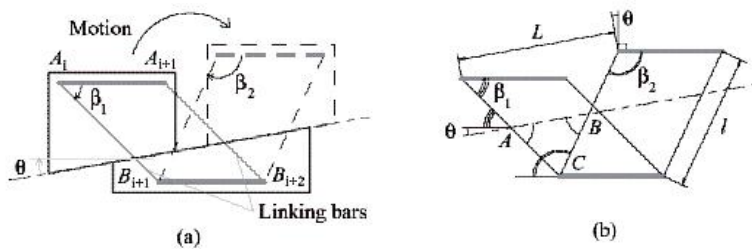
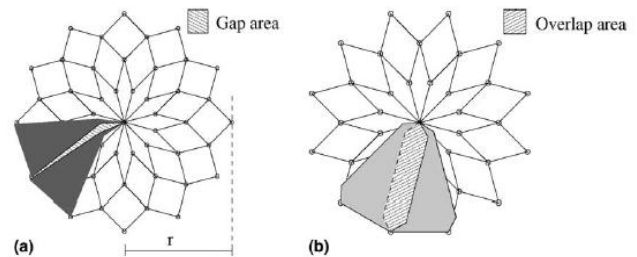


Figure 9: Motion of bar structure covered by rigid plate

3-1- Choosing optimum shape for plates

The first goal that is important in here is deleting free spaces that are between two plates in closed condition. The empty area Q_1 is defined as the uncovered area with covering plates (Figure 10) when the ceiling is closed. Overlap area Q_2 for each of two covering plates and at each level of opening is defined (Figure 10). It is necessary that this be zero for each of paired plates so the movement of the structure will be without any resistance. [7]

Figure 10: a) Gap area b) Overlap area



Another development and completion that is considered in optimized shape of this structure is maximizing the open central area when the structure is wide open. Another quantity will be added for this topic as Q_3 . An uncovered surface is defined as considering a point in the middle of this structure and the knots that are located around this point and on the plates which are not hidden in the wide open condition behind the plates. Then the uncovered space is measured with the triangles that these hypothetical lines create between the middle point and surrounded points. (Figure 11)

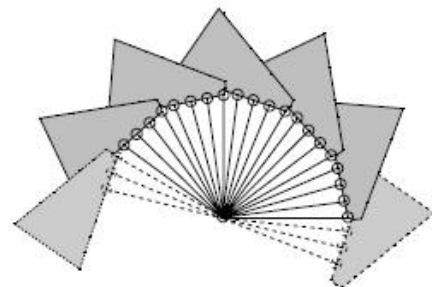
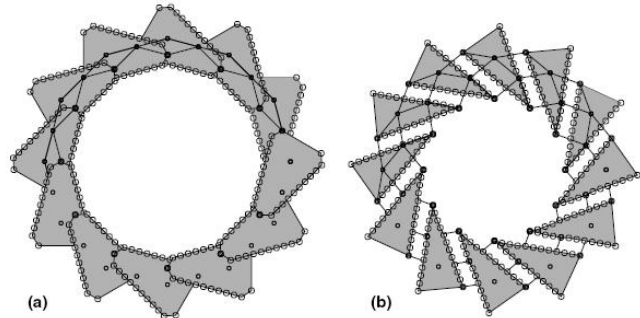


Figure 11: Definition of uncovered surface

2-3- The study of some plate covered structures

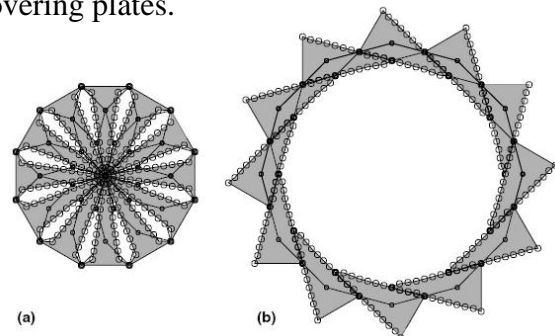
In first tries primary shape of covering plates are chosen to have completely closed or open conditions and also at the average state there should be a little overlapping in some cases. The optimized shape is a triangle that is displayed in figure 12.

Figure 12: a) first shape with overlap b) Optimized shape



In second sample, primary shape is chosen that when the plates are completely closed there is a little gap in the middle. (Figure 13) optimizing procedures will omit these gaps and the optimized shape will create a wedge triangle for covering plates.

