Meng Membrane Lightweight Structure

Solar Protection for the Swimming Pool of the International French School Marguerite Duras in Ho Chi Minh, Vietnam

A Master's Thesis submitted for the degree of
« Master of Engineering »

supervised by
Jürgen Hennicke

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Vienna, November 30, 2018

Affidavit

1, Michel JARNIER, hereby declare

1. that I am the sole author of the present Mater’s Thesis, « **Solar Protection For the Swimming Pool of the International French School Marguerite Duras In Ho Chi Minh, Vietnam** », 162 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master’s Thesis as an examination paper in any form in Austria or abroad

Vienna, November 30, 2018

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Signature

Abstract

A South-East Asian international college swimming pool protection against excessive sun exposure is proposed. The project is located in Southern Vietnam. Local climate is tropical with high humidity and heavy sunshine during the dry season as well as the rainy season. The swimming pool is adjacent to a gymnasium and utility building. Intense solar radiation starts at 9am and lasts till 4pm. It presents a significant health hazard for the skin of young students originating from regions with less sunshine. The specifics and constraints of this project are an opportunity to apply the techniques learned over that last 2 years at TUWien, in the « Membrane Lightweight Structures » master degree curriculum.

Case studies relate the “Shade” function and “Shape” function to one another in an architectural expression. Shape, considered in its textile architectural expression, generates stress. How the structure can handle this stress is analyzed. It defines the architectural limitations of the project. How structural components concur to bring down the forces to the foundations is studied. Various shapes and aesthetic criteria are analyzed in consideration of cables and retention hardware, foundations and stress distribution through the structure. These analyzes are evaluated. A final choice is proposed in accordance with lightweight construction best practice, safety, cost and durability. Aesthetics and added value to the school’s competitive position play a significant role in the final choice.

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1. BASIC INFORMATION RELATED TO THE PROJECT

1.1 Introduction

Sun is essential to sustain life on Earth. Most of us are grateful to our magnificent star. Under the tropics, solar energy and ultraviolets are so intense that men suffer from them, rather than enjoy them. Such high levels of solar energy and UVs affect our health. People living under these conditions avoid direct sun light and seek the shade. Traditionally, shade has been provided by trees, natural obstacles or constructions. Yet, from the time man has learned to weave, he used these materials to cover structures that hide him from the sun.
Over the last 10-20 years, new fabric have been developed from natural and synthetic fibers, in the construction of shades, roofs, facades and marquises.

1.2 Presentation of the school / Lycée Français International Marguerite Duras

Figure 1: Main entrance of « Lycée Français International Marguerite Duras »

Lycée Français International of Hô Chi Minh-Ville is a public school.

Since the 2010 entry, the establishment has over 9 000 m² of newly built and equipped buildings. Over 1000 children are enrolled, from the primary school (3 years old) up to the 12th grade.

The area include sport Facilities : A Soccer Field, gymnasium, Swimming pool, and running tracks.

The school is named Marguerite Duras

Marguerite Donnadieu, known as **Marguerite Duras** (4 April 1914 – 3 March 1996), was a French novelist, playwright, scriptwriter, essayist and experimental filmmaker. She is best known for writing the 1959 film *Hiroshima mon amour*, which earned her a nomination for Best Original Screenplay at the Academy Awards.
Duras was born in Gia-Dinh (a former name for Saigon), Cochinchina, French Indochina (now Vietnam), after her parents responded to a campaign by the French government encouraging people to work in the colony.

wikipedia

Address: Road n°11, Long Binh, District 9, Ho Chi Minh City, Vietnam

1.3. The school architecture and the swimming pool

Main Entrance and Land Occupation

Figure 2: The school main entrance

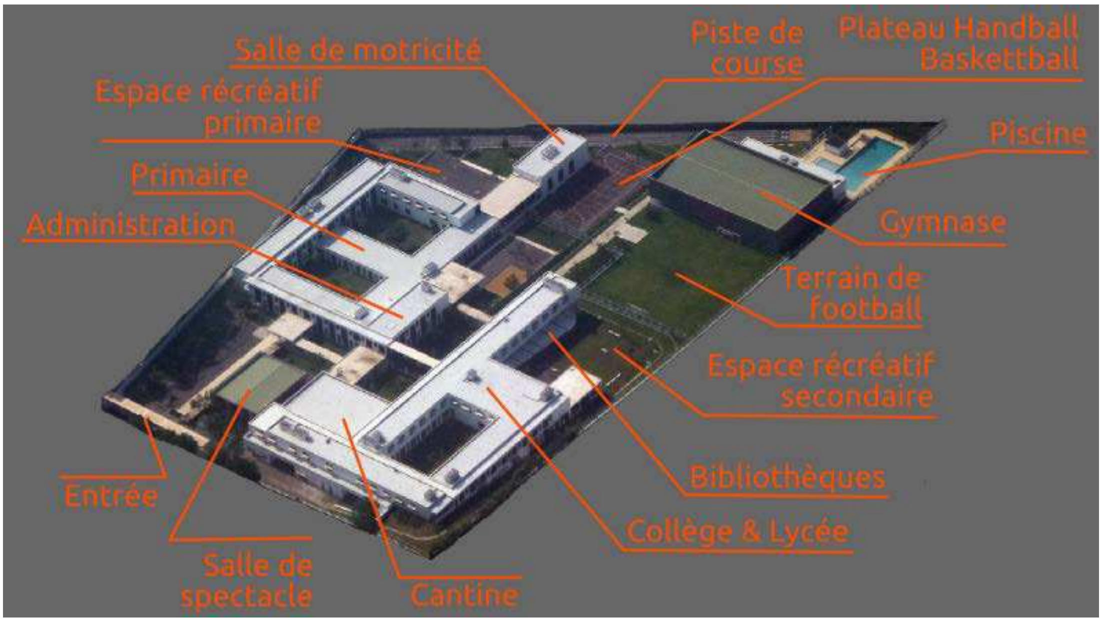

Figure 3: Disposition of the school constructions on the land

Pictures of the swimming pool:

Figure 4: Pool

Figure 5: Pool aerial vue 1

Figure 6: Pool aerial view 2

1. 4 Geographic Location

The project is in Ho Chi Minh City, Vietnam. Ho Chi Minh City is located in the SouthEast region of Vietnam, 1’760 kilometers from the capital city of Hanoi. The geographic position of the city is 10.82, 106.62. The average elevation is 19 meters above sea level. The city has a tropical wet dry climate, with an average humidity of 78-82%. The year is divided into two distinct seasons. The average temperature is 28°C with little variation throughout the year. On average the city experiences between 2’400 to 2’700 hours of sunshine per year.

VIETNAM MAP

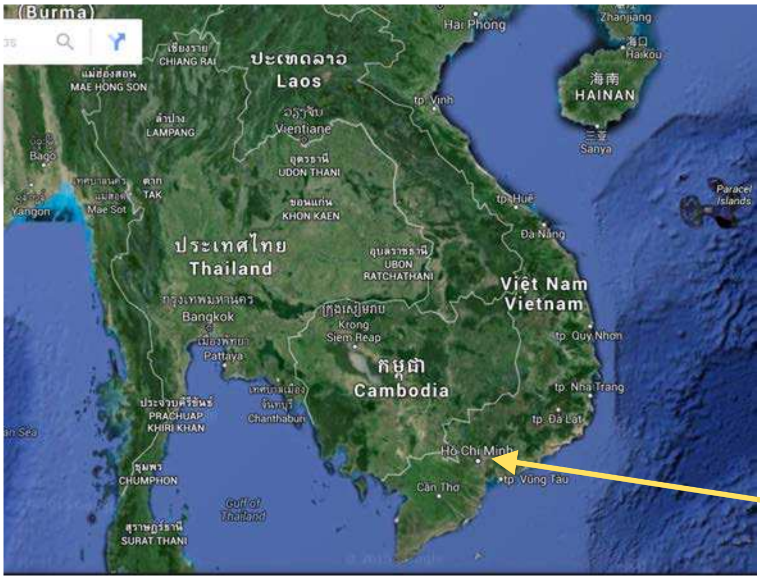

Figure 7:
Vietnam location,
(Google)

