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THE AVICII ARENA RETRACTABLE CEILING – INNOVATIVE DESIGN AND INSTALLATION

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Summary. This paper presents the design and implementation of the retractable acoustic ceiling of the Avicii Arena in Stockholm. The project addressed complex structural, mechanical and acoustic challenges in retrofitting a lightweight movable system on an existing cable net roof. The solution combined lightweight aluminum rails, motorized and passive trolleys, and acoustic panels controlled by a chain-driven mechanism. Verification included fatigue checks of pins, bolts, bearings and chains, and the system was commissioned within one year of arena closure.

1 INTRODUCTION

The Avicii Arena, originally built as the Ericsson Globe, due to its perfect sphere shape, required a refurbishment to adapt its acoustics for both concerts and ice hockey events. Concerts required improved reverberation control through suspended acoustic panels, while sports events required the maximum possible volume. The project therefore demanded the installation of a retractable ceiling system that could transform the acoustic behavior of the arena within minutes.

Figure 1: Avicii Arena (Stockholm, Sweden)

2 PROCESS & MODULAR DESIGN

The project involved a wide range of suppliers, including steel structure specialists, cable net engineers, acoustic consultants, MEP designers, and the retractable system supplier. To manage these interfaces, the design was organized in phases, beginning with concept and tender adaptation, and followed by detailed design and fabrication drawings. After the tender adaptation, a full-scale mock-up of one panel line was constructed to validate geometry, folding sequence, tolerances, and feasibility of assembly.

Each phase required approval milestones not only from the client but also from tangent suppliers. For instance, the tender acoustic engineers defined panel size and inclination angles; however, several of these proposals were geometrically unfeasible. This became a significant difficulty toward the end of the process, as different geometric configurations had to be proposed by the mechanical team to fit within the available space without compromising acoustic performance.

To ensure continuous compatibility, Dalux BIM coordination software was used throughout the project. Every supplier regularly uploaded updated models into a shared coordination platform, where clashes and interferences were detected and resolved. This was particularly critical for verifying that trolleys, rails, and panels did not conflict with MEP systems or other arena equipment.

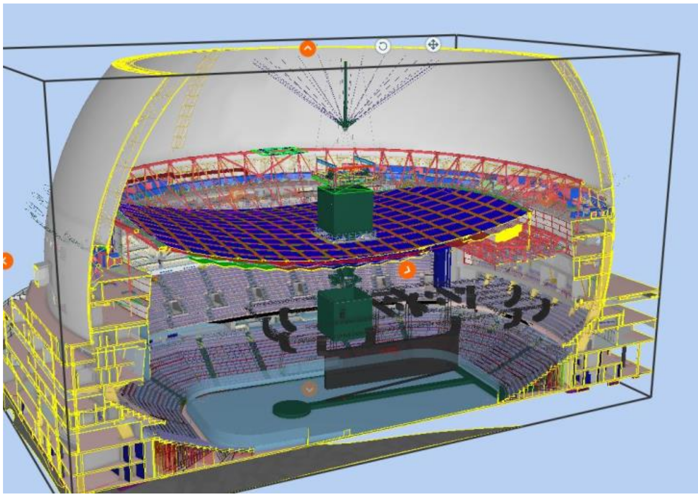

Figure 2: Coordination model

Weekly design meetings were held between the cable net engineers and the retractable mechanism team. In addition, coordination meetings with other suppliers were organized whenever required, especially when interface conflicts emerged. This process not only reduced risks of late-stage incompatibilities but also allowed corrective actions to be taken locally, without requiring a global redesign of the system.

Finally, the retractable system had to tolerate erection tolerances of ±20 mm. For safety, the design was verified against imposed displacements of ±30 mm horizontally and 300 mm vertically between adjacent rails, reflecting deflections caused by the heavy rigging loads of touring shows. This verification was fully integrated into the approval process, ensuring that local adjustments would remain compatible with the global behavior of the structure, and was also confirmed during the full-scale mock-up tests, where even higher values were applied under controlled conditions as part of stress testing.