Figure 13: a) Primary shape with gap when closed b) Optimized shape



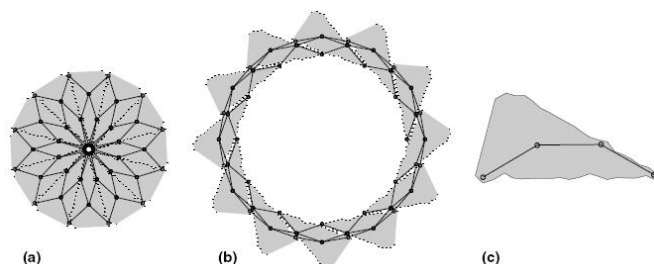
In this level it is worth mentioning the point that for getting the models closer to reality it is necessary to have a defined shape for the hinges. Putting the least diameter for hinges, structure is able to retract until two joints stay away from each other. If we say that r_h is the size of the hinge, so the least diameter of the middle of the hinge in close condition is

$$r_{\min} = \frac{r_h}{\sin(\pi/n)}$$

In this condition it is necessary that all hinges are kept in the same plate. Also one should consider that to avoid overlapping in neighbor plates at closed condition there are some notch at the optimized shape.

It is mentioned here that Matlab software is used for implementing these steps. [8]

Figure 14: Optimized structure



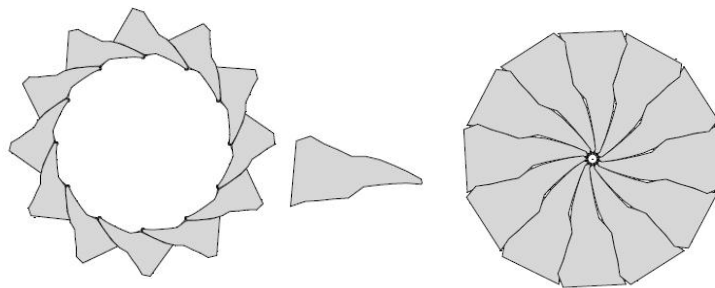
One of the cases that is effective in choosing optimized shape, is maximizing the surface that is not covered is completely open structure. According to last hypothesis of these articles (circular symmetric structure) this free space will be in the middle of the circle. This point is important that we always try to minimize the free space between plates and also the extent of overlapping surface between plates in all condition and stages that is a key point for retractable structures, it is clear that overlapping, of any kind, will reduce the mobility of structure.

With the help of computer software it is possible to get close to this goal. Finally the optimized shape should possess these three conditions that are displayed in figure 15:

- Minimized space between plates
- Minimized overlapping between plates
- Maximized space in the center of structure when the ceiling is completely open

We can see in this figure that there is a lot depression in the edge of inner plates that its reason is the expansion of the plate that is, when the ceiling is open, uncovered.

Figure 15: Optimized shape with Matlab



4. Implementation consideration of retractable ceiling

Points related to maintaining and implementing retractable roof starts from designing concepts and primary designs, in fact primary programs and schematic designs has a great impact on safety, validity and the price of a retractable ceiling when the structure is being constructed and maintained.



Figure 16: The prototype of retractable roof with symmetrical shape

1-4- Maintaining the structure: Water penetration and corrosion is a problem of every exposed structure, retractable roofs are not excluded of this issue. Well programming during

implementation can reduce the time and cost of maintenance and implementation of the building. About retractable structures this is true when they pay good attention to draining and down piping. In fact one of the special features of the building with retractable roof is that it can be sometimes completely open and completely close and sometimes somewhere between these two condition, so there should be enough prediction about the water of rain and snow to come down the roof in whatever possible way. If there is not good designing for the downpipes water can get inside the steel structure fittings or sensors that are related to the structure and cause damage or finally corrosion in a long term. The gap in the ceiling is always exposed to damage so needs occasional and continual investigation.