Ho Chi Minh City
Geographical position

HO CHI MINH CITY MAP

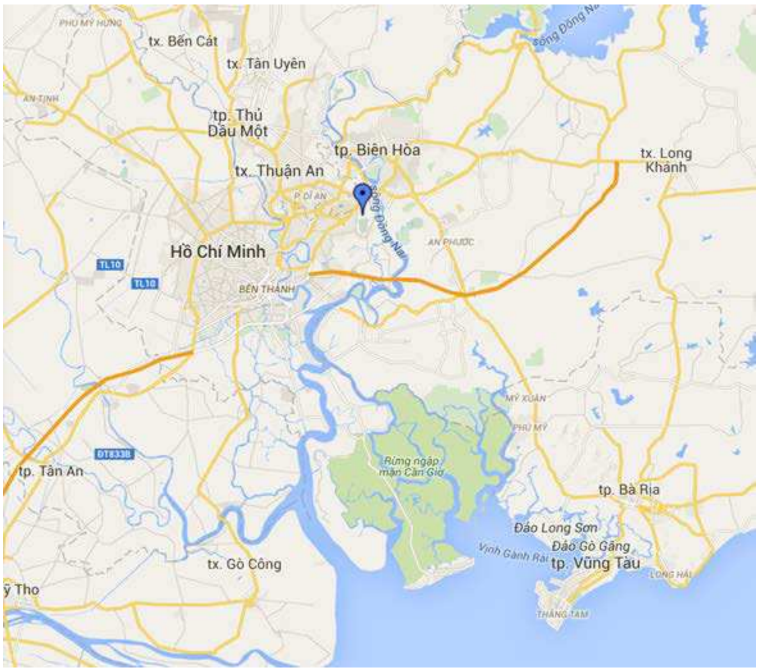

Figure 8:
Project location
(Google)

1.5 Ho Chi Minh city table of sun elevation and azimuth

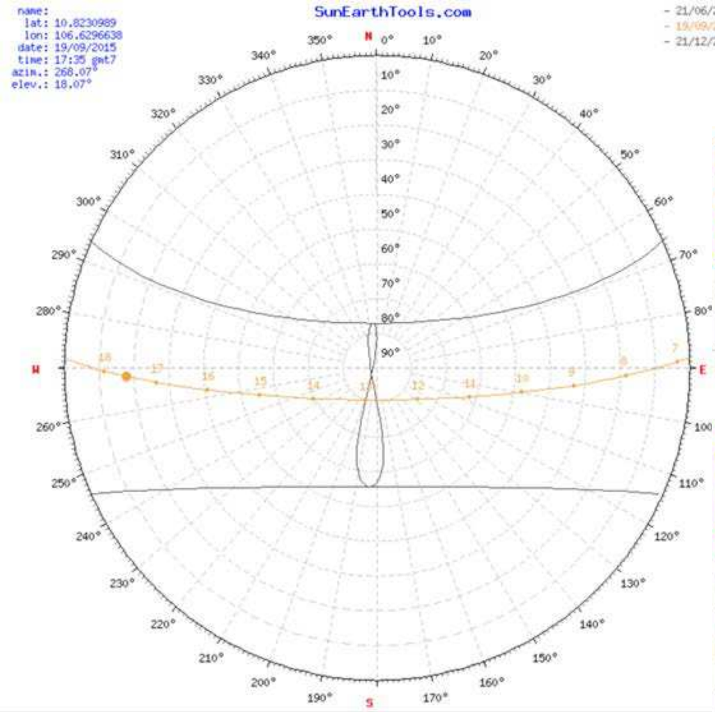

Figure 9: Sun curse, azimuth (Google)

Date:	19/09/2015 | GMT7	
coordonner:	10.8230989, 106.6296638	
emplacement:	Hồ Chí Minh-Ville, Hồ Chí Minh, Vietnam	
heure	Elevation	Azimut
06:42:52	-0.833°	88.1°
7:00:00	3.37°	88.91°
8:00:00	18.1°	91.77°

Date:	19/09/2015 | GMT7	
coordonner:	10.8230989, 106.6296638	
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06:42:52	-0.833°	88.1°
7:00:00	3.37°	88.91°
8:00:00	18.1°	91.77°
9:00:00	32.81°	95.04°
10:00:00	47.42°	99.48°
11:00:00	61.77°	107.13°
12:00:00	75.04°	127.15°
13:00:00	80.27°	198.82°
14:00:00	69.77°	244.08°
15:00:00	55.83°	256.6°
16:00:00	41.33°	262.46°
17:00:00	26.66°	266.25°
18:00:00	11.93°	269.27°
18:51:57	-0.833°	271.7°

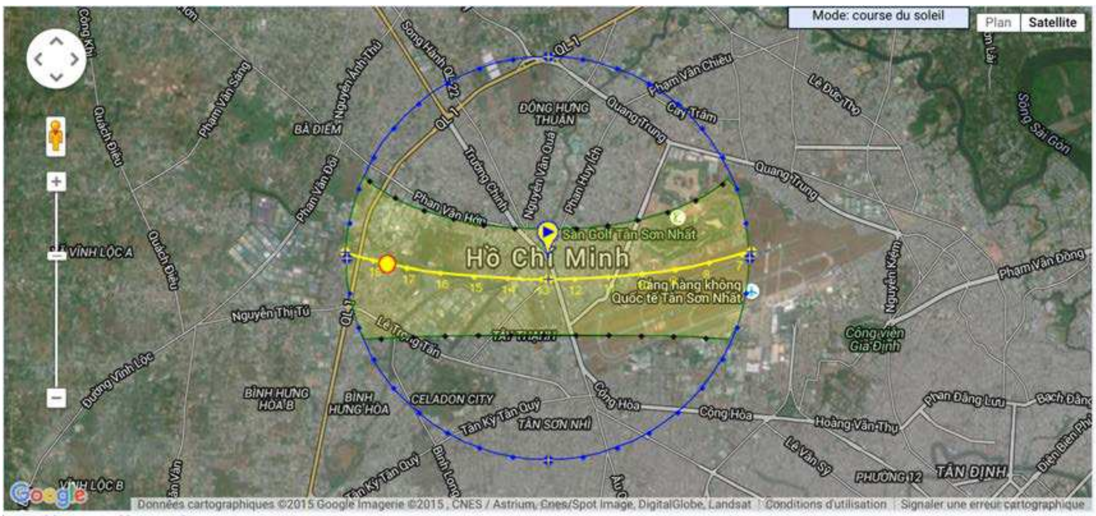


Figure 10: Sun curse (Google)

1.6 Sunshine

The sun typically rises at 7:00 am and sets at 18:00 around (e.g., sunrise at 06:42 and sunset at 18:51 during September 19, 2015)

CLIMATE DATA / THERMAL AND SUN PARAMETERS ALONG THE YEAR

Climate data for Ho Chi Minh City [hide]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	36.4 (97.5)	38.7 (101.7)	39.4 (102.9)	40.0 (104)	39.0 (102.2)	37.5 (99.5)	35.2 (95.4)	35.0 (95)	35.3 (95.5)	34.9 (94.8)	35.0 (95)	36.3 (97.3)	40.0 (104)
Average high °C (°F)	31.6 (88.9)	32.9 (91.2)	33.9 (93)	34.6 (94.3)	34.0 (93.2)	32.4 (90.3)	32.0 (89.6)	31.8 (89.2)	31.3 (88.3)	31.2 (88.2)	31.0 (87.8)	30.8 (87.4)	32.3 (90.1)
Daily mean °C (°F)	26.0 (78.8)	26.8 (80.2)	28.0 (82.4)	29.2 (84.6)	28.8 (83.8)	27.8 (82)	27.5 (81.5)	27.4 (81.3)	27.2 (81)	27.0 (80.6)	26.7 (80.1)	26.0 (78.8)	27.4 (81.3)
Average low °C (°F)	21.1 (70)	22.5 (72.5)	24.4 (75.9)	25.8 (78.4)	25.2 (77.4)	24.6 (76.3)	24.3 (75.7)	24.3 (75.7)	24.4 (75.9)	23.9 (75)	22.8 (73)	21.4 (70.5)	23.7 (74.7)
Record low °C (°F)	13.8 (56.8)	16.0 (60.8)	17.4 (63.3)	20.0 (68)	20.0 (68)	19.0 (66.2)	16.2 (61.2)	20.0 (68)	16.3 (61.3)	16.5 (61.7)	15.9 (60.6)	13.9 (57)	13.8 (56.8)
Average rainfall mm (inches)	13.8 (0.543)	4.1 (0.161)	10.5 (0.413)	50.4 (1.984)	218.4 (8.598)	311.7 (12.272)	293.7 (11.563)	269.8 (10.622)	327.1 (12.878)	266.7 (10.5)	116.5 (4.587)	48.3 (1.902)	1,931 (76.023)
Average rainy days	2.4	1.0	1.9	5.4	17.8	19.0	22.9	22.4	23.1	20.9	12.1	6.7	155.6
Average relative humidity (%)	72	70	70	72	79	82	83	83	85	84	80	77	78
Mean monthly sunshine hours	245	246	272	239	195	171	180	172	162	182	200	226	2,489

