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SCALO CULTURA

"Thanks to the Winter Olympic Games of Milano Cortina 2026, a new village for the athletes will be located in the abandoned railway yard of Porta Romana in Milan. The thesis takes advantage of this opportunity and provides a new masterplan for the area: a project based on the soft mobility and on a new park, to create a new green lung for the city."

A PARK OF LIGHTWEIGHT STRUCTURES FOR THE REDEVELOPMENT OF THE PORTA ROMANA RAILWAY YARD

Dlubal

University of Trento, Italy

MASTER THESIS

Architecture and Building Engineering

THE OLYMPIC OPPORTUNITY

On June 16, 2019, *Milano* and *Cortina* were awarded for holding the ***Winter Olympic Games of 2026***. The organization of the event offers the opportunity to the host city to build a new ***Olympic village***. This opportunity represents a powerful stimulus for the economic and social growth of the hosting cities. In this case, the area chosen for construction is the abandoned railway yard of *Porta Romana* in Milan. The thesis project focused on the redevelopment of Porta Romana area, exploiting the intriguing concepts of the lightweight structures. The first part of the work examines the ***multiple impacts of these events*** (Olympics and Expo are often reviewed together) on the Countries and the host cities. To better understand the problem, we started investigating three events: the Universal Exposition of Lisbon '98, the Olympic Games of London 2012 and the Milano Expo 2015. This analysis shows that, as expected, these mega-events ***speed the redevelopment*** of the host city. For this reason, the Olympic Games represent, for Milan, an excellent opportunity to revitalize the abandoned area of *Porta Romana*.
The realization of ***services and infrastructures*** for the Olympic Games must be facing the future, avoiding wastefulness of resources and money.
The *Scalo Cultura* project aims to give an essential ***legacy*** to the city, thanks to a new park based on soft mobility and a green system. ***Four new open public spaces***, located inside the park and covered by ***four tensile structures***, will provide the goals of innovation and temporariness that these places need.

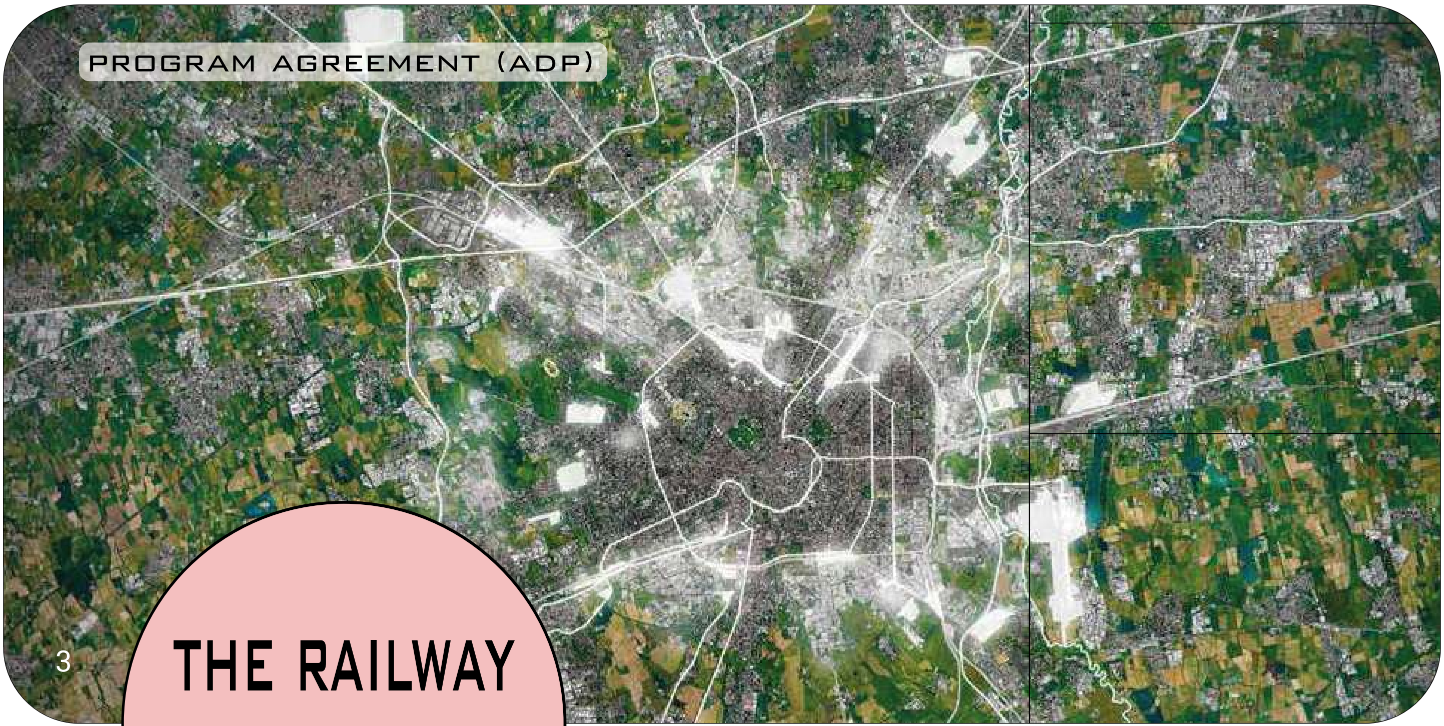
AN IMPORTANT LEGACY TO THE CITY

Note | The present brochure is a graphical abstract of the master thesis "Scalo Cultura, Riqualificazione dello scalo ferroviario di Porta Romana attraverso un parco di tensostrutture". A full version of the thesis is available for the downolad form the link: http://www.ing.unitn.it/~diego.misseroni/thesis/Thesis_Carraro.pdf

PAST, PRESENT AND FUTURE OF THE CITY

The second part of the research debates the past, the present and the future growth of Milan. This analysis aims to understand the ***background of the city*** and the urban context in which the project will develop. These preliminary studies have allowed integrating the project into the Milan urban environment, trying to avoid the "*white elephant*" phenomenon. In fact, the building creation for events like the Olympics is usually a financial endeavour which fails to live up to its expectations. Our ambition is to promote the ***assimilation of the area into the urban pattern*** to allow a more straightforward conversion of the Olympic village to a ***student residence***, once the event will be over.
Furthermore, the careful investigation of the present situation of the city shows the need to improve the actual conditions, as in terms of ***new functions*** as for the necessity to have ***more parks and green areas***.
The seven abandoned railway yards, spread in the city, are ideal for creating a renewed Milan if the projects are suitable for these sites.
Finally, we investigated the relationship of the urbanistic growth of the city with the realization of the new "CityLife" district, and the controversial organization of the "EXPO" held five years ago. We strived to understand the ***future growth of the city*** and its relation with the landscape to improve the actual conditions of the territory.

THE GROWTH OF MILAN



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THE RAILWAY YARDS

A NEW LINK BETWEEN THE CITY AND THE METROPOLITAN AREA

The situation of the ***seven railway yards*** of the city of Milan is very complicated. This argument, deeply discussed over the years, is crucial because these areas are vital for the ***future growth of the city***. Indeed these spaces could represent the new link with the metropolitan area of Milan, playing a crucial role for the urban and economic development of the district.

We started analysing the development of the railways over the years. This investigation is essential to understand why, a long time ago, these railways were abandoned and because, after the redevelopment, the rail traffic will be probably intensified.

Then we proceeded to study the ***program agreement*** (*AdP*). This document is an integration of the urban plan (*PGT*) that prescribes the ***project guidelines*** for these specific areas. The *AdP,* whose discussion started in 2005 was only approved in June 2017.

Finally, we did a comprehensive analysis of ***similar projects***, already completed, for the redevelopment of others abandoned railway yards in Milan.

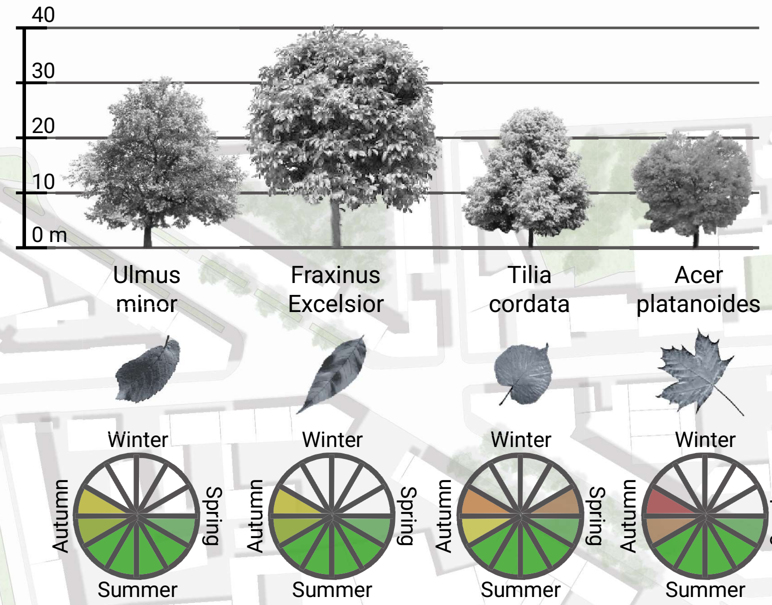
The *Scalo Cultura*, masterplan, aims to achieve several ***goals***.
Firstly the attention is focused on the soft mobility to ***integrate*** the area inside the urban structure of the city. This topic is fundamental because the previous development of the urban context excluded this area. The idea is to create ***two principal paths*** that cross the area from East to West. Such sports routes will create a direct connection between the two ends of the area giving to the area the vitality that it needs. Shorter North-South paths will ***link two areas*** of the city that are currently ***disconnected***.
The new topography of the site will provide a ***new identity*** to the abandoned railway. The hills will adapt their forms to the physiography of the area and the train track. This solution allows creating two ***ecological overpasses*** in perfect harmony with the park and ***mitigating*** the acoustic and visual effects of ***the train***.
Four new public functions will be created inside the area to allow the park to be lived and frequented by the people of the city and its guests. These ***four spaces*** will be ***covered by tensile structures*** which give them the possibility to be used every time during the year.
There will be a new art exposition area in the south part of the masterplan in connection with *Fondazione Prada* and a new playground for children due to the number of nursery schools in this part of the district. The Olympic village, with a new sports area, will locate in the north part of the area. This location is strategic because is linked with the ***majority services*** that the park and the urban context will offer.

