




Exploring Tension Fabric Structure and Material - Bigo Arena and Denver International Airport as a Case Study

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Article History

Received: 04.06.2024

Revised: 14.07.2024

Accepted: 14.08.2024

Published: 26.08.2024

Communicated by: Dr. Orhan Tug

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Abstract:

The fact that tension fabric structures are light and durable, as well as visually pleasing, has become a reason for preference, especially in contemporary architecture. In this article, in addition to a comprehensive evaluation of stretchable fabric structures, two important stretchable fabric systems, Bigo Arena and Denver International Airport, are used as case studies. By comparing these two case studies, this study pays attention to the differences and properties of the materials while also emphasizing the advantages of the tensile fabric structure. It aims to give ideas to researchers working on this subject by researching the materials and techniques used during construction and examining the possibilities, such as their impact on progress and sustainability in architecture. The Denver International Airport and Bigo Arena serve as prime examples of how membrane systems may be used successfully in architectural projects. While PTFE-coated glass fiber material is preferred in the construction of lightweight structures, it also provides the opportunity to capture solar radiation. Through the projects examined in this research, it is emphasized that fiberglass material coated with PTFE is an example of how interior spaces can be more useful by creating both aesthetic and well-lit spaces. In summary, the case studies demonstrate the successful application of membrane frameworks to achieve functional and aesthetically acceptable goals in architecture.

Keywords: *Bigo Arena; Denver International Airport; Tension Fabric Structures; PTFE-coated Fiberglass; Membrane Structure*

1. Introduction

Modern architecture is defined by a constant and unwavering emphasis on progress and innovative environmentally friendly solutions to meet the various challenges that are faced in the construction and engineering sectors. Recently tension fabric design, a new construction technique has gained popularity among various existing techniques. Tension fabric structures have had a significant impact on modern construction by offering flexibility, cost savings, and environmental benefits [1].

Membrane structures are typically defined as structures that primarily experience tensile forces. The constructions can span large distances due to their specific design and material requirements. Membranes or tensioned fabric systems are slender and pliable surfaces that typically bear weights by generating tensile stresses [2], [3]. They can be either suspended or stretched between posts or supported by air pressure, there are multiple systems that have been implemented for tensioned fabric systems. While adhering to the notion of tension fabric design, each system possesses its own distinct characteristics. These systems can be integrated with one another to generate intriguing and even more intricate designs [4].

The architectural design industry is changing with the use of these materials greater in tensile structures, therefore. These buildings are examples of successful engineering. The harmony of the material's tension and elasticity creates spaces that are both aesthetically pleasing and useful. While this technique enables artistic depiction and contemporary design, it also provides solutions to situations where structural integrity is preserved and environmental problems are addressed [2]. It is becoming more important every day because it provides solution opportunities to these problems. As mentioned before, these structures offer a visually pleasing appearance while also meeting the goal of providing operationally efficient areas [2], [5], [6].

The significance of these structures is shown in multiple areas of enhancement. Tension fabric structures are valued for their inherent qualities and shapes, which offer considerable adaptability for their intended applications. That is the reason why they are favored in diverse architectural endeavors, such as sports facilities and public transportation hubs. They are useful because they are capable of meeting both spatial and functional requirements. According to a cost perspective, they are more economical than conventional constructions. Utilizing lightweight materials in elastic fabric structures decreases the burden on the foundation and support systems. Consequently, it is feasible to construct buildings that are more suited to the environment while being more cost-effective [3].

Tensile structures provide significant durability in architectural solutions. Applying energy-saving techniques and constructing sustainable buildings where natural light is kept at a maximum level and ventilation is optimized are very important steps for our present and future. Located in the Porto Antico district of Genova, Bigo Arena successfully displays its architecture, durable structure, and environmental harmony [4]. This structure in 1992 was built, the building, serving as a public area, distinguishes itself from the surrounding regular buildings due to its exceptional architecture. Additionally, its prime location and commanding view of the city's magnificent harbor make it a focal point of interest for visitors. This feature enables you to observe the image displayed in Figure 1. It successfully integrates cutting-edge architectural design and long-lasting sturdiness, together with diverse management capabilities. These various features made it an exemplary model [3], [4].

DIA, a famous airport in the United States, incorporates tension fabric structures as a fundamental element of its architectural design. These structures make good use of stretchable fabric materials to create a visually appealing and useful effect [5]. Figure 2 shows Denver Airport's distinctive roof and terminal buildings, which have gained a lot of attention lately for their outstanding effectiveness, aesthetically beautiful design, and ecologically friendly attributes. Although tension fabric materials can adapt to various weather conditions, they have garnered significant attention in airport architectural design recently [5], [6].



