Transformable Architecture, A key to Improve stadiums & sports buildings

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Abstract:
Nowadays, needs are changing rapidly. New technologies are developed to achieve responsive architecture trends to these changes. One of these trends is called Transformable Architecture. Transformable architecture is listed under the kinetic architecture. It is defined as buildings – in a fixed place - that can change its form, configuration and properties, for a need or a purpose. Its applications are varied from moving the roof structure, building spaces, façade components and interior components and furnishing. Roof structure can be moved by different ways, by moving roof parts; like overlapping, or by transforming roof structure; like retraction or deploying.
By such, transformable architecture introduces a lot of solutions, which can improve the buildings' functional, environmental, aesthetic and economic properties. Functional properties, as making the building alters its function to another, change its form and configuration to host another event. Environmental properties, that makes the building able to host events throughout the year and making it energy efficient. Aesthetic properties, - which caused by motion – as it makes the building attractive with appropriate visual impact. As a result, the economic properties of the building are improved.
So, there is no need to construct very expensive wide span buildings for each game. Particularly, in large crowded cities like Cairo (the capital city of Egypt), where there is no enough free area for such activities. Also, there is an ability to increase income by multi-use, energy efficiency, and tourism attraction. Hence, transformable architecture is a key to improve stadiums and sports buildings, and in turn improve its functional, environmental, aesthetic and economic properties.
This paper tries to highlight the role of transformable architecture in stadiums and show the importance of improving stadium abilities and properties. This is done through review the literature and analyses a number of case studies in order to investigate the different impacts of employing this technique in their buildings. A number of recommendations on using such technique in Egyptian stadiums and sports buildings are drawn as key directions to improve them.

Key Words: kinetic architecture, transformable architecture, dynamic architecture, spatial frame, retractable roofs.

1 Introduction& Research Problem.

Stadiums are designed particularly to host sports events. These stadiums are occupied for sports events up to 20 times a year. It's not feasible to afford mega structure buildings to host just small number of events during the year. Alternately, to increase their fund other events can be hostedby making them multi-purpose buildings. These other events could be; live music concerts, convention, and exhibitions (1).Another point, that the tight urban environment, especially in a metropolitan cities like Cairo (The capital city of Egypt), makes it difficult to build more sports buildings. Land prices are expensive, and having many large stadiums is not a feasible solution, compared to cost and benefit throughout its lifecycle.

Sports activities are carried out on either the open air or enclosures. The seasonal conditions are important factor in the outcome of the game; this can also leads to a conflict and becomes a great factor to set schedules and time for events. Also the grass of the open air turf field is a living plant that needs fresh air and light.

Consequently, there is a need to have solutions that can make a stadium multifunctional and host many events throughout the year. Transformable systems in architecture can give these buildings the ability to do so. It can make the building alters it function from a stadium to a convention or a concert hall. It also makes it able to host another game not just the game which is designed to. And finally it can operate the stadiums whatever the weather condition.

2 Aim &Objectives.

This research aims to show the role of transformablearchitecture in stadiums and sports buildings. And emphasis its importance to improve stadium abilities and properties, as it is a key to improve their capabilities.To fulfill the research main aim, a number of objectives are being achieved. These are:

a. Defining the Term "Transformable Architecture", and discuss the types and techniques of transformation.
b. Studying a number of projects, that applied transformable architecture. And, study the impact of using transformation on these projects.
c. Highlighting the importance of using transformable architecture.

3 Research Methodology.

The current researchdepends on two main techniques; descriptive study and analytical study.Descriptivestudy is employed in order to define the transformable architecture, and introduce its types and techniques to make it easier to study. The analytical study is employed to state the important role of transformable architecture as a key factor to improve stadium projects. This study will discuss some projects that uses transformation techniques, and investigate the improvements occurred as a result of using transformation. So, the outlines of improvement directions of utilizing transformable architecture in stadia and sports buildings can be drawn.

4 Defining transformable architecture.

Before talking about transformable architecture, it is ought to define, the kinetic architecture. Which is released as a responsive technology to the needs (2).It is defined as the design of buildings in which transformative, mechanized structures change with climate, need or purpose. (3) It consists of transformable objects that dynamically occupy predefined physical space or moving physical objects that can share a common physical space to create adaptable spatial configurations. It has three main typologies embedded, deployable and dynamic (4).

