TENSILE MEMBRANE STRUCTURES IN PUBLIC SPACES / CASE STUDY

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ABSTRACT

This paper will present possibilities, in the implementation of tensile membrane structures in public spaces and urban environments, as well as experience of existing projects. The special target is a case study analysis of two characteristic projects.

Tensile membrane structures are one of the youngest technologies and represent one of the most attractive and high-tech architecture advances. However, this is still a developing industry with a lot of innovative solutions coming up every year. As such, it offers a wide range of possibilities and effective solutions for architectural structures. Facilities of different uses like airports, stadiums, sports, and industrial facilities are just some of the possible applications. This paper will present the advantages and possibilities of such technology with special focus on its application in public urban spaces. As an attractive and up-rising architectural approach, more and more such applications can be seen in cities and public spaces. Among others, two in particular are interesting to analyse. Both are situated in the city of Belgrade. The first is a huge canopy covering a pedestrian area in the business district-Airport City, and the second one is the marketplace Cvetkova pijaca. The analysis will explain the design, production, and installation process, but more importantly, the experience regarding five years lifetime after the installation. By the comprehensive monitoring and observation of this membrane structure, a whole quantity of information has been documented since its completion. This can be seen as a significant knowledge base, which will be beneficial for the future development and application of advanced projects in the twenty years of ArTech company experience.

KEYWORDS _ *public spaces, tensile membrane, lightweight*

INTRODUCTION

Urban public spaces have always been a challenge for the architectural and urban planning disciplines, seeking ways to transform them in order to create spaces that meet user needs and provide high levels of physical comfort. One of the effective methods for achieving this is the utilization of tensile membrane structures (TMS). The paper will address various aspects of applying TMS in public spaces and will focus on aesthetics, functionality, and sustainability, with a review of practical examples. The application of TMS will be analysed through two case studies: Zvezdara Market *Cvetkova pijaca* and Airport City, public spaces in Belgrade where TMS has been implemented for functional and aesthetic reasons.

THE CONCEPT OF "TENSILE MEMBRANE STRUCTURES"

Tensile membrane structures follow the concept of lightweight structures. Thanks to their characteristics, they rapidly find a place in the world of architecture, in various structures and uses. In addition, it can be recognized as Textile Architecture, the tensile structures. Mechanical nature of membrane structures is that they are light, and very low self-weight compared to traditional building technologies. Despite that, they are capable of bearing a variety of loads, similar to any other construction, and that makes them applicable in any climate zone or use. Further, membrane structures are a type of object consisting of membrane material that is stretched or tensioned and combined with compressed structural elements, thus forming the designed shape. Pretensioning can be mechanical or pneumatic. Therefore, we can find TMS in those two appearances, as it is family but very different. Such tensioned membranes are capable of withstanding heavy loads from snow and wind, with reduced need for supporting elements, thereby achieving significant possibilities in design and shaping, including the formation of complex geometric forms. Applied materials could be composite membranes or foils (PVC-PES, Glass-PTFE, Silicon-glass or ETFE, PVC foils...etc.)

All mentioned materials are polymeric. They are characterized by high resistance to moisture, UV radiation, and chemical agents. Furthermore, one of the most important characteristics is the transmission of natural daylight, which contributes to creating shaded, protected, pleasant environments under the structures.

THE APPLICATION OF TENSILE MEMBRANE STRUCTURES IN PUBLIC SPACES

The application of TMS is highly prevalent in public spaces. The reasons for this include efficiency in protection against adverse weather conditions, flexibility in design, extensive coverage possibilities, very good sound effects, high transparency to natural light, strong fire resistance, low specific weight, favourable ecological and economic aspects, and extremely attractive appearances.

