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Technical paper

Culture of memory - Prof. Edmund Balgač and his (un)forgotten building opus

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ABSTRACT

The tendency to cover large areas led to the adoption of saddle-shaped geometric forms as the optimal solution for suspended roof systems. The development of suspension systems in the early 1950s was facilitated by advancements in numerical methods for solving complex systems of differential equations. Fred Severud (USA) and David Jawerth (Sweden) provided analytical solutions that enabled the optimal application of these systems. Edmund Balgač (Yugoslavia) enhanced existing models with his theoretical knowledge and practical skills, applying them in the construction of several halls in Serbia. Professor Balgač achieved the uniqueness of his solutions by combining aesthetic and structural requirements for covering large areas. Even today, many buildings utilizing this structural system continue to fascinate with their appearance and functionality. This paper analyzes the theoretical contributions of Prof. Balgač through the calculation of the roof structure of the Great Hall of the Textile Fair in Leskovac and the Fair and Sports Hall in Subotica, highlighting his creativity and the importance of these suspension cable structures as cultural and architectural heritage. Simultaneously, we remember Professor Balgač as a versatile engineer with a special gift for solving specific tasks using the most modern methods and techniques from global practice, thanks to his proficiency in German and English.

We dedicate this work to Edmund Balgač, an engineer, professor, and renowned researcher committed to the progress and development of construction in Yugoslavia during the second half of the 20th century. The unique works of suspended and catenary structures by Prof. Balgač are widely recognized, but much of his theoretical contributions have yet to be fully acknowledged.

1 Introduction

Suspended structures represent specific architectural and construction systems praised for their elegant form and ability to cover large spans. In civil engineering, suspended cable structures embody a fusion of theoretical excellence and practical application, often defining modern cityscapes with their graceful appearance and engineering challenges. These challenges necessitate innovative solutions in architectural design, calculation, material selection, and construction technology to achieve a balance between aesthetics, load-bearing capacity, and functionality. Understanding the principles of prestressing in suspended cable systems, along with the unique challenges posed by suspended cable systems, is particularly crucial. A comprehensive grasp of the benefits and challenges associated with cable structures is essential for design and construction. Despite the structural efficiency, large spans, and material savings offered by these systems, they present challenges such as cable maintenance, dynamic behavior, and construction costs.

The enduring presence of suspended structures in urban landscapes attests to their lasting influence. One of the key figures in this field is Professor Edmund Balgač, whose name is closely associated with the theoretical understanding and practical application of suspended cable systems.

The aim of this paper is to remind the professional and scientific community of the construction achievements that remain iconic in Leskovac and Subotica, and to express gratitude for Balgač's extensive translation work across all areas of construction. The research and analysis of Professor Balgač's contributions to the theoretical understanding and application of suspended cable systems in former Yugoslavia demonstrate how his work shaped the modern interpretation and use of these architectural and engineering innovations. The paper focuses on analyzing his theoretical contributions, with particular attention to projects such as the Great Hall of the Textile Fair in Leskovac and the Fair and Sports Hall in Subotica. Professor Balgač built upon the works of Jawerth from Sweden and Severud from the

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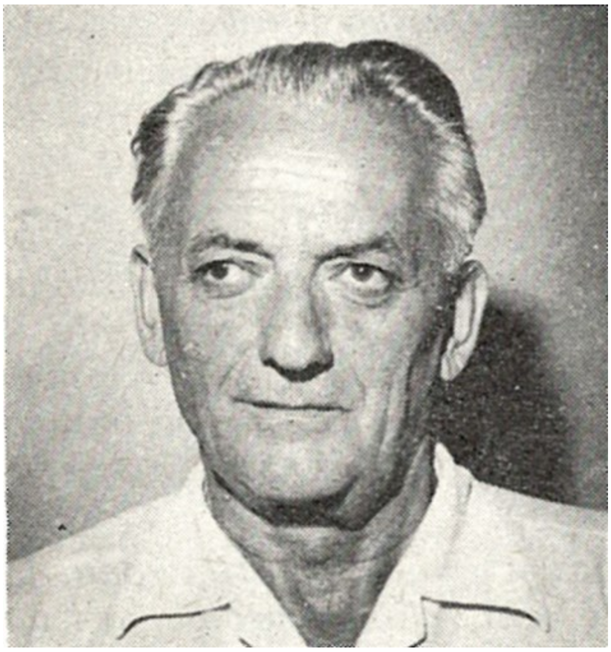

Edm. Balgač

Figure 1. Professor Balgač and his authentic signature [1]

USA, enhancing and expanding the method whose foundations were laid by Kačurin [2]. This work aims to deepen the understanding and appreciation of Professor Balgač's contributions to the theoretical advancement of suspended cable systems through analytical calculation, recalling his constructed works and translation efforts, and honoring the 110th anniversary of his birth.