SOFT MOBILITY

NEW TOPOGRAPHY

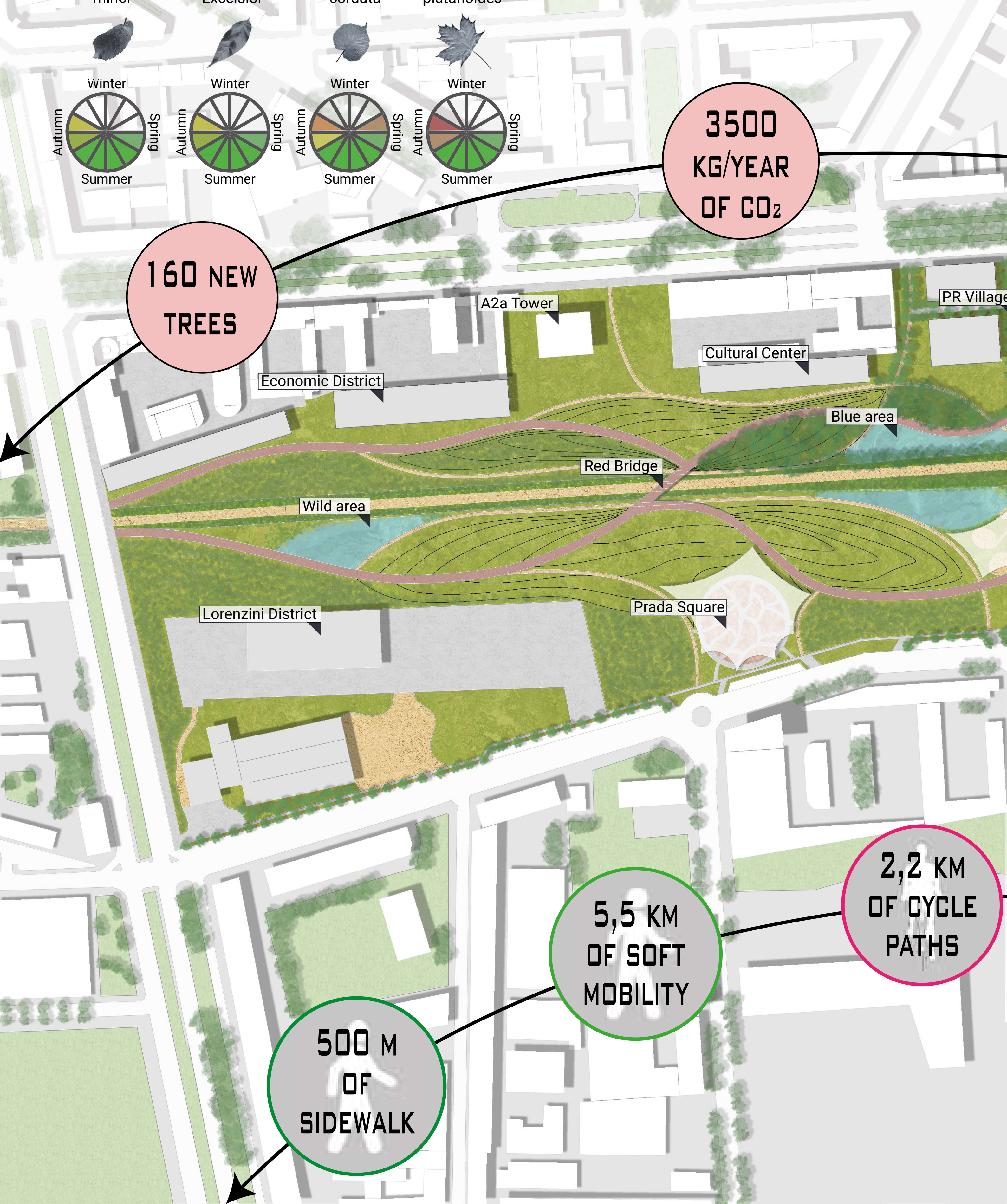
NEW FUNCTIONS

THE GOALS OF SCALO CULTURA

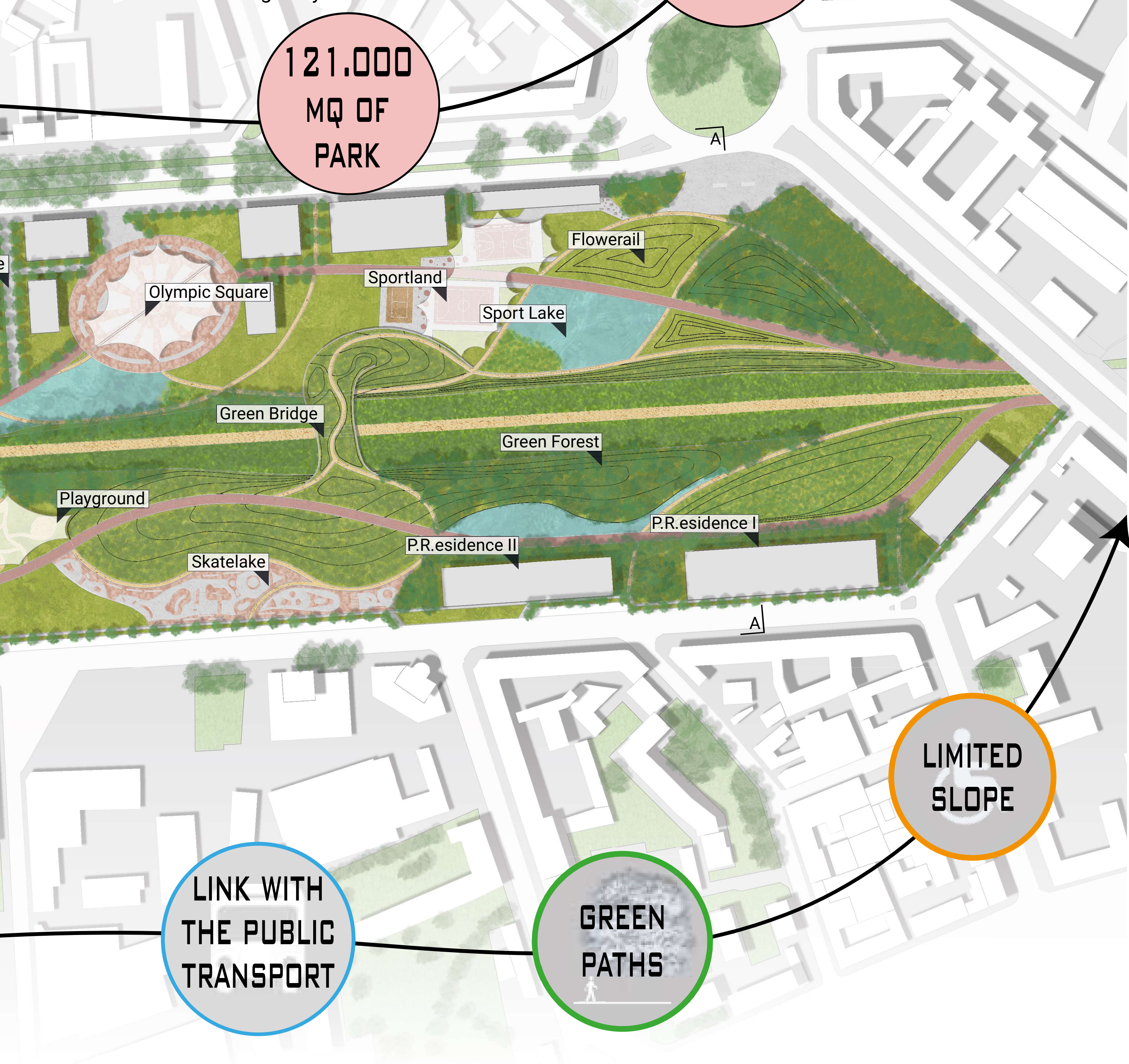


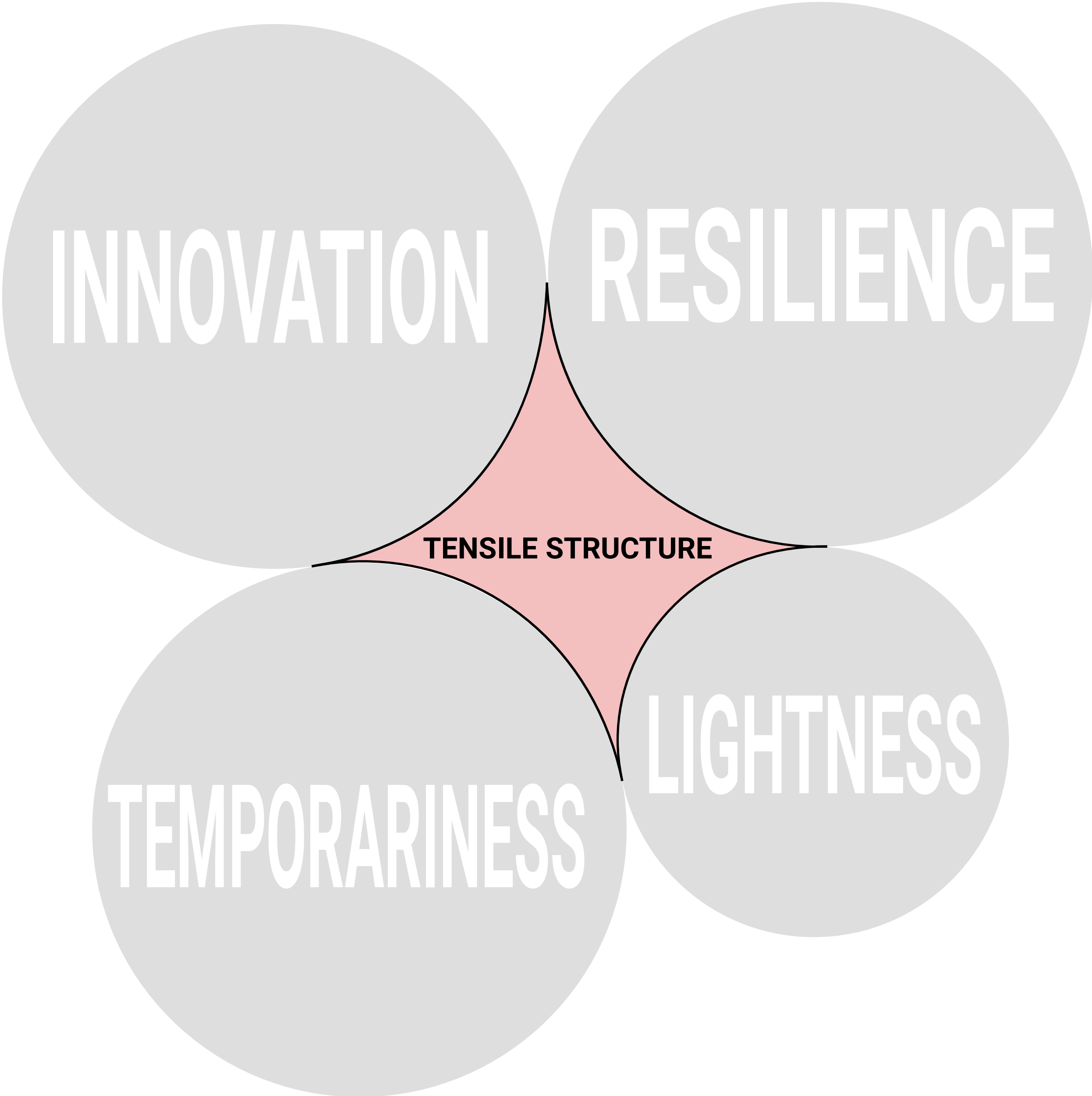
NATURAL SYSTEM

The natural system is composed mainly by ***autochthon species***. This choice offers the best assimilation of carbon dioxide per year, improving the ***quality of the air***. Therefore, it will be beneficial for all the neighbourhoods in the proximity of the railway yard and will become a ***new green lung*** for the city of Milan.

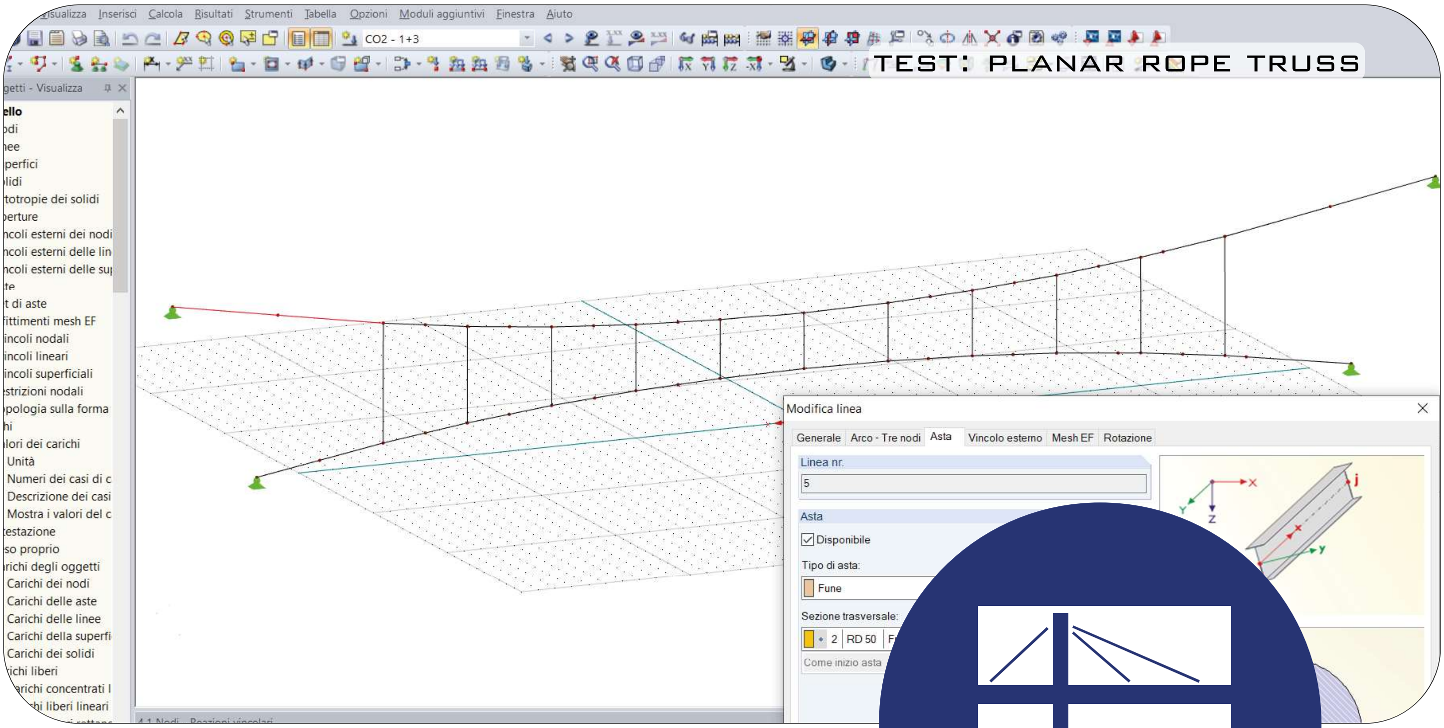


The research also focused on the investigation of the new relationship between the park and the ***urban context***. We examined the ***time*** required to move from one point to another, or the relationship among the function of the tensile structures and the other services distributed in the nearest neighbourhood. The ***materials*** of the paths were chosen considering several factors: i) the functions inside the park, ii) the slope of the track, iii) the speed of realization, and iv) the maintenance during the years.



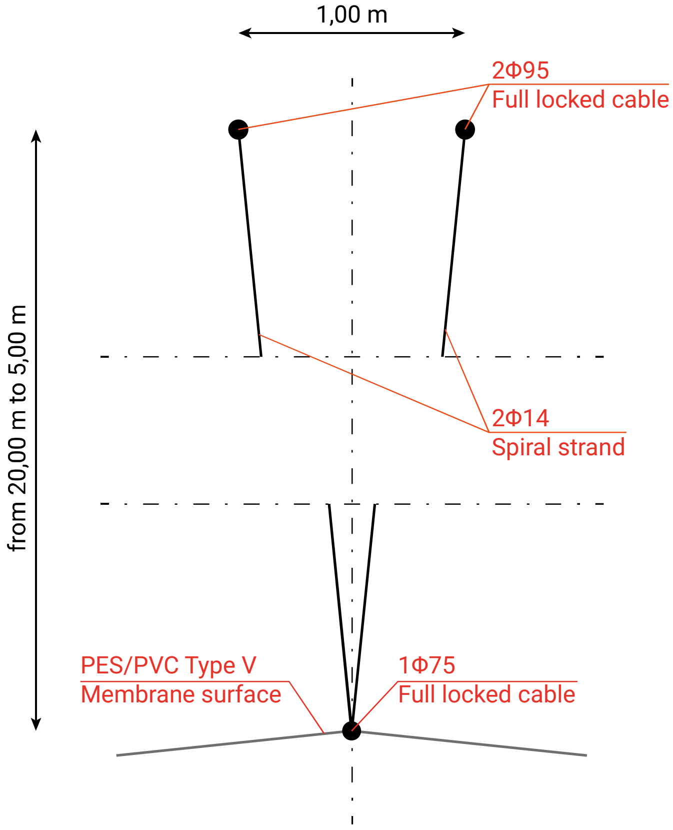


OLYMPIC PARK IN MONACO



The installations for the Olympic games, or Expo events must cover large spaces keeping a temporary nature. For these reasons, ***membrane structures fully meet these requirements*** because of their ***extreme lightness and temporariness***.
After a brief overview of the main categories of such constructions and historical background of the problem, the work highlights the reasons that pushed the project choices of one of the four tensile structures inside the park. In particular, the discussion focuses on one of the vital element for a successful design, the type of building material used in construction.
The most utilised component for architectural constructions is the ***coated fabric***, for its flexibility, strength and durability. The knowledge of the ***mechanical properties*** of these textile materials is always very complicated and required specific studies and the execution of experimental tests. In fact, such properties are not unique but change from manufacture to another. For example, the leading architects in the sector, like *Frei Otto*, were always supported by membrane surface manufacturers.
The last arguments examined face the ***detailing*** and ***cutting pattern*** problems. We designed and verified several types of connections, e.g. between the fabric and the support elements, or between the same textile membrane surfaces.