The efficiency is reflected in the fact that the PVC membranes used in TMS are waterproof and UV-resistant, creating a favourable microclimate within the covered spaces. TMS contribute to lowering the temperature in the covered area, eliminating UV transmission, and with well-planned positioning, they promote good ventilation, thereby eliminating unfavourable air currents or the retention of warm air. This is evident from the widespread application of TMS in extremely hot climatic zones

An advantage of TMS is its flexibility in design. The material can be easily shaped into desired geometric forms, providing possibilities for designing a wide range of structures, from simple to the most complex. This enables the enhancement of aesthetics in various spaces, regardless of their shape and dimensions. An additional benefit is the integration of lighting and sound effects into the structures, further enriching the spatial experience. Membrane materials also possess excellent characteristics in terms of sound reverberation and a high level of fire resistance, which is crucial for their application in public spaces with a large number of users.

The ecological advantage of this technology results in reduced energy consumption and decreased pollution during construction, as there is minimal heavy construction work and less construction waste generated. Additionally, membrane materials are recyclable and can be reused, contributing to sustainable architecture.

The favourable economic aspects pertain to the cost of TMS compared to more traditional constructions. Due to their lightweight nature, TMS can be installed on existing structures without significantly affecting their stability. This means that the amount of heavy construction work (earthwork, concrete work, structural steel work) is minimized, leading to a lower investment cost. The time required for construction work is a significant argument in favour of using TMS in public spaces. The rapid installation of TMS and minimal construction work imply that the urban space under construction can be put to use in a very short time, Application of membrane structures in public spaces is known and used widely. Therefore, we can find examples all around the world in areas with new contemporary architecture as well as in traditional, historical environments.

CASE STUDY: ZVEZDARA (CVETKO) MARKET

Location

Zvezdara Market is one of the oldest and most well-known markets in Belgrade. Situated adjacent to one of the longest and most significant transportation routes in Belgrade. Zvezdara Market stands as a prominent landmark not only within the local community but also at the city level. It holds substantial sociological importance as a gathering spot for people and a hub for information exchange.

Before the reconstruction, the market stalls were located in an open (uncovered) area surrounding commercial facilities. One of these buildings divided the market area into two areas - a larger one with approximate dimensions of 57 x 35 meters, accommodating stalls for fruits and vegetables, and a smaller one measuring 11 x 38 meters, accommodating stalls with assorted merchandise.

Identification of Location Issues and Investor Requirements

The most significant issue identified at Zvezdara Market is the challenge posed by unfavourable climatic conditions. This issue is not seasonal but rather persists throughout the entire year, negatively impacting footfall and consequently affecting the market's economic viability.

The term "unfavourable climatic conditions" encompasses snowfall, rain, exposure to wind, and solar radiation. These adverse climate factors primarily affect the market's tenants who spend the most time on the premises, the goods being sold, and the visitors/buyers.

The investor is required to ensure adequate protection of the space's users from adverse climatic conditions while maintaining the location's identity. Another demand was that the planned structure be modular and demountable and that the construction work be executed within a short time frame and in phases, allowing a portion of the market to remain functional during the construction period.

Space Covering with TMS

The project envisions covering the market space with a canopy composed of so-called "Gazebo modules." The term "Gazebo module" refers to a modular canopy measuring 5x5 meters and with a height of 6 meters at the lower part and 8 meters at the higher part. The canopy has a funnel-shaped design. Inverse multi-cone structure. The primary structure is made of steel profiles, while the covering consists of a PVC membrane.

The Plato will be covered using a multiplication of Gazebo modules, grouping a maximum of four

modules into a single unit with dimensions of 10x10 meters. These grouped units share a common supporting structure (grid-like columns), which on the ground level forms a matrix with dimensions of 10x10 meters.

This approach minimizes the number of columns while maximizing the coverage of space.

The entire structure is seamlessly integrated into the surroundings, thanks to its non-dominant dimensions and the minimal number of structural elements, all in a neutral white colour. This design approach enhances the aesthetic aspect of the entire space, ensuring a harmonious blend with the environment.

Addressing the Issue of Unfavourable Climatic Effects

The challenges posed by adverse weather conditions on the market platform are prevalent throughout the year and include snowfall, rain, wind, and solar radiation.