Figure 1: Notable Architectural Structure of Bigo Arena in Genova, Italy [4]



Figure 2: The DIA Terminal's remarkable roof design [6]

2. Literature Review

2.1 Tension Fabric Structures: Definitions and Characteristics

A tensioned membrane-covered fabric structure that is supported by cables and/or a frame. The fabric used has minimal elongation properties when under tension and can be formed into an anticlastic shape. In the case of fabrics, single flat or curved fabrics are not permitted. Tension textiles are constructions that provide flexible fabrics under tension to support and guarantee safety. These systems are lightweight, highly flexible, and rely on tensile strength for their structural integrity. Typically, those structures include insulation, structural design, and assembly for logo placement. Tension fabric structures are distinguished by their ability to cover extensive surfaces using few structural elements, resulting in distinctive and aesthetically pleasing architectures [2], [7].

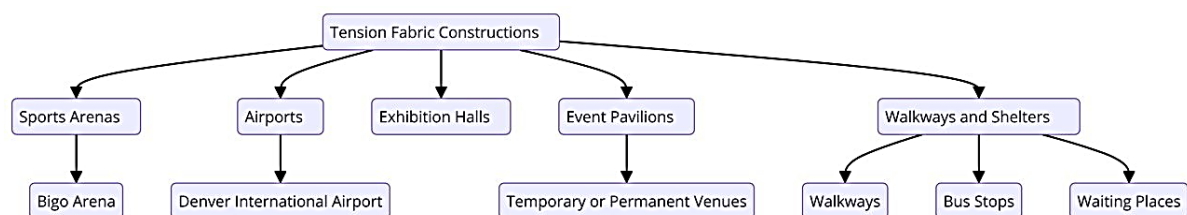
Membrane structures consisting of a thick fabric and a supporting frame may penetrate distances ranging from 3 to 20 m and in extreme cases, may exceed 200 m. When the width of the fabric exceeds 200 m, the fabric is held in place by steel or pneumatic tubing, thus ensuring that the fabric unreinforced width is less than 30 m. Several schemes have been used for reinforced fabric systems. Each design of pressure fabric has its unique characteristics and properties. These systems have the potential to be combined, resulting in more interesting and complex systems [7].

2.2 Historical Development

Tension structures have a historical pedigree that goes back many centuries. Tent-like structures with cloth spread over timber or metal frames were employed by ancient cultures such as the Bedouins [8]. The advancement of tension fabric constructions experienced significant progress throughout the mid-20th century in contemporary society. The architectural form of geodesic domes gained popularity in the 1960s, mostly due to the influential designs of Buckminster Fuller and the pioneering contributions of Frei Otto [9].

2.3 Applications in Modern Architecture

Tension fabric constructions have been widely utilized in contemporary architecture for several purposes, encompassing [9]:



1. *Sports Arenas*: Such as the Bigo Arena, have tension fabric roofs to offer unimpeded sightlines for attendees.
2. *Airports*: Such as Denver International Airport, employ tension fabric structures in the construction of their terminals and passenger shelters.
3. *Exhibition Halls*: Are effectively designed using tension fabric structures, which offer expansive and versatile environments suitable for hosting exhibitions and trade events.
4. *Event Pavilions*: Are versatile event venues that can be either temporary or permanent in nature. These venues are equipped with tension fabric canopies, which serve the purpose of providing protection against severe weather conditions.
5. *Walkways and Shelters*: Walkways, bus stops, and waiting places make use of tension fabric structures to provide shade and protection.

3. Methodology and Material Considerations

Tension fabric systems are dependent on several components, including membrane coatings, support structures, fabric composition, and durability and longevity issues. Every part is essential to the structure's longevity and overall function [10].

