The Impact of using the Pneumatic Structures on the Sustainability of Iraqi Cities During Religious Events

Ammar Kareem Dhumad
Architect, Construction and Projects Department, University of Kerbala, Iraq
E-mail: Ammar.k@uokerbala.edu.iq

Abstract. Pneumatic structures are recyclable structures characterized by adaptability and flexibility. They are an excellent solution for designing structures intended for quick or temporary gatherings. Pneumatic structures are used for sporting, entertainment, military and other events. It is also distinguished by its light weight, ease of installation and disassembly. Also, some cities in Iraq suffer from excessive randomness during religious occasions as a result of creating places of gathering and overnighting in irregular ways and using heavy construction materials that sometimes need digging. This affects the aesthetics of the city and damages the infrastructure. Therefore, the importance of the current research lies in the intent of improving the gathering environment, sustainability of cities, and their appearance during those occasions through the use of pneumatic structures. The study addresses the concept of pneumatic structures and the most important types used to create temporary gathering and accommodation places, in a consistent manner with the nature of the occasion and the environment of Iraqi cities during pilgrimages.

Keywords. Pneumatic structures, Sustainability, Religious events.

1. Introduction

Pneumatic structural systems consist of several components that work together to create a large system. There is a large variety in the types of pneumatic structures that can be designed as well as the vast amount of uses that can be implemented. The first pneumatic structures were invented by Walter Bird in the late 1940s during World War II by the United States Army. They were originally used for emergency shelters and decoys. Later they were most commonly used for temporary radar stations by the army. Nowadays, pneumatic structures are used for sports stadiums, swimming pools, warehouses, and temporary art installations [1]. In 1940, the German engineer (Fritz Leonhardt) wrote the first scientific paper dealing with the need to design lightweight structures due to the difficulty of importing materials in that period. He stressed the importance of the structure being made as light as possible by reducing the total amount of materials involved in the manufacture of structures. He also emphasized the necessity of the structure being resistant to external loads and that the smaller ratio between the weight of the structure and the bearing capacity of the structure indicates the degree of lightness of this structure [2]. The important question is: how can the structure be designed with less material? The answer to this question depends on the progress of materials science and knowledge of structural design. Membrane structures provide options for creating wide shapes and properties such as (Tensile membrane structures, cable-net structures, pneumatic structures, lattice Grid shells, geodesic domes) which are examples of lightweight structures. These structures represent an answer to the question above. Various construction techniques emerged as an alternative to traditional structural
design after the 1950s, due to the development of materials and design methods in this period [3]. Because Iraq suffers from a long period of randomness problem of establishing environmentally and aesthetically unsuitable gathering places at high costs during religious gatherings, which is the research problem, so the importance of research came to find a solution to this problem by employing more sustainable and convenient structures than the current traditional methods. The main objective of this study is to create awareness about the pneumatic structures in Iraq as a modern technology that is economically, environmentally and aesthetically sustainable, in order to benefit from it in festivals and annual visits to holy cities to preserve and sustain cities during these visits.

2. Methodology
The study addresses in its methodology the concept of pneumatic structures and their most important characteristics, what the most important types of pneumatic structures are, how they resist loads, and the most important materials used in the manufacture of membranes for pneumatic structures. Then it presents three applied projects to clarify the mechanism of work of these structures, leading to the conclusions and recommendations of the research. The most important are: pneumatic structures, due to their advantages in terms of resistance, ease of use, appropriate cost and attractive architectural appearance. They are considered one of the most important solutions for the sustainability of Iraqi cities during religious gatherings and events.