Embedded systems are systems that exist within a larger architectural whole in a fixed location primary function control the larger architectural system or building in response to change, like seismic control. (4)

Deployable Kinetic structures typically exist in a temporary location and are easily transportable. Such systems possess the inherent capability to be constructed and deconstructed in reverse, Like Bedouin tents and temporary exhibitions.

Dynamic systems in architecture are systems exist within a larger architectural whole but act independently with respect to control of the larger context. Such can be subcategorized as Mobile, Transformable and Incremental kinetic systems.

So, Transformable architecture is one of Dynamic systems in architecture. Are those that can change to take on different spatial configurations and can be used for space saving or utilitarian needs(4). It can be in many typologies; either by transforming interior, façade or structure components. (5)

The Transformation of the roof structure is commonly used and applied in some stadiums in the world, especially in the second half of the 20th century. It can make great effect on the architectural whole. Also, it has some issues to apply especially large span ones;like technical, economic and interdisciplinary issues.The Transformation of the roof structure is commonly used and applied in some stadiums in the world, especially in the second half of the 20th century. It can make great effect on the architectural whole. Also, it has some issues to apply especially large span ones;like technical, economic and interdisciplinary issues.

5 Classification Of Transformable Roof Structure.

Transformation of roof structure was classified by many researchers Like Felix Escrig(6),ArielHanoar(7)and MaziarAsefi(8).MaziarAsefi is a researcher in Liverpool University who madethe most recent classification of transformation of roof structure(8). it can be used to describe the forms of motion of the roof structure.

This classification [*fig. 1*] categories transformable architecture into two major groups: transformable tensile architectural structures and transformable compressive architectural structures.Following this categorization, these structures can be further developed in respect of the structural principles and materials they employ. The classification parameters can be applied at any scale, and any structural type within it.