3.1 Fabric Materials

The choice of fabric material is vital for tension fabric structures. Factors such as tensile strength, tear resistance, flexibility, and UV stability are critical considerations. Tensile fabric structures prefer utilizing these materials due to a multitude of factors. These materials possess the necessary structural capacity to accommodate such systems and have been utilized for the past five decades, resulting in a wealth of available data on their behavior. These materials have undergone standardization, resulting in increased accessibility and ease of acquisition and design compared to other materials [7], [11]. Common fabric materials include:

1. *Polyester Fabric*: Offers good strength and durability. Since the early 1960s, the predominant preferred fiber for architectural fabrics has been driven by its affordability, commendable mechanical properties, and anticipated longevity. The potential deterioration caused by ultraviolet radiation and the response to fire can be effectively enhanced through the application of a suitable coating [12].
2. *PTFE (Polytetrafluoroethylene) Fabric*: Known for its high resistance to heat and chemicals. The utilization of this material is typically limited to certain projects that necessitate and emphasize its distinctive brightness, primarily due to its significant expenses [12].
3. *ETFE (Ethylene Tetrafluoroethylene) Foil*: Lightweight and translucent, allowing natural light transmission. The tear strength of ETFE film is significantly enhanced by this particular characteristic. The utilization of composite woven foil between the film has the potential to enhance the total tensile strength [7], [12].
4. *PVC (Polyvinyl Chloride) Polyester*: Provides weather resistance and versatility. PVC-coated polyester fabrics have been utilized and subjected to extensive testing since the 1960s. The extensive utilization of this material can be attributed to its affordability, as well as its convenience in terms of handling and it has tensile strength from 350 MPa to 1,200 MPa. Nevertheless, it is worth noting that the life expectancy of these entities is rather short, ranging from 10 to 15 years. Additionally, it is important to acknowledge that there is room for enhancement in terms of fire ratings [7].

3.2 Membrane Coatings

Membrane coatings give fabric materials extra qualities, including dirt resistance, UV protection, and waterproofing, which improves their performance. Among the coating technologies are [13]:

1. *PVDF (Polyvinylidene Fluoride) Coating*: Provides UV stability and weather resistance.
2. *Acrylic Coating*: Offers a range of colors and improves fabric durability.
3. *PTFE Coating*: Offers resistance to environmental factors and non-stick qualities.

3.3 Support Structures

The concept of support structures refers to the various mechanisms or systems that are put in place to provide assistance, stability, and reinforcement to the support framework of tension fabric systems. Including many components such as frames, cables, and other elements, which are crucial for maintaining stability and structural integrity. Commonly utilized materials for support structures include *Steel* which is a material that offers both strength and durability. Aluminum is a material with

the desirable characteristics of lightweight and corrosion resistance. Fibers are strong having tensile properties, which are used to increase the strength of the fabric [7], [8].

3.4 Structural Engineering Challenges

3.4.1 Load-Bearing Analysis

Load-bearing capacity analysis plays an important role in the fabric absorption system. This requires stresses and strains on the structure, where static loads (such as the weight of the structure itself), variable loads (such as occupants or equipment), and environmental factors are important [7], [11]:

1. *Tensile Forces*: A comprehensive analysis of the tensile forces exerted on fabric materials.
2. *Analysis of Support Systems*: An analysis of the load-carrying capacity of the support system.
3. *Finite Element Analysis (FEA)*: demonstrates the use of computer tools for practical purposes
Advanced programming tools.

3.4.2 Wind and Snow Loads

Careful calculation of wind and snow loads is essential when designing deflection curtains, especially in areas prone to strong winds engineers must consider the effects of wind forces and snow accumulation to the structural stability of a system is ensured. An in-depth analysis of wind loads, with particular attention to factors related to wind speed, direction, and turbulence effects. A snow load analysis is an analysis of the effect of the weight of accumulated snow on a structure. The aerodynamic design focuses on creating airtight fabrics [7], [11], [12].

3.5 Sustainability in Tension Fabric Structures

The sustainability aspects of tension fabric structures include the design, construction, and application of these environmentally friendly and low-impact designs. Tension fabric structures, in which tension fabrics are used for roofing or other architectural designs, provide a unique opportunity to incorporate design ideas in a sustainable way. When evaluating the durability of tension fabric constructions, it is important to consider the following key factors [14].

3.5.1 Energy Efficiency

Improving the energy efficiency of tension fabric structures requires an optimized manufacturing process to reduce energy consumption and increase overall performance. Build the concept of construction to increase the use of lunch light knowledge, so the need for light reduces the need for light. Translucent membranes can be used, or openings can be strategically placed to achieve the desired effect. It is advisable to use energy-efficient LED lighting systems in situations that require artificial lighting, as they help reduce energy consumption [10], [11], [14].