Source #1: World Meteorological Organization (UN)[25]

Source #2: (mean temperature, sunshine, record high and lows, and humidity)[24]

Figure 11: Thermal data (Google)

SUN CURSE, ELEVATION, AZIMUT

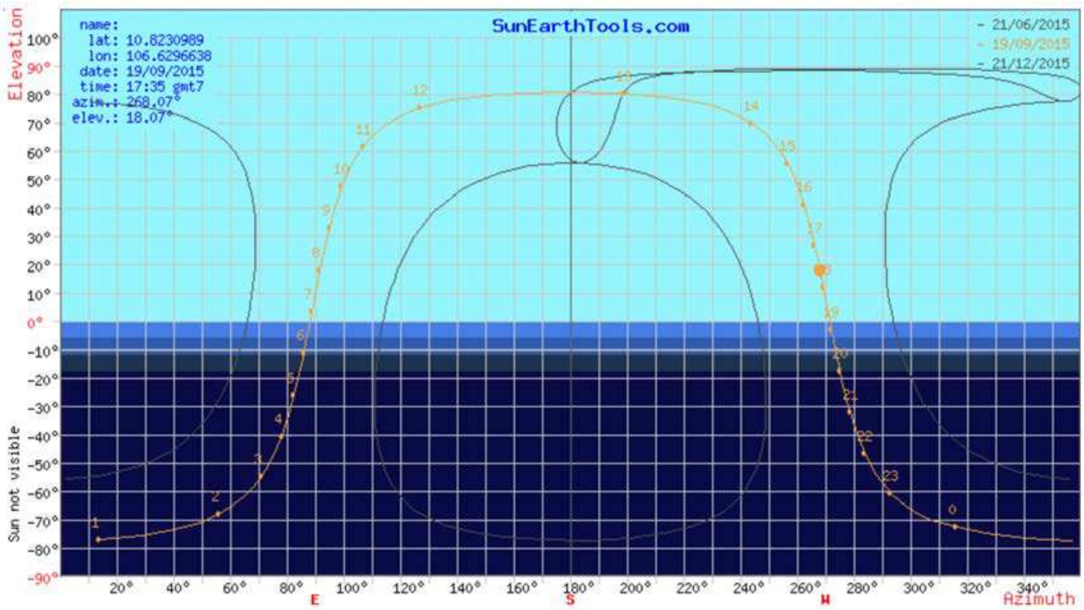


Figure 12: Sun curse, elevation, azimuth (Google)

1.7 Land and restrictions

The swimming pool include; an access from service building, a deck, planters, a technical room and the pool itself. The school management mainly require shade on the main part area covering the long pool and the deck around. This area dimensions are 19 x 30 meters.

Columns and construction elements can be installed on the side deck with a minimum impact for safety reason and the deck must stay free of cables.

The North land limit is 1 meter from the deck edge.

The pool is limited on it’s East side by the service building which separate the pool area from the gymnasium. The service building include restroom, locker rooms, sport material storage. The pool is accessed from the service building. The building is 6,90 meters hight, the construction is a reinforced concrete columns & beam with wall fill with brick. Structural elements from the new project can only be bolt on the building concrete reinforced structure and for low constrain only. The school management would prefer a project which does not solicits the building structure with high forces.

The land behind the South side pool edge fence belongs to the school and concrete block, guying cable, stays could take place here if necessary.

On the West side some land actually planted with grass could be used for guying cables and concrete mass if necessary.

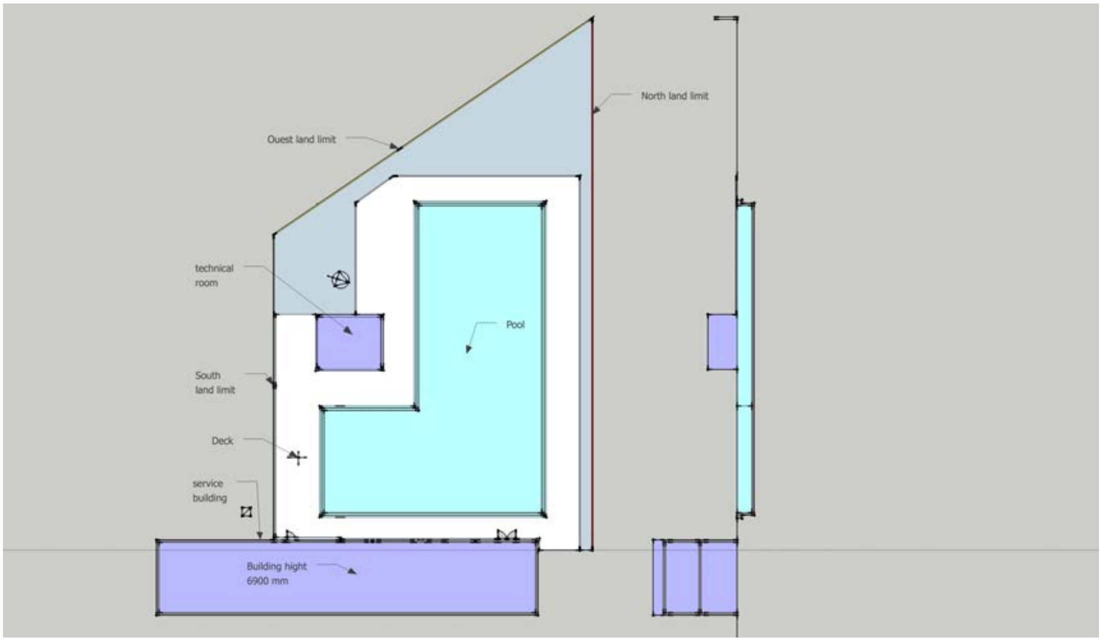


Figure 13: Project plan view

1.8 Description of the project area.

Main drawing of the project area

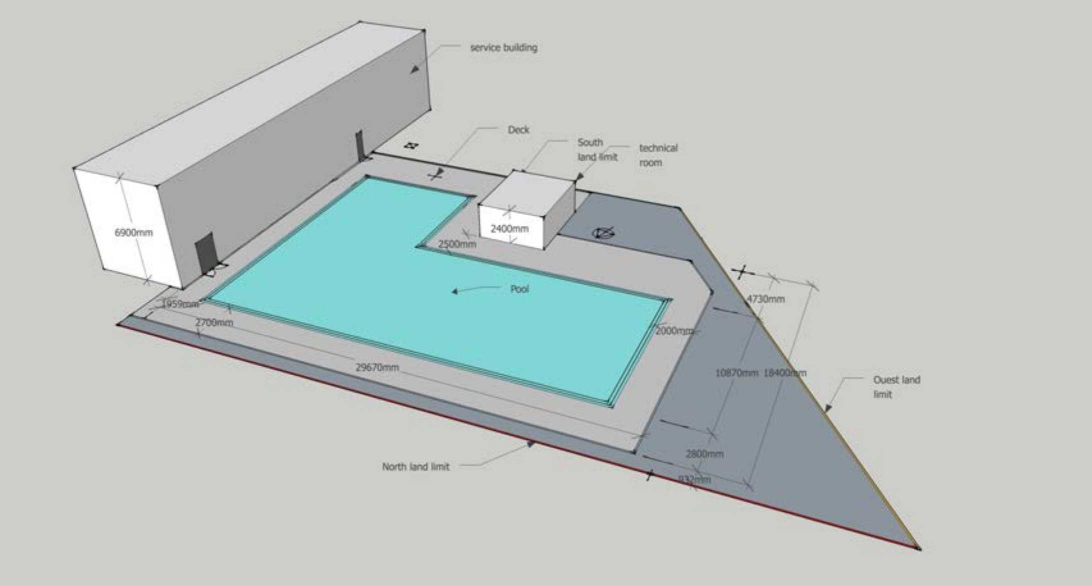


Figure 14: project 3D drawing

Drawing of the area with shade part (in red color)
The red color area is the surface to be protected by a shading roofing system.
Main dimensions of this area: 20 x 30 meters

