

Design of a 40,000-Seat Football Stadium in Tehran with an Approach Focused on the Application of a Pneumatic Structural System, Emphasizing the Design of ETFE Cladding Details

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ABSTRACT

The present study aims to design a 40,000-seat football stadium in Tehran using a pneumatic structural system, with an emphasis on the design of ETFE covering details. The research method is to examine implemented cases, based on the criticism and study of the works of the greats and their conformity with the theory of architecture and the approach of stylization. Therefore, we intend to compare and contrast modern architecture with the works of the greats of architecture and, on this basis, to adopt a deductive and integrated method of induction and deduction for the stylization of the structural system in the construction of the complex. The proposed site is located at the junction of Tehran and Karaj cities and has a trapezoidal shape. This site is located north of the Tehran-Karaj highway and south of the Kharrazi highway, with close access to the Vardavard metro. The results showed that, in structures such as stadiums, due to their high volume and mass, the principles of lightweighting and modular design should be applied, and the structure should be divided into sections to reduce the weight of each module, thereby reducing earthquake forces and forces acting on the building. The reason for using this approach (lightweighting) is to reduce the building's weight and, consequently, the force exerted by the earthquake on it.

Keywords: *Football stadium design, Pneumatic systems, Tension and cable architecture, High-tech architecture*

INTRODUCTION

Iran lies in one of the world's most active seismic belts, and a survey by the International Institute of Seismology and Earthquake Engineering in Iran identified about 24 active faults, indicating a high earthquake risk. There are 3 important faults in Tehran (the North Fault, South Fault, and Masha Fault). Therefore, buildings should be designed and built with measures to address this natural event. According to the force formula (Newton), to prevent or reduce damage caused by an earthquake, the earthquake force should be reduced. Earthquake acceleration is a variable we have no control over, so the only variable that reduces earthquake force and can be controlled is the building's mass and weight. The lower the weight of the structure, the less force the earthquake will produce. Another approach that is discussed in the design discussion is the modular design of the structure. This method ensures that, in critical situations such as earthquakes, fires, or terrorist attacks, if part of the structure is destroyed, the rest will not be damaged and will remain able to withstand the loads independently (Behrouz, 2010).

Lightening the structural and non-structural components of the building structure is achieved when these components reduce gravity loads, increase efficiency, and improve the functional characteristics

of the structure. The benefits of lightening the building structure can also be examined from two perspectives: first, reducing the mass of the load-bearing structure and consequently increasing the useful interior space; and second, reducing the structure's mass and consequently reducing the impact of seismic loads on the building. To achieve this goal, it is necessary to use the inherent properties of building materials, along with the optimal geometry of load transfer within the system and the elements of the building structures. Therefore, selecting lightweight materials, especially those with a fine grain size, for building components will be the first step in lightening the building. In the following, while selecting outstanding examples of traditional Iranian architecture, the process of upgrading these works from the perspective of efficiency and structural lightening has been analyzed, and practical and applied methods and principles for lightning-resistant building structures have been identified. Considering the optimal design of the load transfer geometry of the structural system in the structural components, and in addition to that, in the combination and selection of their optimal dimensions, proportions, forms, and orientation, can also achieve maximum efficiency of materials in bearing and transferring loads and stresses (Taghdiri, 2011).

Modular design involves connecting standard units (modules) to create a larger, more complex

combination. In some cases, units can be removed or separated, or the same structure can be used for a new work that differs from the initial form or the configuration result (Razjoyan, 2009).

The importance of the research can be mentioned as follows. Designing a national sports center that is up to date with international standards and considered a respectable symbol, which currently does not exist in our country. Also, a modern and structurally safe center against natural hazards such as earthquakes that meets the needs of countless people interested in national and club sports. Also, in Tehran, popular teams do not have their own stadiums. In general, such a building on a municipal and national scale provides cultural and sports services. In the present study, an attempt is made to propose details and methods to reduce the building's weight. The issue raised in the discussion of implementation is industrialization, which increases quality and execution accuracy, reduces costs, and ensures the implementation method.