3.5.2 Environmental Impact

It means fostering sustainability with tension fabric constructions. To this end, the selection criteria of materials, construction techniques, and use of geography information, play a defining role [11]. To further this cause of sustainability, the selection process of course emphasizes the use of eco-friendly materials. Opting for natural materials with low embodied energy, such as reclaimed or locally sourced materials, of course, is going to bring benefits all around the board bush. When it comes to closed-loop systems, picking materials that are inherently recyclable or have exceptional levels of recycling may be the best way to encourage a newfangled circular economy on purpose. This is helpful in saving new raw materials and contributes towards the reduction of waste. The inclusion of sustainable materials in tension fabrics significantly improves their longevity and biological sustainability [14].

3.5.3 Material Selection

One of the most significant steps to help advance sustainability, namely a selection of eco-friendly materials, also impacts heavily due to the importance of material selection. Your choice of materials can also help you to lower the embodied energy, as recycled or locally sourced materials can have a lower impact. Conscious decision-making of materials that can be recycled or reused multiple times can accelerate the path to a circular economy, reducing the use of virgin raw materials along with the overall waste generation. The reliability and environmental protection of these tension fabric constructions increase from the use of sustainable materials used in them [14].

3.5.4 Construction Practice

Sustainable construction technologies are indicative of measures required to minimize the environmental implications related to the construction process. This is a way of reducing energy and environmental costs by saving the time consumed by on-site construction using prefabrication and modular construction methods. Proper waste management practices, construction waste recycling being one of them, are required to minimize environmental damage. Building in a sustainable way, it does not only aid in environmental conservation but also enhances the efficiency and cost-effectiveness of the construction process [14], [15].

3.5.5 Recyclability and Life Cycle Assessment

Recycling and life cycle analysis (LCA) became two key components that ensured the long life of tension fabrics during the 1990s. Perhaps the most critical factor to consider about the chosen materials for the construction of these is reusability. Selecting materials that are less prone to be recycled at a future moment in life is in line with the principle of circular economy, which aims to reduce the need for fresh raw materials and the production of waste. Tension fabric structures made of recyclable materials contribute significantly to the efficient use of materials and reduce the overall environmental impact [18], [19].

4. Results and Discussion

4.1 Case Study 1: Bigo Arena

Bigo Arena was completed in 1992 and built in Genoa, Italy, by architect Renzo Piano's company. It was designed as a multi-purpose activity area and has a covered open space of 1800 m² in Fig.3. The material used in the membrane structure is PTFE. In addition, steel ropes, belts, and pillars were used to support the system [4]. The symbol of the exhibition is "Bigo", a membrane structure combined with an imaging elevator that offers panoramic views of the port area [18].

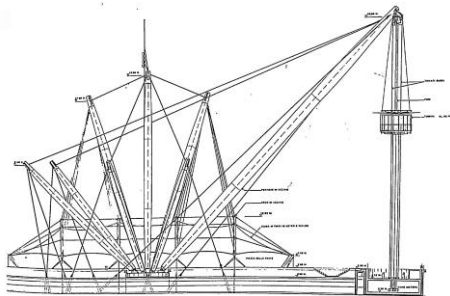


Figure 3: Membrane structure and elevator view of Bigo [18]

4.1.1 Architectural Characteristics

The "Bigo" sculpture, a vessel Vinci-like structure with eight giant pillars, was created by Susumu Shingu, "The Wind of Columbus," at the port entrance Fig. 4. The sculptures, made from a laminate PTFE fabric called 'tenara', react to the wind and can turn into different lights, symbolizing the wind that aided Columbus' voyage to America [18], [19].



Figure 4: General View of Bigo [18]

Large narrow steel bars were prefabricated and then assembled in the field. A group of eight pillars is built on a strong foundation in the port basin. The cables of the four shorter pillars structurally stabilize the four larger ones. One of them carries an elevator, 70 meters long, while the other two carry the roof shown in Fig. 5. The membrane canopy is 60 m long and 40 m wide [4]. The closed area is open in the side walls, and so the walls of the port form a visual background. The semi-square membrane of the PTFE-coated glass fiber provides shade without cutting the lower area. One of the units that created the structure is the circular elevator, which allows a panoramic view of the Genoa landscape. This elevator moves up and down with the help of steel ropes shown in Fig. 6. On a daily basis throughout the year, at regular intervals of 10 minutes, the circular cabin ascends 40 meters in a serene manner, providing an extensive panoramic perspective of the harbor and the city [4], [13].



Figure 5: The interior view of the Bigo [19] Figure 6: Panoramic lift [20]

4.1.2 Construction Features

The maffian pillars are placed on a platform in the view of an island formed in the sea as shown in Fig. 7. The two pillars carrying the membrane system are each 48 m high. The essence of the carrier system of the structure is the presence of supporting elements that ensure that the structure remains in balance, apart from the 4 steel belts each hanging from 8 points with cables to 2 giant pillars.