2 Biography

Edmund Balgač was born on May 24, 1913, in Sombor in the former Austro-Hungarian Monarchy. His high intelligence and inclination toward natural-mathematical and technical sciences directed him to study civil engineering, which he completed in 1939 at the Faculty of Civil Engineering in Belgrade. Throughout his illustrious career, he worked in construction companies in Sombor, Srbobran, Novi Sad, and Belgrade. For a significant portion of his career, he served as a construction manager in the complex construction companies "Trudbenik" and "Rad." His extensive work experience, professional knowledge, proficiency in German, and extraordinary ability to synthesize qualified him for the position of professor at the Higher Technical Construction School in Subotica (1965-70). In 1982, he was appointed a full professor by invitation at the Faculty of Civil Engineering in Subotica.

During his time in the operational department, he collaborated closely with leading experts such as Milan Krstić, PhD, Đorđe Lazarević, PhD, and Milorad Ivković, PhD. He learned from them and together they developed and applied new knowledge and modern global achievements. He made significant contributions through his research and teaching work, as well as with numerous realized projects that continue to impress with their function and form. A significant professional and scientific contribution was also made through his exceptional translation work.

As a professor, he left behind a considerable body of research in all areas of civil engineering, especially suspended cable systems, construction, and foundation theories [3-11]. With his theoretical contributions, he earned the reputation of being one of the pioneers and originators of suspended systems in the former Yugoslavia, as well as in Europe and the world. One of his most significant contributions to science was the introduction of numerical analysis into the geometrically nonlinear problem of prestressed suspended systems. He improved and applied the existing analytical methods of Prof. Nowicki and Severud (Dorton Arena) and Jawert (Johannesov Arena) for facilities in Leskovac, Zemun, and Subotica. His research laid the foundations for future advancements in the construction of these structures. As a researcher, he made significant contributions to numerous scientific works, including the textbook "Engineering Structures: Reinforced Concrete Structures," which was published at the Higher Technical School of Construction in Subotica in 1966.

In addition to his theoretical work, Prof. Balgač was one of the most outstanding civil engineers of his era. As an engineer at "Rad" from Belgrade, Balgač left behind many buildings that continue to serve as benchmarks in the urban landscape. Among his notable projects are the Great Hall of the Textile Fair in Leskovac, the Fair and Sports Hall in Subotica, and the Sports and Cultural Center "Pinki" in Zemun [12, 13]. In the company Kosovo Project, he addressed the interaction of the foundation with the soil for the bridge over the Tisa River near Novi Kneževac. He demonstrated his versatility and ability to synthesize in concise works that addressed the issues dominating Yugoslav congresses of constructors and geotechnicians. At the same time, he enjoyed the respect of all his colleagues, and his insights on the work of professors and meritorious engineers were appreciated and valued.

Prof. Edmund Balgač passed away at the age of 77 on September 12, 1990, in Belgrade, leaving behind an indelible legacy with his theoretical work and constructed projects that continue to remind us of his greatness and importance.

3 Contribution in translating literature

Through his translation work, Prof. Balgač significantly improved the education of many generations of students at technical faculties in Yugoslavia. During his career, Prof. Balgač translated several important works and books in the fields of spatial structural systems, concrete structures, and traffic construction. Some of his notable translations include:

- "Spatial Roof Constructions: Details and Execution. Concrete, Wood, Ceramics, Steel, Plastic Material." Part 1 and Part 2, Construction Library - Herman Rile with a group of authors, translated by Edmund Balgač, 1977, Construction Book (488 pages).
- "Prestressed Concrete in Practice" (Spannbeton für die Praxis) - Leonhardt Fritz, translated by Edmund Balgač, 1959, Construction Book Belgrade (526 pages).
- "Traffic Engineering Manual" - Ludvig Kirgs, translated by Edmund Balgač, 1962, Construction Book Belgrade (635 pages).
- "Theory of Reinforced Concrete Structures" - Gothart Franz, translated by Edmund Balgač, 1979, Construction Book Belgrade (390 pages).

4 The theoretical contribution of Prof. Balgač

4.1 Historical overview of the works that contributed to the development of the analytical solution

When discussing the theoretical work of Prof. Balgač in the field of suspended cable structures, it is essential to mention pioneers like Fred Severud [14, 15] and David Jawerth [16], who laid the basics for further advancements in the calculation of cable systems. Prof. Balgač continued to refine the analytical method for calculating geometrically non-linear structures established by Severud and Jawerth. The first major breakthrough in creating suspended constructions was the optimization of analytical calculations, wherein the stabilization of catenaries by weight was replaced by prestressing, introducing a revolutionary concept in this field [1, 14, 17].