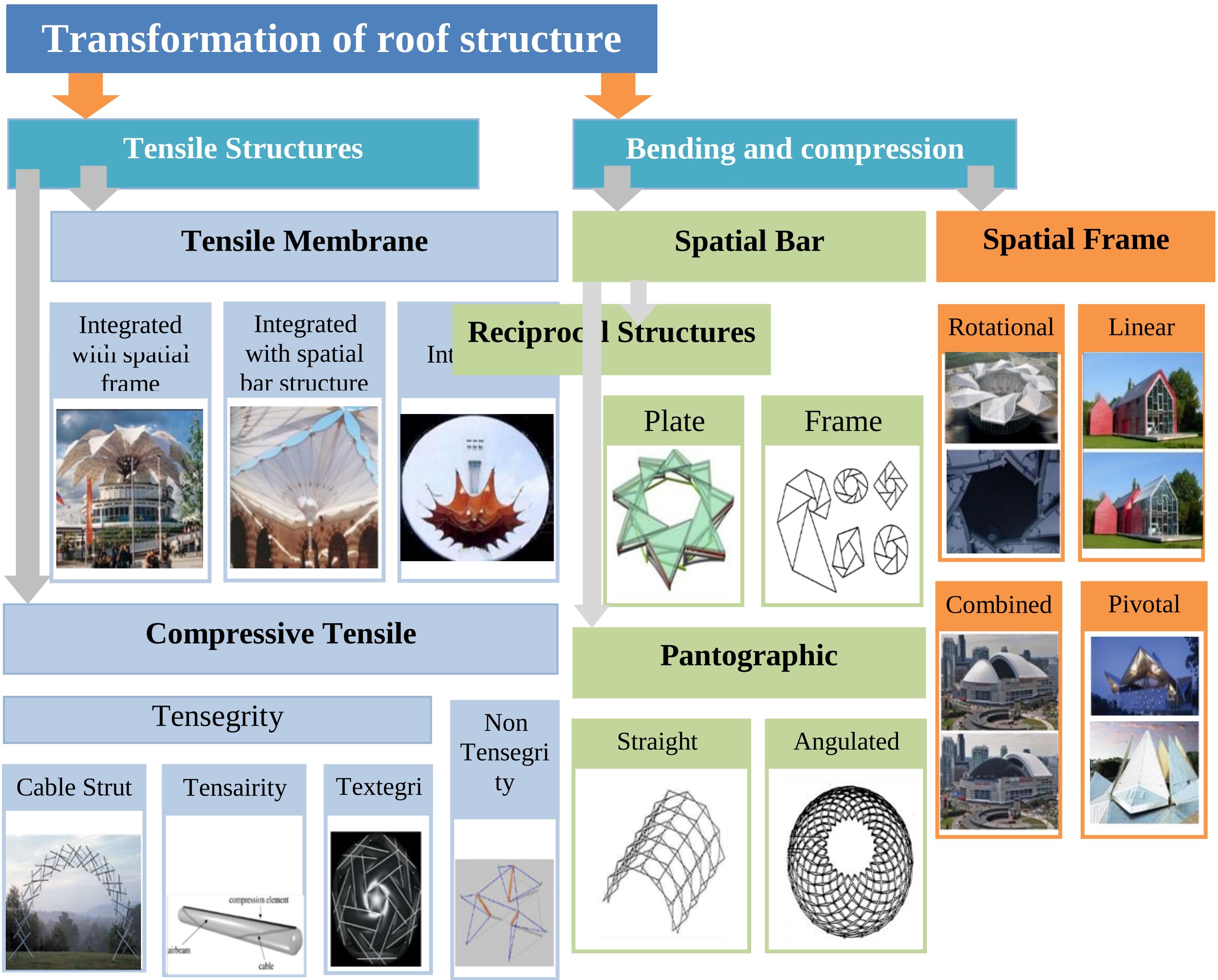


Fig. 1: classification of transformable roof

5.1 Tensile structures.

5.1.1 Tensile membrane.

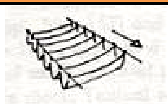
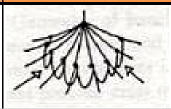
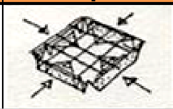
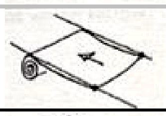
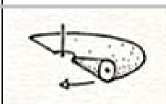
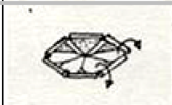
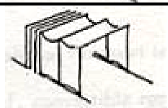
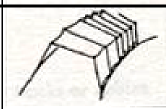
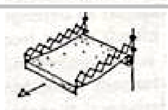
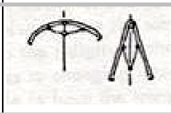
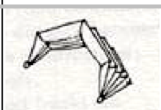
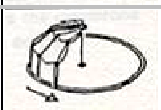
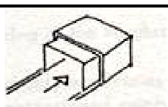
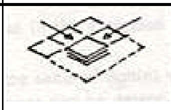
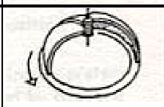
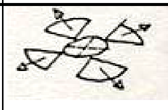
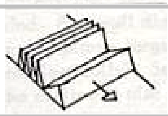
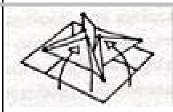
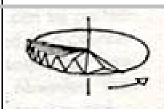
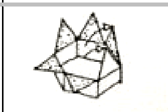
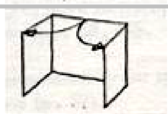
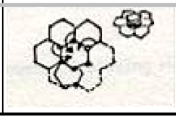
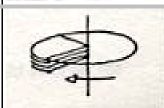
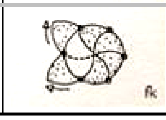
This type of structures is considered the most efficient type, with less material consumption and energy efficient. It is considered a good alternative for traditional structures, by making transformations and deformations easier. This type of structure depends on pre-stressing its tension member; to increase the stiffness and stability of the structure. It can be deformed and alters its shape by motion, or keeping its form in a stressed case during the transformation, or releasing the stress to make a motion.

While Tensile structures main stability depends on tension, it is supported by compression members. These members are usually the motion controller.

The kinetic degree of freedom (KDOF) of tensile member is infinite, so a compression member is needed. The KDOF of transformable structure never exceed the first degree, the second degree are deployable (i.e. less controllable)(7).

There are two types of tensile architecture, pneumatic and tensile fabric structure. The pneumatic ones are depending on air inflation to achieve stability. They are not commonly used in transformable architecture like tensile fabric structures. Tensile fabric structures are the most commonly used ones(8). They have a great variety of motions, easier to control and more efficient. There are three types of tensile member structures: nonintegrated fabric – which does not need a rigid structure to support -,integrated fabric with a spatial bar structure [*see 5.2.1*] , and an integrated fabric with a spatial frame structure [*see 5.2.2*].[*table 1*]

Table 1: shows the tensile fabric structures motion matrix (9).

	Motion	Paralel	Central	Circular	Peripheral
Non-integrated	Bunching				
	Rolling				
Integrated with a spatial bar structure	Sliding				
	Folding				
	Rotating				
Integrated with a spatial frame structure	Sliding				
	Folding				
	Rotating				

5.1.2 Compressive Tensile Structures.

This type of structure Integrates between tension and compression elements effectively to achieve structure stability, with low cost and light weight. This type is subcategorized into Tensegrity and Non-Tensegrity structure [*fig. 1*].