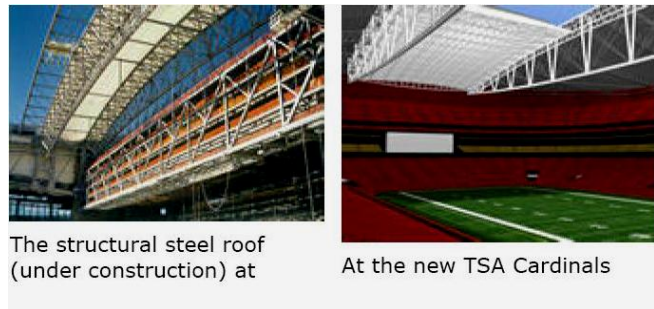


Figure 17: Structural system in cardinal stadium

2-4- points and consideration related to people and material: Mechanism of retractable ceilings and related other systems have a great place from the constructing view point, and of this point of view are categorized in the remote controlling structures. But in addition to this it should be possible to reach the ceiling. So providing comfortable and at the same time safe materials and also the comfortable and safe condition for the personals of ceiling control is one of the significant and prioritized points, because this is an important factor for safety and at the end effective on the final price of implementing and maintaining of the building. For easing the availability and safety of people and materials, there has to be elevators to make the higher parts of the structure reachable. In addition with elevators standards stairs for workers and staves of ceiling are required and also movable standard ladders for emergency situations. Designers of projects should be sensitive about different parts of the structure that needs maintenance and make sure that this part are in easy reach, with predicting narrow ways and cat walk path will reach the places that need visionary investigation.

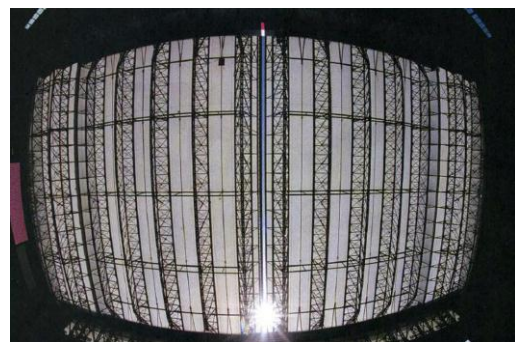


Figure 18: Rielant stadium roof

Of the common issues in the cover of the retractable ceilings is fabric material (fiberglass with Teflon cover). These in addition with persistence and strength are transparent too. The ceiling of Reliant stadium is made of these materials.

These fabric materials are also used in Georgia dome at Atlanta. Other examples are Metro dome, Minneapolis, Edward Jones dome, Olympic Stadium of Rome, Hiroshima Stadium of Japan and Shanghai stadium of china.

Project designer says: “we used materials with highest transparency, that let 25% of natural light pass to the inner space of the house, While for example in Georgia dome, he used these materials and just 25% of the light passed in the inner space of the building.”

He also adds: “ceiling cover with fabric material is really expensive, but is able to withstand fast tornados of the region, at the same time there in not a lot load on the ceiling structure.”

About how to control these retractable ceilings the best solution would be sensors that have remote control. In the ceiling of Star light theater (Rakford) these sensors are used. (Figure 1)

In each panel of this ceiling a set of transducers are located in a line that are manufactured by Minneapolis-based Truck Inc. When panels are opening and closing LDT sends the related location data via device net to programmable logic controller (PLC) that is in control room. PLC easily starts human mechanic interface (HMI) program that this controls the mobility of the building. Data communicate the situation of panels and say that each of them is in which level of retraction. PLC stops the panel exactlywhere its downpipe is located so that it will contact downpipes of other panels. (Figure 19)

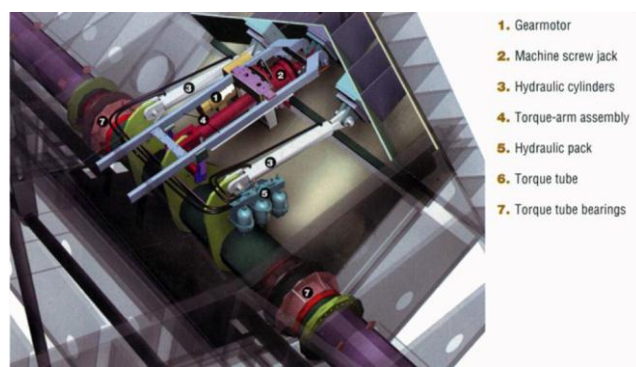


Figure 19: Mechanism of Motion of roof

So panels will be open in 12.5 minute. All this is done by Unit Corporation. Also for better safety of controlling panels data driven from the wind is also paid attention to. Although they review weather condition before everything in opening and closing the ceiling.