Swedish engineer David Jawerth developed an innovative system to mitigate the undesirable swaying of cable trusses - a hanging prestressed system in the vertical plane - using the analytical model of Kačurin [2]. A cable truss system, composed of two tensioned cables of opposite curvature, is often referred to as a Jawerth system. Due to its tensioned nature, it prevents excessive movement and swaying of the roof. The cable system is interconnected by rods, forming a truss, while the anchor structure with diagonal stay cables ensures the immovability of the support nodes and balances the forces within the cable structure. According to Jawerth's recommendation, the ratio of the added load (v) to the total gravity load (q) should be taken as $v/q < 0.6$ for the calculation. This theoretical solution was applied in the design of the Ice-Skating Rink in Johannesov, Stockholm (Figure 2), with the project carried out by architect Hedquist and the calculations by engineer Jawerth. The skating rink in Johannesov, Sweden, was the first facility built with a system of prestressed cable trusses. It was designed in 1956 and completed in 1964, with a capacity of 16,000 spectators [1, 18].

A real revolution in the construction of suspended systems with a spatial arrangement of prestressed catenaries was brought about by the construction of the state fair hall in Raleigh, North Carolina. The ingenuity of the idea in its geometric, constructive, and conceptual solution came from Nowicki [14, 15, 19, 20].

Maciej Nowicki, an architect and professor, was born in Chita, Siberia, in 1910. After World War II, he worked on the reconstruction of Warsaw. As a delegate of Poland, he went to New York in December 1945 to work on rebuilding Poland's infrastructure. From 1948 until his tragic death in 1950, he taught and worked in the department of architecture at the newly formed "North Carolina State College School of Design." As a teacher, designer, and urbanist of international repute, his legacy is mainly reflected in the inspirational influence he exerted at the School of Design, the lost potential to change the course of contemporary architectural and planning thinking and practice, and in the radical design of his only completed project in North Carolina, the famous Dorton Arena, completed after his death. In collaboration with engineer Fred Severud, Nowicki drew up the plan for the arena in Raleigh (Dorton Arena) (Figure 3). The shape of the arena is determined by two inclined parabolic arches of reinforced concrete that meet near the ground, connected below ground level by braces. A net of prestressed cables between the arches supports the roof and forms the surface of a hyperbolic paraboloid. Dorton Arena has gained wide and lasting admiration, becoming one of the few North Carolina facilities to achieve international recognition. The extraordinary hyperbolic-paraboloid structure became a model for a series of later buildings designed in the "saddle dome" form around the world during the 1950s and 1960s. For North Carolina in the mid-20th century, it became a bold symbol of modernity and progress, a celebrated icon of modern architectural design from the day it was built. With his concept, Professor Nowicki also influenced the development of an analytical solution for the calculation of cable structures, together with Fred Severud. The calculation of the suspended roofs of several important halls in the USA was carried out by the project bureau known today as Severud Associates (Madison Square Garden 1968, Dorton 1953, Ingalls Hockey Rink 1958).

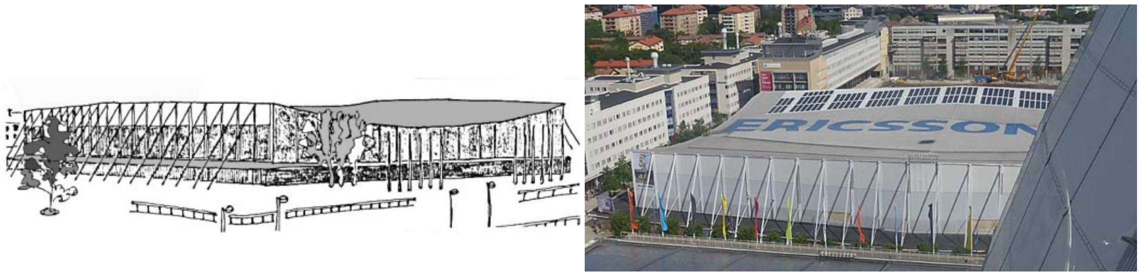

Figure 2. Ice-Skating Rink in Johanneshov, Sweden, 1956. (David Jawerth), today Hovet arena (author's drawing – left, author's photograph – right)

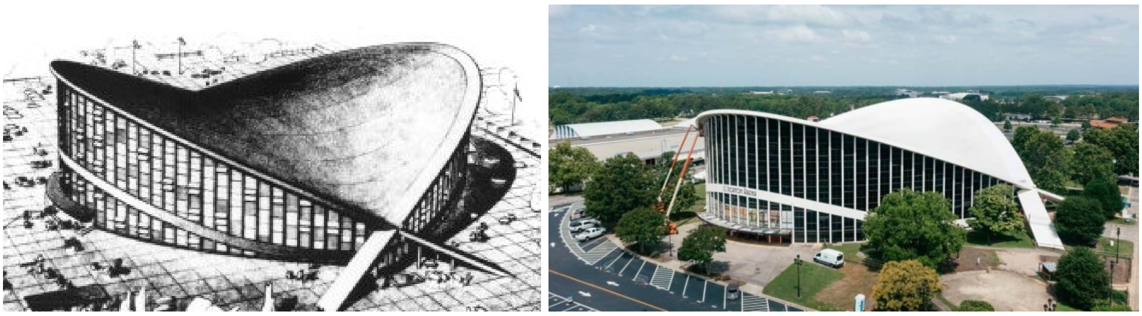

Figure 3. Dorton Arena, Raleigh, North Carolina, USA, 1952 [21] and today (Maciej Nowicki, Fred Severud) [22]