The PVC membrane is designed to withstand the weight of a snow cover. Thanks to the funnel-shaped structure, snow accumulates in the center (within the grid column space, beneath the metal lining). The structure provides protection from rainwater (as well as snowmelt) due to its funnel-shaped design, directing water towards the base of the columns and into the rainwater drainage system. The column cladding prevents water from spreading across the market platform. Protection from the sun is facilitated by the material characteristics of the PVC membrane, which allows natural light to pass through while blocking UV radiation, thereby preventing the platform from overheating. An additional planned effect is vertical and horizontal air circulation. This circulation is carefully planned, and controlled and finally forms additional benefit to the ambient under structure.

The process of constructing the canopy-phased construction.

The project facilitated the phased execution of all structural components, including foundations, electrical installations, and rainwater drainage. Simultaneously, another section of the market platform remained operational. This was primarily achieved due to the structural design that enabled each module to stand independently, eliminating the need for interconnections with neighboring modules.

This provides the opportunity for successful construction site organization, involving zoning different areas for various activities. The construction period lasted a total of 3 months, spanning in winter time!

Experiences

In terms of aesthetics and functionality, the structure completely met the Investor's requirements and the needs of the space users. The space's aesthetics were improved while maintaining and enhancing its identity, as the structure contributed to highlighting the market within its surrounding context. After the market's reopening, a smaller number of vendors initially expressed concerns that the structure's columns might obstruct visibility to customers and impact sales, which proved to be inaccurate.

Users' feedback indicates that the working conditions are much more than satisfactory.

After the market's reopening, a higher number of customers was observed, and due to the creation of a pleasant microclimate beneath the canopy, customers tended to spend more time within the market area. This had a positive impact on sales, as well as on fostering increased social interactions. This positive trend persisted even after a considerable period following the canopy's construction.


Figures 1-2: Zvezdara "Cvetko" Market

CASE STUDY - MEMBRANE STRUCTURE "AIRPORT CITY"

Introduction & background & focus

In 2018. *Airport City office park* in Belgrade, Serbia, and their client at the time, *Telenor*, a mobile network operator company, commissioned the construction of a permanent awning structure above a pedestrian area situated between office building blocks.

Airport City, Belgrade stands as the first multi-use commercial facility in Serbia, comprising a collection of standalone office buildings, interconnected walking corridors, and open plazas, creating a distinct "City within a City" environment.

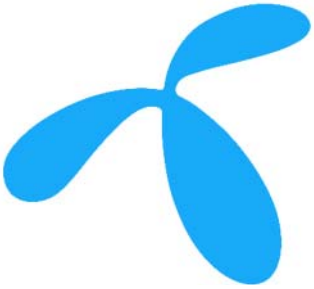
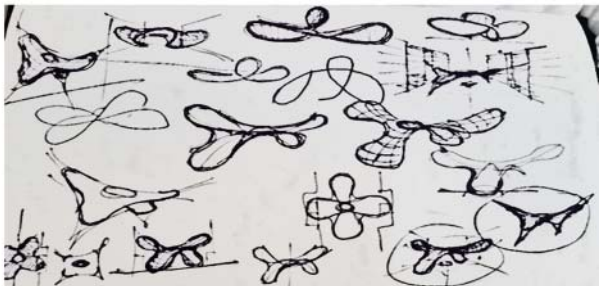



Figure 3 (left): Clien't logo; **Figure 4 (right):** two-dimensional sketches

Telenor occupied two office towers that faced each other. Their primary objective was to create coverage between these two buildings, establishing a sheltered and dry connection. This new canopy would seamlessly integrate into the existing architectural landscape, characterized by contemporary office building blocks covered with curtain-wall glass facades. These structures were uniformly cube-shaped, following an orthogonal arrangement that defined the layout of the office park. The challenge was to design a new structure that could stand out as a prominent landmark while minimally disrupting the existing urban block. Overcoming obstacles such as urban furniture, flora, underground installations, and curtain wall facades was imperative for the success of this project. The project's design had to navigate various technical limitations posed by these considerations. Throughout this process, the structure's overall form took inspiration from the client's desire for a shape reminiscent of their logo.