3. The concept of pneumatic structures
In the field of human constructions, pneumatic structures are considered modern and did not appear tangibly until the second half of the twentieth century. It has faced difficulty in competing with structures made with traditional materials, such as wood, concrete and stone. The idea of using air to support loads is old, but reliable techniques must be provided for sustainable implementation at the level of the membrane materials. These are the method of linking the different parts of the membrane, the methods and means of construction, as well as the means of pressure. Current achievements highlight the maturity of manufacturing processes. Moreover, the evolution of theoretical knowledge in the different domains (materials, loadings, behavior) as well as in the methods and means of modeling today makes it possible to justify their sizing in a more and more reliable way. It is hoped that recent technical developments will be followed by other innovations in the field, so that pneumatic structures are naturally part of the modern architectural environment [4]. The word Pneumatic is derived from a Greek word (pneuma) which means “breath of air”. So we can simply say that it means, “filled with air” or “anything working due to compressed air”. [5] Pneumatic Structural Systems are structures or buildings that utilize air pressure to ensure its structural integrity. Pneumatic structural systems usually resemble what looks like a bubble or dome to ensure maximum volume for the interior space. Cables are used to make the exterior membrane more rigid and sturdy to resist the loads and anchored to the ground [6]. Air envelope systems are tensioning structures, based on the use of membrane skins, which are stabilized by differential pressure between their outer and inner sides; For the purpose of having sufficient rigidity to maintain equilibrium position and the ability to support external loads [5].

3.1. Advantages of pneumatic structures
The most important advantages of pneumatic structures [5]:

- The construction costs are very appropriate compared to the costs of traditional structures.
- The structure is portable and foldable and can be moved anywhere.
- Very light structures.
- Rapid deployment and erection.
- The materials used in the manufacture of the pneumatic structures from fibers or plastic can be completely recycled.
- It combines structural efficiency by shape, and the inherent tensile strength of a material.
- Availability of large areas due to the absence of columns and bridges.
The structure does not require foundations, so the costs will be reduced due to the absence of excavation.

- Transparent materials are sometimes used to provide natural light during the day while the night lighting system is designed.

- In the pneumatic structures, places are designed to collect rainwater and store it for use in days of shortage.

4. Types of pneumatic structures

The study (A. Sciences, 2019) deals with the mechanism of action of the air-supported structures, where the pressure of the air applied to the surface of the membrane forms a closed area and thus the surface of the membrane acquires an engineering design. If the air pressure on the surface is equal to the atmospheric pressure, the surface of the membrane will be unstable. However, when the air pressure applied to the surface is higher than the atmospheric pressure, tensile stress will be generated on the surface, and due to that stress, the surface of the membrane acquires structural properties that work to resist external loads. The stress distribution on the surface of the membrane depends on the geometry of the shape, where the shape affects the stability of the surface. The study classified the types of air supported structures into:[3]

- **Air-beams**: They are single or two-dimensional carrier elements having a cylindrical shape or derived from it, and require high internal pressure. These beams can be supported by steel cables, and the structure consists of a group of beams stacked side by side.

- **Air Hall**: The membrane surface is installed on the basis of forming the boundary frame, and the stress is gained by air pressure. The membrane surface usually consists of a single layer. The internal pressure is higher than the external air pressure. This pressure difference does not bother the people inside. The doors are arranged so as not to lose internal pressure. The building is being fed regularly by the compressed air supplier unit. It is used in sports, storage, bivouac areas.

- **Cushion**: It consists of two or more layers. The edges of the cushion are fixed to the construction. Surface stresses are transferred to the masonry. It is used as a roof and facade covering element. Air-cushions are the most widely used air membrane structure system.

- **Vacuum**: The pre-stressing on the surface of the membrane is achieved by vacuuming the air inside the pad. Figure (1)

![Figure 1. Basic forms of pneumatically prestressed membrane structures [7].](image)

Sumovski and Lanchester (2005) dealt with the book (Thomas Herzog), in which they classified the various possible forms of pneumatic structures, and we will mention the most important differences that they addressed:[4]

- **Low pressure systems**: In low pressure structures, linear support and support points, often made of cables, can be used to reduce the radius of the bends, which affects the tension in the fabrics. Low-pressure structures can be single or double-membrane, and pneumatic structures are divided into negative and positive pressure structures. Herzog mentioned that the most prominent disadvantages of negative pressure structures are snow and water pockets and shape instability due to aerodynamic loads, but compared to high pressure structures, tubular structures are suitable for some purposes. Table (1)
Table 1. Various forms of low pressure pneumatic structures [4].