We designed the lightweight structure with the ***RFEM*** of ***Dlubal Software S.r.l***, suitable for facing these complicated problems e.g. ***form-finding*** and ***cutting-pattern***. It gives the opportunity to create surfaces with particular mechanical properties, such as ***orthotropy***, that are essential to study the behaviour of fabric surfaces.
Before to proceed with the final design, we improved our skills in the use of the software by performing several preliminary simulations. We replicated well-known examples, such as the *Hypar* and the *planar rope truss* problems, and compared the numerical results with the analytical solutions.
After this "training" process, we performed a ***parametric analysis*** to identify the best configuration for the ***rope truss***, assuming as an input parameter the inclination of the connecting ropes. Finally, we moved to study a fully 3D problem. The membrane is attached at one side to the bearing ropes truss and on the other side to the boundary cables, connected to the external supports.

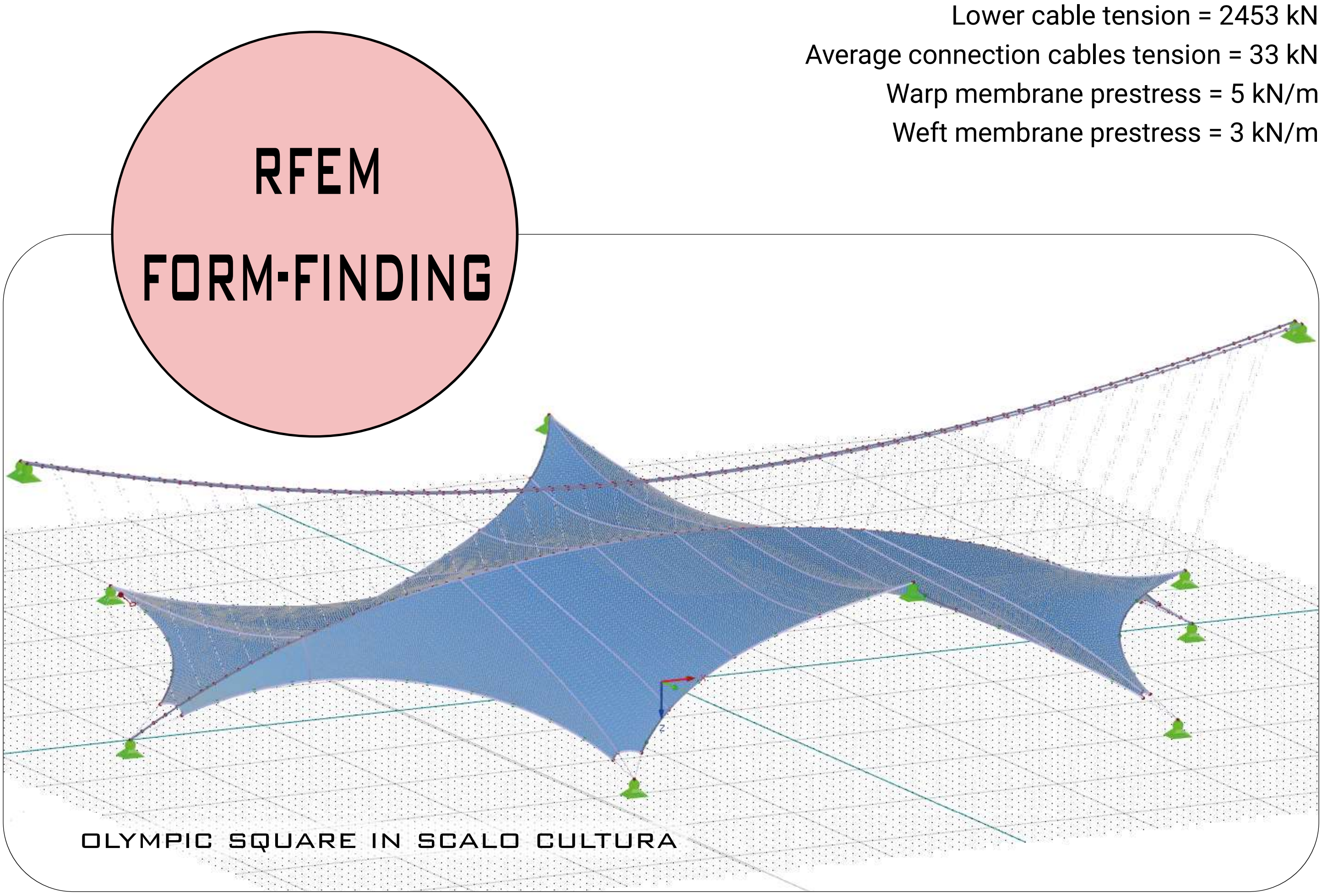


Planar rope truss configuration

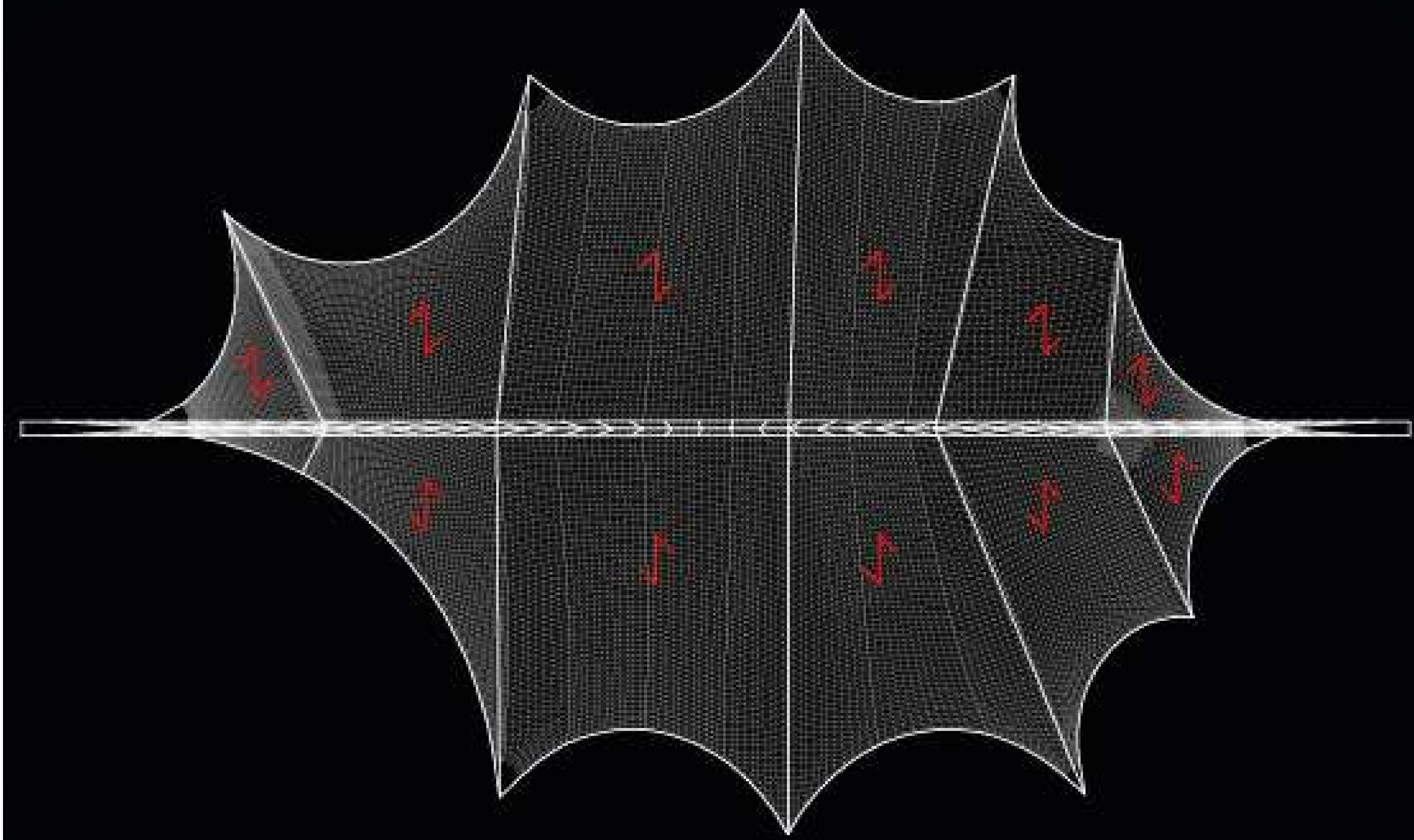
We decided to design the covering above the ***Olympic Square***, the most fundamental structure of the whole masterplan. The particular shape of the fabric is conceived coherently with the design of the path within the park. Indeed, the form of membrane structures is not freely selectable but is the result of a "*form-finding*" process that takes into account the ***constraints***, ***loading conditions*** and ***prestresses***.
The ***final form*** of the structure that accomplishes all the requests is the results of a very demanding iterative process. For this reason, ***architecture***, ***landscape*** and ***engineering*** are merged to achieve the perfect project.
The main structure consists of a ***planar rope truss***, with two bearing cables at the top and one stabilising cable at the bottom. The first bear the downward pressure from the snow, the latter the upward pressure of the wind. Several ropes are attached to the stabilising cable to give support to the membrane surface. The final shape of the membrane must be ***anticlastic***, namely with a double curvature, so to better transfer the loads acting from each direction.

DATA

Covered area = 2550 m^2
Central high of the membrane = 10 m
Span of the planar rope truss = 80 m
Upper cables tension = 3583 kN
Lower cable tension = 2453 kN
Average connection cables tension = 33 kN
Warp membrane prestress = 5 kN/m
Weft membrane prestress = 3 kN/m