Theoretical Basis of Research

Pneumatic Systems

Pneumatic structural systems (or air-supported structures) are structures or buildings that use air pressure to ensure their structural integrity. Pneumatic structural systems are usually shaped like a bubble or a dome to maximize the interior volume. This bubble shape is created by uniformly increasing the air pressure inside the structure to slightly above atmospheric pressure. Cables are then used to stiffen the outer membrane, carry the load, and attach it to the ground. (Sayyadi and Maddadhi, 2012). Walter Byrd invented the first pneumatic structures for the United States Army during World War II in the late 1940s. Originally, they were used for emergency shelters and decoys. Later, they were commonly used by the military for temporary radar stations. Today, pneumatic structures are used for sports stadiums, swimming pools, warehouses, and temporary art installations (Fakhr Tabatabaei, 1996).

Types of pneumatic structures

1. Air-supported structure: This is a structure in which there is direct pressure under the envelope or membrane. The average life of an air-supported structure is 20 to 25 years. Design and construction are simple; it offers flexibility for seasonal activities, and the cost of such a structure is relatively low. Air-supported structures can be used for sports stadiums, where "bubbles" cover tennis courts, swimming pools, and other temporary structures. (Collins, 1996).
2. Air-inflated structure: A structure in which air under high pressure is contained solely by the supporting elements of the structure, enabling it to support itself. There are no restrictions on the number or size of openings or on design geometries. These structures can be used for

sheds, shelters, custom buildings, permanent roofs, and warehouses (Grueter, 2004).

3. A few decades ago, architects could only imagine their creative ideas and amazing buildings, as such ambitious projects were not possible to build. But today, building a floating area of glass bubbles, a sports stadium woven from steel beams, or even a transparent tent-like covering spanning thousands of square meters of land - which could only be imagined, has become a practical reality. The construction of such structures owes more than anything to the unique properties of the material, which is abbreviated as ETFE (Hosseini, 2011).

Design and analysis of pneumatic structures

Pneumatics are superior in terms of tension structures, because only with them is it possible for all structural elements to work exclusively in tension. As is usually the case with tensile structures, in a pneumatic structure, shape cannot be created because the membranes do not resist bending; thus, the geometry and loads must interact until equilibrium is reached. The design of a pneumatic structure involves determining the initial or appropriate configuration, including the structure's shape and the corresponding stress field. In addition, the appropriate shape must satisfy both architectural requirements (shape and performance) and material-structural requirements (strength and stability). The design of rigid structures is necessarily integrated for analysis, in a process that includes procedures for finding shape, pattern, and load analysis (Pirnia, 2008).

Before the widespread use of computational tools, the design of pneumatic structures was done either analytically or using physical models. Analytical methods are accurate, but should be applied only to regular shapes. Physical modeling is versatile, but lacks precision. In particular, the method of determining the shape of pneumatic structures using physical models requires impermeable fabrics or films capable of maintaining a pressure gradient to hold the model in the inflated configuration. Furthermore, it is essentially a trial-and-error process in which the shapes of the unstressed patterns from which the model is made are judged by the designer's experience (Jenkes, 2002).

Since a closed envelope is always under pressure and reaches an equilibrium state regardless of the shapes of the unstressed patterns adopted, the process is somewhat less stringent than for forms that require tents, and only the final shape of the model needs to be checked. If these requirements are not met, the designer attempts to modify the initial cut patterns to minimize defects in the inflated configuration. Computers make this trial-and-error process much easier while circumventing material problems. Furthermore, once a suitable shape is known, they allow stress-free patterns to be found through flattening, a more or less standard process in

computer-aided design of tensile structures. Thus, the amount of guesswork required by the designer is reduced. Furthermore, the assessment of stresses acting on the membrane is much more accurate than that obtained from reduced-scale physical models (Dehkhoda, 1946).

Tensile and cable architecture

Tensile structures are structures in which the main load-bearing members transmit the applied loads in the form of tensile stresses without applying compression or bending to the foundation or supports. (The purest structural behavior is that it only supports tensile forces. Tensile structures are well-suited to carrying large loads; therefore, their equilibrium under dead and live loads is studied. Field applications of this type of structure include temporary shelters and warehouses, field tents, suspended ceilings, and suspended systems.

Cable-stayed structures have the purest structural behavior. Cable-stayed structures have a purely tensile behavior. They utilize all their strength. The form of these structures is self-formed and highly efficient. No other structure can span more than a kilometer (perhaps 500 meters). The natural form that a cable takes under load is a rope-like curve. A load spread out at equal horizontal intervals gives the cable a parabolic shape, and a load spread out at equal intervals along its length gives it an elliptical shape. A cable cannot support a load without sag. The length of the cable is directly proportional to its sag. The force of the cable, the cross-section of the cable, and the thrust force of the supports are inversely related to the sag of the cable. (Clark, 1991).