| Low pressure system | Single membrane structures |
|---------------------|---------------------------|
|                     | no additional support | additional point support | additional linear support | additional point and linear support |
| negative pressure   | ![Image](image1)          | ![Image](image2)          | ![Image](image3)          | ![Image](image4)          |
| positive pressure   | ![Image](image5)          | ![Image](image6)          | ![Image](image7)          | ![Image](image8)          |

| Double membrane structures |
|---------------------------|
| no additional support | additional point support | additional linear support | additional point and linear support |
| negative pressure       | ![Image](image9)          | ![Image](image10)         | ![Image](image11)          |
| positive pressure       | ![Image](image12)         | ![Image](image13)         | ![Image](image14)          |

- High pressure systems: The high-pressure pneumatic structures have a tube shape, and the air pressure inside the structure increases its rigidity and helps to resist external loads. In order to distinguish between these structures, the following features must be taken into account:
  
  • The pattern of the elements: straight, buckled, arched.
  • The kind of connection of the elements to each other: single element, discontinuous or continuous [6]. Table (2)

Table 2. Various forms of high pressure pneumatic structures [4].

| High pressure system | Single element | discontinuous | continuous |
|----------------------|----------------|---------------|------------|
| straigh              | ![Image](image15) | ![Image](image16) | ![Image](image17) |
| buckled              | ![Image](image18) | ![Image](image19) | ![Image](image20) |
| arched               | ![Image](image21) | ![Image](image22) | ![Image](image23) |

5. Pneumatic structures materials
In 1955, Frei Otto used in his first project a textile material as a membrane, but it could not resist extreme stress and environmental influences. After that, Otto resorted to the use of synthetic materials in his later works. In 1957, he used a membrane made of glassy fabric coated with polyurethane, and it
did not succeed because the membrane was affected by moisture. In the same year he used polyamide in his project in Berlin and it did not resist and began to tear after six weeks of installation. In 1963 Otto used the first PVC coated polyester. This material has become the standard for tensile membrane structures since the 1970s.[7]

5.1. polymers
Polymers are used in the manufacture of membranes. They consist of two parts (mer) meaning unit and (poly) meaning multiple. They are manufactured from repeating the same unit, where each unit consists of a group of molecules or atoms forming a chain. Each unit forms a monomer, and these monomers are transformed into a unified and integrated material through the polymerization process. Polymers are classified into industrial and natural, such as structures found in nature (silk and cellulose), and the chains that make up polymers are divided into straight, branched, or interconnected forms. [3] Given the thermal and mechanical properties of polymers, they are divided into: figure (2)

- Thermoplastics: They are long molecular chains (branching or unbranched). These chains intertwine without a physical connection, as van der Waals forces hold them together. They melt upon exposure to heat, they are sensitive to temperature. Thermoplastics are generally used in the manufacture of membrane structures. [8]
- Elastomers: The are made up of long molecular chains with light cross-links. The geometric shape of the chains is spiral or dashed. The elastic deformation may exceed 200% under tensile load. The shape of the chains changes when exposed to load, but returns to its first shape after the disappearance of the load, and becomes soft with heat, and does not melt. The silicone rubber used to coat the glass film is a synthetic rubber. [9]
- Thermosets: Its chains have three-dimensional shapes (straight or branched) connected by solid crossed links. They are stronger than thermoplastic but fragile, do not soften when heated, and burn at high temperatures. They are produced with a variety of techniques, and ar difficult to recycle. Epoxy is an example of thermosets. [10]. Figure (3)

![Figure 2. Polymeric membrane materials (By researcher about [3]).](image-url)

![Figure 3. Type of polymer chains [8].](image-url)
5.2. Membranes
The materials used in tensile structures are divided into two categories: [3]

- Textile membranes: It is composite materials consisting of a woven membrane that acts as a protective coating or as a load bearing element.
- Film membranes: It is a plastic material made of one layer.

The materials used in the manufacture of membrane structures must have the following characteristics:

*Strength*: Withstand the tensile load of wind and snow loads within acceptable deformation limits.

*Weldability*: Linked with a strong and suitable method to be able to transfer tensile loads.

*Durability*: Resistance to chemicals (acids), biological (fungi), physical (UV), and mechanical (creep) effects.

*Flexibility*: Its ability to resist damage during the manufacturing, transportation and installation process.

*Safety*: It meets safety standards in terms of fire resistance.