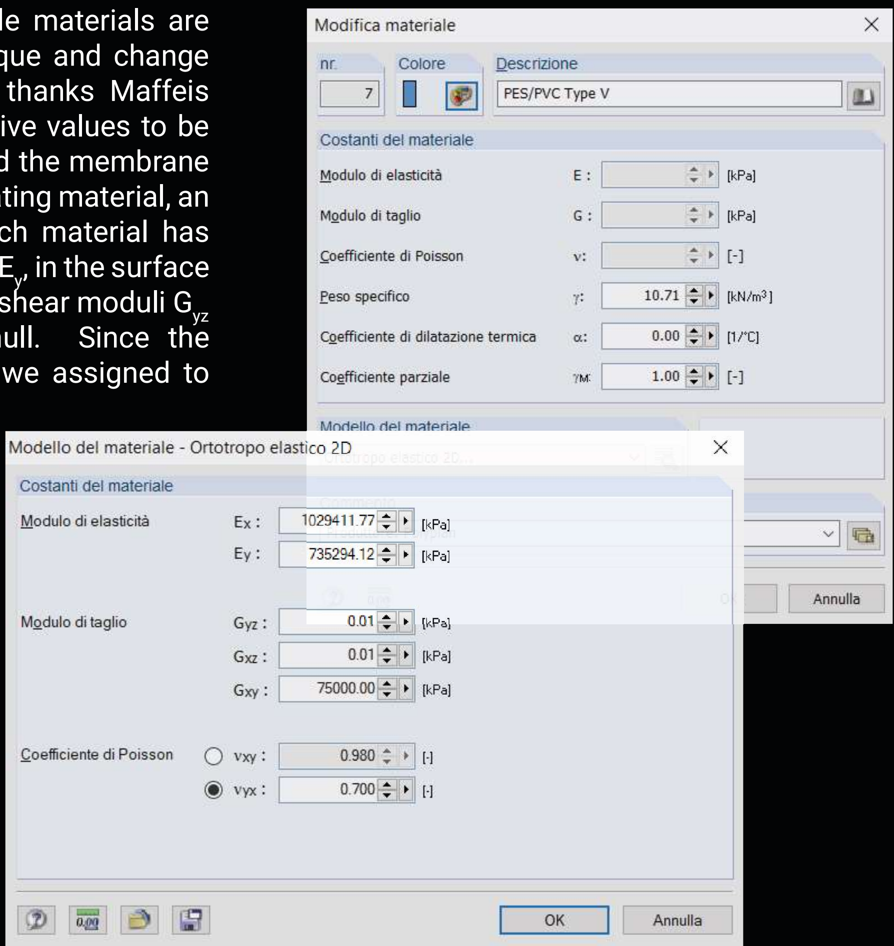


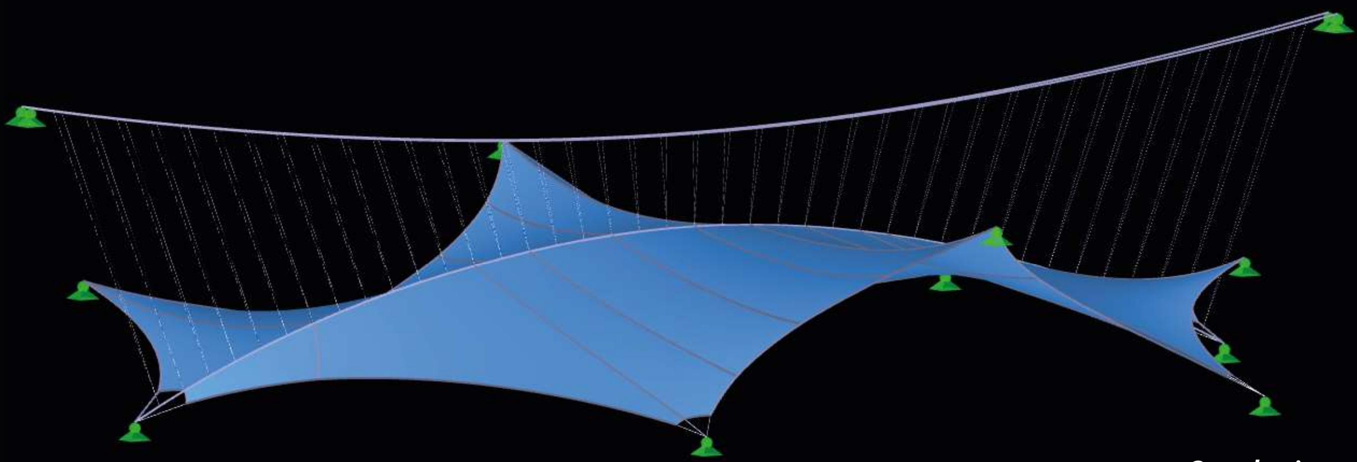
WARP DIRECTION OF THE FABRIC



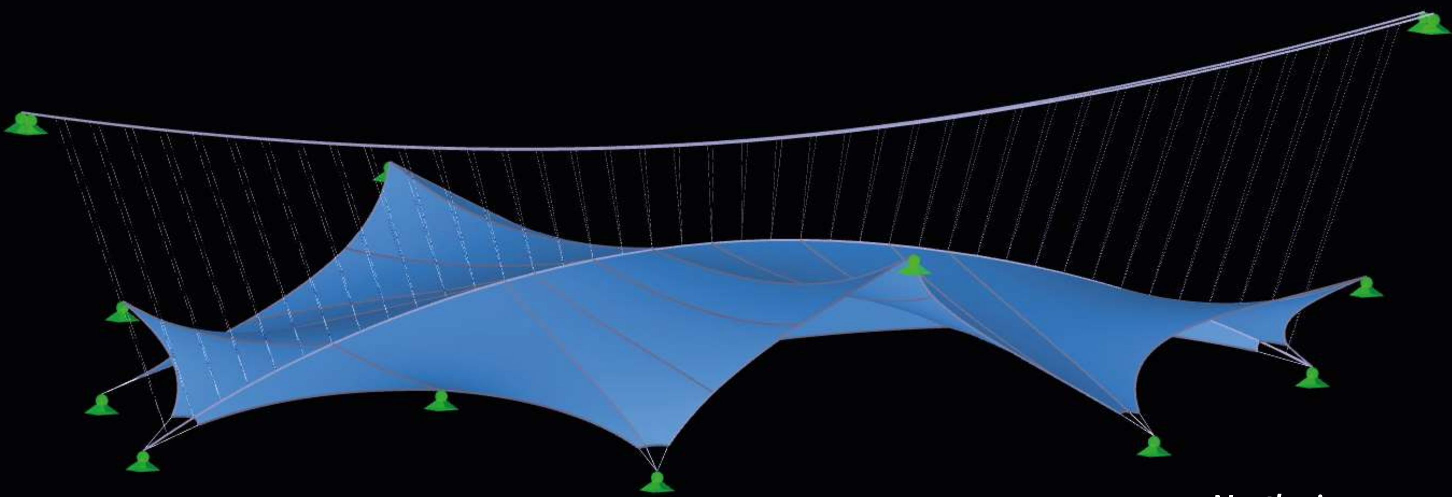
MECHANICAL PROPERTIES OF THE FABRIC

The mechanical properties of textile materials are hard to find since they are not unique and change from manufacture to another. We thanks Maffeis Engineering for providing us indicative values to be entered in the software. We realised the membrane structure with a ***PES/PVC Type V*** coating material, an ***orthotropic elastic 2D material***. Such material has different bending stiffnesses, E_x and E_y, in the surface directions x and y, respectively. The shear moduli G_{yz} and G_{xz} theoretically should be null. Since the software requires a no-zero value, we assigned to them a lower number.