The earliest known design of a cable-stayed bridge is described in the book "Machines Nova," published in 1595. However, the idea was not accepted until the present century, when engineers began using cable-stayed bridges. During World War II, when steel was scarce, this design was used to rebuild bombed bridges whose foundations were still standing.

Climate-friendly architecture

According to studies, between 15 and 20 percent of total energy consumption in each country is used in residential spaces, which represents a high cost and large-scale destruction of natural resources and environmental degradation. Therefore, taking a step towards reducing energy consumption in this area, which depends on optimizing the thermal efficiency of buildings, can lead to huge savings in limited natural resources. Twentieth-century architecture, due to the excessive importance it has given to technology, has led to the elimination of many of the subtleties and meticulous attention to the climate factor in traditional architecture. Today, little attention is paid to the climatic and local materials of each place in architecture, and for this reason, we are witnessing an international style worldwide. It aims to introduce and examine the manifestations of climate-friendly architecture in traditional Iranian buildings, using

inexpensive, practical methods to leverage climatic conditions to provide comfort in the living space, such as windbreaks and... (Abdoli, 2006).

Sustainable Architecture

The application of sustainability and sustainable development concepts in architecture has given rise to the field of sustainable architecture, with the most important headings being "Eco-Tech Architecture", "Architecture and Energy", and "Green Architecture". Sustainable architecture can perhaps be considered one of the important contemporary trends, a logical reaction to the issues and problems of the industrial age. For example, 50 percent of fuel reserves are consumed in buildings, which, in turn, has led to and will continue to lead to environmental crises. Therefore, the need to create and further develop the category of sustainability in architecture is clear. Sustainable architecture, like other categories of architecture, has its own principles and rules and includes three stages: saving resources, designing for returning to the life cycle, and designing for humans, each with its own specific strategies. Knowing and studying these measures will lead the architect to a greater understanding of the environment he must design.

Hi-tech architecture

Hi-tech architecture or high-tech architecture is a style of architecture that emerged in Europe and America in the 1970s. This architecture used the world's advanced technology and industry in building design to further portray the role and position of technology and industry. This style was first introduced in 1979 in a book titled "High Tech: Industrial Style and Source Book for Home". This book contains hundreds of images of how designers and architects used modern industrial advances in their work. In the 1970s, technological and scientific advances had a significant impact on societies at the time. These advances reached their peak with the trip to the moon and Neil Armstrong's step on it in 1969. These scientific developments, in turn, changed people's perspectives and, in particular, architects' attitudes towards using modern technologies more and more. From the perspective of high-tech architects, today's buildings should reflect the intellectual and technical essence of the present era, namely technology. Therefore, one of the obvious goals of this architecture is to increase. The focus was on the building's industrial components by exposing them, because, in their opinion, the technical aspects create the building's beauty. One of the most prominent examples of this excess is the Georges Pompidou Cultural Center in Paris (Hamze Nejad 2006).

Eco-tech architecture

It is an architectural style in which the design is based on the principle that the building is a small part of the surrounding nature and should act as part of the ecosystem, integrated into its life cycle. Eco-tech

architecture is a popular design, so the quality of the building's interior spaces is particularly important. The way and manner of using technology in harmony with the natural environment in all types of buildings are not, and will not be, the same. In some important and iconic architectural and urban buildings, the latest technical innovations are sometimes used in ways that make it seem the methods are not very feasible for developing countries in the contemporary era. However, the experiences of European countries in some fields, especially in small buildings such as residential units, can be very insightful. Some architects use the connection and harmony between humans and the natural environment through architectural space, leading to the use of natural materials. In some cases, the use of local methods and the re-acquaintance of the characteristics of traditional

materials with the characteristics of local architecture, which is the result of the acceptance of folk architectural criteria as a design method by architects, is a means of continuing deep-rooted values in a new context (Sayyadi and Maddadhi, 2012). In 1971, two young architects of Italian descent, Richard Rogers, living in England, and Renzo Piano, living in Italy, were declared the winners of the Georges Pompidou Center building design competition in Paris, among 681 participants. The facade of this building consisted of a series of chimneys, water towers, utility pipes and columns, beams, windbreaks, staircases, and walkways. These architects were the initiators of a style in Europe that became known as high-tech, or highly advanced technology, introduced into architecture (Sayyadi and Maddadhi, 2012).