3 SYSTEM DESCRIPTION

The retractable system is composed of more than 2 km of customized aluminum rails suspended from the cable net. Each rail segment was fabricated with a controlled curvature in order to match the geometry of the cable net. Geometric checks were continuously performed during installation to ensure compliance with the designed geometry. The rails were fixed to the supporting structure through custom-designed steel brackets, equipped with adjustable connecting points to correct any deviations observed on site with respect to the coordination models. These brackets were in turn connected to the cable net by stainless steel cables, a configuration that allowed local displacements to be absorbed without transmitting secondary stresses into the mechanism.

A total of 488 trolleys circulate along the rails. Standard trolleys, weighing approximately 21 kg, provide guidance and support, while motorized trolleys, weighing around 29 kg, are strategically placed to transmit the motion. Together, they carry 452 acoustic panels, each with a nominal weight of 110 kg. In operation, a complete panel–trolley assembly reaches approximately 212 kg, including the panels, the driving beam connecting the pairs of panels, and the trolley units.

Table 1: Main components and weights

Component	Quantity	Weight (kg)
Rails	2.060 m	38.892,80
Chains	4.120 m	15.038,00
Engine group	36	2.865,60
Tensioning group	36	1.080,00
Connections	632	7.156,30
Trolleys	488	10.824,00
Panels	452	35.888,00
Driving beams	244	10.638,40

The motion of the panels is achieved through closed-loop roller chains, which drive the trolleys directly. The trolleys, in turn, support and guide the acoustic panels along the rails. During deployment, chain tensions reach approximately 8.6 kN in closing movements, while retraction phases produce peak pulling forces of up to 23 kN due to the accumulation of panels in the stacked position. These forces formed the basis of structural verification of both the trolleys and the rail attachments. With an operating speed of 7.4 m/min and a total panel travel of 74 m in the longest bay, the system completes a full opening or closing cycle in about 10 minutes.

Motor groups are located at one end of the rails and consist of electric motors coupled with hollow shaft gearboxes. The opposite end of each rail houses the chain tensioning assemblies, which allow tension correction of the closed-loop chains during operation. Each drive unit was designed with a capacity exceeding twice the nominal operating load, providing redundancy and ensuring safe operation even under unbalanced conditions. The design of shafts, pinions, and bearings was verified through static and fatigue analyses in compliance with EN 13001 and ISO 281 standards.

The system is managed by a control interface capable of operating the bays either synchronously or independently. Through a touchscreen panel, operators can supervise and control speed and position, while real-time alarms are displayed for immediate response. Safety functions include emergency stop buttons and manual override procedures, which allow recovery in case of power loss and maintenance tests. To ensure secure use, the software was configured with differentiated login credentials, providing distinct access levels for operators, maintenance personnel, and administrators, thereby preventing unauthorized changes to critical parameters while maintaining usability for routine operations.

4 ACOUSTIC PANELS

The acoustic panels form the visible and functional surface of the retractable ceiling. Their design was driven by the need to achieve both the required acoustic performance and the structural stiffness necessary for movement and retraction.

Each panel consists of an aluminum frame extruded in EN AW 6063 T5, designed according to EN 1999-1-1. The profile geometry was developed specifically to allow the installation and tensioning of the upper and lower acoustic membranes without the use of keder edges, which significantly reduced fabrication and assembly time. The frame weighs approximately 3.5 kg/m of extrusion. The panel assembly includes two fabric membranes and internal structural elements connected through corner plates, riveted joints, and a central aluminum beam.

Figure 3: Acoustic panel assembly

The design loads considered for each panel included self-weight, fabric pretension, and operational loads transmitted through the trolleys and driving beams. The nominal fabric pretension was defined as 0.5 kN/m, while the self-weight of the panel corresponds to approximately 2.2 kg/m². Load combinations followed the Eurocode recommendations, applying partial safety factors of 1.35 for ULS and 1.0 for SLS.

Finite element analyses were performed using Strand7 (Straus7), with both global and local models to verify the behavior of the extrusion and its connections.

In the global model, the frame was modeled with beam elements in both deployed and stacked configurations. Maximum Von Mises stresses reached approximately 38 MPa, compared to a design limit of 100 MPa, confirming compliance with EN 1999-1-1.

In the local models, plate elements with 5 mm to 6 mm thickness were used to assess stress concentrations near the corner plates, rivets, and junctions between panels. The highest local stresses remained below 54 MPa, providing a comfortable safety margin.