Tensegrity structure named for its tension integrated structure. It is a system where the tension member is continuous while the compression member is not. The compression member lies within a continuous tension member (10).

It can be subcategorized into Cable Strut, Tensairty – where pneumatic tension membrane is used-, and Textegrity – where tension fabric is used .The Non-Tensegrity structures are the ones which contain some continuous compression elements. These structures are under research and rarely applied in static buildings; that is because it's neither reliable nor durable (11). There is no kinetic building of this type of structure, just prototypes and models made by researchers(8).

5.2 Bending &Compression Structures.

5.2.1 Spatial Bar Structures.

This type of structure consists of compression and tension bars in spatial configurations. Its form is mainly like traditional steel structures, with the ability of deformation and transformation. It can be subcategorized into two types, pantographic and reciprocal spatial bar structures(8) [*fig 1*].

Pantographic structures –scissor pair structures (7)–are a spatial lattice consists of members that linked together by hinges. It can provide various forms and spatial configurations. It is not commonly used in architectural scale, as it has a complicated mechanism, expensive and not reliable. it has just used in kinetic sculptures and art works, like Hoberman'sIris Dome [*fig. 2*]. It also simply used as sun shades like Santiago Calatrava'sMilwaukee Art Museum [*fig. 3*].

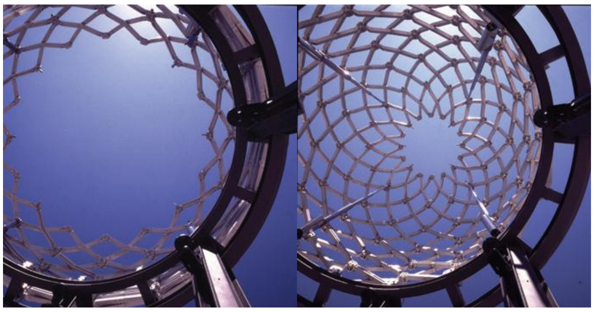


Fig. 2: Hoberman sphere (Iris Dome)(12).

Fig. 3:Milwaukee art museum.(13)

Reciprocal structures are mainly a three dimensional structure where linear elements are connected reciprocally in a closed geometry. It is supported from it perimeter with a static structure. At least 3 elements can form a reciprocal frame structure. It is usually used for building roofs. There are two types of reciprocal structures: reciprocal structures with linear elements, and reciprocal structures with plates. The reciprocal plate structures are considered spatial frame ones, but it differs as its elements supports each other reciprocally(8). [*see 6.4*]

5.2.2 Spatial Frame Structures.

Spatial frame structures are the most commonly used type of transformable roof structure. It consists of two-dimensional or three dimensional rigid plate supported by a secondary structure, which is moved by means of a mechanical driving system without changing its shape during motion. It is usually divided into several parts that are independently supported by a secondary structure. All separate retractable frames are overlapped or connected in the fully closed state where they should be properly integrated in order to achieve sufficient stability and rigidity to withstand external loads. So, the transformation happens by moving of plates on defined driving tracks. Thus, they can only convert a fully closed space into a partially or fully open space, and no deformations occurred on the structure elements.The movements of these structures are often linear, rotational, pivotal or combined movement(8)[*fig. 1*].

6 Transformable Roof Stadia.

In this section some projects are discussed to show the impact of using transformable roof structure on building stadia, and the improvements added to the functional, environmental, aesthetic and economic properties of buildings.

6.1 Montreal Stadium, Montreal, Canada.

The Montreal Stadium was used for the Olympics in 1976. The retractable tension membrane roof was installed in 1987, and designed by Schlaich and Bergmann. It covers approximately 20,000 m^2 elliptic area of the stadium. Its movement is intended to make the building as both an outdoor and an indoor space, and consequently make it suited to different functions and events extending use into the winter months.


Fig. 4: Montreal Stadium, Canada(14)

The roof operates by heavy hydraulic jack that makes it move from the edge of the permanent roof to the head of the tower by rolling on 26 pretension cables [*fig. 5*]. The jacks are first released to loose the membrane and pull the membrane and cables toward the hollow shaft of the 175 m tower. So, the membrane could be retracted in a controllable fashion a lasso cable was installed around the edge of the membrane and a number of fixed cable anchored to the tower were attached to the membrane(8).
After many technical problems of the tensile transformable roof structure; due to technical limitations of the time, it is replaced by a fixed Teflon coated fiberglass in 1993(15). It nevertheless is an example of three main features of transformable architecture: multifunctional, environmental,and interaction.