Design process - Conceptual design

Given the aforementioned design parameters and limitations, the concept design phase emerged as the project's most critical juncture, presenting a substantial challenge in devising a solution that could satisfactorily address all specified criteria.

The first stage of design was an iterative process that implied the client's preferences and personal insights garnered from past experiences. By filtering the two-dimensional sketches, the definitive structure configuration emerged – a hyperbolic paraboloid (hyper). Geometrically most pure tensile forms, are distinguished by simplicity, where the shape is entirely governed by force systems.

Concealed within this design lay an underlying concept - to underscore the corporate identity and significance of the primary user. Thus, a deliberate choice was made to mirror the resemblance to the client's logo, enabling easy recognition. The resultant composition adopted curvilinear spatial lines and a flowerlike shape.

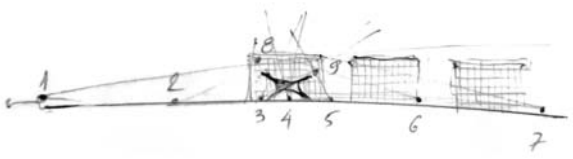
Final design proposal & manufacture & installation

In the second stage of design - a holistic approach had to be implemented. The broader context needed to be taken into account in order to shape the design's trajectory from its initial concept to its ultimate realization. It is important to stress that all stages of design are inherently interdependent and are not linear.

Two-dimensional sketches

The conclusive design proposal introduced a solution that involved a 45-degree rotation of the structure around its central axis, resulting in a symmetrical and diagonally oriented arrangement, which provided a clear corridor. From an architectural perspective, this positioning was strategically chosen to offer visitors a comprehensive vantage point, allowing them to observe the structure from various angles and fully appreciate its form. Simultaneously, this "twist" introduced a disruption to the otherwise orderly orthogonal matrix, injecting an element of unexpected visual dynamism into the environment.

By being in the open piazza, the structure's multiple facets are revealed through a sequence of perspectives: visible from a distance, gradually as one approaches, experienced from beneath while passing beneath it, and retained in one's vision as they continue in the same direction. The visual dimension of urban design or the visual aesthetic was important since the canopy was beheld as a public, art form for observers to experience. The provided sketches display significant observation points (Fig.5. and Fig. 6.) within the project. These points strategically engage with the urban context, offering a diverse range of perspectives.



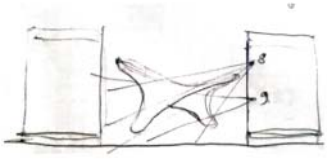


Figure 5 (left): perception analysis sketch-longitudinal; **Figure 6 (right):** perception analysis sketch-vertical

Architectural environment

Despite being supported by only four support points, the physical interaction with the architectural environment was challenging. The scheme involved attaching two high points to the office buildings and two low points directly to the ground.

The placement of lower anchor points required meticulous consideration to ensure that key pedestrian pathways remained unobstructed, including the transversal route connecting the entrances of the two buildings. A seamless integration was pivotal, hence these anchor points had to blend in as urban

furniture that would not interfere with the flow of movement. To achieve this, the low support points were nestled within green spaces, with their foundations concealed beneath the piazza's surface. Apart from ensuring structural stability, this approach harmonized the design with its environment, maintaining a balance between functionality and aesthetics.

Form-finding, structural analysis, and materialization

Being a permanent structure, the canopy needed to be considered as a sustainable structure that is temporary enough not to be in man's way. With a substantial span of 28 meters and an approximate coverage area of 487 square meters, withstanding all internal and external loads, the structure called for special attention.