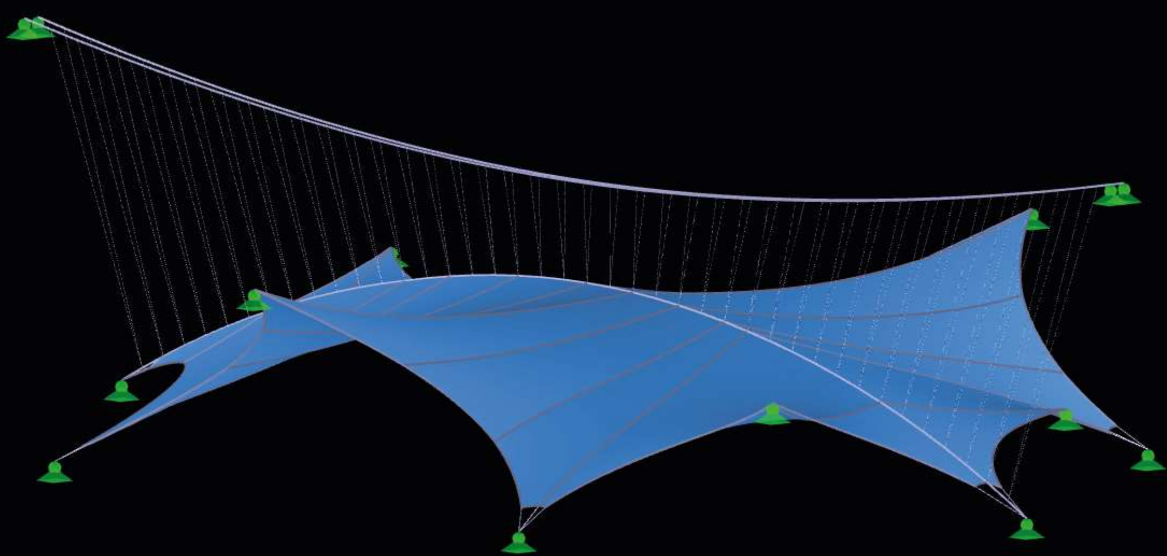




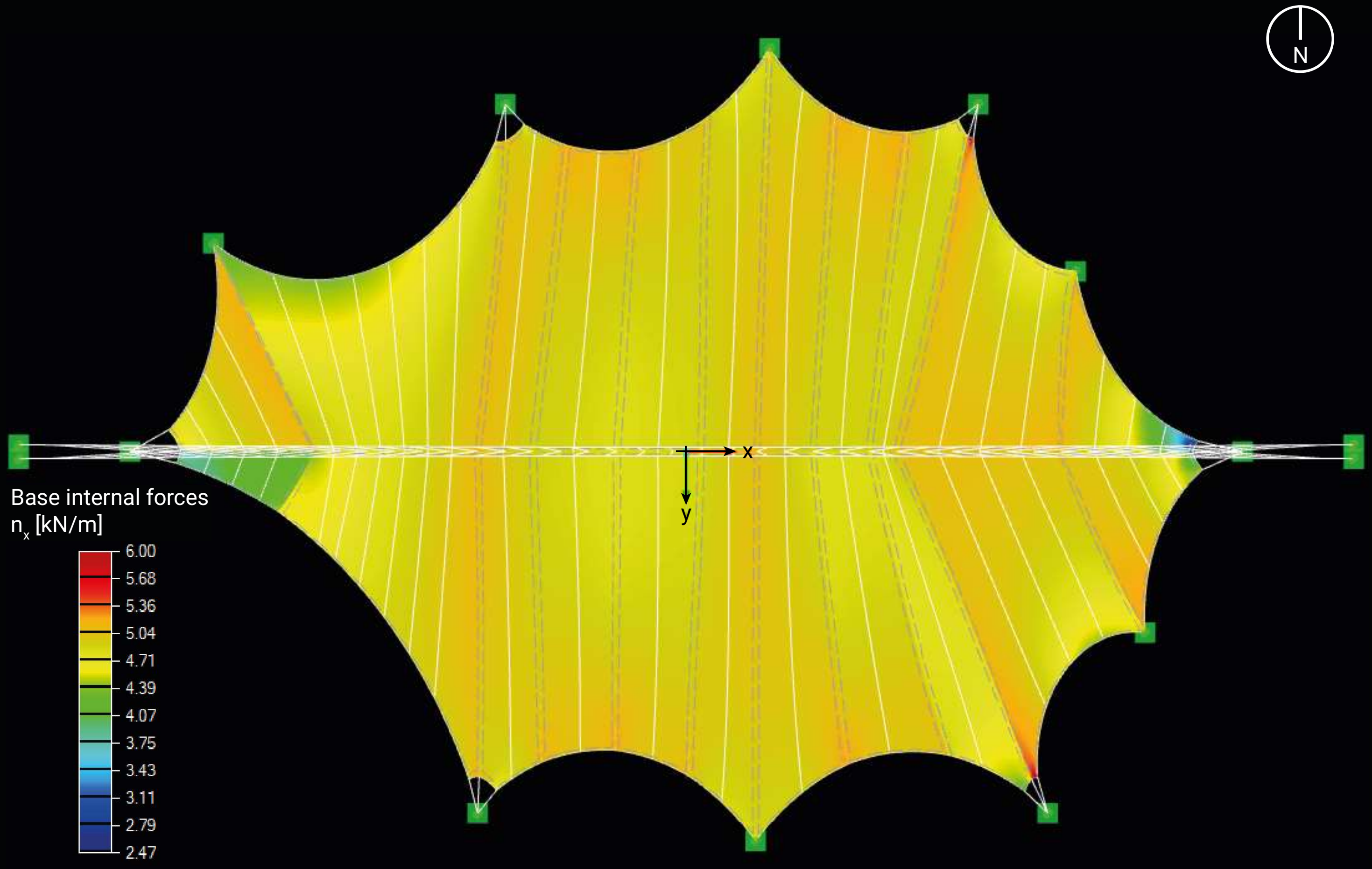
South view



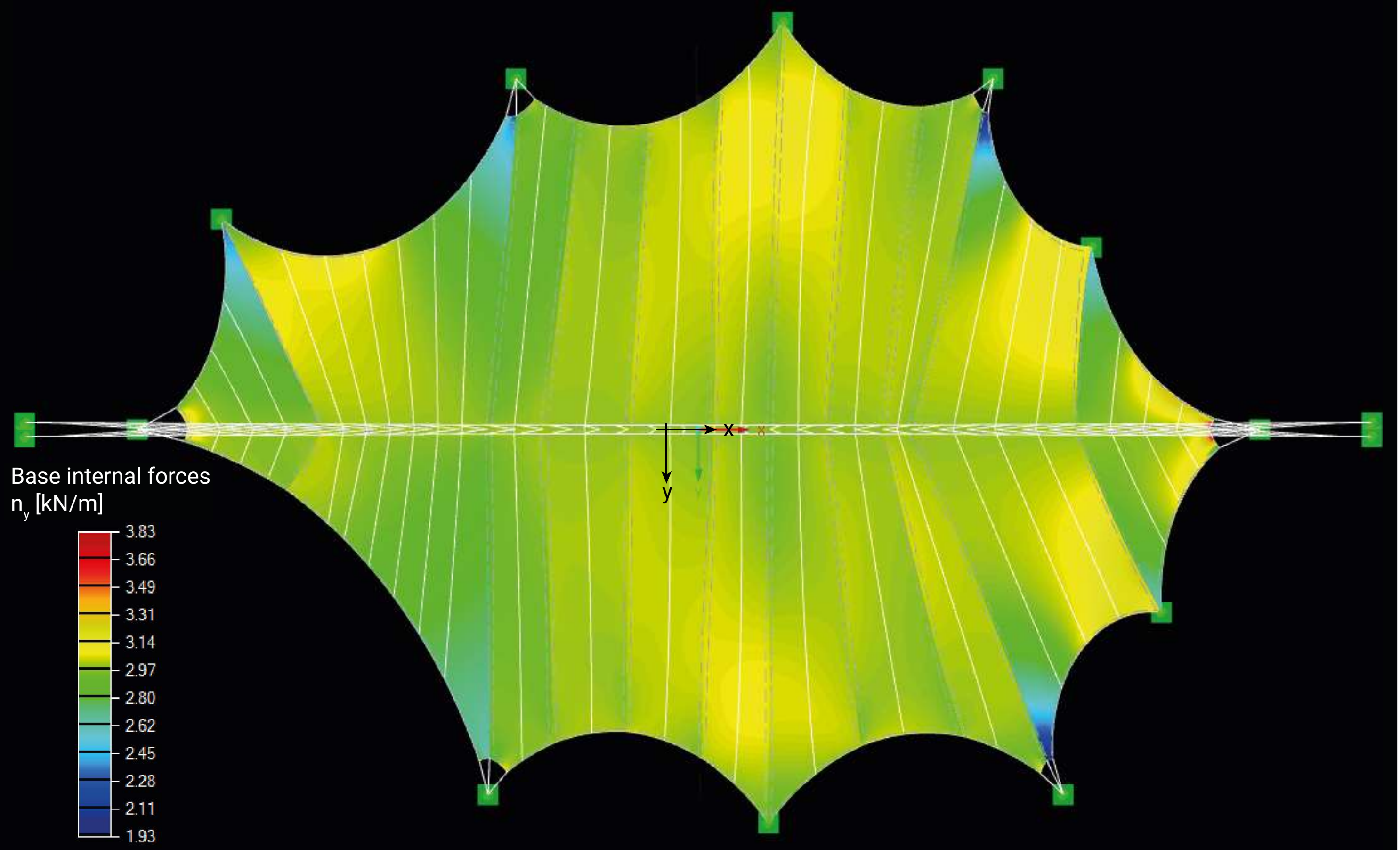
North view



East view

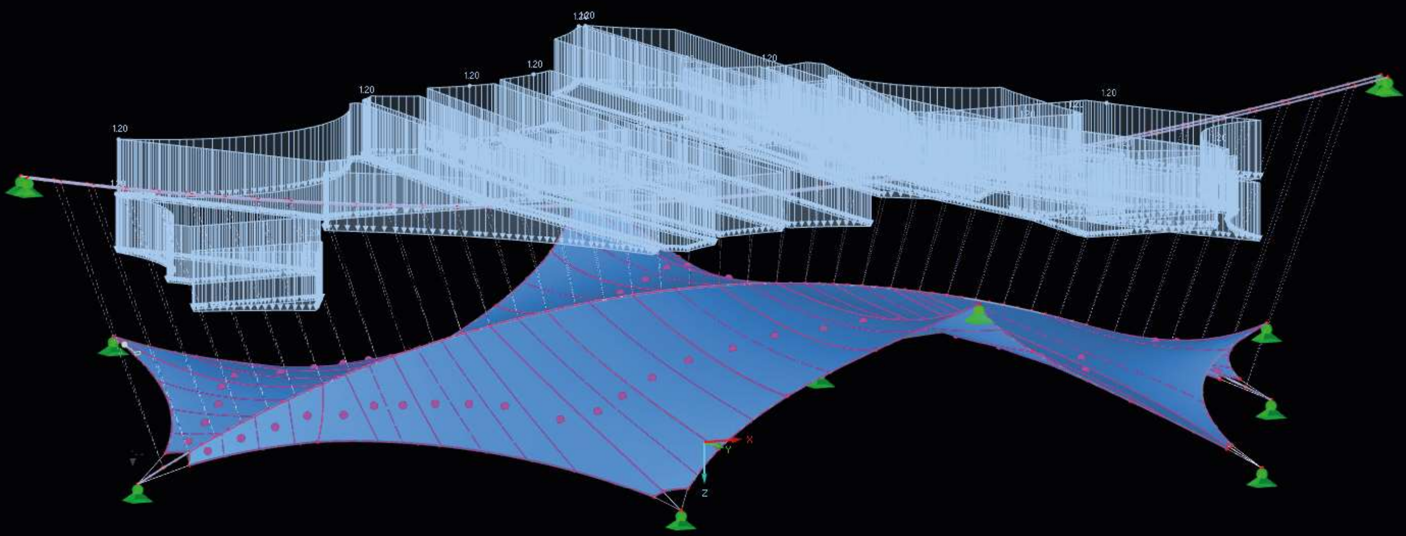


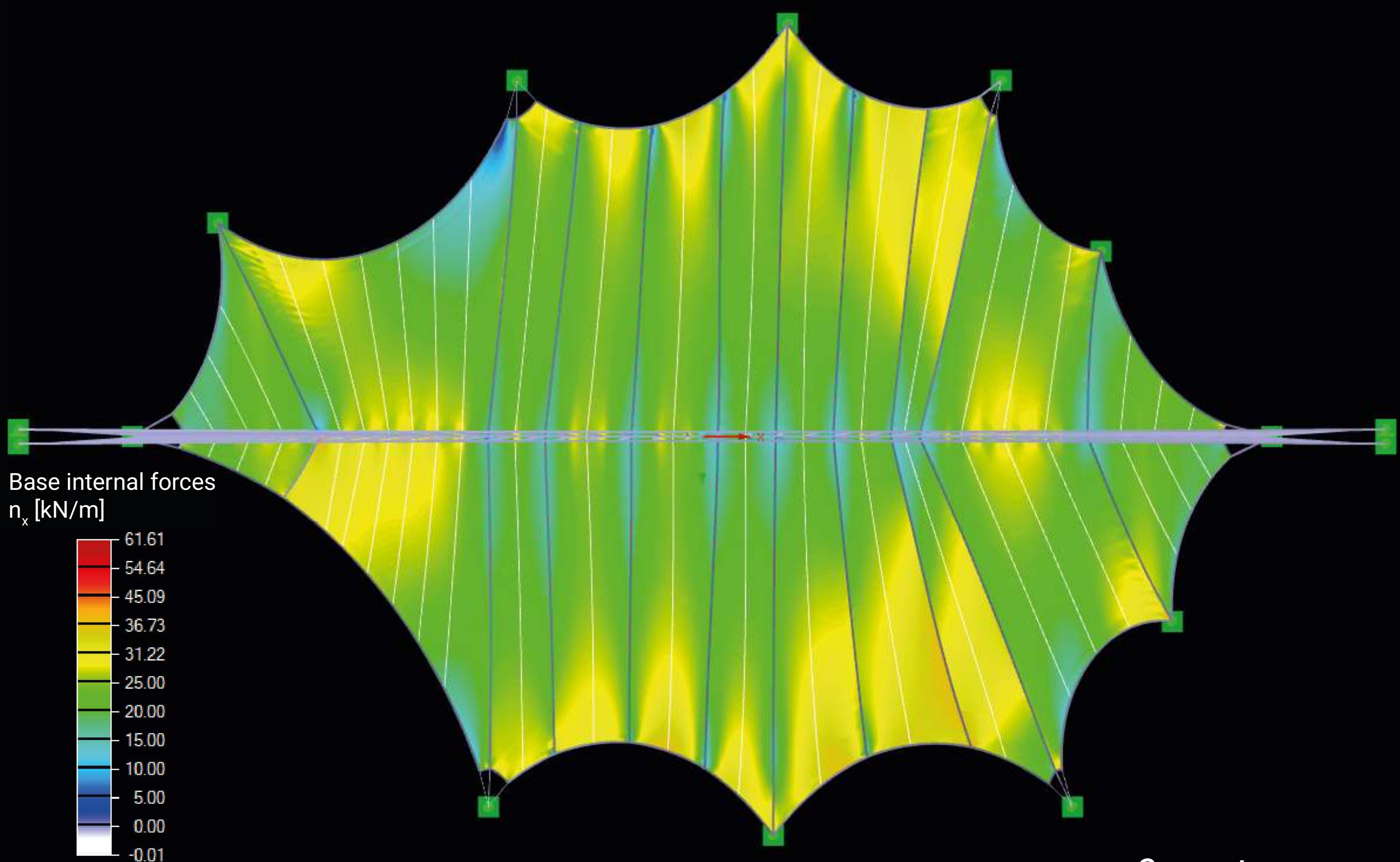
Permanent stress n_x



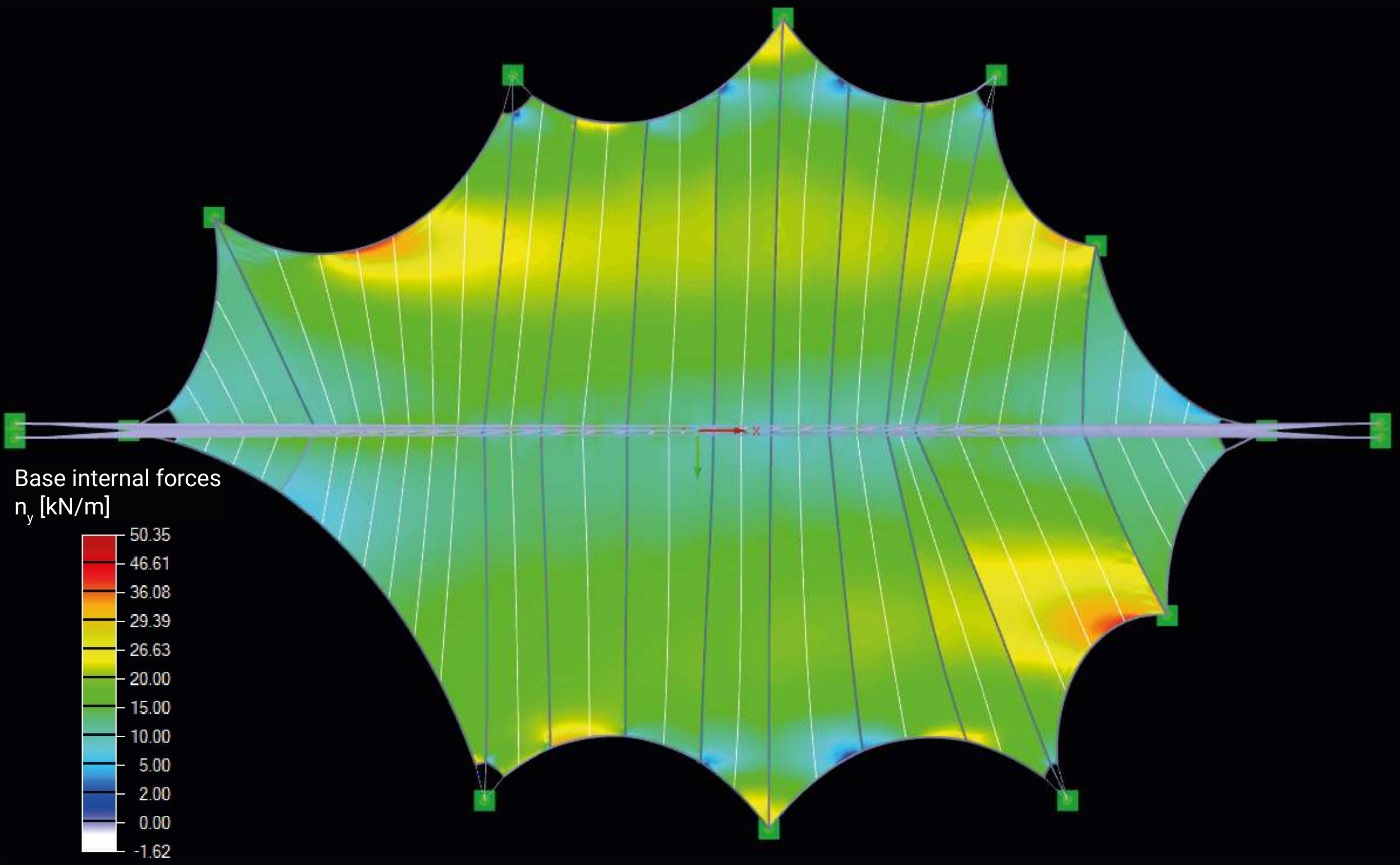
Permanent stress n_y

SNOW COMBINATION RESULTS

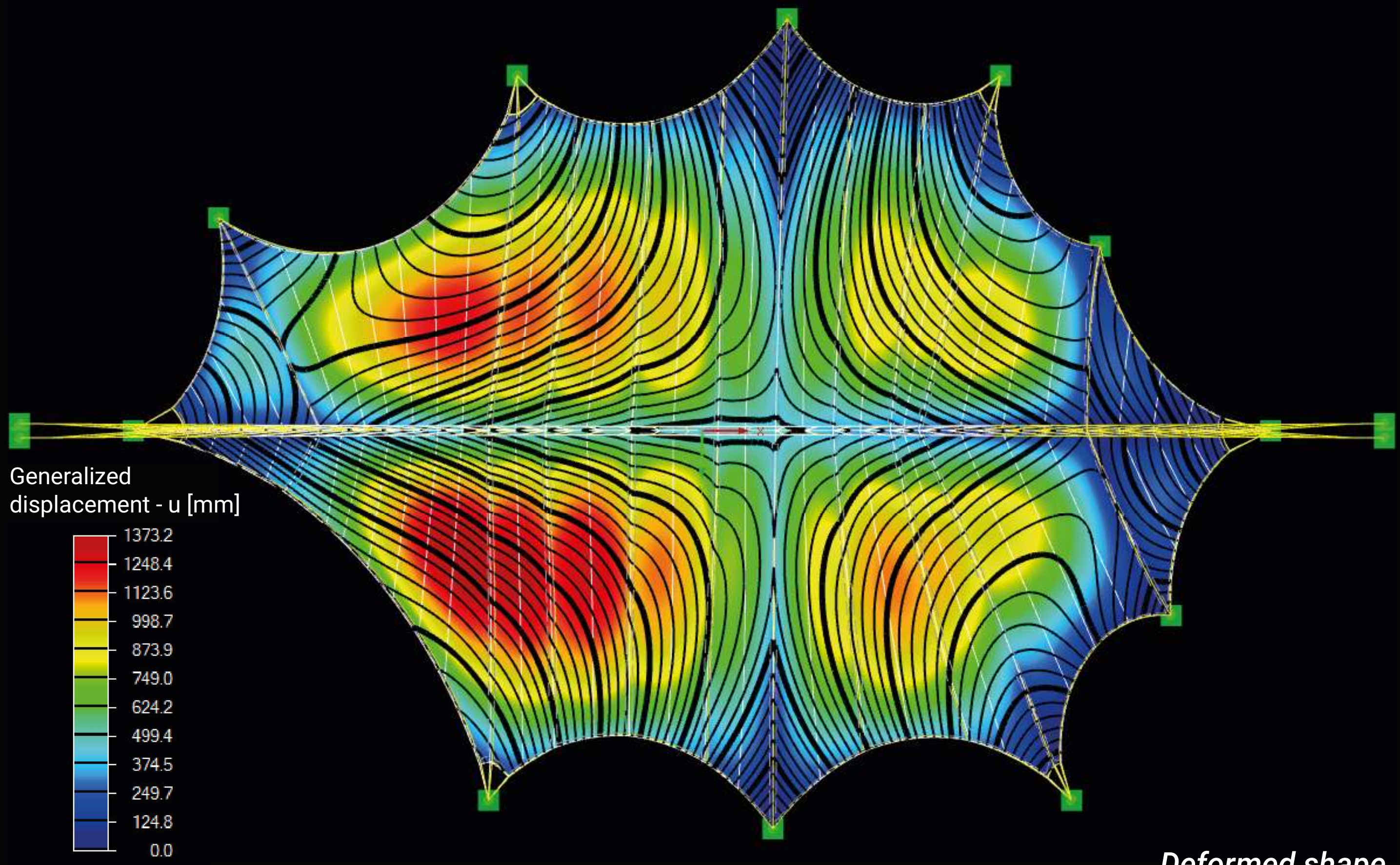




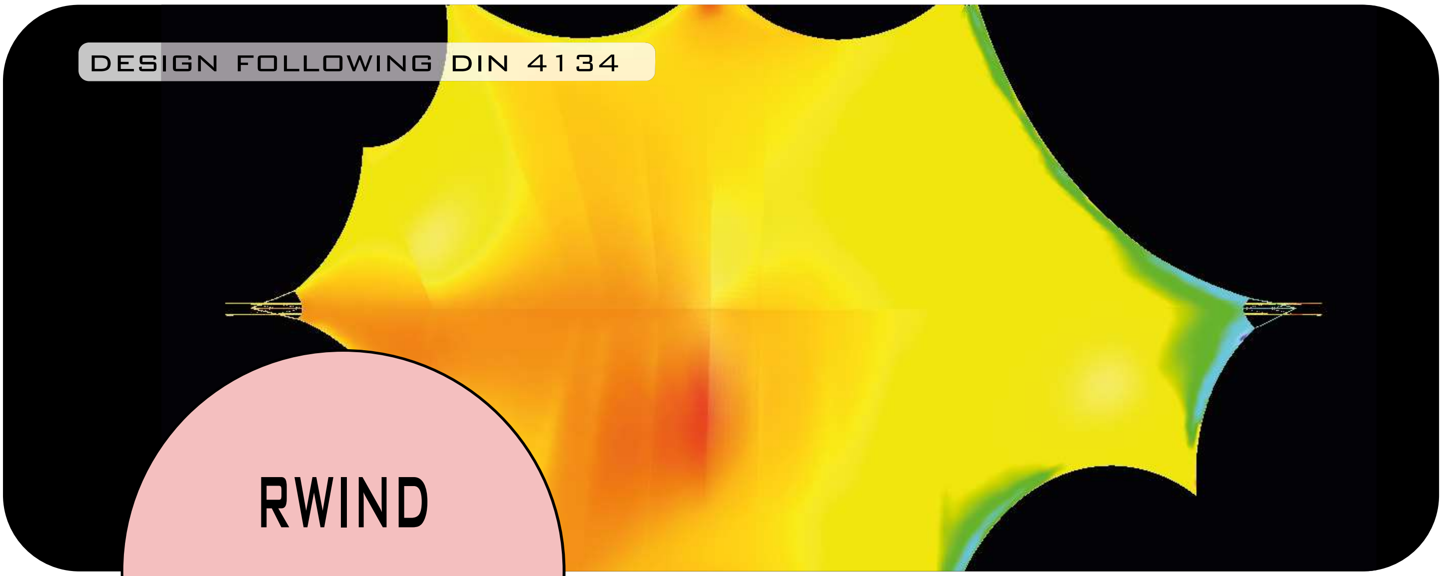
Snow stress n_x



Snow stress n_y



Deformed shape under snow loading



RWIND SIMULATION

The project was carried out accordingly with the *German design code DIN 4134* and the dissertation of "*Mechanical Behaviour of connections of coated fabrics*".
The German design code approach, prescribes three different design load cases, namely ***permanent***, ***maximum snow*** and ***wind storm***. The present technique computes the ***allowable stress*** through the use of the factor of safety, similar to the old permissible-stress design method. The safety condition is satisfied if the stresses developed in the structure due to service (unfactored) loads remain lower than the allowable stress.