Figure 7: Pillar Views [20]

In calculating the structural dimensions of the Bigo, particular attention should be paid to wind conditions, as strong storms are frequently seen along the coastline, supported by mountains. The visual lightness of the structure, one of the designer's goals, also played a role in these calculations. The building regulations require that these calculations take account of the profit burden. The last form of the barrier is the result of several wind tunnel tests carried out at the University of Bristol. For this reason, statistically recorded weather data were also considered. The roof reactions in storm conditions have also been simulated [20], [21].

4.2 Case Study 2: Denver International Airport (DIA)

The landside terminal at the DIA, which was constructed in 1993, holds the distinction of being the largest cable-supported roof in the United States up to now. The project shown in Fig. 8. which was conceived by architects W.C. Fentress, J.H. Bradburn & Associates, and engineer Horst Berger, stands as a notable example of very effective fabric structures within the realm of lightweight constructions [22].



Figure 8: Denver International Airport [22]

4.2.1 Architectural Characteristics

The architectural concept of this airport draws inspiration from the geographical features of the Rocky Mountains. Fig. 9 shows the terminal's ceiling is designed with a tensile PTFE membrane structure, resembling adjacent snow-capped mountains. During the periods of sunrise and sunset, the gentle illumination emitted by them becomes apparent. Snow-covered mountains possess a captivating allure.



Figure 9: Roof design of DIA [23]

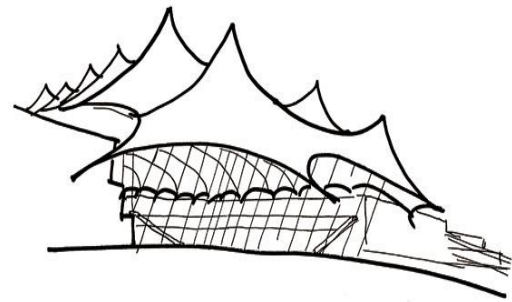


Figure 10: DIA's Concept Sketches [24]

The decision to incorporate a fabric roof into the architectural design of the airport terminal building was made during the latter stages of the design process and upon being engaged in evaluating the preliminary design furnished by Perez & Associates, a renowned architectural firm based in New Orleans, Fentress, and Bradburn embarked on a mission to identify strategies for cost reduction, necessitating a substantial savings of \$40 million [22], [25]. After preliminary consultations with Horst Berger, it was discerned that fabric tent structures could serve two purposes: firstly, as an architectural concept Fig. 10. that connects the primary roof design and the mountainous terrain encompassing Denver, Colorado, and secondly, as a financial efficient design solution.

The architectural structure is meticulously arranged into a series of 17 tent-like modules, strategically positioned at intervals of 60 feet, resulting in an impressive overall length exceeding 1,000 feet. The structural support for the modules is provided by two parallel rows of masts, with a spacing of 150 feet in the shorter dimension of the building. The majority of the masts have a height of 104 feet, with the exception of two sets of four masts each, which reach a height of 125 feet. The installation of taller masts results in the fragmentation and segmentation of the building facade into three equal sections [25].



Figure 11: View of the fabric roof of DIA [26]

The fabric roof membrane is composed of two layers that are separated by 24 inches. The edges of the membrane are enclosed by catenary cables. The primary function of the outer layer is to act as a seamless fabric canopy, extending beyond the two elongated sides of the building through cantilevering. Fig. 11 depicts the dimensions and proportions of the outer membrane canopy. According to Berger and De Paola, the inner membrane serves the purpose of thermal insulation and acoustic absorption shown in Fig. 12. It is connected to the upper section of the inner perimeter walls, which are upheld by a network of cable trusses [25], [26].



Figure 12: Outer membrane tied canopy [27]

4.2.2 Fabric Material

The fabric membrane consists of two layers composed of a Teflon-coat fiberglass material known as "Sheerfill II". This type of architectural membrane is employed as a durable tensioned membrane construction. Within several sectors, including sports, transportation, retail, and specialty markets. The membrane incorporates composite materials comprising fiberglass and polytetrafluoroethylene (PTFE) or its trade name Teflon.