3-4- Safety: in addition with all consideration that is for safety every structure designers who deal with retractable ceilings should pay special attention to safety, this should be about hardware and instruments of rotation and mobility of the ceiling, figurative research for the path of the ceiling when in moves for safe implementation is necessary, audio and visual danger signals before implementation of the structure is necessary. Anti-shock sensors are used for closing the system when something suddenly happens.

4-4- Control system: These controls and also related systems can be as easy as a pushing bottom or as complicated as a modern touch screen that is attached to many computers and programmable logic controllers. As optimized these systems are a relationship between human and machine that is almost made of a mouse and a screen on that usually a lot of information is displayed. The best control system is made of a weather reporting, the situation of mobile parts, speed of system and its feedback positions, error diagnosis and error solving screen. To optimize these systems, these complicated systems can be attached to construction systems via DSL and it be possible to solve the problem at when it happens. Most of the



current retractable ceiling systems because of mobile motors and the number of sensors that are in different parts of the structure are very expensive.

Designing team should pay good attention to the location of base. This location can be far from the project but it should be reachable by operator and should also have straight eye contact with the ceiling and how it is moving.

5-4- Coloring system: An appropriate covering system is necessary for every steel structure and for retractable ceilings. Structure should be periodically checked for every possible corrosion or damage in color.

6-4- Hyper-corrosion: Most of retractable ceilings move on a steel rail. These rails should be repeatedly checked to know if they have any damage in color or any sound which is not common. These damages can be due to disordered system so preventing maintenance to avoid sudden accident is necessary.

7-4- Storm and extreme wind predictions: Because of multi-position of the ceiling that is witnessed in retractable ceiling, these structures generally are designed for different degrees of wind. The most winds, when ceiling is open or close, can tolerate is different. For extreme winds like storm ceiling should be closed and some parts need to be furred with wood, this is important that the owner of project knows the needs of the structure for different winds and staves be trained for different situation. For this a weather station is needed around the structure.

8-4- manual maintaining and implementing train: Other important factor for a successful retractable ceiling is providing effective training facilities and increasing quality of maintenance and implementation. These are necessary for a profitable start and is better done by the owner of the project. Security team should prepare themselves for the opening day to keep the planning safe. Implementation equipment for special situation should be provided and also the owner should participate in meetings that is with designers of machines and systems of ceiling.

9-4- Guarantee contract: In addition with following all principles most of the implementation mechanisms of the ceiling should be guaranteed with a year by all performing engineers. So they will be responsible for the project. Of course owners always desire to have a longer contract, in this case before starting a project owner should mention all his requirements.

10-4- Depot of spare parts: Necessary spare parts especially those that are more important to the project should be kept in a depot at a suitable condition to be replaced very fast when it is needed. For example there are some parts that are being imported, the list of these parts should be given to the owner to make further desicions about them. Also when some parts do not have special design it is a better idea to buy them when ordering the first one.



11-4- Equipment and instruments that are for implementation and maintenance: Headquarter of support and security needs to keeps maintenance equipment and instruments at the depot. Some of the equipment related to repair are helping jacks that are used for changing wheels of the ceiling, equipment for lifting and moving the ceiling etc.

12-4- Determining budget for implementation and maintenance: Maintaining and implementing retractable roofs is one of the great conflicts between designers and the owners of the project. Because there is no history for implementing and maintaining retractable roofs (these are new technology) there are different prices offered with companies and teams. Some of the prices are listed here: Constructing price of a retractable roof in North America is around \$25m to \$70m(2005). This price is for mobile part of the ceiling, controlling part of the ceiling and the rails that ceiling moves over it. Retractable system of the ceiling makes around \$7m to \$14m of the price. Generally if one team is responsible for maintaining and implementing of the ceiling, the owner will get more profits, contract of providing service for all parts, instruments and maintenance gets two to 4 percent of the constructing price, for example a ten years contract is between 2m\$ to \$4m. Of course if inflation rate is low. This contract can finally be the best contract for the owner.

5. Current architecture of Iran and the importance of reaching to technology

We might say that the most important feature of art is leading and fore-handing and also redefining the frames. Of the basic concepts of conceptual design to constructing the structure there are many stages and levels, and until problems related to constructing are not well analyzed, the structure cannot possess national and international quality standards.

Power and development of every society depends of facilities and optimizing power of its needed equipment. And new sociology completely clarified this issue that economical, scientific and technological development is with following all cultural desires.