Adjacent panels are connected at the bottom by a stainless-steel link cable, designed for an axial load of 2.8 kN (ULS) and a minimum breaking load of 7 kN, accounting for dynamic effects. The upper connections to the driving beam transfer both axial and bending loads from the retractable mechanism. Riveted and bolted joints were verified in shear, tension, and bearing according to EN 1993-1-8 and ISO 14589, achieving safety factors above 1.7 in tension and 3.3 in shear.

All checks were performed for both the packed and deployed configurations to simulate non-ideal support conditions and to ensure that the panels would remain structurally sound even under unbalanced loading. The analyses confirmed that both the extruded frames and the connections operate well below their design limits, guaranteeing long-term durability and safety during operation.

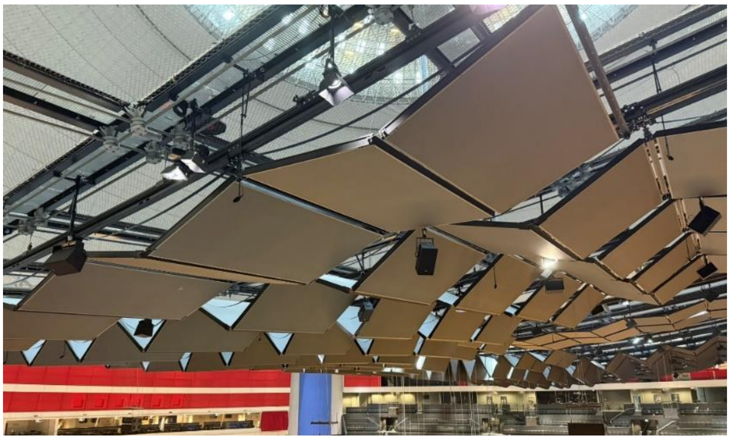

Figure 4: Acoustic panels during deployment

5 LOADS, STRUCTURAL VERIFICATION AND FATIGUE

The design of the retractable ceiling required the evaluation of loads under multiple operating conditions, following the principles of Eurocode 3 and EN 13001. Both Ultimate Limit States (ULS) and Serviceability Limit States (SLS) were considered, as well as fatigue verification to confirm long-term durability.

5.1 Load cases

Deployment produced pulling forces of approximately 17.3 kN, while retraction, where the panels accumulate in the stacked position, generated peak forces up to 23.0 kN. The closed-loop chains reached design tensions of 8.6–11.5 kN, values adopted for the dimensioning of shafts, gearboxes, and brackets. To simulate acceleration and braking, a dynamic amplification factor of 1.2 was applied to motor torques, in accordance with EN 13001. Impact loads were also considered, with bumpers installed on both sides of the trolleys to absorb the kinetic energy of abnormal contact. The buffer capacity was verified against the kinetic energy of a moving panel–trolley assembly:

$$E = 1/2\, mv^2 \quad (1)$$

where m is the mass of the trolley–panel group (~212 kg) and v the nominal operating speed (7.4 m/min).

5.2 Connection verification

The custom steel brackets fixing the rails to the cable net were checked for shear, bearing, and combined stresses according to EN 1993-1-8. All bolts were grade 8.8 with self-locking nuts, preventing loosening under vibration. The brackets were also designed for eccentricity induced by the supporting cable net, which was assumed to deform up to ±30 mm horizontally and 300 mm vertically under rigging loads. These imposed displacements were directly applied to the connection nodes during verification to ensure robustness.

5.3 Fatigue verification

Fatigue analyses were carried out for all main components using Wöhler S–N curves and Goodman/Haigh mean stress corrections, following EN 13001 and EN 1993-1-9. Stress ranges for the trolley pins were evaluated between 139 MPa and 590 MPa, compared to endurance limits of 250–280 MPa. The cumulative damage index was determined using the Palmgren–Miner rule:

$$D = \sum \frac{n_i}{N_i} < 1.0 \tag{2}$$

with results of D < 0.1, confirming that the expected 2000 design cycles would not lead to fatigue failure.

Bearings were verified according to ISO 281. The SKF 30202 support bearings were calculated for more than 3.6 million cycles, while the SKF 6002 lateral bearings exceeded 6.1 million cycles, both values well above the ~900,000 cycles required. Gearboxes were rated for 10,000 hours of continuous service, compared to approximately 600 hours of expected operation, resulting in a margin of more than 16. Chains were dimensioned for maximum tensions up to 11.5 kN, with safety factors above 3.0 against breaking loads.