Table 1: Case study analysis

Row	Plan name	Image	Description
1	Allianz Arena Munich Stadium		The most creative part is the design of the shell and its facade, which are made of ETFE, and the exterior color can be changed to match the colors of the Munich club teams' jerseys.
2	Wembley Stadium, London		The stadium seats 90,000 spectators, unevenly divided into three tiers. By moving the main metal arch and reducing one of the tiers for less important matches, it can be transformed into a stadium with a capacity of 60,000, which is amazing.
3	Beijing Bird's Nest Stadium		After the roof structure was installed, an ETFE coating was selected for it. This coating was used on an area of 40,000 square meters and in 1,038 different components.
4	Tehran Azadi Stadium		The stadium design is based on full visibility for all spectators, so that the maximum spectator visibility from the center of the field is 126 meters to the north and south, and 129 meters to the east and west.



The geometric shape of the cover skeleton is a horse saddle. The cover is connected to the rigid concrete side of the stadium on one side and is restrained by a composite cable on the other, serving as the non-rigid internal side.

Site location analysis

The site selected for the design is in Tehran. The prevailing wind in the desired climate is the west wind, which, although it provides suitable wind in spring, is considered unsuitable in winter and causes problems. While good eastern winds, which are the dominant wind of the second degree, blow in summer, this is considered a completely suitable wind. Therefore, the east-west orientation in the desired climate is the appropriate direction for the building. Because in this direction, the building has the least contact with the west wind. It makes the most of the south and southeast wind. Of course, to benefit as much as possible from the southeast wind, it is better to turn the building slightly to the southeast.

For this reason, in this climate, it is better for the building to be elongated along the east-west axis. To make maximum use of the light. 15 degrees to the east. Of course, the openings should be designed facing

south of the canopy. To prevent direct summer sunlight while directing winter sunlight. Therefore, considering two factors: the direction of the prevailing wind and the location of the sunlight, as well as the type of climate in the area, which is hot and dry, the optimal direction of the building is along the east and west, with a rotation angle of 25-30 degrees to the southeast.

The selected site is located in Vardavard, west of Tehran. Hemmat and Hakim highways are to the north and east, as well as the Tehran-Karaj Freeway and Shahid Fahmideh Highway to the south. The proposed site is located at the junction of the cities of Tehran and Karaj and has a trapezoidal shape measuring 1000, 750, 850, and 350 meters. This site is located north of the Tehran-Karaj highway and south of the Kharrazi highway, with close access to the Vardavard metro (Figures 1 and 2).

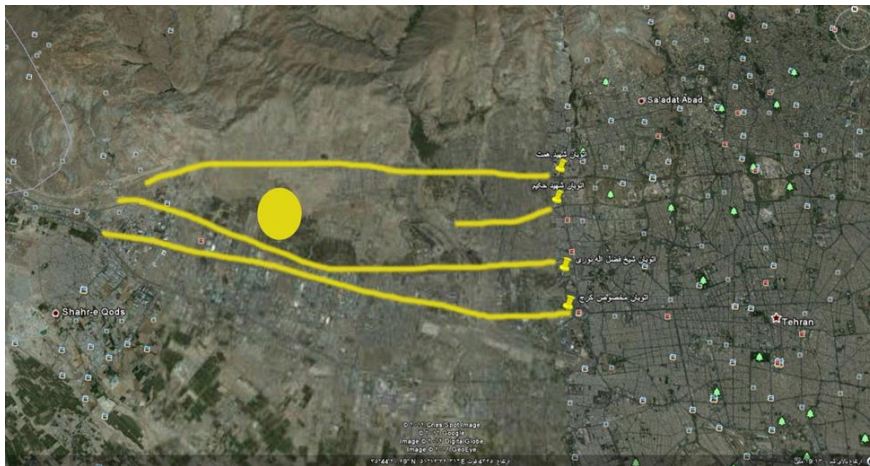


Figure 1: Project location and access (URL12)