SNOW RESULTS

Upper cables tension = 4771 kN
Lower cable tension = 1151 kN
Average connection cables tension = 101 kN
Warp membrane maximum stress = 45,09 kN/m
Weft membrane maximum stress = 44,14 kN/m

WIND RESULTS

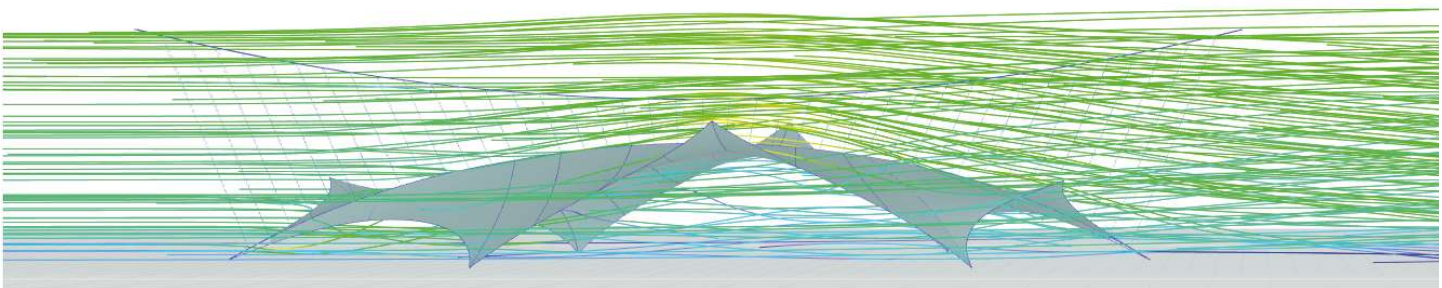
Upper cables tension = 3833 kN
Lower cable tension = 2559 kN
Average connection cables tension = 57 kN
Warp membrane maximum stress = 37,50 kN/m
Weft membrane maximum stress = 24,18 kN/m

Maximum snow

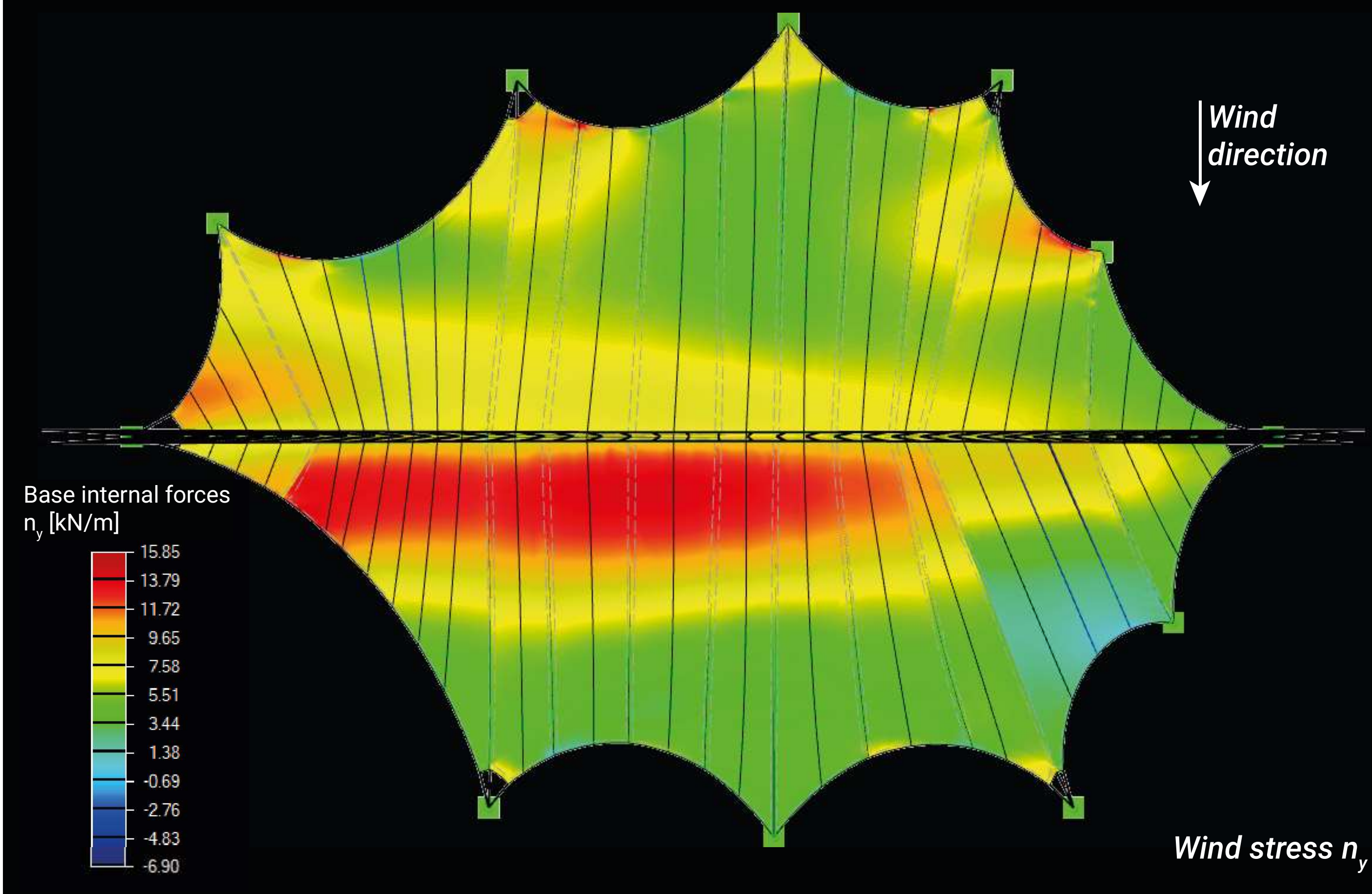
In addition to the tensile stress, the maximum snow combination imposes to verify the ***ponding effect***. Due to the nature of textile material, it is mandatory to avoid the accumulation of snow on the membrane surface since it could lead to its failure. The snow can runoff from the surface of the membrane, and therefore the verification is met if all the level curves do not turn into closed lines.

Wind storm

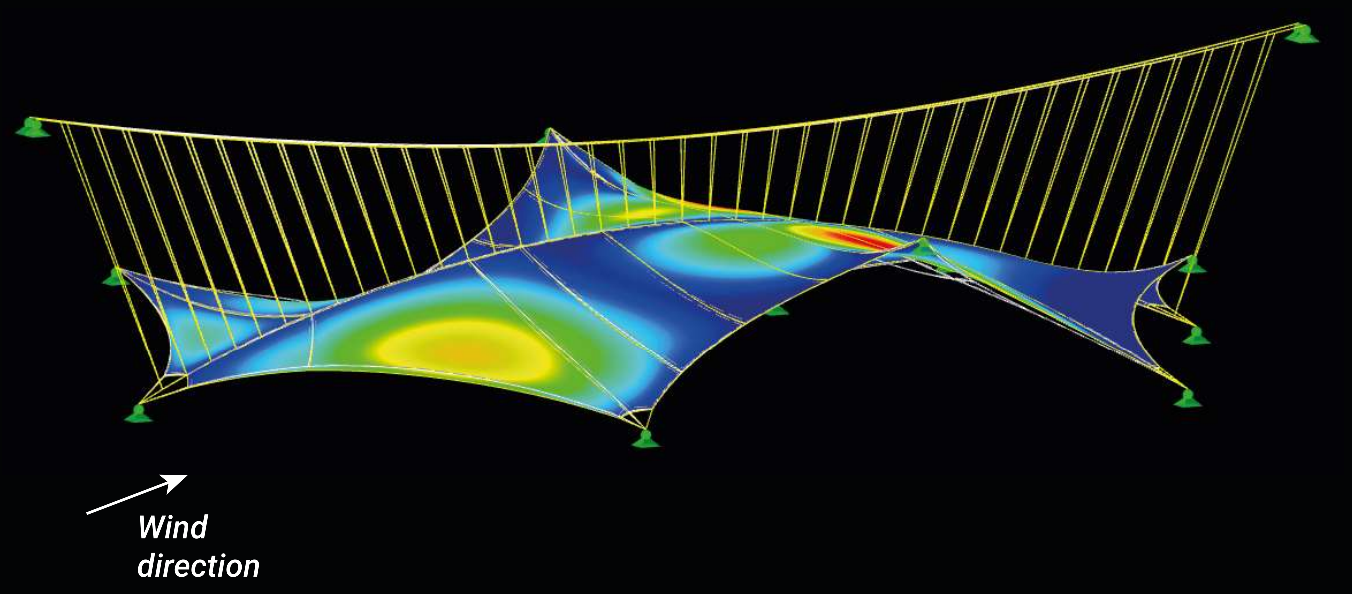
In the case of very ***irregular shapes***, as in our case, we cannot apply the usual coefficients of pressure, specific only for standard form. For this purpose, we exploited the ***RWIND-simulation*** plug-in (by Dlubal company). This application uses a CFD (Computational Fluid Dynamics) numerical model to simulate a wind tunnel and determine the (wind) pressure acting on the membrane surface. We performed ***4 different simulations***, one for each wind directions (North, East, South and West).