5.4 Serviceability criteria

Operational reliability was also verified under SLS conditions. Maximum rail misalignment was limited to ±5 mm to avoid trolley jamming, a threshold that was configured and monitored through the control software. Vibration and noise levels during panel movement were evaluated, confirming acceptable comfort levels for arena use.

Through this combination of static, dynamic, and fatigue verifications, supported by serviceability checks, the system demonstrated compliance with its defined design life and a significant durability margin, ensuring safe and reliable long-term operation.

6 MATERIALS

The retractable system combined lightweight alloys with high-strength steels in order to satisfy strict weight restrictions while ensuring durability. The rails were manufactured in aluminum alloy (6065 T6), selected for its low density and ease of millimetric bending to match the cable net curvature.

The structural components of the trolleys and brackets were fabricated in S355J2, C40, C60, and 30CrNiMo8 steels, materials chosen for their strength and fatigue resistance. The higher-grade alloy steel (30CrNiMo8) was applied to the most stressed pins and shafts, benefiting from increased endurance limits verified against Wöhler curves and EN 1993-1-9 procedures.

The trolley wheels were produced in polyamide, a material with a tensile strength of 80 MPa and a design stress limit of 72.7 MPa, providing sufficient wear resistance while minimizing weight and noise during operation.

All bolted connections were made with grade 8.8 bolts and secured by self-locking nuts. Verification was carried out according to EN 1993-1-8 and EN 13001-3-1, including checks against shear, bearing, and fatigue. All materials were supplied with certification and traceability, and quality control inspections were performed prior to installation to ensure compliance with the project specifications.

7 ENGINEERING CHALLENGES

Integrating the retractable ceiling into the cable net of the Avicii Arena presented several engineering challenges. The most relevant difficulties were related to the rail geometry, the reconciliation of acoustic requirements with the mechanical layout, the strict safety conditions of operating above an audience, and the large deflections of the cable net under rigging loads. Each of these aspects required dedicated design solutions and extensive verification.

7.1 Rails curvature

The rails had to follow the complex double curvature of the cable net surface. To achieve this geometry, each rail segment was not only bent with a controlled camber of approximately 9 mm at mid-span, but also angle-cut at the extremities. The combination of bending and angled joints allowed the assembly to reproduce the shape of the cable net with high accuracy. Continuous survey verification was carried out during installation. The rails were supported by custom-designed steel brackets, which were in turn connected to the cable net by stainless steel cable links. This configuration allowed local displacements of the cable net to be absorbed without transmitting secondary stresses to the mechanism.

7.2 Acoustics versus layout

The acoustic engineers defined the number, size, and inclination of the panels, which directly influenced the system geometry. Several proposed layouts were structurally unfeasible within the available envelope and had to be revised. The final configuration was the result of a coordination process that balanced structural feasibility and acoustic performance, ensuring that the mechanical design could be realized without compromising the required acoustic function.

7.3 Safety design

Because the system operates above a large public audience, safety requirements were critical. All bolts were grade 8.8 and secured with self-locking nuts to prevent loosening. Anti-fall measures were integrated into every suspended element, and bumpers were installed on both sides of the trolleys to prevent collisions even in case of abnormal operation. The buffers were dimensioned to absorb the kinetic energy of impact, and failure scenarios such as sudden power loss were considered in the design of emergency and manual recovery systems. Given that the Avicii Arena hosts up to 16,200 spectators during concerts, these redundancies and safety measures represented a fundamental requirement for the project.

7.4 Cable net deflection

The cable net is subject to variable rigging loads, as each event held in the arena allows presenters to suspend their own equipment and structures. This created a condition where the supporting nodes of the retractable system could undergo large displacements (up to ±200 mm vertically and ±30 mm horizontally). The system was therefore designed to be highly adaptable. The steel brackets included stainless steel cable links of different fixed lengths, since each connection point on the curved rails required a slightly different adjustment. The brackets allowed fine tuning on site, while the variety of cable lengths made it possible to match local conditions precisely.