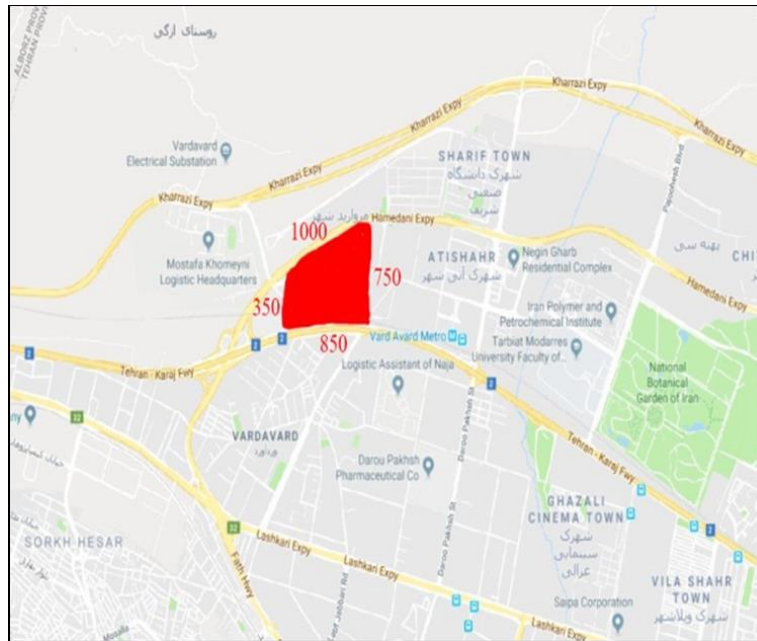


Figure 2: Google Earth aerial maps of the site

The site has a normal slope, with a height increase of 6 meters from south to north over a length of 200 meters.

Method

The research method is based on the review of implemented cases, grounded in the criticism and study of the works of the greats and their conformity with architectural theory and the approach to stylization. Therefore, we aim to compare and contrast modern architecture with the works of the greats of architecture and, on this basis, apply a deductive, integrated method of induction and deduction to the stylization of the structural system in the construction of the complex.