The fabric was coated by Chemfab and subsequently installed by Birdair Inc. It is important to acknowledge that while the cost of fabric material is higher compared to a steel or concrete roof, the overall cost of the structure is still lower due to the significant reduction in the size of supporting elements. Sheerfill II possesses a translucency of approximately 7%, thereby enabling the ingress of ample natural daylight to obviate the need for artificial lighting within the airport terminal. The fabric's notable reflectivity and minimal heat absorption contribute to the mitigation of heat accumulation within the building. These characteristics lead to reduced energy consumption and overall cost savings.

4.2.3 Construction Features

The airport terminal building construction was a linear process starting from the north end and moving south. The process involved the erection of masts, mast top units, fabric installation, and fabric panels. The fabric membrane and interior cable-net system were joined, and the fabric panels were attached to edge catenaries and valley cables shown in Fig. 13. The roof was then pushed down sequentially with hydraulic jacks until the roof stresses reached the specified design values. The construction was fast-paced, requiring approximately \$100 million worth of work each month. The fabric roof was completed in 1993. Fig. 12 provides an interior view of the completed airport terminal.



Figure 13: Interior view of DIA [27]

The fabric membrane roof is upheld by a structural arrangement consisting of cables, ties, and vertical masts. The ridge cables are suspended over the masts and secured to a sturdy supporting structure, as

depicted in Fig. 14. On the other hand, the valley cables are positioned between the ridge cables and fastened to the base perimeter of the building. The primary means of securing the roof are vertical tiedown cables, which are affixed approximately 6 feet from the perimeter wall of the building. The utilization of tiedown cables extends to the application of stress on the fabric after its installation.

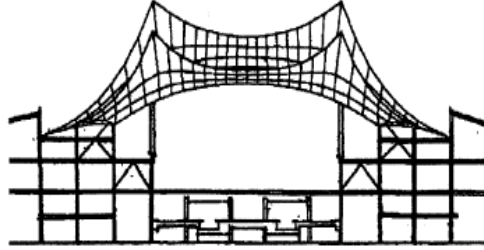


Figure 14: Elevation view of DIA [27]

The issue of ensuring the security of this complex system, which includes edge cables, internal cable nets, and valley cables, presented considerable difficulties. The concept recommended employing octopus-shaped connectors with eight sides to ease the connection of many cables emanating from various directions. The hydraulic jacks located above the octopus connectors apply downward force to generate strain in the valley cables, resulting in the distribution of stresses across the entire membrane structure.

As a conclusion, to reach the sustainable development in tension fabric structures, a good design is essential. It involves the careful choice of materials, well-conceived buildings, and an understanding of the kind of real estate that should be built. Table 1 is the Bigo Arena and DIA project summary, architectural/aesthetic importance, material selection/design, construction issues, and sustainability features.

Table 1: Comparative Analysis of Tension Fabric Structure Characteristics of Bigo Arena and DIA

Characteristics	Bigo Arena	Denver International Airport (DIA)
1. Project Overview	The Bigo building is a notable architectural feature of Genoa's historic shoreline. The building was designed by Renzo Piano in 1992 [15]. Bigo Arena is in the vibrant downtown area and is well-known as a major sports and entertainment venue. It hosts many sporting events, concerts, exhibitions, and other events, and has significant seating. The main feature of this theater is its spaciousness. Solid fabric ceiling, making the visitors feel open and comfortable [4].	DIA, which opened in 1995, was designed by Fentress and Bradburn Architects. In 2020, DIA celebrated its 25 th honorary anniversary. In 2024, It was the 6 th busiest airport in the world according to yearly passenger traffic among the top 10 busiest airports worldwide [16]. The main terminal of the airport is spacious and contains check-in areas, airline check-in, and security screening. The most prominent feature tension fabric structure, crafted by DIA, plays a vital role in the airport's architecture, providing essential weather protection and enhancing its visual aesthetics [17].