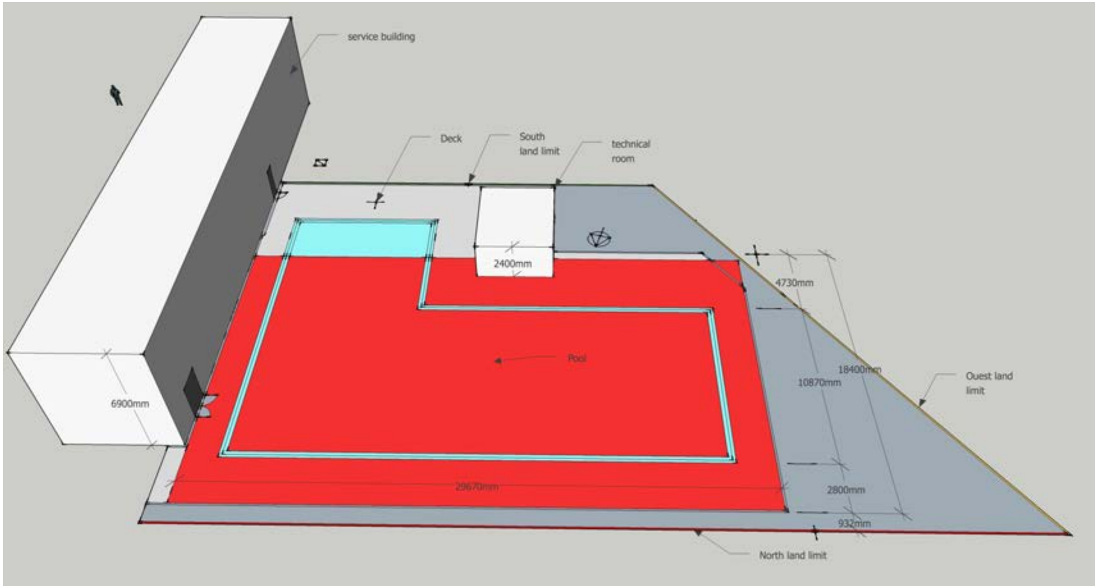


Figure 15: project 3D drawing, area to be shaded

Additional areas:

The main area (Area A) can be completed by the Access area and extra shade can be brought to the small pool (Area B) and -if required by the design- the triangle area on which the technical building is situated can be covered too (Area C).

Dimensions:
Area A: 16 x 30 m = 480 m2
Area B: 9 x 14 m = 126 m2
Area C: (9 x 16 / 2) m = 72 m2

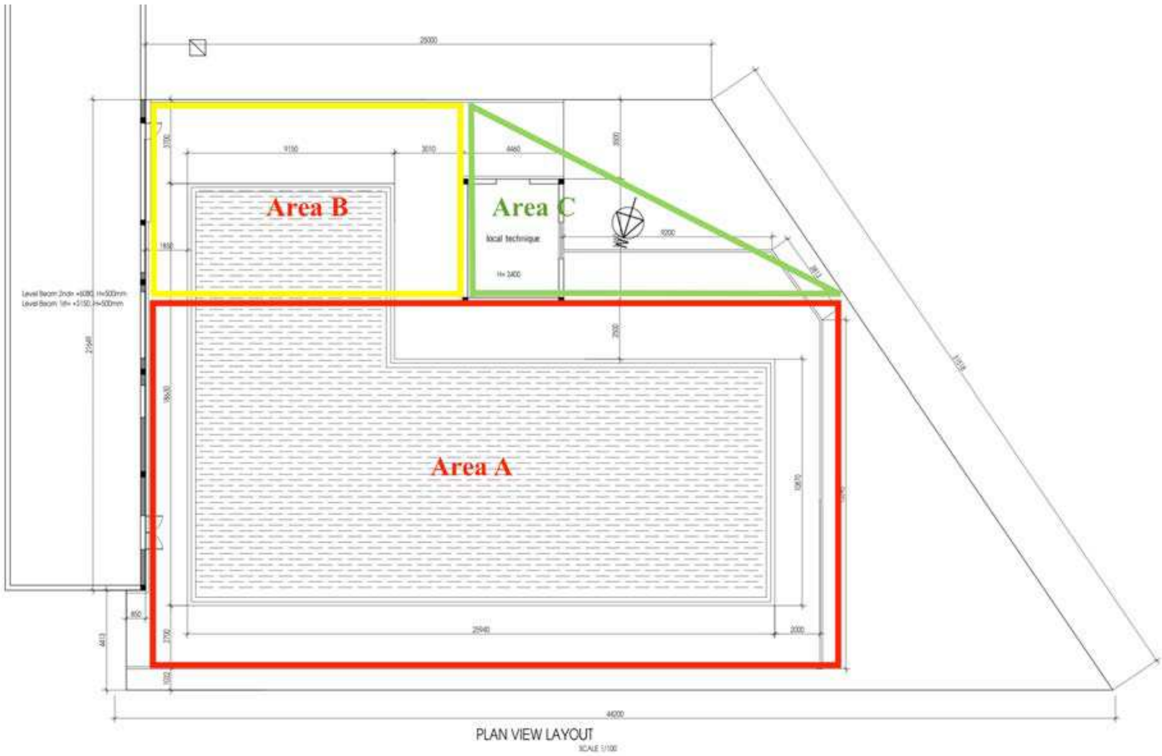


Figure 16: Zones layout

Different options for Surfaces to be shaded:

Area A only: 480 m2
Area A + B: 606 m2
Area A + B + C: 678 m2

1.9 School Management requirement

- The project must be financially economical
- Soil infrastructure must be reduce to minimum to reduce construction time and impact during school operation. The two months summer holidays will be the right time for concrete work and steel structure construction.
- Avoid heavy load on the reinforced concrete structure of the adjacent service building .
- Avoid heavy load on the technical room already consider as weak (or rebuild it).
- Use the school land area only
- Try to limit the construction high to 7 m
- Form finding aesthetic free of design
- The design should favor to textile lightness architecture and minimize as possible the concrete and steel structure.

2. STATE OF THE ART

Background information

2.1 Permanent Installations Textile Membrane Composition

Permanent textile works components include the covering membrane, the sustaining structure, the fittings, stands and anchorage

2.1.1 Covering membrane

It's shape, area, tensile forces and technical specifications define it. Further constraints arise from the strips layout, welding and edges

2.1.2 Fittings

Include all items securing the membrane to its stands, e.g., lacings incl. lacing ropes, grooves, tensing and stiffening elements, shackles

2.1.3 Sustaining structure

The membrane is supported by the self-sustaining structure. Fittings attach one to the other. As such, the structure defines all fixed or quasi-fixed locations where the membrane attaches. It conveys the forces soliciting the membrane to the stands and anchorage.

2.1.4 Stands and anchorage

The links attaching the sustaining structure to the ground

2.2 Materials

Physical properties and characteristics of fittings must be specified.
Theirs adequacy with the calculated constraints must be demonstrated.

2.2.1 Membrane

The membrane parameters, i.e., type of membrane, composition and materials, its physical characteristics, must be defined:

- Material and composition
- Supporting yarn mass and total mass in g/m²
- Upper- and undersurface coating material type
- Mesh structure
- Average tensile strength in N/5cm along the warp and weft directions

- Elasticity modulus
- Stress vs. strain 2D diagram
- Shear resistance
- Adherence
- Welding resistance at 65°C
- Flame retardancy

2.2.2 Membrane types

Membranes are classified according to their composition, mechanical characteristics, weight, welded joints minimum width, translucency and flame retardancy

Table further below indicates PVC-coated polyester membranes classification.

Table 1: PVC-coated PVC-Polyester fabrics typology

Type	I	II	III	IV
Weight in g/m2	750/900	1050	1050/1250	1350/1850
Tensile Strength, N/5cm, warp & weft	2800/2800	4200/4000	5600/5600	8000/7000
Tear Resistance in N, warp & weft	300/280	550/500	800/650	1200/1100
Elongation before break, %	15/20	15/20	15/25	15/25
Minimal seams width in cm	3	4	4	4
Solar Transmittance at 550 nm. White translucent	13	9.5	8	5
Fire resistance*	M2	M2	M2	M2

Figure 17: PVC-POLYESTER membrane data

Table 2: PTFE-coated glass-fiber fabrics typology

Type	I	II	III	IV
Poids en g/m2	800	1050	1250	1500
Tensile Strength, N/5cm, warp & weft	3500/3000	5000/4400	6900/5900	7300/6500
Tear Resistance in N, warp & weft	300/300	300/300	400/400	500/500

Elongation before break, %	3-12	3-12	3-12	3-12
Minimal seams width in cm	3	4	4	4
Solar Transmittance at 550 nm. White translucent	12-18	12-18	10-16	10-16
Fire resistance*	M2	M2	M2	M2

Figure 18: PTFE membrane data

2.3 DESIGN

Textile architecture works must satisfy criteria applicable to the covering membrane, the fittings and the sustaining structure.