Findings

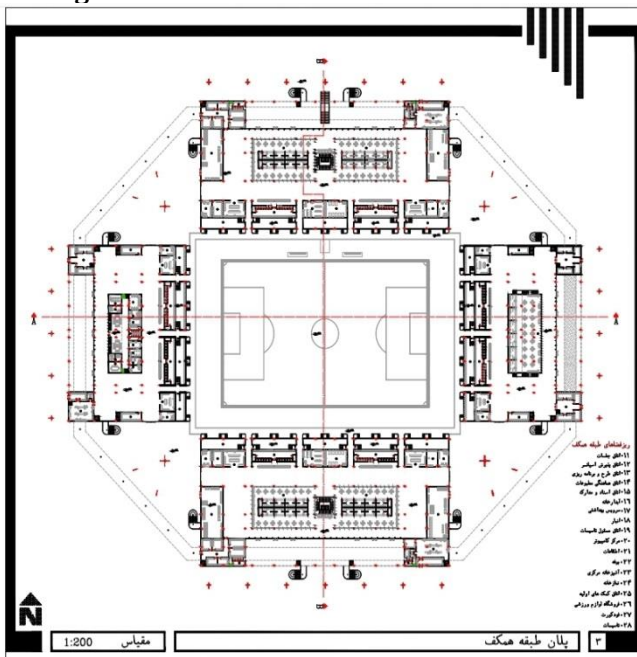


Figure 3: Ground floor plan

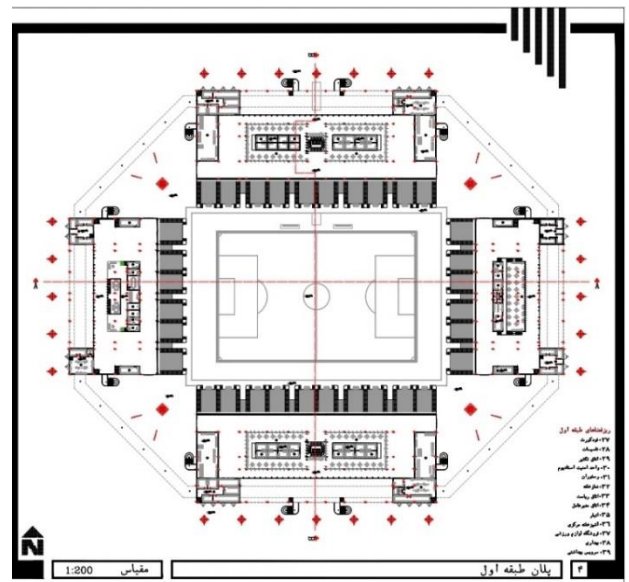


Figure 4: First floor plan

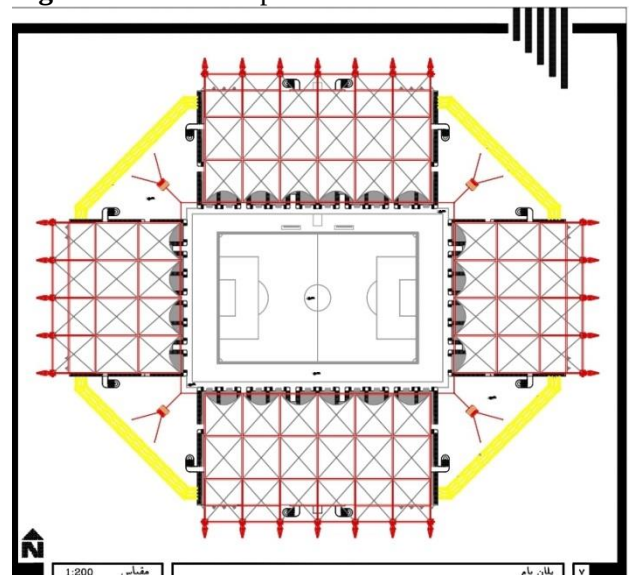


Figure 5: Roof plan

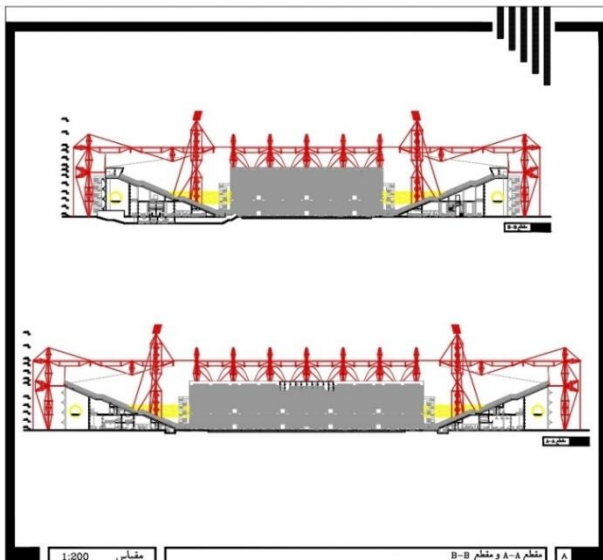


Figure 6: Section 8-8 and Section B-B

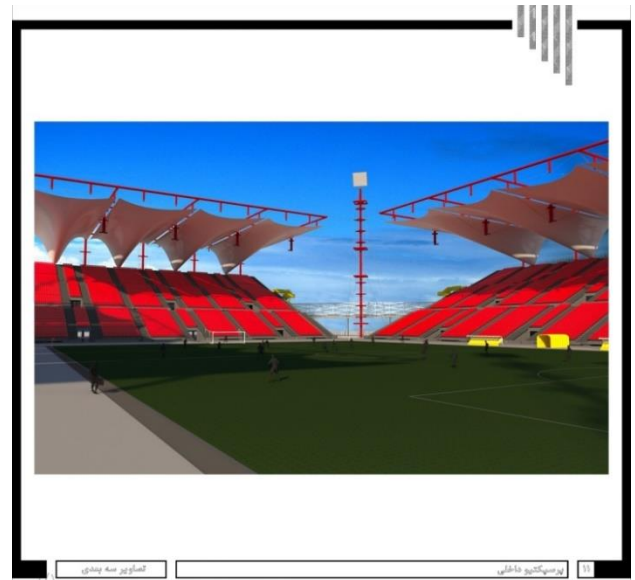


Figure 9: Interior Perspective