WIND COMBINATION RESULTS



Wind stress n_y



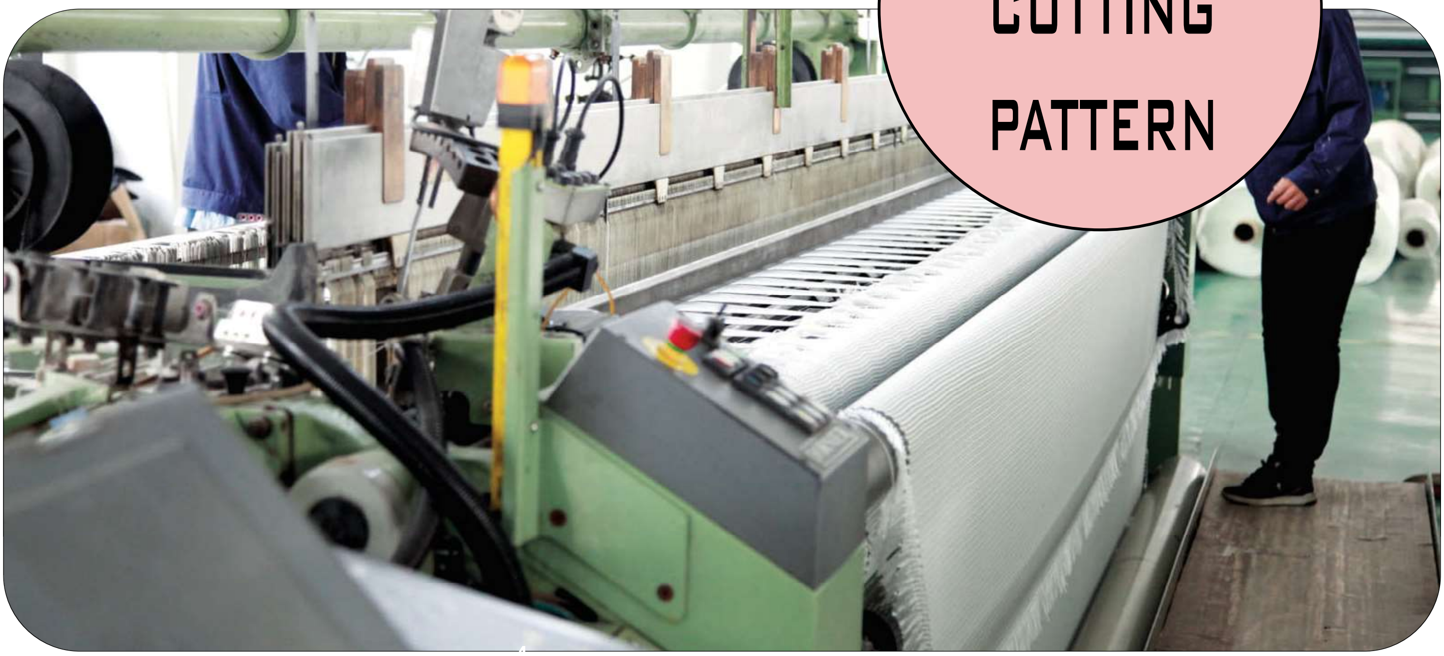
Deformed shape under wind loading

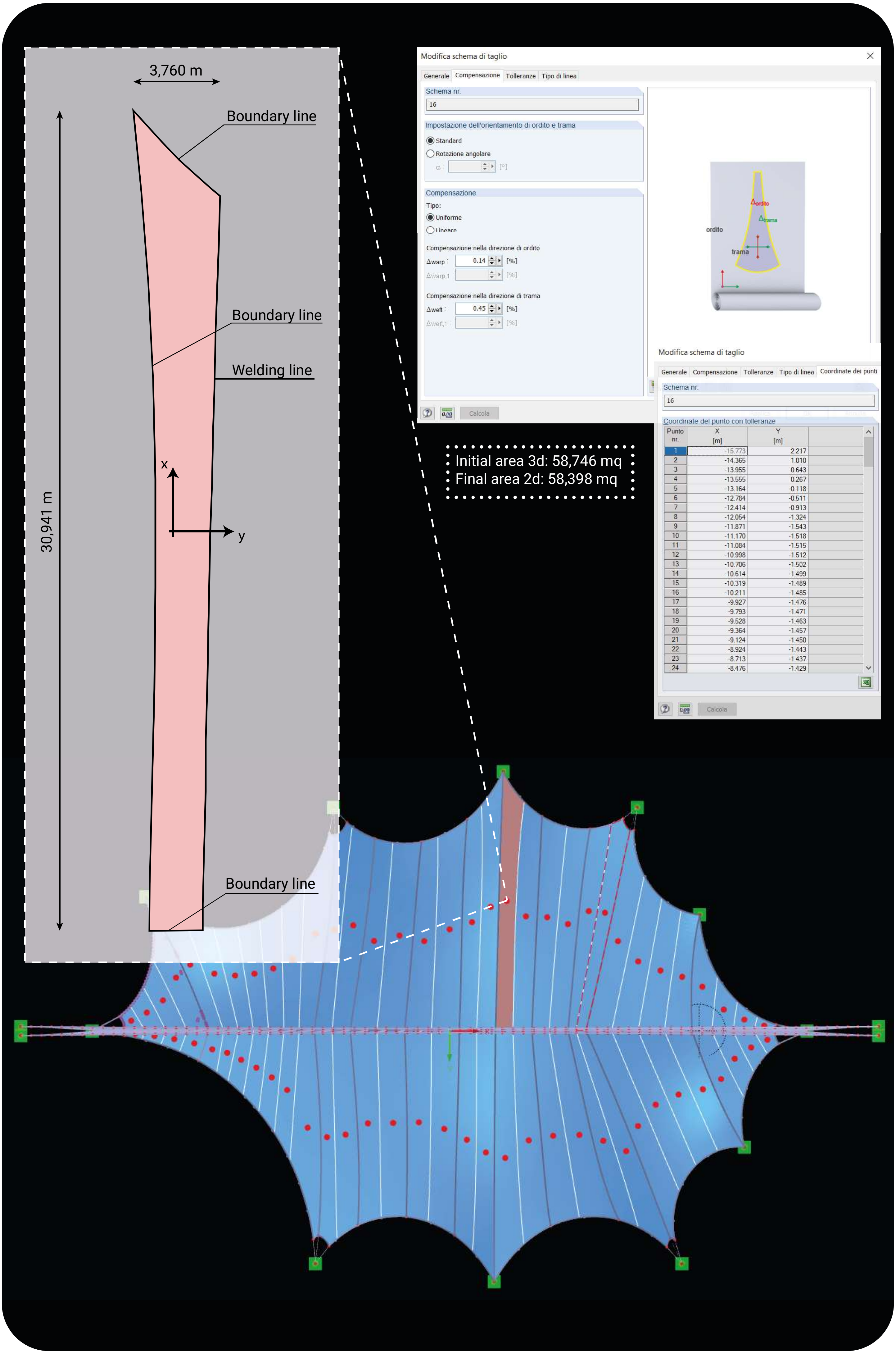
An essential aspect of being considered in the project of membrane structures is the ***maximum dimension of a single membrane piece***. This material is manufactured in rolls having a maximum width of about 5 meters (depending on the manufacturers). Therefore, the larger dimension can be attained only by joining together more pieces. The position of the joining line and the way to cut these pieces must be studied carefully. On the one hand, the seams are less resistant than the membrane surface. On the other hand, the ***direction of the seams*** changes the warp and weft direction of the fabric. For aesthetic reasons, we decided to align the line of the seams with the cables that bear the fabric, so that they result to be orthogonal to the plane of the rope truss. Even more critical is the definition of the correct cutting-pattern to give to the manufacturer for its execution. The definition of the optimal cutting lines requires specific calculation. Each membrane piece is cut-off from a flat and relaxed (without prestress) fabric roll. In contrast, the equilibrium shape of the curved membrane surface gives a three-dimensional prestress form.
The cutting-pattern problem is solved through two main steps. The first step, called "***Development***", creates a two-dimensional cutting-pattern from a three-dimensional form. The second step, called "***Compensation***", applies a correction to the geometrical surface (obtained in the previous step) keeping into account the stretching resulting from the structural prestress.
We performed such a cutting-pattern analysis via the "***RFEM Cutting-Pattern***" module (by Dlubal). It generates and organizes cutting patterns for membranes that are available as results of the form finding process. It is worth to mention that we "only" estimate the cut-scheme for few pieces because the analysis requires some mechanical properties of the fabric challenging to find.

JOINING TOGETHER MORE PIECES

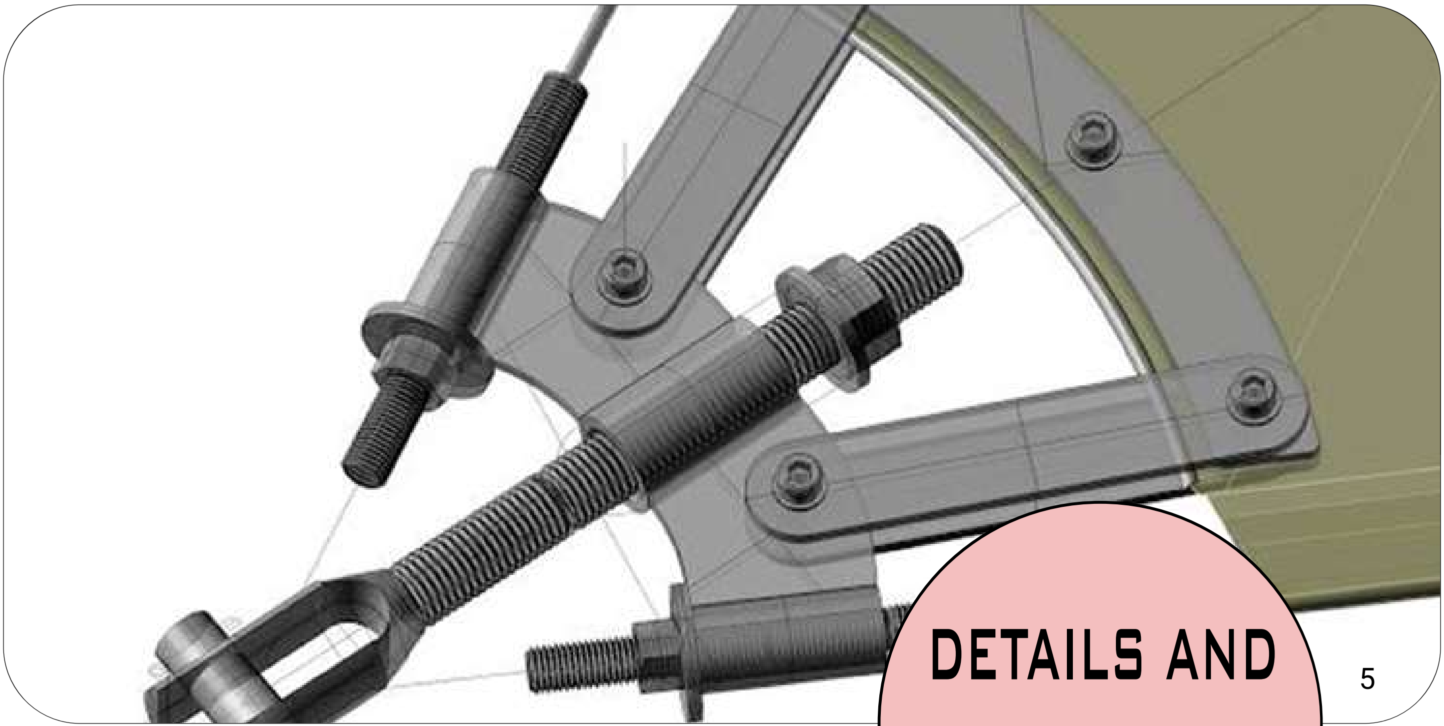
CORRECT CUTTING-PATTERN TO GIVE TO THE MANUFACTURER

RFEM CUTTING PATTERN



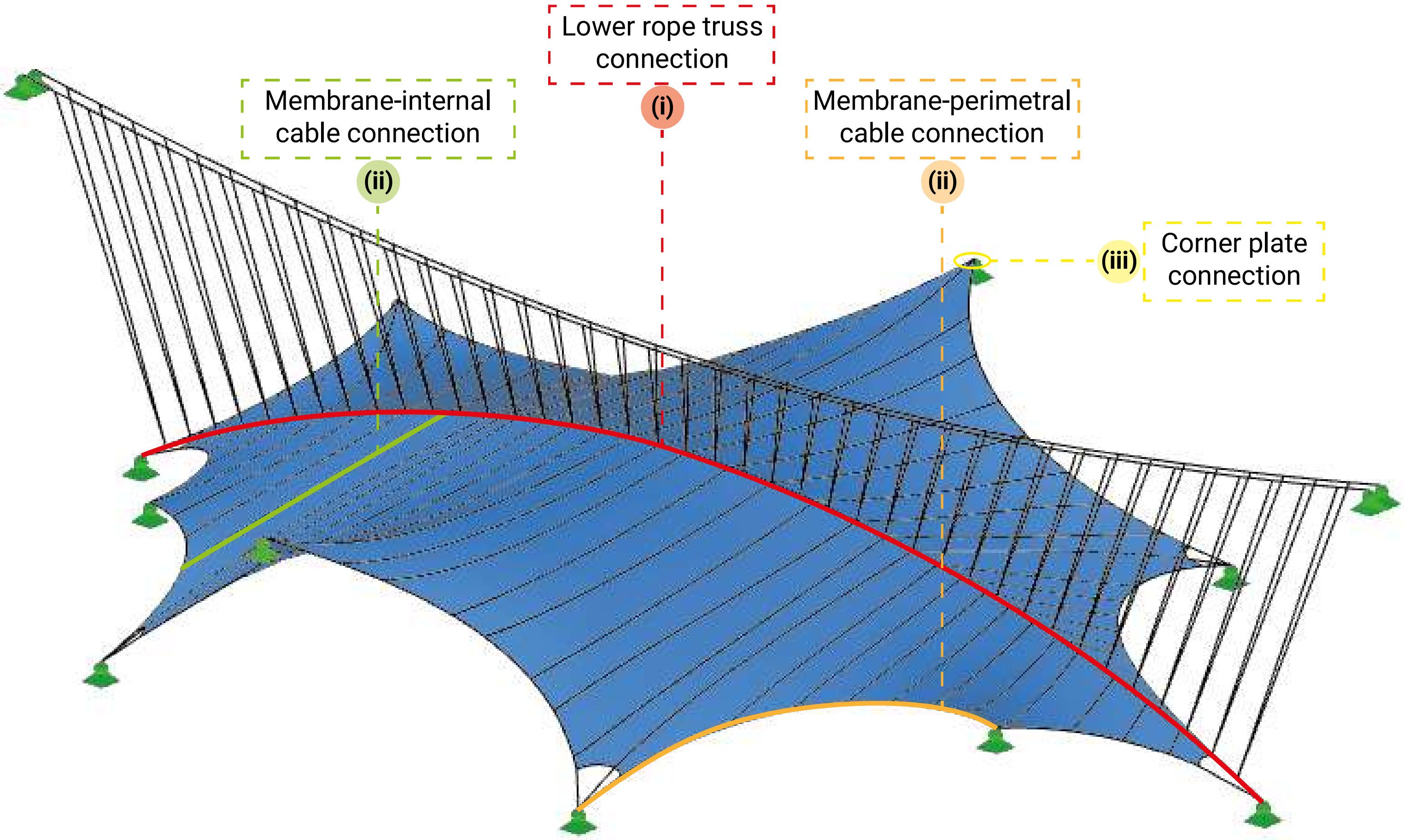


Punto nr.	X [m]	Y [m]
1	-15.773	2.217
2	-14.365	1.010
3	-13.955	0.643
4	-13.555	0.267
5	-13.164	-0.118
6	-12.784	-0.511
7	-12.414	-0.913
8	-12.054	-1.324
9	-11.871	-1.543
10	-11.170	-1.518
11	-11.084	-1.515
12	-10.998	-1.512
13	-10.706	-1.502
14	-10.614	-1.499
15	-10.319	-1.489
16	-10.211	-1.485
17	-9.927	-1.476
18	-9.793	-1.471
19	-9.528	-1.463
20	-9.364	-1.457
21	-9.124	-1.450
22	-8.924	-1.443
23	-8.713	-1.437
24	-8.476	-1.429



DETAILS AND CONNECTIONS

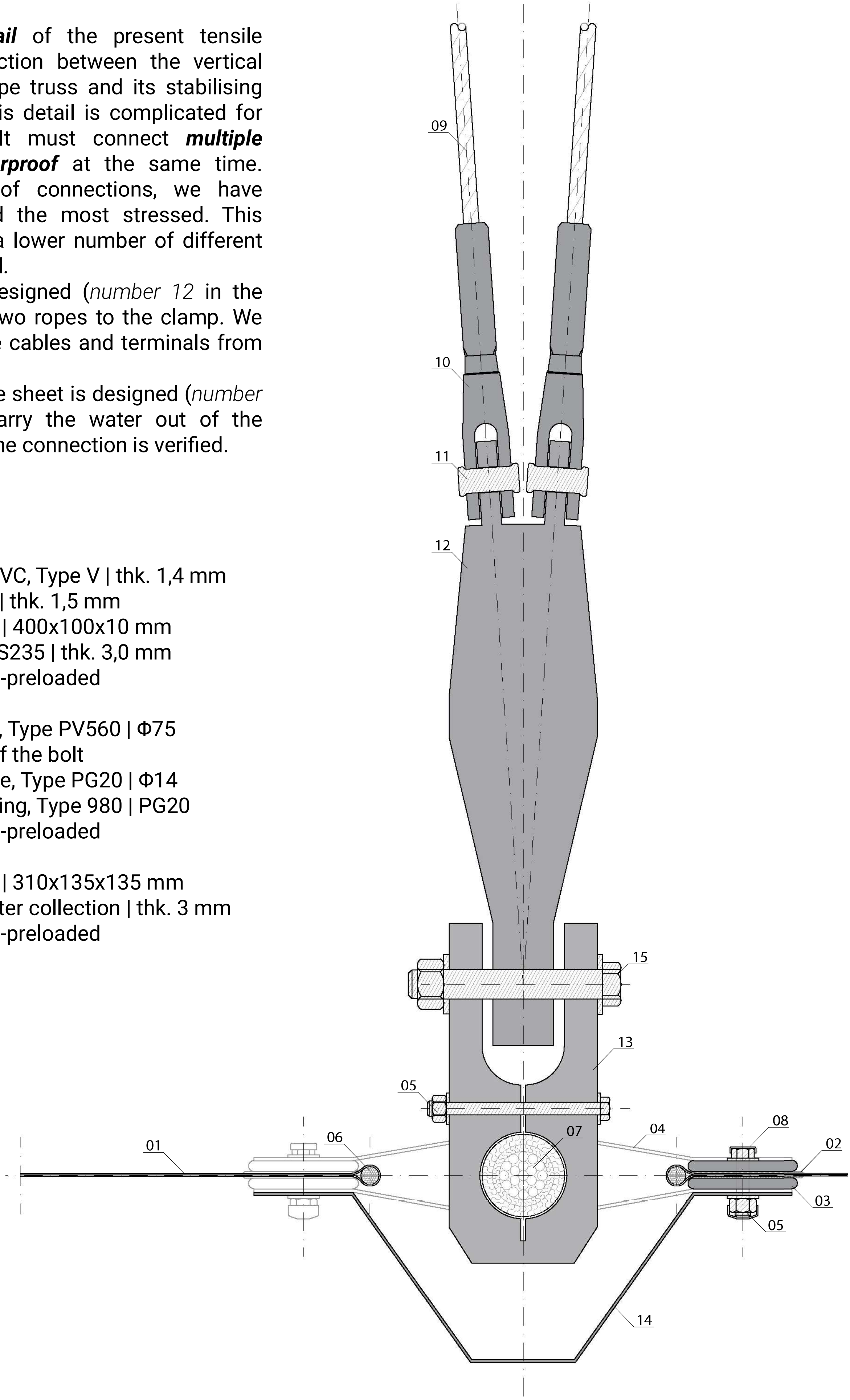
Careful design of the ***details*** and the ***connections*** is fundamental to permit the structure to deform in the right way under the influence of loading. Due to the high flexibility materials used, it is essential to give them the freedom to stretch in all the directions.
We designed several details: i) the clamps to connect the cables in the planar rope truss; ii) the clamps connecting the membrane surface and the cables (both perimetral and internal); iii) the corner plate that holds together three cables and two fabric pieces.