2.3.1 Covering membrane

Criteria include the shape, tensile forces, curvature, edges slope, strips layout and foreseen conditions of use

Shape: Textile membrane shape must be a double curvature. Curvature radii vary from location to location, from a section to another section. Therefore, the chosen shape criteria is global. Limits must be set to admissible chord-to-sag ratio and subscribed circle arc radius with equal chord and sag between strip edges.

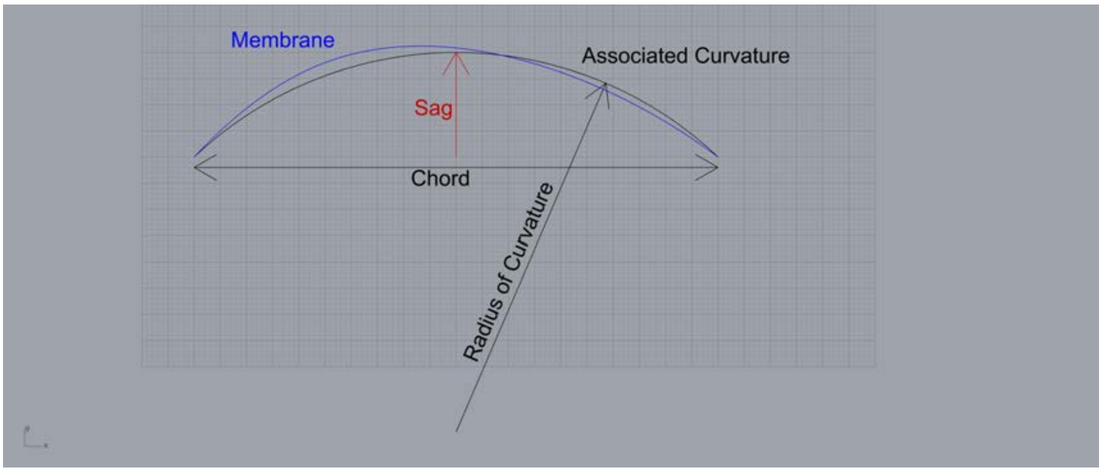


Figure 19: Curvature, Cord to sag ratio

2.3.2 ARTWORK, Membrane and associated curvature

Under stress, the membrane chord-to-Sag ratio, its associated curvature between the strip edges in the same plane, must stay within the limits:

chord/sag ratio ≤ < 20 and arc radius ≤ 70 meters

Note: The former condition roughly corresponds to Arc radius ≤ 2.5 times the Chord and ≤ 50 times the boom

Stabilizing devices such as valley and/or ridge cables, catenary cables and ridge purlin can be used.

des dispositifs stabilisateurs de forme tels que des cables de vallée, des cables d’arête, des pannes faîtières, peuvent être utilisées.

2.3.3 Pre-constraint
By design, an initial tensile force must be applied to textile membranes. It should be ≥ 15 kN/ml

2.3.4 Slope and edges
Textile membranes must feature enough slope at the edges to allow rain water to fall. When the slope is positive, the slope at the edges must be > 20% under the applied tensile force

2.3.5 Splitting
No single membrane element - as delimitated by its edges or lacings - must exceed 500 m2 in 2D projection, unless special reinforcements are designed-in.
For membranes - made of several strips - which include sliding stands, the the 2D-projected area must be < 400 m2.

2.3.6 Membrane area limits by membrane type
Type I PVC-coated polyester fabric is acceptable for covered elementary area < 30 m^2 of 2D-projection.
Types II, III or IV PVC-coated polyester fabric are mandatory for covered elementary area > 30 m^2 of 2D-projection.

2.4 Fittings
Lacings curvature radii must not exceed 25 m.

2.5 Sustaining structure
It is imperative that the structure be stable in the absence of membrane cover.

3. FORM FINDING PROCESS

Methodical approach description (modeling, literature study, information…).
Textiles used in architecture differ from conventional materials by their superior flexibility and lower weight. Textile membranes design must follow state of the art rules and recommendations. Tensile forces and curvature radii are essential parameters to be respected.
Using textiles in architecture make possible a variety of shapes and economy of material. Foray into shapes is an essential step of great interest to architects and designers pursuing original projects.

3.1 The main forms in textile architecture

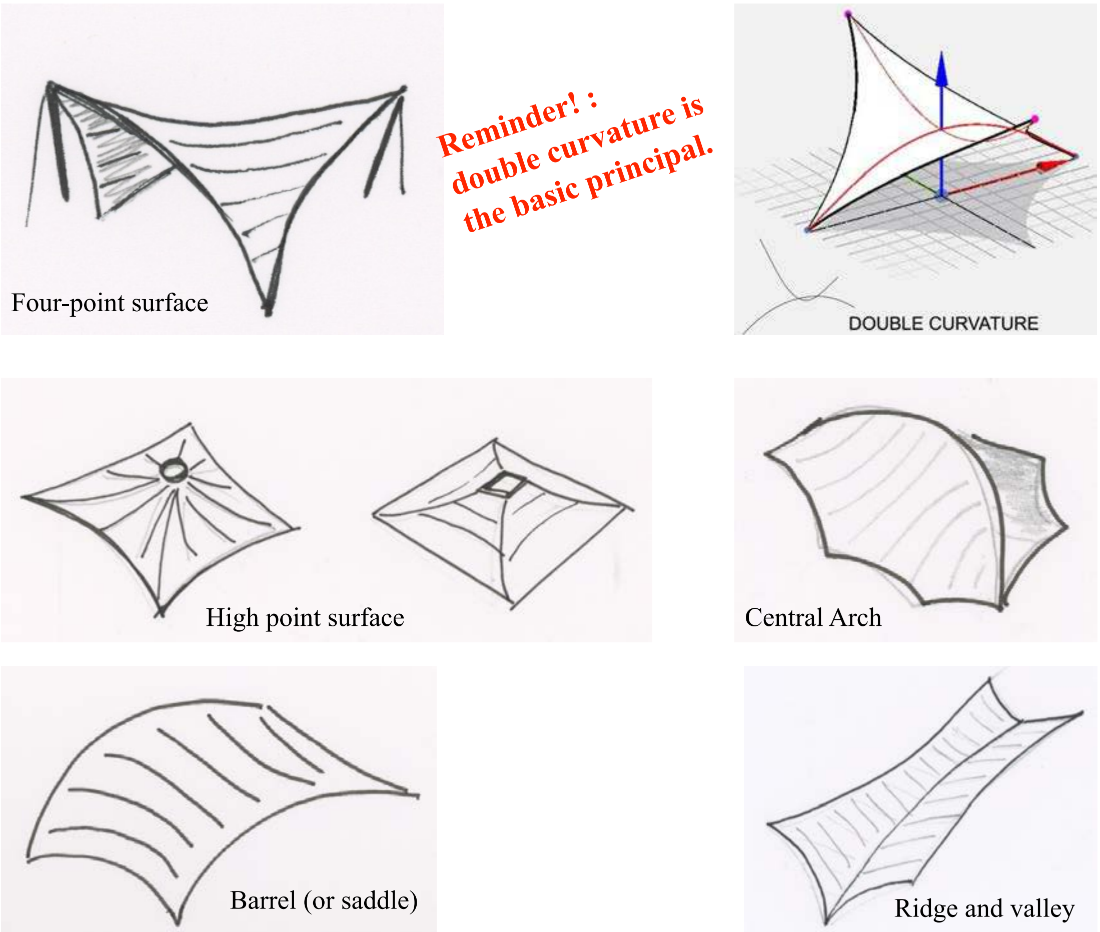


Figure 20: Basic forms hand drawing

These basic forms can be associated to offer hybrid more complexe forms. The following page show a set of possibilities for membrane tensioned projects, thanks to mechanically pre-stressed surfaces.

3.2 A variety of mechanically prestressed surfaces well adapted to the tension textile projects:

a/ four-point sail with flexible edges, b/ four-point sail with rigid edges, c/ five point sail with with flexible edges and sail batten, d/ Triangular surface with rigid arch along one edge, e/ Sail with alternating ridge and valley cables, f/ Sail with ridge cable and planar flexible edges, g/ Undulating star with alternating ridge and valley cables, h/ High-point surface with eye loop and ridge cables, i/ Low-point surface with with stiff ring, j/ High-point surface with cable loop supported at two points, k/High-point surface with cable high loop, l/High-point with « hump », m/arch-supported surface with arches along two edges, n/Arch-supported surface with inner arch, o/Addition of arch-supported surface, p/Arch along edge stabilized by outer flexible edge.