The panels were also connected to each other, both at the top and at the bottom, in order to ensure alignment during operation. At the top, they were linked through a driving beam connected to the flexible joints of the trolleys, allowing the panels to follow the movement of the rail while remaining independent from local deviations. At the bottom, the panels were tied together by a stainless-steel link cable, which provided stability and adaptability without transmitting stresses. This arrangement ensured that the panels remained perfectly vertical by gravity when deployed or retracted, even under cable net deflections.

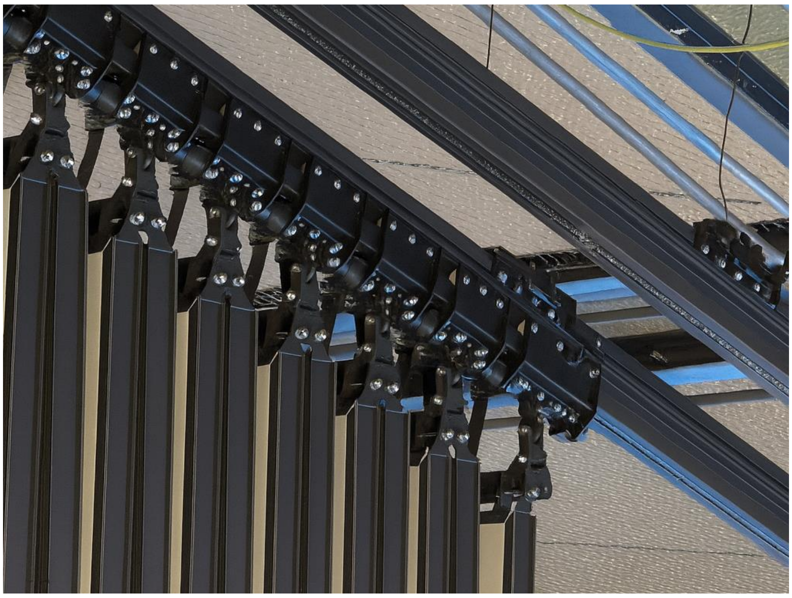

Figure 5: Flexible joints of the trolleys and connection to panels

This combination of flexibility at the brackets, joints, and panel connections ensured continuous operability despite imposed displacements. The mock-up confirmed that the system remained functional under these conditions, validating the adaptability strategy.

8 ELECTRICAL AND CONTROL SYSTEM

The retractable system is operated by a centralized electrical and control system, designed to guarantee both reliability and ease of use. The motor groups located at the rail ends are powered through dedicated switchboards, with two units installed on the north side and one on the south side of the arena. Each switchboard is physically connected to a defined set of bays, but the control architecture allows any switchboard to operate the entire system. This configuration provides both redundancy and operational flexibility, as operation can continue even if one unit is unavailable. The switchboards are installed at the technical level, above the cable net, and are directly linked to the arena control room for alarm communication.

The system is managed by a programmable logic controller (PLC) connected to a touchscreen interface. The operator can select either synchronous or independent movement of the bays, or choose among four pre-programmed operating scenarios defined at the client's request. The interface provides real-time information on panel positions and motor status, with alarms displayed for immediate intervention.

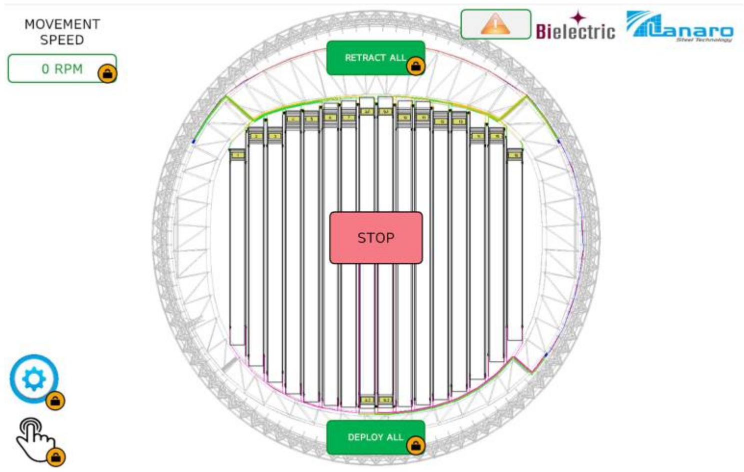

Figure 6: Control and monitoring schematic

Differentiated login credentials were implemented to restrict access: standard operators can only execute opening and closing commands, while maintenance personnel and administrators have access to advanced functions such as parameter adjustments and system diagnostics. This layered access structure prevents unauthorized modifications while maintaining usability for daily operations.