After the construction of Dorton Arena, Prof. Balgač used the analytical procedure applied by Fred Severud, advanced the analytical part of the method, and applied it to the construction of three halls: Pinki in Zemun in 1973, the Textile Fair Hall in Leskovac in 1959, and the Fair and Sports Hall in Subotica in 1968 [1, 14, 17, 23, 24, 25].

4.2 Basic principles of analytical solution

The main feature of the theoretical work of Prof. Balgač is reflected in the introduction of numerical methods into the analytical techniques applied by Jawerth and Severud. Professor Balgač based the calculations for achieving roof stability on his original method, which, for prestressed networks, implied an additional load on the supporting cables. The establishment of balance was obtained by applying additional load to the supporting cables in direct contact with the prestressing cables. In this way, the reactive load between the supporting and prestressing cables was introduced into the calculation, which changes intensity depending on the load phase of the roof. In the no-load phase, the reactive load causes the highest tensile forces in the stabilizing cables. By loading the roof net, in the load-bearing and stabilizing cables, the greatest forces will occur in the phase of the greatest gravity load, and the least in the phase of prestress. Conversely, in the stabilizing cables, the greatest forces will occur in the phase of prestress, and the least in the phase of full workload. For the input data of the calculation, the principle of identical change of deflections in the carrying and prestressing cables in all phases of the load was applied. The calculation of the loads acting on the cables takes into account the accurately calculated values of the reactive forces k during loading, i.e. k1 when the roof is unloaded. According to the Professor's method, the additional load of the supporting cables (*v*) should have an intensity of 0.15 kN/m^2 to 0.20 kN/m^2 [1, 14, 17].

Prof. Balgač based his calculation of the forces in the cables on the assumptions that load - bearing and prestressing cables in the unloaded state, and later under continuous load, have the shape of a parabola. During the calculation of the hanging roof of the Great Hall of the Leskovac textile fair, for the calculation of the geometry of the supporting cables, a deviation of 2% occurred.

4.3 The practical application of Balgač's analytical procedure

Starting from the assumption that the cables of the prestressed net are affected by equally distributed vertical loading, the characteristic phases through which the roof will pass during construction and exploitation are defined as:

(0) the phase without loading;
(1) the prestress phase;
(2) the prestress and self weight phase;
(3) the prestress, self weight, snow, and pressure or suction of the wind phase.

The calculation procedure could be divided into two phases [1, 14, 17, 26-28]:

I The previous calculation of the form of the load-bearing and stabilizing cable for the aforementioned phases of loading

This procedure includes the determination of the changes in the sags of the main cables due to the loading or unloading of the construction, by using formulas (1), (2) and (3) [1,14, 17, 26-28]. We assume that the sags f_0 and f_{p0} occur during phase (2), during the so-called designed state. Due to complete unloading, phase (0), a change will occur in the sags of the load-bearing cables for Δf_0 whose value can be determined using the formula (2).

The structure of the load d uring phase (2) is:

$g = g_{nos.} + g_{pom.}$,

where: $g_{nose.} = a \cdot v_p + k_{ver.} + a \cdot g_p - k_{1,ver.}$; $Mr._{Pom.} = a \cdot v_p + k_{ver.} - k_{1,ver.}$

The probable increased pressure, with which the stabilizing cable presses onto the load-bearing one, due to the unloading of the roof $k_{ver.} \approx g_p \cdot a$, that is, the probable decrease in pressure of the load-bearing cable on the stabilizing one due to the load of the roof $k_{1,ver.} \approx v_p \cdot a$ (based on author's personal experience) must be assumed precisely enough so the previous calculation would not have to be repeated. Due to full loading, the unloaded roof moves into the phase of the greatest gravitational load (phase **(3)**), while changes in the arrows are calculated using formula (1). By means of the successive unloading of the roof for the value of the load of the wind and snow, that is, the weight of the roof itself, the roof moves into phase **(2)** of the loading, that is (1), and the change in the arrow is calculated using the formula (2). The obtained arrows of the load-bearing cables over the phases of loading are input into formulas (4), (5) and (6) [13, 16, 17, 24-27], which leads to the expected values for k and k_1 . If $k_{ver.} \neq k$ and $k_{1,ver.} \neq k_1$, the previous calculation must be repeated with adjusted values of $k_{ver.}$ and $k_{1,ver.}$.