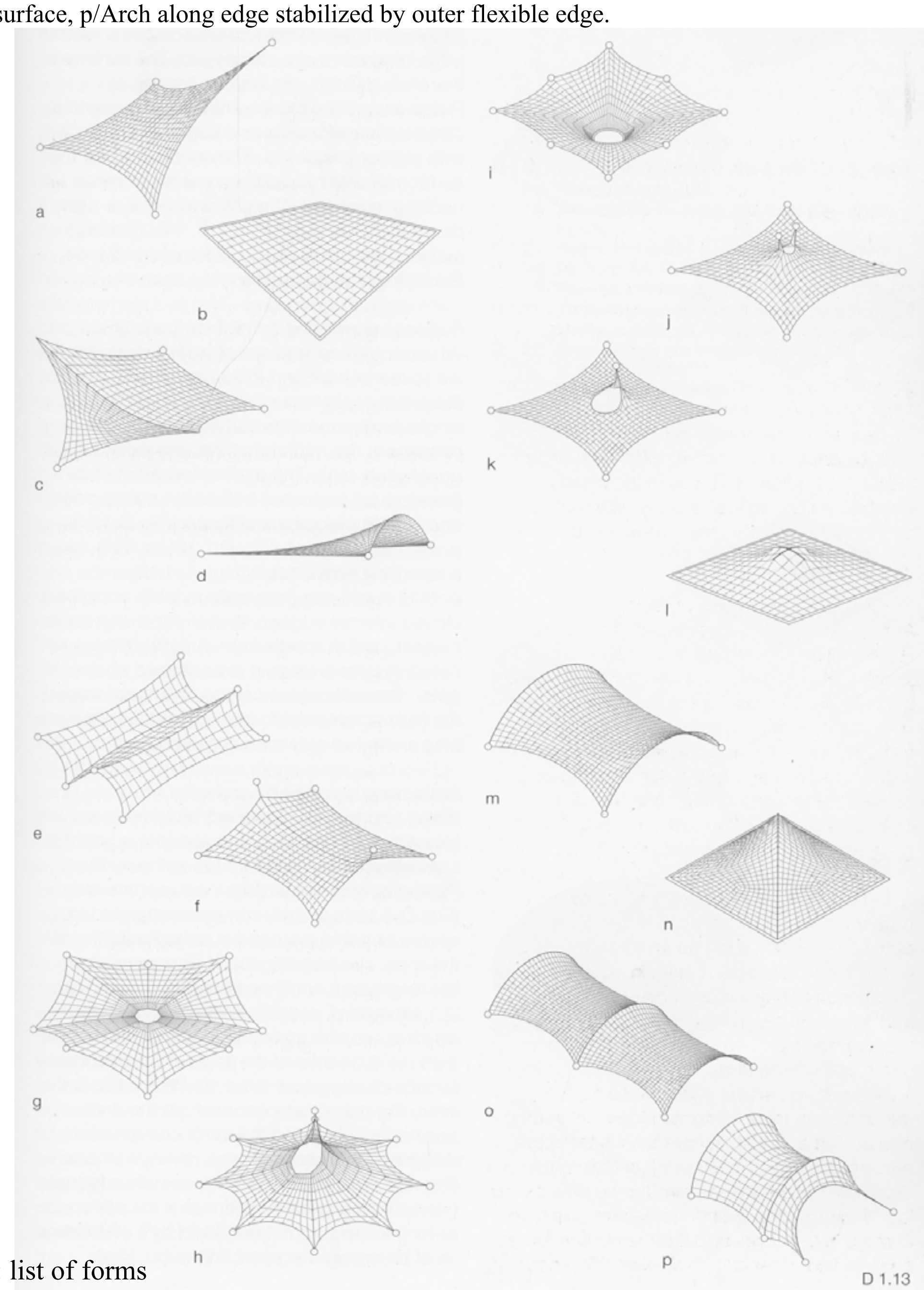
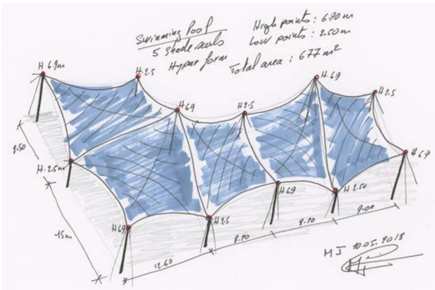


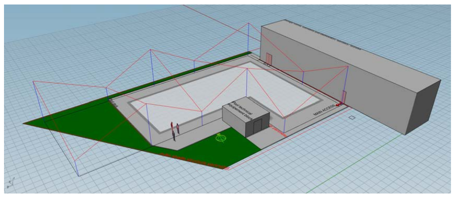
Figure 21: list of forms

3.3. Methodology: Process from Hand drawing to final realistic membrane shape.

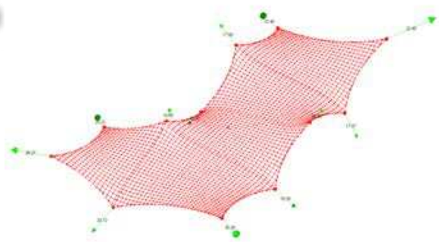
HAND SKETCH
Hand drawn sketch suggests the shape and defines the main dimensions parameters



3D CAD DRAWING
The hand drawing is copied in a Cad program to fix dimensional parameters in all 3 directions so the membrane boundary is precisely defined in space. System points and boundary lines are drawn in 3 directions; x, y, z. This boundary frame drawing is then exported to a Form finding program. EASY from Technet co. was used for this purpose



FORM FINDING
With the help of Easy Form the geometry of a stressed surface can be evaluated. In Easy Form a stress harmonic surface will be configured under consideration of user-defined conditions.
The membrane mesh is then exported to the CAD drawing program for a commercial rendering execution.



RENDERING
The mesh representation of the exact membrane shape is imported in the three dimensional drawing and « patch » with a plain surface for a comprehensive and realistic rendering result. This drawing can be use as a base for future architect and customer discussion.

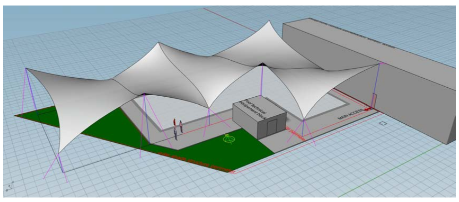


Figure 22: form finding sketch drawings

3.4. Exemple: Form Finding is described in the following steps:

3.4.1. Hand drawing

A initial hand drawn sketch suggests the textile project in space, with shapes and other elements, position of the anchor points. This L-shaped example of 677 m² area includes a 15 x 20 m rectangle, an 8.5 x 12.6 m small area orthogonal to the rectangle. All being covered by five hypars membranes whose low points are located 2.5 m above ground and high points 6.9 m above ground.

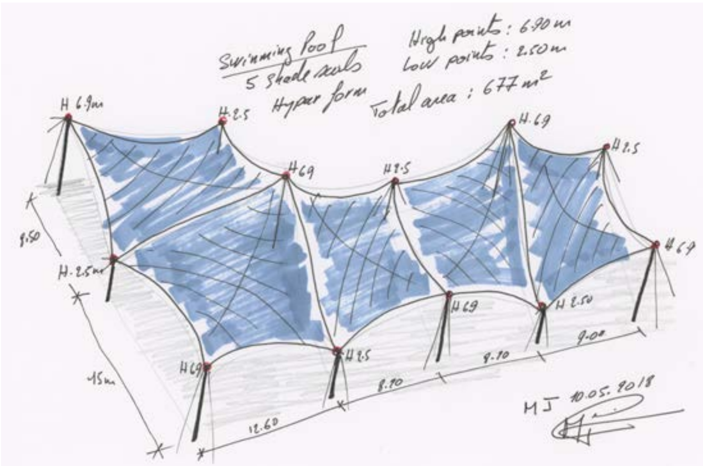


Figure 23: Five shade sails hand drawing

3.4.2. CAD DRAWING (in Rhino)

Using a CAD drawing program, Rhino in this case, allow realistic definition of the membrane boundary system in its environment. Each membrane corner is precisely defined in its three coordinates, X, Y ,Z. The complete set of angle points is called the system point. Lines (in red color on following drawing) join system points and defined the membrane boundary elements.