Safety was integrated at all levels of the control system. Emergency stop buttons are provided on each of the three switchboards, allowing immediate power cut-off in case of malfunction. In addition, the software continuously monitors the synchronization of the chains through encoder feedback: if a misalignment between parallel rails is detected, the corresponding bay is stopped automatically to avoid damage. Similarly, if the software detects an abusive use of motor power, operation is interrupted to protect the equipment.

The system also incorporates a complete logging function. All operations, alarms, and emergency events are recorded, and the number of operating cycles is also logged, providing a basis for preventive maintenance scheduling and traceability of use.

9 INSTALLATION, COMMISSIONING AND TRAINING

The installation of the retractable ceiling required careful planning due to the precision demanded by the rail geometry and the challenging deadline of the project. Before construction, a full-scale mock-up of one panel line was assembled to validate geometry, tolerances, stress behavior, and folding sequence. The mock-up also served to test conditions beyond the design values, providing confidence in the adaptability of the system under extreme scenarios.

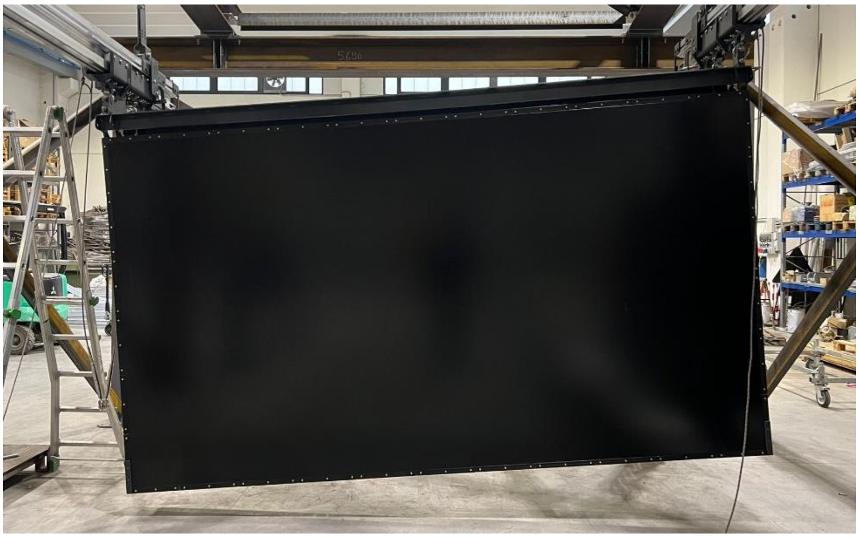

Figure 7: Deflection testing using the mock-up

On site, the rails were delivered in pre-assembled modules, each consisting of two rail segments joined together, for a total length of nearly 9 m. This approach minimized work at height and accelerated the erection process. The first and last rail modules were also pre-assembled with their respective motor or tensioning units, further reducing installation time. These measures were critical for meeting the very strict project deadline.

The modules were hoisted from the ground and hung into position, where they were connected to the cable net through brackets and stainless steel cable links. Geometric verification was carried out during assembly, while the availability of different fixed cable link lengths and adjustable bracket connections allowed local deviations to be accommodated on site.