6. Applied examples of pneumatic structures

6.1. Ontario’s celebration zone pavilion
It is located in Harbourfront Center, 235 Queens Quay, W, Toronto, ON M5J 2G8, Canada, where the 2015 Olympic Games were held, and designed by architects Doron Meinhard, Mani Tabrizi, with an area of 1200 square meters, the structure was constructed within a week on a simple basis. The structure is 60 meters long and 15 meters high, and the purpose of its construction was to establish areas for eating and drinking and the performance stage. For gravity load, catenary shape was used and for wind load, pneumatic form was built. It accommodates 1,500 people, with venues for cultural exhibitions, concerts, digital media and food services. [11] The shape was created through digital programs for the purpose of reaching the appropriate architectural expression, meeting the requirements of the program, and resisting wind and gravity. As wind resistance is achieved by inflation pressure and height control by surface hardness. Tensile membrane fabric was used in the structure industry, where two types of fire retardant textiles were used, opaque fabric for arches and transparent fabric for cushions to create effects with interior lighting [4], as shown in Figure (4).

![Figure 4. picture for Ontario’s Celebration Zone pavilion [4].](image)
6.2. Inflatable structure for Gaudi Institute
It is a temporary exhibition organized by the Gaudi Institute to promote the 150th anniversary of the construction profession in more than 24 cities, and the design and implementation of this inflatable structure was supervised by Buildair. Used in the year 2002-2003 to host the traveling exhibition, the design was inspired by the work of the engineer Anthony Gaudi in order to highlight the work of this designer. The technology was based on the high pressure tube technology, where 58 tubes were used to cover the structure area of 250 m (28 m long, 12 m wide, 9 m high). [1], [6], [12]. Figure (5)

![Figure 5. Inflatable Structure for Gaudi Institute [6].](image)

6.3. Coolhurst Tennis airhall
Birds Portmouth Russum, London, UK. 2006
Low air pressure used by fans to support the single casing dome, and air is conserved through the doors that make up the airlock. The Airhall covers two tennis courts and is removable as it is inflated during winter to protect from the weather. The Airhall has a sturdy white PVC underframe with a transparent PVC crown to let in light during the day and facilitate light in at night. The structure can be installed and dismantled within two days despite its large size. A network of external cables was used to reinforce and support the body membrane, which are installed on the ground anchors around the perimeter of the structure [13], [14]. Figure (6)

![Figure 6. Coolhurst Tennis Airhall [13].](image)

7. Discussion and conclusions
It is clear from the above and through the study of the pneumatic structures, and their types and the materials used in their manufacture that they are the most appropriate structures to establish temporary places for various occasions. They are suitable in terms of cost, shape, function, easy to install and disassemble and transport. Also, they can be used for long periods and for several years and they can be recycled. The nature of the material used in the manufacture of the pneumatic structures can be chosen in terms of its resistance to fire and environmental conditions in terms of heat, cold, resistance to wind and snow loads. Moreover, transparent materials can be used to take advantage of natural lighting during daylight periods, therefore, these structures are very suitable for use in Iraqi cities during religious occasions. Through the research, it became clear that the pneumatic structures are of many types, but they can be limited to two types; low pressure structures and high pressure structures. Each type is characterized by a set of characteristics. Low pressure structures are used for large areas and can consist of single or double diaphragms, and supporting wires are sometimes used for the
purpose of increasing the resistance, but they need fans for the continuous air support to provide an air pressure slightly higher than the air pressure to maintain their shape and stability. As for the high pressure structures, they are tubular in shape and are either single, or interconnected or continuous, where the air pressure supports the structure in obtaining the required shape and resisting the loads imposed on it. The research recommends the use of pneumatic structures by the concerned government agencies for accommodation and resting places for large areas according to a clear plan and specific places to preserve cities and improve their appearance during seasonal visits. The research also proposes conducting educational and guiding conferences to introduce the importance of pneumatic structures and contracting with international companies to supply quantities of these structures in line with the nature of the Iraqi environment. They could sell them to the Hussaini hospices at moderate prices to eliminate randomness, uniform the appearance of cities, and achieve a comfortable and safe environment for visitors.

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