$$\Delta f^3 + \Delta f^2 (3f - A) + \Delta f (2f^2 - 2Af) - A(B + f^2) = 0$$
$$A = \frac{q l^2}{4EF} \qquad B = \frac{3}{16}(l^2 + h^2) \tag{1}$$

$$\Delta f_{0p}^2 \left(\frac{f_{0,qv}}{m_G} - \frac{3 f_{p0}}{m_P} \right) - \Delta f_{0,p} \left(\frac{2 f_{0,qv}^2}{m_G} + \frac{2 f_{p0}^2}{m_P} \right) + p = 0 \tag{2}$$

$$\Delta f_0^{\,2} \left[\frac{3 f_0}{m_G} - \frac{f_{p0}}{m_P} \right] + \Delta f_0 \left[\frac{2 f_0^{\,2}}{m_G} + \frac{2 f_{p0}^{\,2}}{m_P} \right] - p = 0 \tag{3}$$

$$k = p - \frac{2 f_{0,qv}^{2} \Delta f_{0,p} - f_{0,qv} \Delta f_{0,p}^{2}}{m_G}$$

$$m_G = m + m_I + m_{II} \qquad m = 3\frac{l_0^4}{64 E F} \qquad m_I = \frac{f_{0,qv}^{2}\, l_0^{2}}{4 E F} \qquad m_{II} = \frac{3\, l_0^{2}\, h^2}{64\, E F} \tag{4}$$

$$k = \frac{2\, f_{p0}^{2} \Delta f_{0,p} + 3\, f_{p0} \Delta f_{0,p}^{2}}{m_P}$$

$$m_P = m_p + m_{pI} \qquad m_p = \frac{3\, l_{p0}^{4}}{64\, E\, F_p} \qquad m_{pI} = \frac{l_{p0}^{2}\, f_{po}^{2}}{4\, E\, F_p} \tag{5}$$

$$k_1 = p - \frac{f_0}{m_G} \Delta f_0 \,(\, 2 f_0 + 3 \Delta f_0 \,) \quad tj. \quad k_1 = \frac{f_{p0} \Delta f_0}{m_P} (\, 2 f_{p0} - \Delta f_0) \tag{6}$$

II The calculation of the geometry and forces in the cables

By using the equation (7) and the equations (8) and (9) [1, 14, 17, 26-29] we obtain the geometry of the prestressed net, that is, the force in the load-bearing cables.

It is clear that in the load-bearing cables, the greatest force will be found during the greatest gravitational load, and the smallest during the prestressing phase, while in the stabilizing cable the greatest force will occur during the prestressing phase, and the smallest in the full load phase.

Stabilizing cables, even under the greatest gravitational load, must retain within them the tensioning force which will, using its vertical component, press down on the load-bearing cables with a certain load *v.* Professor Balgač recommends that the intensity of this load, the so-called "contact force", should be $v = 0.15 - 0.20\ kN/m^2$. In this way, the stability of the prestressed net roof, that is, the tensioning force in all the members of the system is guaranteed. This represents the quality of this method of calculation, in addition to the simplification which was introduced into the calculation.

This budget model was first published in the scientific literature [14] in 1961, with full explanations and mathematical expressions. Balgač himself states in the bibliography of the work [14] that he used the model according to which the Dorton Arena was designed (Severud's model) [15, 30]. Later published works by Sobotka [31], Kasilov, Bandel, Irvine [32], Leonhardt [33], Schlight [34], Jawerth [16] and others show similar equations used for calculation due to static loading and temperature changes. It is clear that Prof. Balgač was among the pioneers of the application of a successful analytical solution for which we have no evidence that it is completely original, but it was certainly reduced to an applicable procedure by which many hanging halls were built in Europe and of course in our country. Collaborating with professors from the Faculty of Civil Engineering in Belgrade, the constructed roof of the Great Fair Hall in Leskovac was checked in relation to the calculated values, by on-site testing [14]. The geometrical parameters as well as the measured forces in the cables showed minimal deviations that can be considered within the limits of the expected deviations, so the calculation model was thus verified.

5 Engineering contribution

Conventional space-surface structural systems (shells) have proven to be expensive from a technical perspective due to the complexity of formwork and scaffolding, and from a technological standpoint due to the challenges of installing concrete on curved and sloping roof surfaces. The idea of introducing hanging systems with identical geometric forms arose as a vision of Nowicki, with the calculation model applied by Severud at Dorton Arena. This approach maintained the geometric form of the hyperbolic paraboloid, satisfying aesthetic requirements, while the introduction of chain prestressed systems liberated the roof surface from complicated scaffolding and formwork. This resulted in the construction of highly aesthetic, attractive, functional, and economical medium- and large-span buildings.