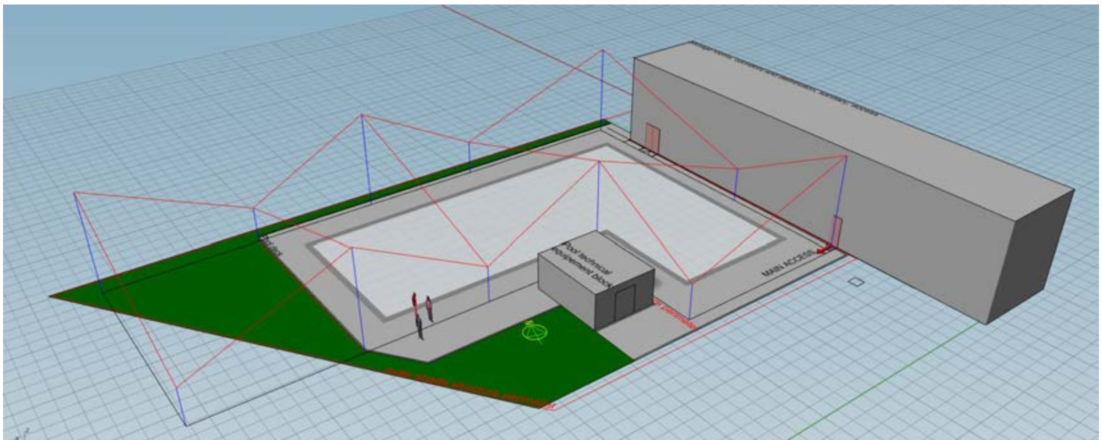


Figure 24: Boundary preparation

The boundary line drawing is then exported to a membrane 3D program which determines and calculates a realistic membrane form in full equilibrium. We use EASY for this particularly and important part.

3.4.3. Form Finding In EASY

Easy step 1: The membrane system point previously defined in the CAD drawing program is imported

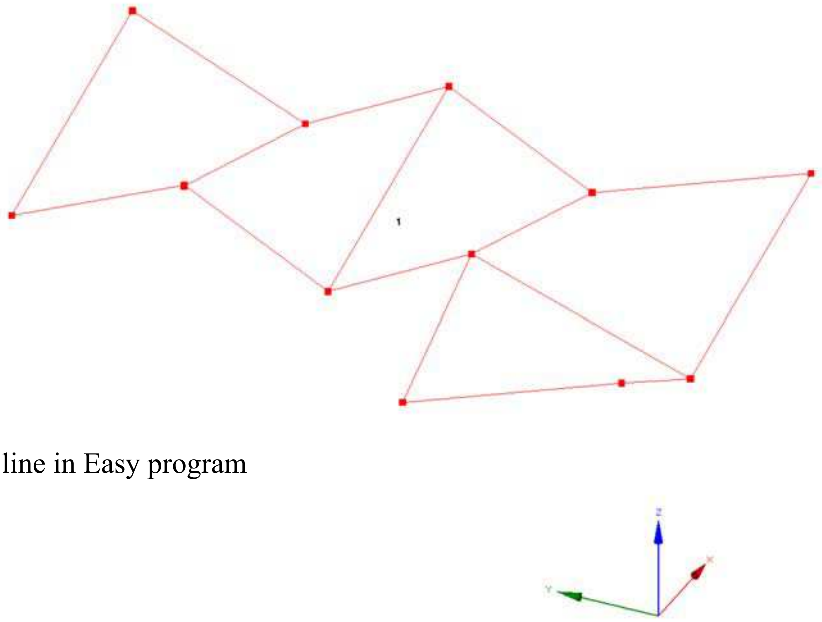


Figure 25: Boundary line in Easy program

Easy step 2: Main parameters of the membrane boundary are precisely defined. Position of corner points, type and curvature of membrane edges.

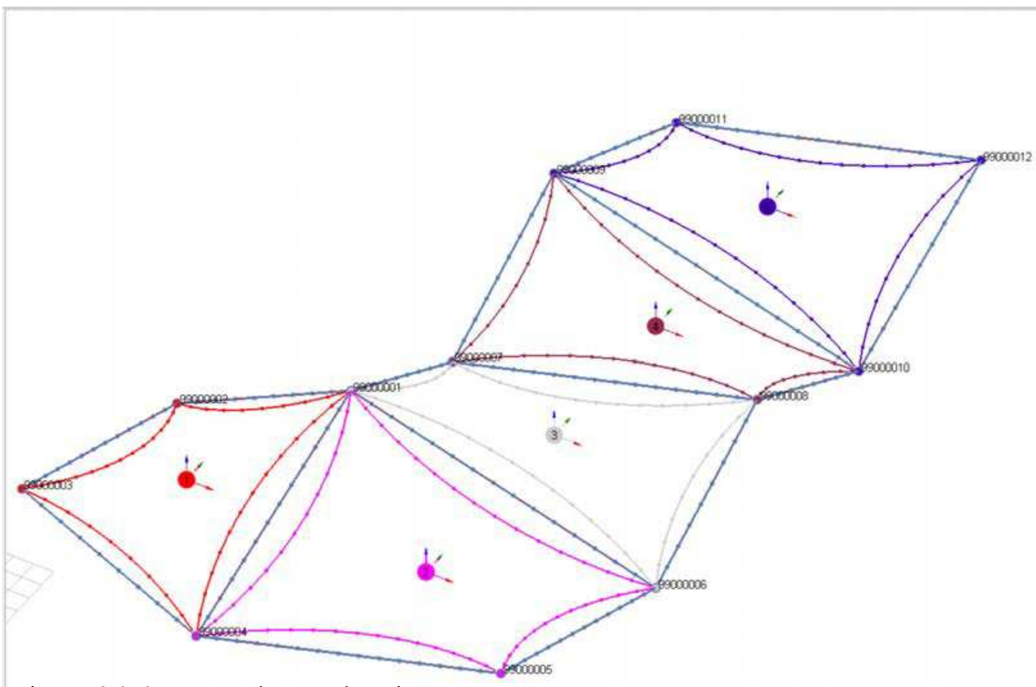


Figure 26: 3D curved Boundary in Easy

Easy step 3: Definition of the membrane mesh, showing a cable net drawing where each nodes are in equilibrium in the 3 x, y, z directions. This cable net show the true shape of the

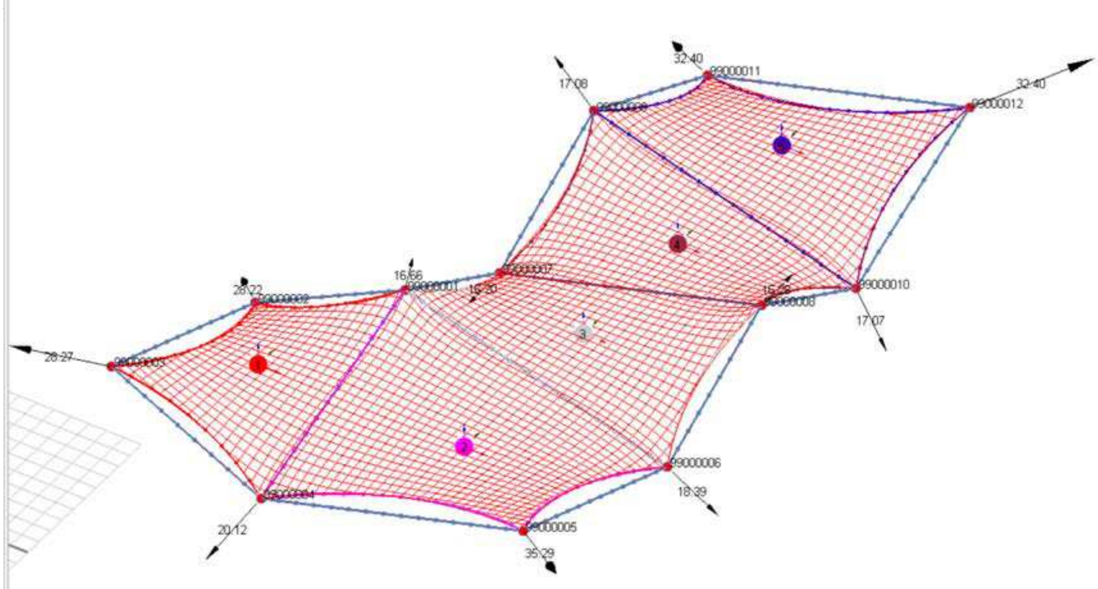


Figure 27: membrane mesh creation in Easy

The mesh is exported in DXF

3.4.4. Final CAD drawing and rendering

Importation of the mesh previously calculated in Easy program.
The membrane mesh calculated in EASY is imported in Rhino CAD drawing previously used to draw the system point. Vector loads show the forces direction at membrane connection and will help to place the structure elements in the right directions.