2. Architectural and Aesthetic Significance	The architectural design of the Bigo Arena is distinguished by its captivating and magnificent features. The tension fabric roof improves the overall visitor experience by facilitating the entry of natural direct sunlight and generating a feeling of expansiveness. The decoration of the arena is in keeping with the modern architectural style combining aesthetics and practicality.	DIA emphasizes impressive tension cloth canopy. This is a co-architectural decision that has practical value as well as artistic one. Furthermore, it enhances the passenger experience with an intended wow moment and protects against inclement weather. Just beneath the hotel has a charming airport area for convenient dropping off and picking up of passengers, as well as meeting [17], [24], [25].
3. Material Selection and Considerations	At Bigo Arena, this is what the selection of the materials translated into to ensure long-lasting durability and performance of the tension fabric roof. The membrane fabrics are selected to cope with the toughest weather conditions and to block damaging UV rays. They are typically coated with materials such as PTFE or PVC over polyester. Thus, it is considered depending on reviewing the fire resistance and maintenance requirements [4].	DIA tension structure is constructed of long-lasting fabrics that are chosen to meet the specifications exactly. Usually, this material is a high-resistant fabric, often coated with Polyethylene or Vinyl Chloride (PVC) to provide additional weather protection. Materials of such kind generally have a reputation for impact resistance and longevity. It makes the support system much more durable since the fabric uses tensile forces. and safety [24].
4. Structural Engineering Challenges	A detailed design and engineering process of the tension fabric roof for Bigo Arena designed to meet the criteria of integrity and stability and required load carrying. Design forces, wind, snow, dynamics, load is such that there is no damage, and fabric membrane can stay barely stretched and this is the job of structural engineers [19], [20].	The DIA stress management system requires many challenging technical decisions. The building must be able to withstand large loads due to weather conditions such as snow, strong winds, and changes in temperature. Structural engineers were responsible for ensuring that the fabric could carry its weight and withstand changes from external forces. The packaging devices and supporting systems were carefully designed to overcome these limitations and preserve optimal aesthetics [24], [25].
5. Sustainability Aspects	Working in the arena is sustainable from the perspective of materials, energy sources cutbacks, natural sunlight, and crop collection practices. This is a great way to lower the carbon footprint of a building and with a constant push on sustainable design this will start to become common practice [18], [19].	The tension fabric structure is structured in a way that allows the cloth to let light in, which in turn allows for more daylight environmental control instead of relying on the use of an electricity supply. The choice of materials and coatings also considers the environmental impact, meaning that sustainable solutions are chosen. This tension-fabric canopy located at the passenger drop-off and pickup could be used to provide solar shading and thermal control to the space and, with a high probability, significantly

		reduce the heating/cooling load income [25].
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5. Conclusion

The purpose of this article is to examine the various tensile designs and materials used. Two examples were selected, the Bigo Arena and the Denver International Airport, these projects allowed for a closer examination of the materials and a deeper understanding of such materials. Denver International Airport and Bigo Arena case studies illustrate the successful application of innovative membrane systems in large-scale construction projects in the 1990s. Denver International Airport's cable-stayed fabric displays a well-demonstrated combination of design, cost-effective techniques, and practical design. The use of Teflon-coated fiberglass material, which is the most sustainable material in the textile and construction industry, serves two purposes: allowing natural daylight penetration and reducing energy consumption. It also highlights some of the importance of careful material selection. The effectiveness of the chosen design and construction method is evident in the precise layout of the building and the timely reception of the roof section. Effect of PTFE-coated fiberglass fabric showing remarkable versatility and flexibility on long-term membrane frameworks manufactured at the Bigo Arena in Genoa, Italy the design concept emphasizes the importance of lightweight construction, the flexibility of the material, and the durability of the material in areas frequently exposed to strong winds. The study highlights the potential of using PTFE-coated fiberglass to improve interior aesthetics. It highlights the unique characteristics of this material, enhancing the creation of beautiful and well-lit environments. In summary, the presented case studies demonstrate the successful application of membrane frameworks to achieve functional and aesthetically acceptable goals in architecture.

6. Recommendation

To advance the field of tension fabric structures, future research efforts should focus on enhancing material technologies, optimizing structural analysis tools, and exploring ecologically sustainable options for fabric structures. Furthermore, the implementation of specific regulations and legislation for tension fabric constructions can improve construction procedures by encouraging safety protocols and operational effectiveness.

7. Conflict of Interest

There is no conflict of interest for this paper.

8. Author's Contribution

We confirm that all named authors have read and approved the manuscript. We also confirm that each author has the same contribution to the paper. We further confirm that all authors have approved the order of authors listed in the manuscript.