$$z = 4\ f_0\ \frac{x}{l_0} \left(\frac{x}{l_0} + \frac{h}{4\ f_0} \right) \tag{7}$$

$$H_0 = \frac{q\, l_0^2}{8\, f_0} \qquad V_2 = H_0\, tg\, \alpha_2 = \frac{q\, l_0}{2} \left(1 + \frac{h}{4\, f_0} \right) \qquad V_1 = -\, H_0\, tg\, \alpha_1 = \frac{q\, l_0}{2} \left(1 - \frac{h}{4\, f_0} \right) \tag{8}$$

$$S_2 = \sqrt{H_0^2 + V_2^2} = \frac{q\, l_0^2}{8\, f_0} \sqrt{1 + \left(\frac{4\, f_0 + h}{l_0} \right)^2} \qquad S_1 = \frac{q\, l_0^2}{8\, f_0} \sqrt{1 + \left(\frac{4\, f_0 - h}{l_0} \right)^2} \tag{9}$$

The modern approach allowed for the replacement of shells with catenaries, optimizing construction with minimal material use and faster building times. These systems enable the elegant covering of large spans without the need for internal supports, utilizing high tensile strength materials. Architecture later embraced hanging systems, leading to diverse variations. Steel ties, ropes, and cables became standard materials, manufactured to high steel standards. Research improved the efficiency of building structures, encouraging further exploration.

The use of suspended roof systems to cover large areas brings innovative, bold, and economical solutions. These systems are integrally tensioned structures, resulting from the geometric characteristics of load-bearing roof elements (cables and ropes). Cables do not transmit pressure forces, only tension forces, and they are extremely long with small cross-sections, making their bending stiffness negligible. Their carrying capacity is maximally utilized, making them economical structural elements. Advantages of hanging systems compared to other constructions for covering large spans include fast preparation through CAD and CAM technology, cheap transportation, and simple connection of elements with less qualified labor. However, suspended roofs are subject to aerodynamic challenges due to loads such as self-weight, snow, wind, earthquakes, and other vibrations. Ensuring the stability of the structure is crucial to prevent negative effects like roof swaying, ceiling cracking, and installation damage.

Modern cable truss systems are stabilized by applying weight loading, preload, and a combination of bending elements. A modern approach involves prestressing by introducing tensile forces into the roof cables during construction. These cables, when pre-tensioned, exert pressure on the structural elements, and stabilization is achieved using high compressive strength elements and cables of opposite curvature in different spatial arrangements [1, 14, 17, 23-28, 35, 36].

The multitude of advantages characterizing hanging chain systems led to their massive application in the mid-20th century, both globally and in the former Yugoslavia. Among the engineers who created halls using this system, Prof. Edmund Balgač stands out, having left behind several halls built with prestressed chain links. This work includes case studies on the Great Textile Fair Hall in Leskovac and the Sports Fair Hall in Subotica. These halls continue to captivate with their aesthetic value even after 6-7 decades, serving as landmarks in the cities where they are located.

5.1 The Great Hall of the Textile Fair in Leskovac

The Great Hall of the Leskovac Textile Fair, also known as the Round Pavilion or "Šajkača" (Serbian traditional hat) was designed by Prof. Edmund Balgač and architect Milorad Cvetić. The pavilion is the second facility in the world and the first in Europe built according to the revolutionary design and construction principles pioneered by the famous "Dorton Arena" in the United States of America. The building was constructed in 1959 in the eastern part of the Fair complex and has a characteristic circular shape (Figure 4).

The roof's structural system is a prestressed net of steel cables in the shape of a hyperbolic paraboloid. The main cables have a cross-section of 8Φ5 mm, while the auxiliary cables are 3Φ5 mm. Reinforced concrete clamped arches with a cross-section of 70/300 cm are inclined outwards and serve as supports for the prestressed cable network. This forms an approximately circular base with a diameter of 60 m. The perimeter supports are slender columns with a cross-section of 40/90 cm and variable height. The facade consists of 180 cm high parapets made of brick and glass surfaces up to the arched supports. The gallery, in the form of an inner ring separated from the main structure, is 8 meters wide with staircases on the north and south sides. Although originally planned to be covered with copper, the pavilion is actually