LOWER ROPE TRUSS CONNECTION

The most ***critical detail*** of the present tensile structure is the connection between the vertical cables of the planar rope truss and its stabilising cable. The design of this detail is complicated for mainly two reasons. It must connect ***multiple elements*** and be ***waterproof*** at the same time. Among all this kind of connections, we have searched and designed the most stressed. This solution allows having a lower number of different elements to be produced.
A special element is designed (*number 12* in the figure), to connect the two ropes to the clamp. We selected the appropriate cables and terminals from the PFeifer datasheet.
Finally, the polypropylene sheet is designed (*number 14* in the figure) to carry the water out of the structure. Every bolt of the connection is verified.

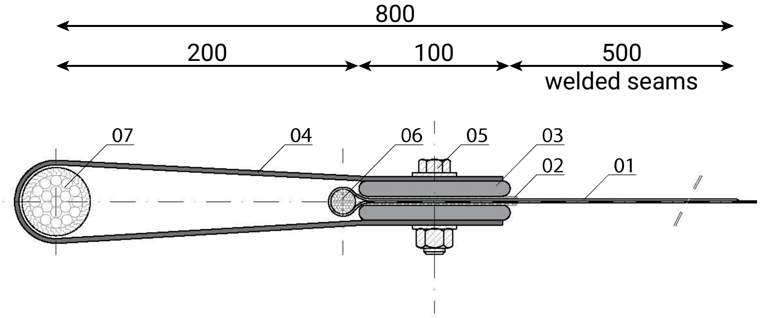
Elements:
01 –-> Membrane PES/PVC, Type V | thk. 1,4 mm
02 –-> Protective rubber | thk. 1,5 mm
03 –-> Steel clamp S235 | 400x100x10 mm
04 –-> Sheet metal loop S235 | thk. 3,0 mm
05 –-> Bolt M14/8.8, non-preloaded
06 –-> Keder Φ16
07 –-> Full Locked Cable, Type PV560 | Φ75
08 –-> Plastic covering of the bolt
09 –-> Spiral Strand Cable, Type PG20 | Φ14
10 –-> Open Swaged Fitting, Type 980 | PG20
11 –-> Bolt M22/8.8, non-preloaded
12 –-> Steel plate S235
13 –-> Steel clamp S235 | 310x135x135 mm
14 –-> Polypropylene water collection | thk. 3 mm
15 –-> Bolt M27/8.8, non-preloaded



1:5 | Clamped connection of the lower part of the rope truss

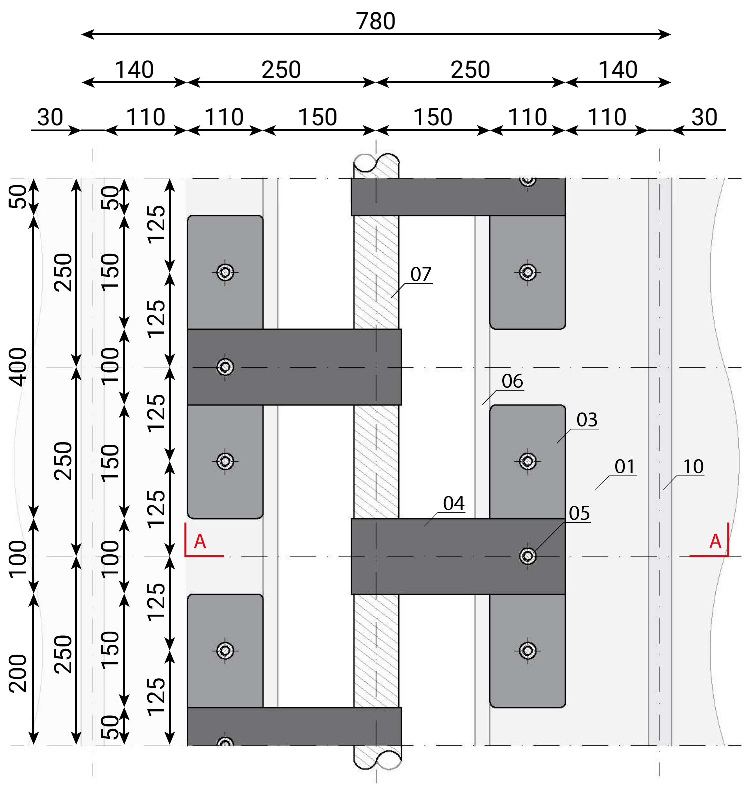
The **clamp** was the only possible connection due to the high value of the tensile stress in the membrane surface. This kind of clamp does not exploit friction, but it takes advantage of the "***keder***" located at the end of the fabric (*number 6* in the figure). The working principle is the following. The force is transferred from the "keder" to the clamping plate. Then, it is transferred from there onto the external rope through sheet metal loops. All these elements are designed following the *UNI EN 1993-1-8*. We calculated the ***bearing resistance of the bolted connection*** subject to a shear loading condition.

MEMBRANE-PERIMETRAL CABLE CONNECTION



1:5 | Clamped connection cable-membrane

MEMBRANE-INTERNAL CABLE CONNECTION

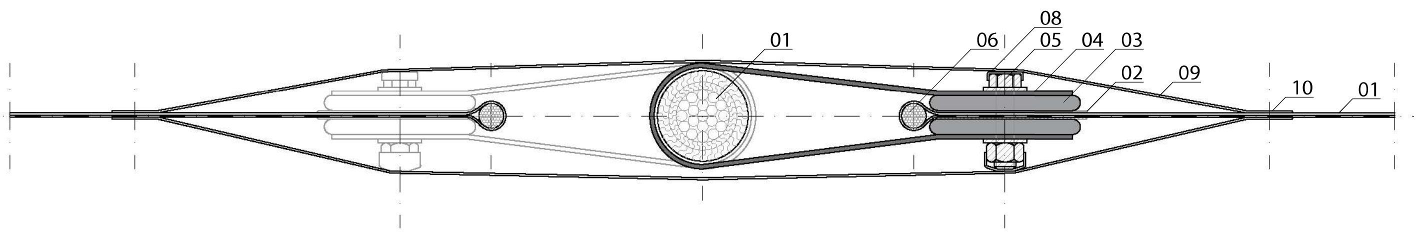


1:10 | Membrane-internal cable clamped connection

Elements:

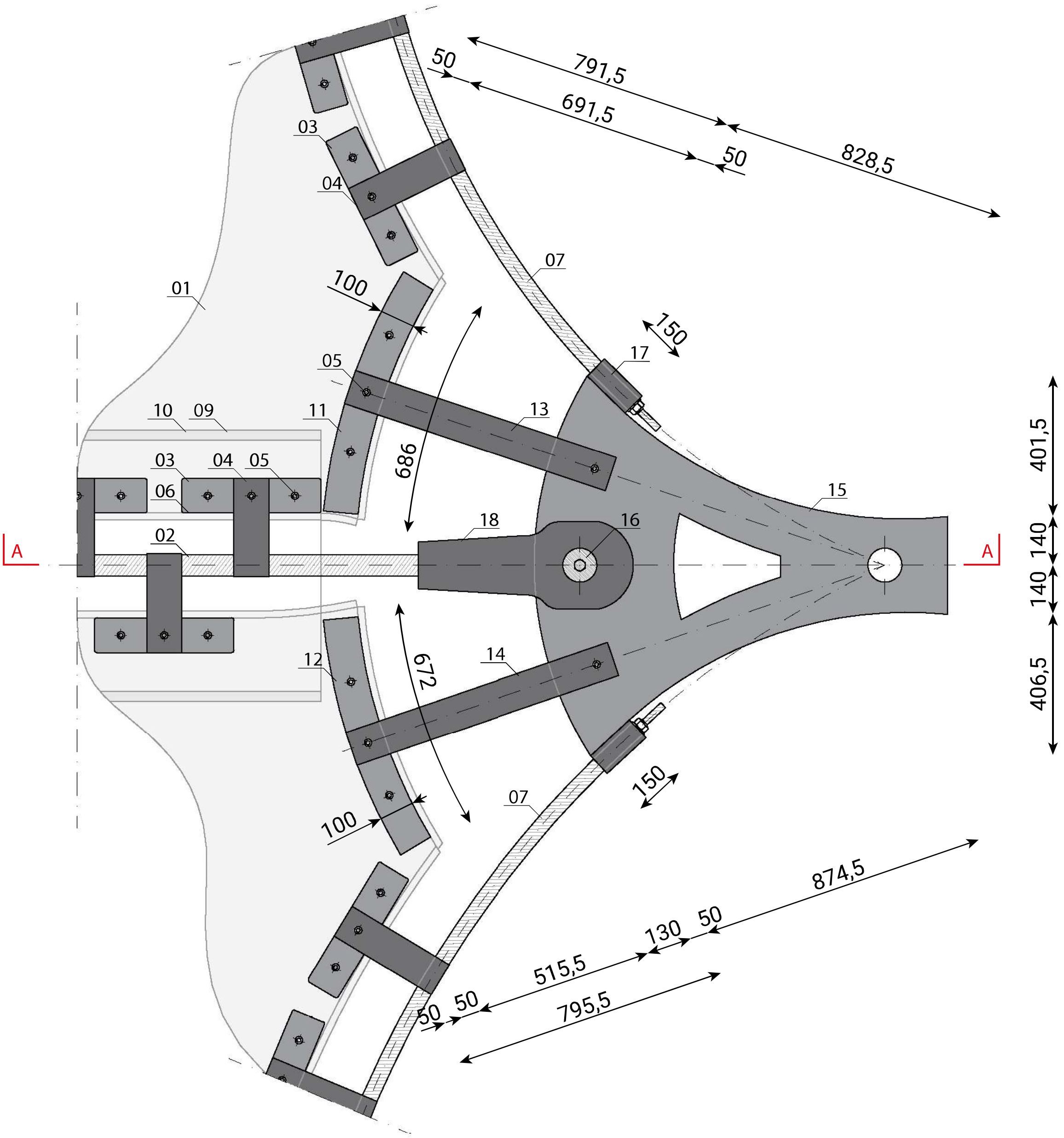
01 —> Membrane PES/PVC, Type V | thk. 1,4 mm
02 —> Protective rubber | thk. 1,5 mm
03 —> Steel Clamp S235 | 400x100x10 mm
04 —> Sheet metal loop S235 | thk. 3,0 mm
05 —> Bolt M14/8.8, non-preloaded
06 —> Keder Φ16
07 —> Full Locked Cable, Type PV360 | Φ60
08 —> Plastic covering of the bolt
09 —> Membrane PES/PVC, Type I | thk. 1,4 mm
10 —> Hot-air welding | width 30 mm

The connection between the internal cables and the membranes allow for transfer the stress from the fabric to the rope. However, this is not the only stress that occurs to the cable, indeed the membrane prestresses orthogonal to its axis has to be transmitted from one surface of the fabric to the other. The ***same joint*** used for the previous connection ***between the membrane and the external cable*** is adopted for this detail, to design a single clamp that can be used for all the joints.

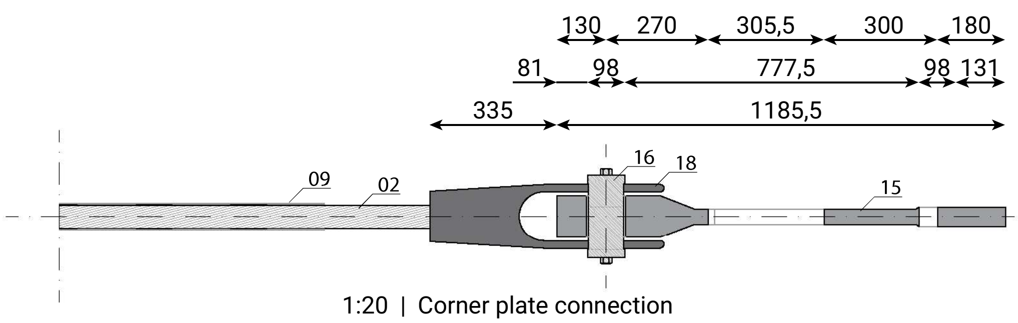


1:5 | Membrane-internal cable clamped connection
Section A-A

CORNER PLATE CONNECTION



1:20 | Corner plate connection



1:20 | Corner plate connection
Section A-A

Elements:

01 —> Membrane PES/PVC, Type V | thk. 1,4 mm
02 —> Full Locked Cable, Type PV360 | Φ60
03 —> Steel clamp S235 | 400x100x10 mm
04 —> Sheet metal loop S235 | thk. 3,0 mm
05 —> Bolt M14/8.8, non-preloaded
06 —> Keder Φ16
07 —> Full Locked Cable, Type PV560 | Φ75
08 —> Plastic covering of the bolt
09 —> Membrane PES/PVC, Type I | thk. 1,4 mm
10 —> Hot-air welding | width. 30 mm
11 —> Bended clamp S235 | 686x100x10
12 —> Blended clamp S235 | 672x100x10
13 —> Sheet metal loop S235 | thk. 3,0 mm
14 —> Sheet metal loop S235 | thk. 3,0 mm
15 —> Steel corner plate S235 | thk. 4 - 5 - 11 mm
16 —> Bolt PFeifer | Φ98
17 —> Swaged Fitting with Thread, Type 988 | PV560
18 —> Open Spelter Socket, Type 802 | PV360

PHOTOGRAPHY

1 | Image taken from the presentation document of the Milan PGT 2030

2 | Image taken from the presentation document of the railway yards makes by FS

3 | Image taken from *www.flickr.com*

4 | Image taken from *www.specialityfabricsview.com*

5 | Image taken from *www.tensaform.com*