References

- [1] Soto-Rubio M & Michalski A. Tensile membrane structures and the education of the architect. In Proceedings of IASS Annual Symposia 2016. International Association for Shell and Spatial Structures (IASS). 2016 Sep 26;(21):1-10.
- [2] Bridgens BN, Gosling PD, Birchall MJ. Tensile fabric structures: concepts, practice & developments. Structural Engineer. 2004 Jul 20;82(14):21-7.
- [3] Vural Y. Tensile Membrane Structures: Form, Material and Design. Master's thesis. Anhalt University of Applied Science. 2019. <http://dx.doi.org/10.25673/36270>

-
- [4] Ishii K, editor. Membrane designs and structures in the world. 新建築社. New Architecture Society. 1999:92-94.
- [5] Szyliowicz JS, Goetz AR. Getting realistic about megaproject planning: The case of the new Denver International Airport. Policy Sciences. 1995 Nov;28(4):347-67.
- [6] Huntington CG. Exploring the Ideals and Character of Structural Elegance. In Proceedings of IASS Annual Symposia. International Association for Shell and Spatial Structures (IASS). 2019 Oct 7;(28):1-8. ISSN 1028-365X
- [7] Son ME. The design and analysis of tension fabric structures. Doctoral dissertation, Massachusetts Institute of Technology. 2007.
- [8] Llorens J, editor. Fabric structures in architecture. Elsevier; 2015 Mar 28. ISBN 978-1-78242-240-2. <http://store.elsevier.com>
- [9] Markofski L. Tensile fabric structures: The influence of technology on temporary traditions. State University of New York at Buffalo. Master's thesis. 2006.
- [10] Houtman R. Materials used for architectural fabric structures. In Fabric Structures in Architecture. Woodhead Publishing. 2015 Jan 1:101-121. <https://doi.org/10.1016/B978-1-78242-233-4.00003-6>
- [11] ELNokaly A, Chilton J, Wilson R. Environmental aspects of tensile membrane enclosed spaces. Lightweight structures in civil engineering. School of the built environment, university of Nottingham, United Kingdom. 2002:903-909. <https://core.ac.uk/reader/17353406>
- [12] Tolani A, Vadalkar V, Patil A, Patil G. Project report on applications on tensile structures. BSc. Thesis. Mumbai: Datta Meghe College of Engineering Airoli, University of Mumbai. 2015.
- [13] Bögner-Balz H, Blum R, Köhnlein J. Structural behaviour of fabrics and coatings for architectural fabric structures. In Fabric structures in architecture. Woodhead Publishing. 2015 Jan 1:123-157. <https://doi.org/10.1016/B978-1-78242-233-4.00004-8>
- [14] Martin N. The Sustainability of tensile fabric structures, sustainable canopies. ArcCan shaded structures. 2021 Sep 13. <https://www.arccan.com>
- [15] Casanova M, Acacia S, Musso SF, Traverso S, Rottura F, Olivieri C. Contemporary architecture in Genoa since 1945 - knowledge and use through geoservices for the citizen. Sustainability. 2022 May 25;14(11):6471. <https://doi.org/10.3390/su14116471>
- [16] Bovenizer N. The top 10 busiest airports in the world. 2024 Mar 13. <https://www.airport-technology.com/features/the-top-10-busiest-airports-in-the-world/>
- [17] Roy AS. The winged city. Creation of a cultural hub in Incheon, South Korea, 2014. <https://www.academia.com>
- [18] Koch KM, Habermann KJ. Membrane structures: innovative building with film and fabric. Prestel. 2004. ISBN 3791330497
- [19] Tian D. Membrane materials and membrane structures in architecture. The degree of master of architectural design. The University of Sheffield. School of Architecture. 2011 Sep. <https://www.academia.com>
- [20] Genova. BIGO- Panoramic Lift. www.acquariodigenova.it/bigo-panoramic
- [21] Topping BH, Iványi P. Computer aided design of cable membrane structures. Saxe-Coburg Publications; 2008 Jan 1. <https://dl.acm.org/doi/abs/10.5555/1571808>
- [22] Noel TJ. Denver international airport roof. 2020 Sep 14. <https://coloradoencyclopedia.org/article/denver-international-airport>
-

-
- [23] Wikipedia. The free encyclopedia. Denver International Airport. https://en.wikipedia.org/wiki/Denver_International_Airport
- [24] Fentress A. Denver International Airport. A Truly Revolutionary Design. Colorado, United States. 2010. <https://www.architonic.com/en/project/fentress-architects-denver-international-airport/5100647>
- [25] Berger H. Creating architecture with tensile membrane structures. International Journal of Structural Engineers World Congress (SEWC). 2013 Aug;3(1):3-10. ISSN:2249-183x
- [26] Berger H, De Paola EM. Tensile terminal. Civil engineering. 1992;62(11):40-3. ISSN: 0885-7024
- [27] Birdair. Denver Int'l Airport. <https://www.birdair.com/>. <https://www.birdair.com/birdair-portfolio/denver-international-airport/>
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