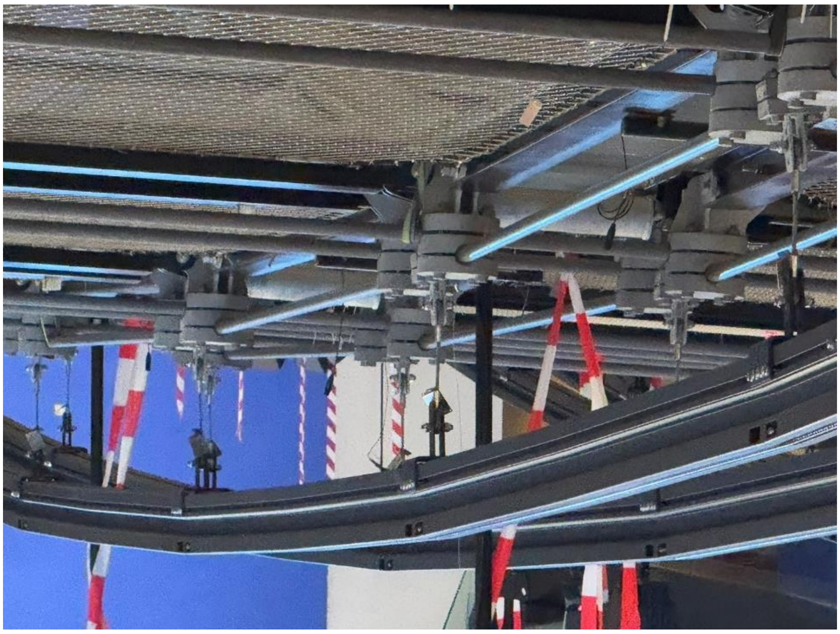

Figure 8: Rails connected to the cable net

The commissioning phase involved full opening and closing cycles to confirm proper operation. In addition, several risk situations were deliberately run to verify that the safety parameters of the control system were functioning correctly. These included encoder misalignment checks, motor overload conditions, and emergency stop activation. All tests were performed under controlled conditions, ensuring that the system could be validated without exposing the structure or personnel to unnecessary risk. Alarm communication with the arena control room was also tested and verified.

Finally, a training session was provided to the local staff, covering daily operation, selection of pre-programmed scenarios, emergency stop procedures, and interpretation of alarms. Maintenance personnel received additional instruction on inspection routines, parameter adjustments, and the use of system logs — including the cycle count function — for preventive maintenance scheduling. This ensured that the arena operators could safely and independently manage the retractable ceiling during its service life.

10 MAINTENANCE

The retractable system was designed with a preventive maintenance strategy to guarantee long-term reliability. Scheduled inspections are planned once per year, including servicing of the drive units, verification of structural connections, and software updates. Bearings were dimensioned for a service life exceeding ten years, while chains and trolleys are intended to be replaced on a condition-based approach rather than at fixed intervals.

All components of the retractable ceiling were conceived to allow selective replacement if necessary, without requiring dismantling of the entire mechanism. This design-for-maintenance approach ensures efficient interventions and minimizes downtime for the arena. The control system also logs the number of operating cycles, providing a direct basis for maintenance planning and life-cycle management.

11 CONCLUSIONS

The retractable acoustic ceiling of the Avicii Arena represented a complex integration of structural, mechanical, acoustic, and control systems within a cable net roof.

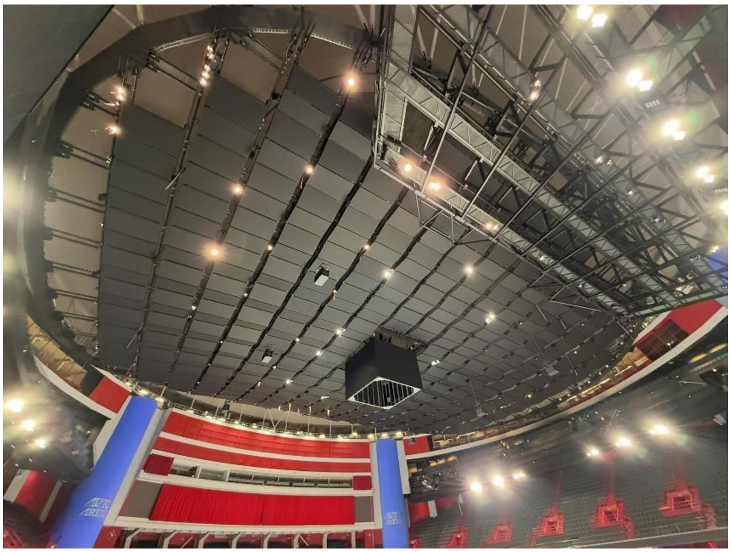

Figure 9: Completed roof

The project required precise rail geometry, adaptable connections, and flexible joints to accommodate large cable net deflections, while ensuring strict safety requirements for an arena hosting up to 16,200 spectators. Extensive structural and fatigue verifications demonstrated that the system provides durability far beyond its design life, while commissioning and risk testing confirmed the reliability of the safety functions.

The solutions adopted in design, installation, and maintenance established a robust system capable of long-term operation and efficient servicing. The project demonstrates how advanced retractable mechanisms can be successfully implemented in large venues, combining adaptability, acoustic performance, and public safety in a single system.

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