Through advanced computational techniques and finite element analysis engines, it was possible to simulate various load scenarios, ranging from external wind and snow loads to prestressing of the membrane. This rigorous analysis guaranteed that the design would not only full fill functional requirements but also withstand the test of time, safeguarding its longevity and reliability.

As a part of the form-finding process, the hyper shape was further advanced through the incorporation of a central round opening, measuring 2 meters in diameter. This served the purpose of facilitating the drainage of excess atmospheric water resulting from rain and snow. Furthermore, this design choice minimized the impact of external load, which reduced the necessity for secondary elements to be as massive.

Figures 7-8: Airport City canopy

Physical comfort in open public space

Overall, creating a comfortable environment within the membrane structure requires an approach that balances the functional, aesthetic, and technical aspects of architecture. Factors like climate, lighting, and structural integrity needed to be considered to provide occupants with an enjoyable and safe experience. Striking the right balance between providing shade, allowing light and air to flow, and integrating aesthetically pleasing design contributed to a comfortable and inviting outdoor space.

The inherent properties of PVC material membranes offered effective shading, but also because of membrane translucency, natural light was allowed to filter through. This created a bright and pleasant environment without the need for artificial lighting during the daytime. Additionally, the reflective properties of the material played a pivotal role in temperature moderation. By reflecting sunlight, excessive heat accumulation beneath the structure was mitigated. Sound effects appeared as a new quality of this covered area. As the shell above it, nicely reflects and amplifies the sound of water and makes nice relaxing ambient.

The central aperture in the canopy, mentioned earlier, served a dual purpose encompassing both structural integrity and environmental considerations. In addition to its structural role, this opening facilitated the efficient dissipation of hot air from within the canopy, making it a comfortable and thermally regulated space.

CONCLUSION

It has been demonstrated that the application of tensioned membrane structures (TMS) in open public spaces represents an innovative solution with advantages in terms of aesthetics, functionality, and sustainability. Through the analysis of various aspects and case studies such as the Zvezdara Marketplace and Airport City, it has been proven that TMS can transform public spaces and create environments that provide for the community's needs. Aesthetically, TMS has been shown to be favourable due to their flexibility, allowing for the creation of diverse geometric forms that become urban landmarks. They enable the utilization of public spaces in various climatic conditions. The lightweight construction reduces material and energy consumption during construction and due to the characteristics of PVC material, energy consumption for lighting and ventilation during operation is reduced, aligning with sustainable building principles.

The application of TMS represents a significant potential for continuously enhancing the quality of diversity of open public spaces.

REFERENCES

- Vučur, A. P.; Filz, G. H. Airport City Belgrade Membrane Structure: design, production and installation process. In *IASS 2019 Annual Symposium of the International Association for Shell and Spatial Structures & Structural Membranes 2019: IASS 60th Anniversary: Form and Force*; Lazaro, C., Bletzinger, K.-U., Onate, E., Eds.; International Association for Shell and Spatial Structures (IASS): Madrid, 2019.
- Airport City Belgrade, Business Park, http://www.airportcitybelgrade.com/business-park/ accessed 31 May 2019.
- Kostic, D.; Milosevic, V.; Bogdanovic, V.; Vasov, M.; Vučur, A. P. Influence of Single and Double Membrane Roofs on Thermal Behaviour of Enclosed Space. *Teh. vjesn.* 2018, *25.* DOI: 10.17559/TV-20161205160405.
- ArTech inzenjering, Belgrade, photo-archive 2017-2023.
- Ruan G, Filz GH, Fink G (2022) Master Builders revisited - The importance of feedback loops: a case study using salvaged timber and wooden nails only. In: Filz GH, Savolainen P, Lilius J (eds) Architectural Research in Finland: ARF 2022, vol 1
- Popovic Larsen O, Filz GH (2023) The Meaning of Material, Materiality and the Digital for Baukultur. In: Bögle A, Popova E (eds) BuildDigiCraft : New Mindset for High-quality Baukultur in Europe: Bridging Craft and Digital. HafenCity Universität Hamburg, pp 260–293