Fig. 5: transformation of the roof structure of Montreal Stadium (14).

6.2 Rogers Centre, Toronto, Canada.

Rogers Centre [*fig. 6*] – previously named Skydome- was designed by Rod Robbie and structural engineer Mike Allan as they won this building design competition. It was completed in 1989(16). The building was designed to host games like baseball, American football, and soccer. And has a range of facilities like restaurants, concert hall, conference center and 350 bed hotel 70 look onto the pitch.

This buildingis considered the first one that took a lot of research and in retractable roof structure which covers about 32500 m2 with 205 m.The retractable roof consists of two parabolic arches A and B [*fig. 7*] in the form of a barrel vault in the middle with two panels C and D at each end in the form of a quarter dome. During the retraction, both panels A and Bretract telescopically to the part D. then part C rotates to overlap part D. The roof structure consists of hollow tubular steel members. In addition it includes acoustic and thermal insulation, vapor retarder and PVC membranes, to be enable it to resist high speed winds and hurricanes. It can also withstand the accumulative loads of five years of snowfall. This roof proves its efficiency as its operates about 100 times a year, expected to last for 100 years(8).

This building offers a fast conversion time in the tight urban site. The total retraction time is about 20 min, with running speed 10m/min, exposing 91% of the stadium area to the open sky(17). It also offers manual transformation of half of the seats – all about 57000 seats – depending on the activity that is taking place. Also, the play field is convertible to a bare floor in 8 hours, and from baseball to football in 16 hours. So it is unfeasible to use natural grass. As the building costs about 570 million dollars, it records in 1997 that it was used for 302 days throughout the year and seated a total of 4.5 million people (1).

Fig 6: Right, Rogers Center in closed state. Left, half open state(18).

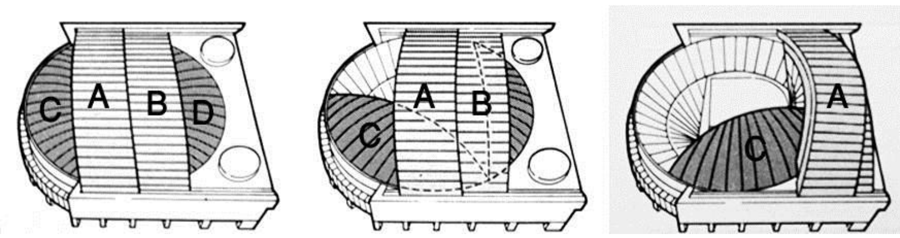


Fig 7: schematic view shows the transformation of Rogers Center (19).

6.3 University of Phoenix Stadium, Arizona, USA.

University of Phoenix stadium [*fig. 8*] - also named Arizona Cardinals stadium -was designed by Peter Esminan in 2003, and was completed in 2006.It was designed to host not only events like American football events including the Super Bowl – annual NFL championship - , but it also considered a major conference and special events venue. That is because it offers an opening roof and a rollout field [*fig. 9*]. This 365-day design criteria was brought to improve income opportunities and optimize events scheduling flexibility by hosting non-football events throughout the year(20).also, its 63000 permanent seats can be expanded to 73000 for special events (1).

The retractable roof is built in two translucent fabric covered space frame panels that retract to uncover the entire playing field, it was about 78.3 m by 43.3 m. it retracts by using 8 electrical cable drum 7.5 horse power motor supplied by safety brakes. It retracts within 11 minutes with a speed 25 ft./min (20).

The stadium's natural grass field rolls outside the stadium within an hour, where it will stay most of the year for growth and maintenance. The permanent concrete floor inside has an embedded service grid to allow maximum flexibility for trade shows and concerts(1).The stadium building cost about 450 million dollars, it achievesapproximately 150 million dollar a year.(21)

Fig. 8: University of Phoenix stadium: left, at day (closed), right: at night (Open)(1).