Heidegger in his famous article “The question concerning technology” writes: “technology is not a dangerous or devil matter, machines and systems that are naturally fatal are also not threatening, threaten of technology stems from the heart of fate, danger is where human cannot rely on what he is and tries to stand against technology but instead turns to a technology itself that is an ordered technology”

This is reality that communication and universal business today is like it has no geographical and political territory in it, it can be used with scientific, independent and free meetings that are away from prejudging and ignorant prejudices.

We should understand our culture and society and also financial and mechanical power and based on these take our steps.

5-1- Retractable roofs, structure and architecture similarities

Study in different fields show that in creating memorable and effective structures either from physical viewpoint or from appropriate spaces with human rates, finally, architecture and structure have a creative mixture with each other. This imaginative mixture takes the obstacles and limitations away from the designers and gives them more operational freedom for designing spaces that are for their interest.

Of the view point of engineers and architectures there is no doubt that just when architecture have a good understanding of structure then a modern forms of structure can be made. [9]

In old Iran architecture and civil were the same major and they were that mixed in creating a place that separation, differentiation and contradiction was completely gone. Architects of that time were that familiar with features of the job that they could be called engineers. This is while today, architecture and civil engineering are completely separated from each other.⁴⁶ So today society of Iran needs a reconsideration and a scientific and practical move to development And before going down needs a new movement. Today we are back in many fields of the world that the worst one is in architecture and the modern related technology to this.

A designer who starts designing without any information related to designing, is like a poet who his bank of vocabulary is poor. Being aware of human science and its relationship with architecture is a very important issue. [10]

Understanding of building`s behavior is counted as a first step in precise recognition, exact design and assure implementation... If we want that architectural innovations solve new problems that are with developing activities of construction, we should have a great cooperation between architecture and civil engineer, that is a coordinate mixture of building`s behavior by an architect and a general constructing science which is common, effective, real and clear.

Foldable and retractable ceilings are of the newest fields that coordinate civil and architecture. Structures are not targets in these places but are a tool to help presenting a place, a modern place that is with culture and logic. One of the topics that keep the mind of most of architects and civil engineers busy is creating places that have flexible ceiling that will make it possible to use natural air and the pleasant light of sun for the time of the day when air is clear.

5-2- Check the country needs to retractable structures

Use of retractable structures in today words has caused many glorious beautiful places such as recreational, sport and business places that not only displays the power of operational team but also with presenting a modern and updated structure has an effective role in attracting people attention.

Considering the need of our dear country to sport, recreation, holy, exhibition and other places that should have the modern technology of the world and also be beneficial and practical, it is necessary to do a big study over foldable and retractable structures and find the advantages and disadvantages of each.

In our country, using retractable ceiling for different places is a great solution that we can list the examples as below:

- Covering the ceiling of every religious place, holy places and location that Friday prayer is being hold.
- Creating exhibition places that are permanent or temporary with natural ventilation and the use of day light
- Beautification of beaches and creating sunshade that are retractable when are not needed.
- Ceiling of sport places like soccer stadiums and swimming pools which will let sport fans to enjoy fresh air.
- Department stores ceiling covers, restaurants and coffee shops that in addition with optimizing place will be useful for attracting customers.
- Creating permanent or temporary cover to keep cultural heritage
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6- Conclusion

Of the civil engineers and architectures view point there is no doubt that just when we can reach for modern structural forms and use their design that we have a good understanding of how they work. For this in the first part of this article we had a general understanding about this symmetric retractable circular structure and in second part we continued with covering parts of the structure that is used at the ceiling of places like stadiums, swimming pools, and department stores.

Retractable structures can be implemented with different ways. For creating a retractable structure with circular panels foldable bars are use which have angulated parts. But this skeleton cannot work alone as a ceiling or shelter for an architectural place but they need to be correctly covered with rigid plates.

Usage of this rigid plates that are fixed together with joint fittings, can be useful in the ceiling of a place. In this article we studied different shapes of these rigid plates and finally the best shape was suggested using Matlab software.

In the third part we emphasized on the implementing consideration that exist in retractable structures and it was added that because of the especial condition that these structures have they need especial care as well. Finally it is worse mentioning that the urgency of reaching this technology in the country and the need of our country to these retractable structures that in the fifth part of the article we dealt with- it is necessary that technology training and the designing basics of this be focused in the architecture universities of Iran. And there be held conferences for civil engineers and architectures to get more familiar with this technology.

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