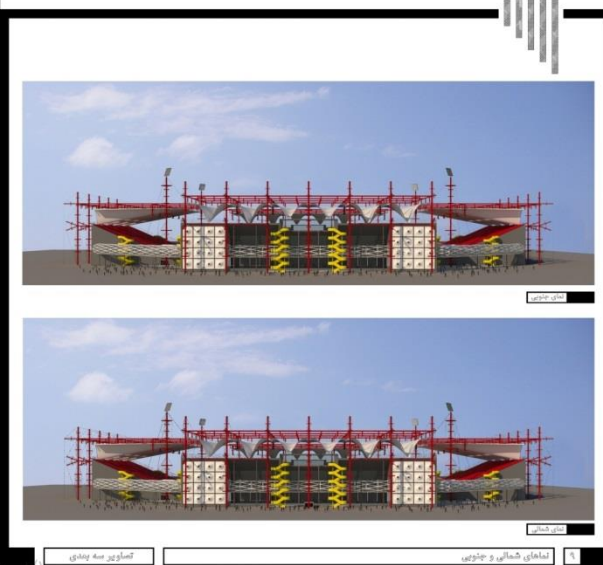


Figure 7: North and South Views

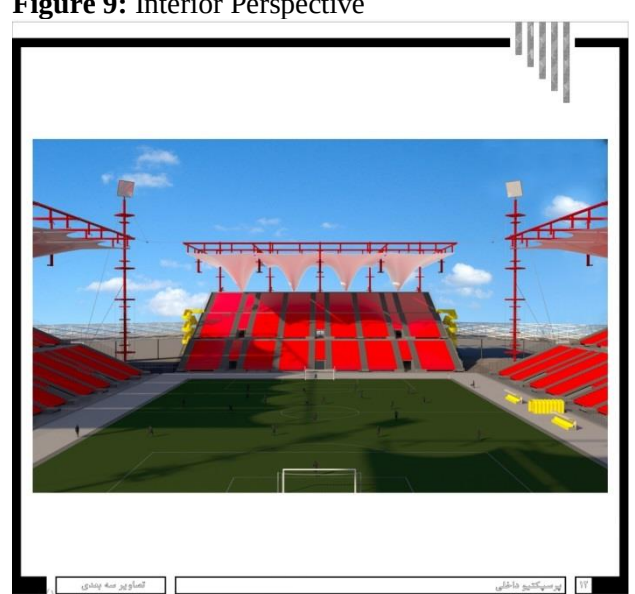


Figure 10: Interior Perspective



Figure 8: East and West Views

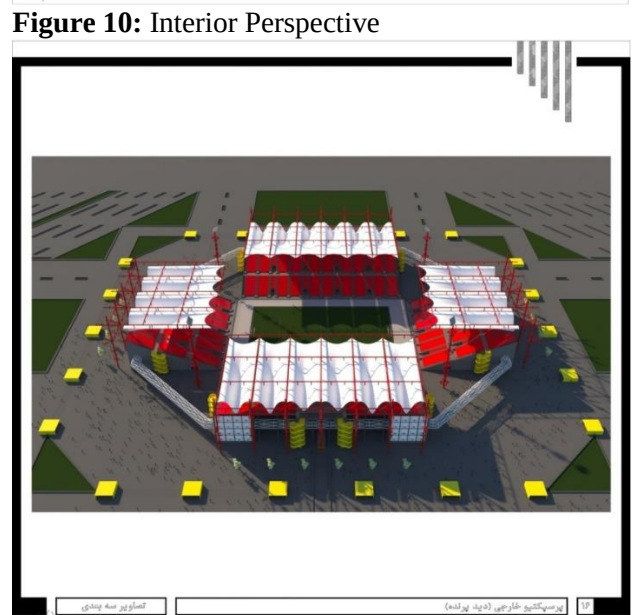


Figure 11: Exterior Perspective (Bird's Eye View)

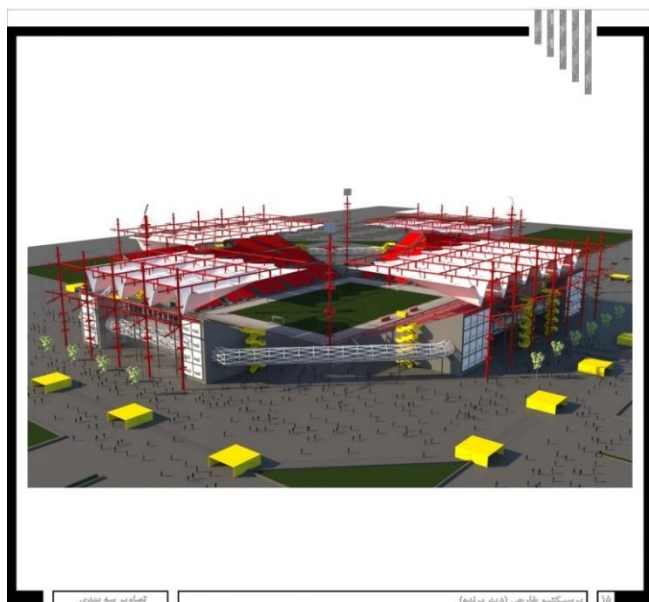


Figure 12: Exterior Perspective (Bird's Eye View)