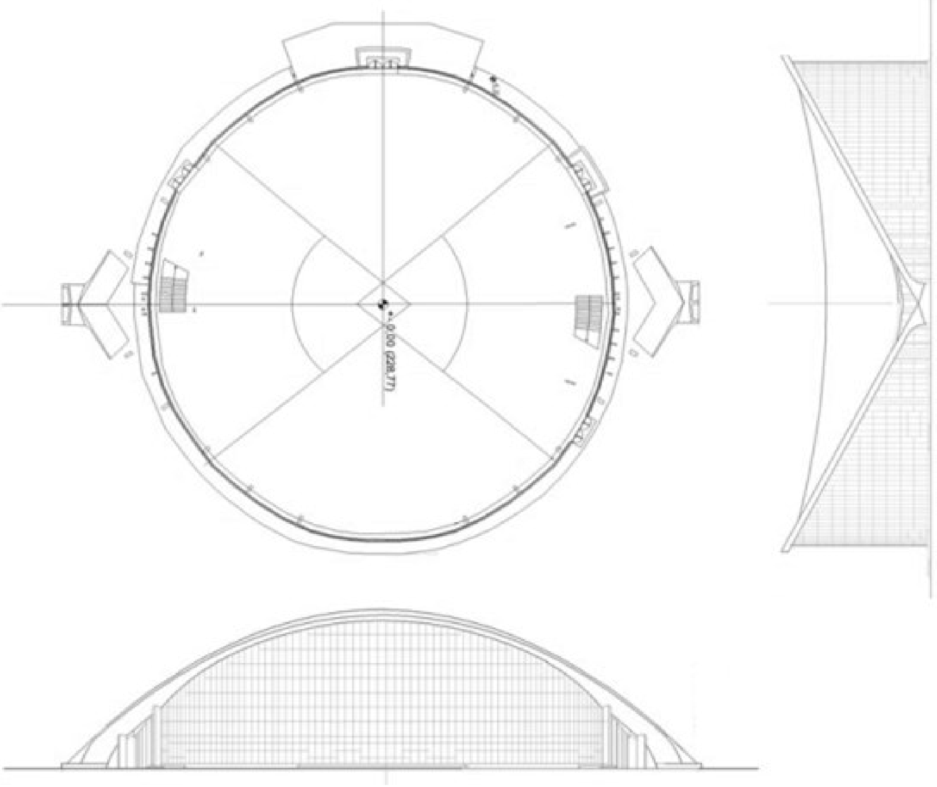

Figure 4. Basis and facades of the Large Hall of the Textile fair in Leskovac, Serbia, 1959 [37]

covered with galvanized sheet metal. The ceiling is made of lightweight volcanic tuff concrete with an average thickness of 6 cm. The total usable area of the building is 3440 m², with the ground floor covering 2375 m² and the gallery 1065 m² [1, 14, 17, 24, 26-28].

Revitalization of the building partially started in 2017, and in 2021 the building was given a new look and restored its shine. The pavilion was reopened in 2021, now serving as a shopping center (Figure 5 right). Unfortunately, the inner ring of the gallery space was permanently removed due to the new function of the building. During renovation, the roof structure made of concrete elements and the cover were renewed, while the cables were preserved, maintaining the unique geometric form of the roof structure [37].

5.2 The Sports Fair Hall in Subotica

According to the project of Prof. Edmund Balgač and architect Ivan Antić, the Sports Fair Hall in Subotica was realized in 1969 (Figure 6). The location of Dudova Šuma was chosen for the new hall. The building has a square base with sides of 57.6 m, dominated by an attractive roof structure with the geometric shape of a hyperbolic paraboloid. The new facility was intended for multifunctional use with simple adaptation for fair exhibitions, sports events, and cultural and artistic events. The hyperbolic paraboloid construction was realized in the form of a hanging structure of a prestressed cables net, similar to the hall in Leskovac. Steel cables with a cross-section of 6Φ5 mm placed at 50 cm intervals form the supporting cable structure, while auxiliary cables have a cross-section of 3Φ5 mm. A network of prestressed ropes is tensioned on a clamped spatial framework made of reinforced concrete. The frame consists of two clamped triangular concrete elements measuring 80/380 cm in section. The triangular structure has different slopes, resulting in different roof heights at opposite ends. The edge construction of the concrete frame is supported by columns placed at 7.2 m intervals. Edge posts have variable height and cross-section, with the tallest column having a cross-section of 50/120 cm [25, 36].

From the very beginning, the hall faced issues with the small capacity of the atmospheric sewage system, leading to overflows on the low supports of the roof, and the large volume of space created difficulties in heating. Consequently, the hall underwent two reconstruction processes. The first reconstruction in 1988 involved installing prefabricated stands, giving the building a purely sporting character. The hall was divided into two parts, creating two separate courts and increasing spectator capacity. In 2011, the stands were reconstructed again. Although the spectator capacity was reduced, the reconstruction addressed the discomfort of the existing seating area. The existing bleachers had non-standard dimensions, necessitating the reconstruction after 2011. The hall's area remains unchanged, with hopes for future solutions to improve space utilization.