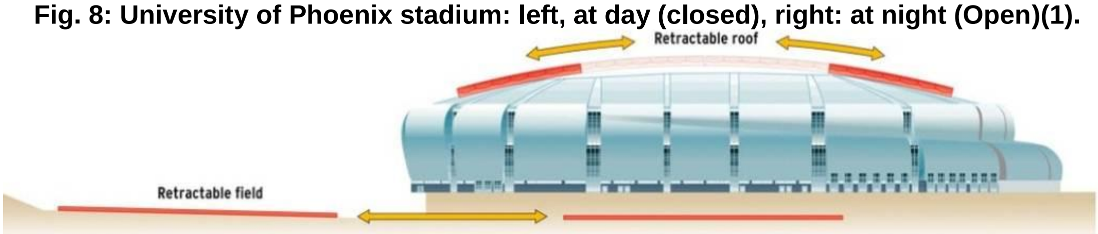


Fig. 9: shows the motion of the roof and flooring of University Of Phoenix stadium.(22)

6.4 Qizhong Stadium, Shanghai, China.

Qizhong tennis stadium [*fig. 10*] was designed by Mitsuru Senda, completed in August 2005. It has a unique form of transformation as its transformable plate structure utilizing a reciprocal pivotal mechanism. Its movement –

opening and closing - is like blooming of a magnolia flower (the Shanghai city flower). It can host an event with about 15000 spectators(8).

The retractable roof system of the stadium includes eight petal shaped sections and each rotates around a fixed shaft by means of three concentric driving tracks, each wing of the roof consists of a steel pipe roof truss covered by a steel plate the retractable roof is supported by a fixed spatial steel ring truss of 123 m diameter. The roof operates within 8 minutes, and covers about 14000 m^2(8).

This building illustrates the great potential of spatial frame structure by the integration between art, science and technology. As It offers indoor and outdoor environment, it delivers a great visual impact that act like an attraction to visitors.

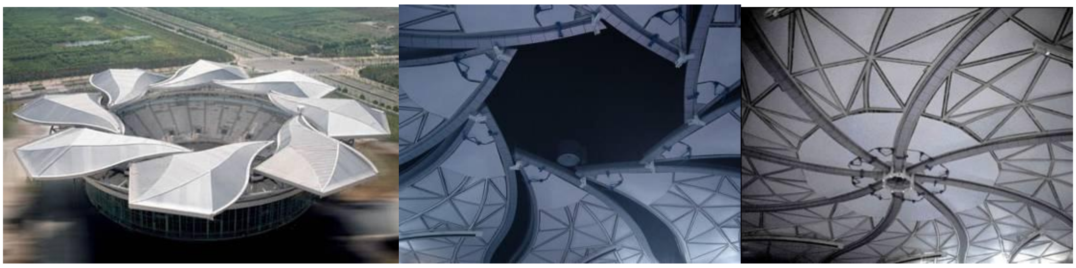


Fig 10: shows the Transformation of Qizhong stadium(3)

7 Conclusion.

The current research was mainly aimed to show the role of transformable architecture in stadiums and sports buildings. As it is a key to improve sports building. It carries out a lot improvements in 4 main directions:-

1. Functional: the building can alters its shape and host multiple events, multiuse, reconfiguration according to the event, as shown on Rogers Center and phoenix stadium [*see 6.1*]
2. Environmental: the building can host events throughout the year, without taking weather limitation in mind. As shown in the whole previous projects.
3. Aesthetic: the building move, it makes a dynamic scene with great visual impact and attraction. As shown in the movement of Qizhong stadium whichwas like blooming flower [*see 6.4*].
4. Economic: as a result of the previous improvements, the building can attract visitors to see the building in motion and not just for the function of the building. The functional and environmental improvements makes the building usable any time during the year forseveral events, so there is no scheduling problems like traditional stadiums. These buildings are relatively expensive to build, but -as shown [*see 6.2 and 6.3*] - it offers great income through its lifecycle on the long run, compared to its construction, operation and maintenance cost.

So, to achieve these improvements; it is ought to take some considerations in mind. These buildings need an integrated collaboration between several disciplines: architectural, structural, mechanical, control and material specialists. These considerations can be divided mainly into architectural, technical and design process considerations. Architectural considerations like considering functional, environmental and aesthetic issues for transformable design. In addition, technical considerations like considering maintenance and safety issues, environmental loads, material selection criteria and economic issues. Finally, design process considerations to define the rules of each discipline to ease the integration between them.

Consequently, it is recommended to use this type of architecture especially in metropolitan cities such as Cairo (the capital city of Egypt), as it enables multifunctioning of stadium buildings to optimize land use. Also, it is recommended to have transformable stadiums especially for a developing country like Egypt, as it offers great income compared to its cost. This income could be achieved through multi-use of the building, energy efficiency achieved, and tourism attraction, as shown in the projects mentioned in the research.

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