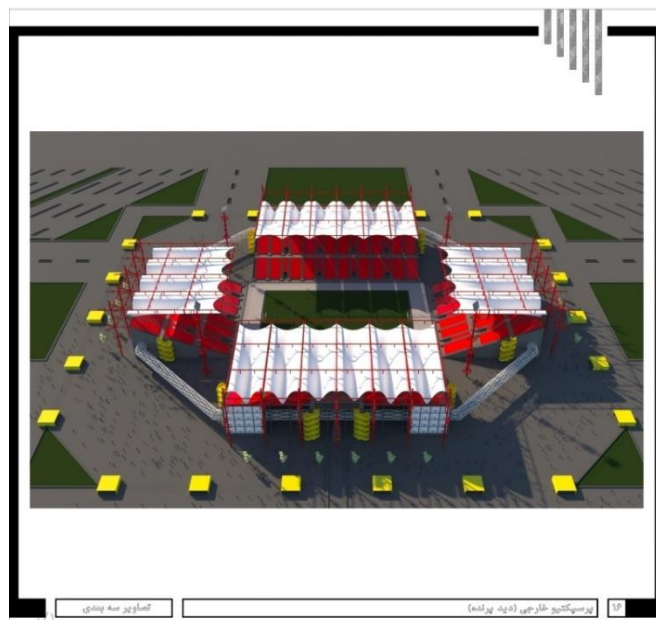


Figure 15: Exterior Perspective (Bird's Eye View)



Figure 13: Exterior Perspective (Bird's Eye View)

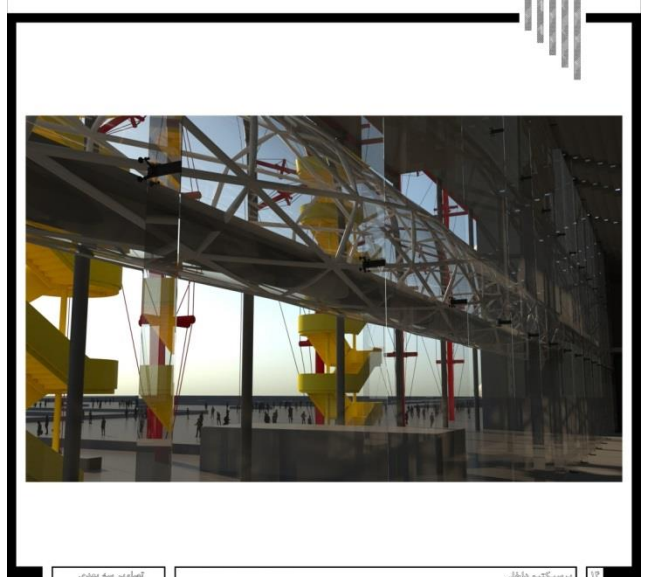


Figure 14: Interior Perspective

Conclusion

The present study aims to design a 40,000-seat football stadium in Tehran using a pneumatic structural system. Studies have shown that today, due to the growth of technology and land elevation, we should use designs that, in addition to reducing the exploitation of underground resources and subsequently reducing and consequently depleting them, move in a direction that minimizes the use of fossil energies and subsequently reducing the speed of resource depletion, as well as reducing environmental pollution caused by the exploitation of these resources, leading to the use of fossil energies and depleting resources. We should also use designs that are up to date and that provide user safety. In stadium structures, due to their high volume and mass, the principles of lightning, modular design, and segmenting the structure should be used to reduce the weight of each module and, consequently, the earthquake forces acting on the building. The reason for using this approach (lightening) is to reduce the building's weight and, consequently, the force exerted by the earthquake on it.

By updating conventional details in traditional architecture, efficient, modern details can be achieved. Modular systems enable faster implementation and lower costs. Also, by using industrial building production systems, implementation costs are reduced, and by using natural ventilation tailored to the country's climate, maintenance costs are significantly reduced. It is also intended that the final form be completely derived from the performance of the complex. Traditional architecture of Iran and the Middle East, such as arches and vaults, as well as elements like windbreaks, can be used in a modern way and in accordance with current technologies.

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