The Sports Fair Hall in Subotica is an exceptional example of architecture and cultural heritage that reflects the city's rich history and development. This imposing sports hall features a striking architectural style, recognizable by its elegant roof structure and adaptive function. It has served as a venue for sporting events and a central gathering place for citizens during cultural events and manifestations, making it a vital part of Subotica's cultural life. Its architectural value lies in balancing aesthetics and functionality, contributing to its status as a cultural monument. In January 2022, the Institute for the Protection of Cultural Monuments considered

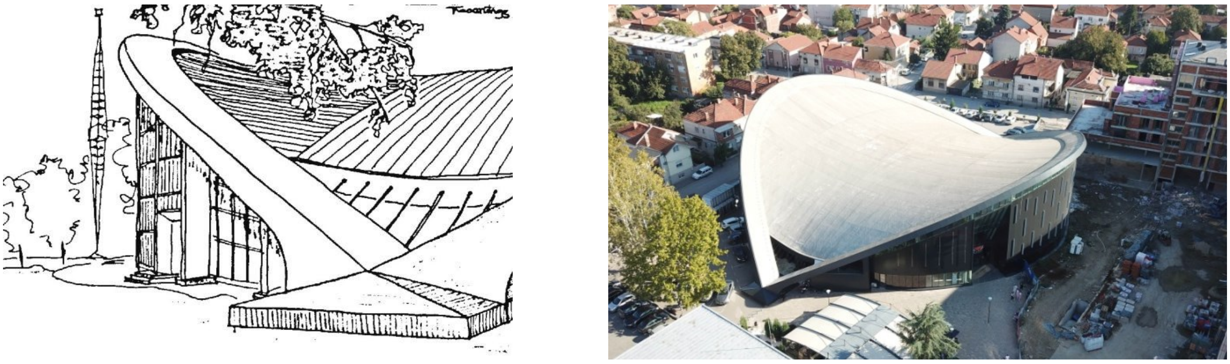

Figure 5. The Large Hall of the Textile fair in Leskovac: Original building view 1959 (author's drawing – left), Reconstructed new purpose shopping mall, 2024 (author's photograph – right)

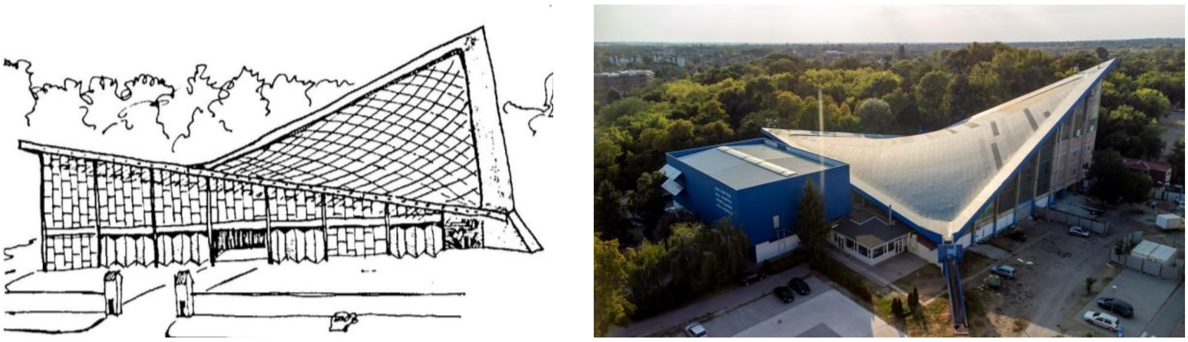

Figure 6. Sports and fair hall in Subotica, Serbia, 1969 (author's drawing – left) Aerial view after seies of reconstructions (Marko Bulatović – right)

the hall, but it was not included in the list of Immovable Cultural Properties after assessing its historical, artistic, and cultural value.

6 Conclusion

Professor Edmund Balgač's contributions to the field of suspended cable structures are both profound and enduring. Through his innovative application of numerical methods to the analysis and design of geometrically non-linear structures, Balgač advanced the theoretical understanding and practical implementation of these systems. His work, particularly in projects such as the Great Hall of the Textile Fair in Leskovac and the Fair and Sports Hall in Subotica, exemplifies the successful integration of aesthetic and structural principles, creating iconic landmarks that continue to impress with their elegance and functionality.

Balgač's ability to build upon and refine the analytical models introduced by his predecessors, such as Fred Severud and David Jawerth, highlights his role as a key figure in the evolution of suspended cable structures. His pioneering efforts in applying numerical analysis to prestressed systems not only advanced engineering practices but also facilitated the construction of large-span structures with minimal material use and reduced construction complexity.

As we commemorate the 110th anniversary of his birth, it is evident that Professor Balgač's legacy endures through the buildings he designed and the principles he established. His work remains a testament to the harmonious blend of theoretical rigor and practical application, continuing to inspire and guide the field of structural engineering. The enduring presence and functionality of his projects stand as a tribute to his vision and expertise, cementing his place in the annals of architectural and engineering history.

CRediT authorship contribution statement

Conceptualization – DK; Data curation - PR, DK, RF; Investigation - DK, PR; Methodology – DK; Supervision – RF; Visualization – DK; Writing - original draft – PR, DK; Writing - review & editing – VM, PR.

Declaration of competing interest

Authors declare no conflict of interest.

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