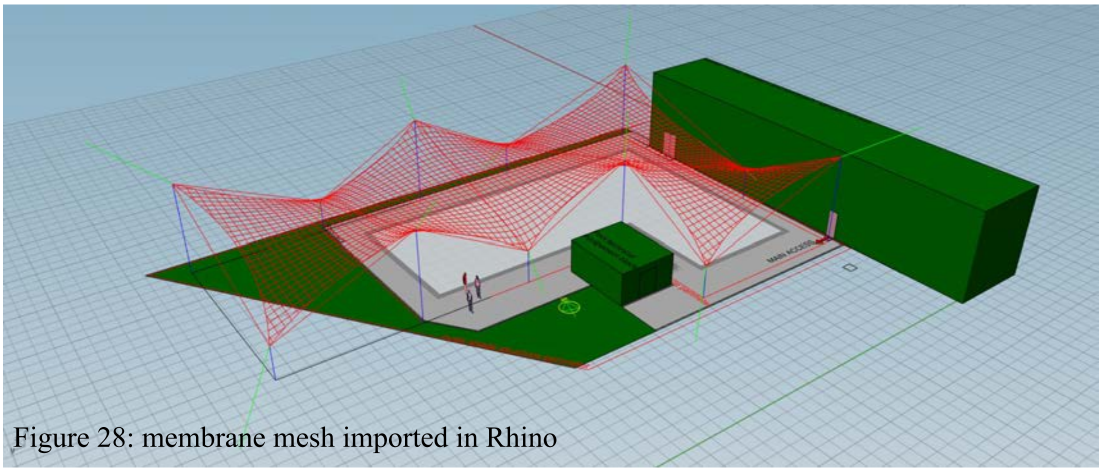


Figure 28: membrane mesh imported in Rhino

A surface is created on the mesh to show a realistic membrane shape and material

3.4.5. Rendering

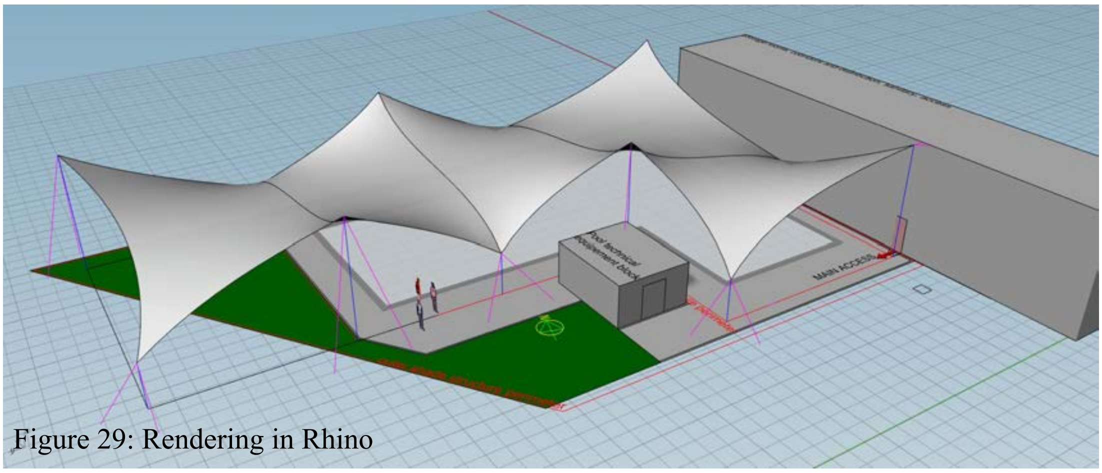


Figure 29: Rendering in Rhino

Columns and guying elements are then added to complete the rendering drawing, which can now be presented to the architecte and customer.

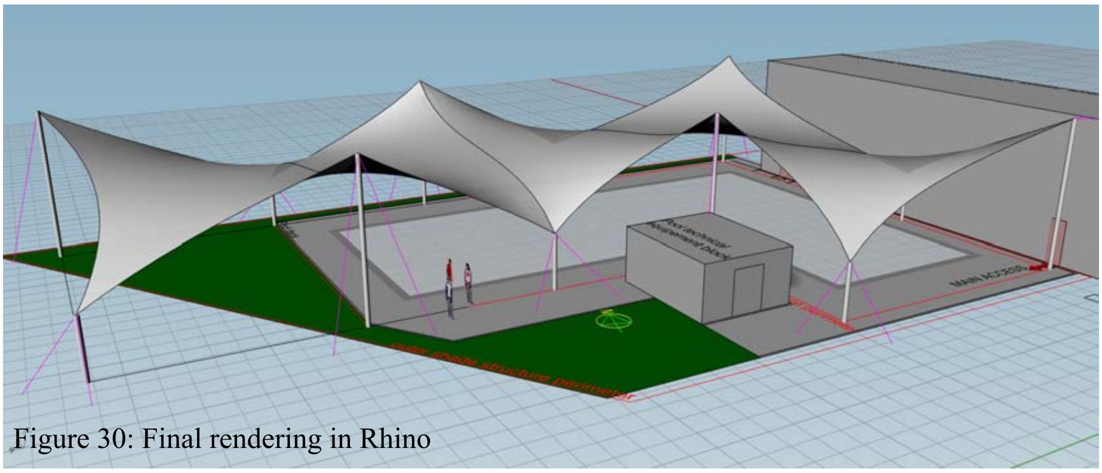


Figure 30: Final rendering in Rhino

At this stage the FORM FINDING is complete.

Base on this first step information, the designer, architect and customer have a meaningful information to go evaluate the project proposal, consider modifications or proceed to the engineering calculation and statical analysis. Statical analysis will give information on the membrane and edge cables forces. Base on such data, it will be possible to choose the membrane type and proceed with calculation on the structure itself.

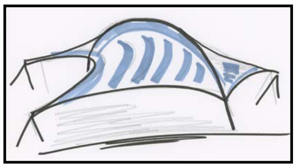
4. CASE STUDIES

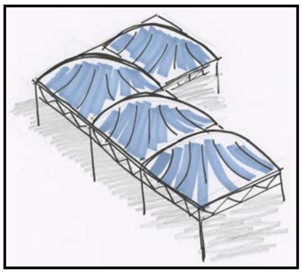
Different architectural scenarios are proposed to cover the swimming pool and bring shade to the area.

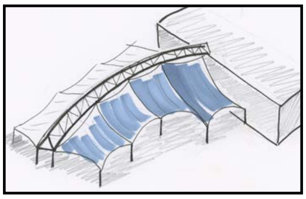
A list of different designs follow, they are classified by form type.

4.1/ Different Forms proposal / List of case studies

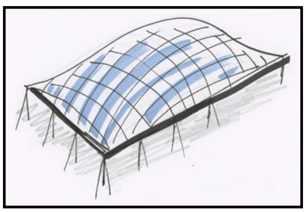
ARCH SUPPORTED TENT



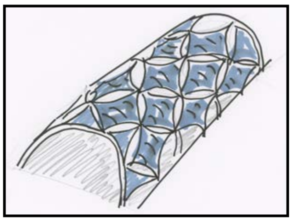




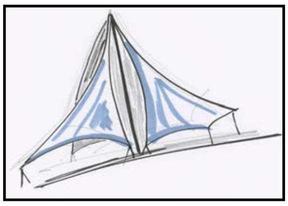
DOME SHELL

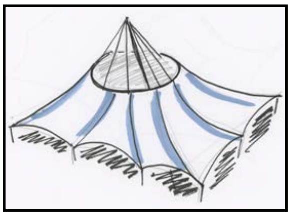


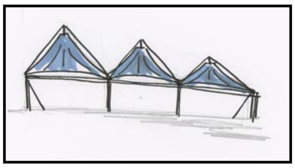
FOUR-POINT SURFACE

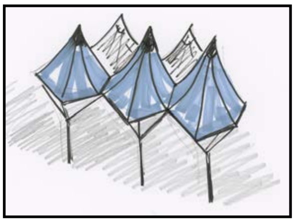


HIGH-POINT & LOW-POINT

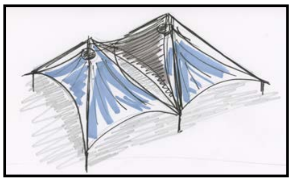




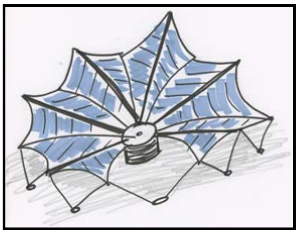




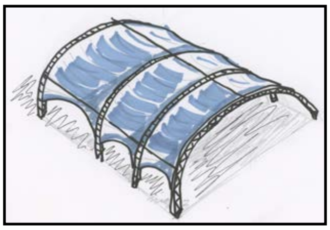
FOUR-POINT TENT & HIGH-POINT TENT

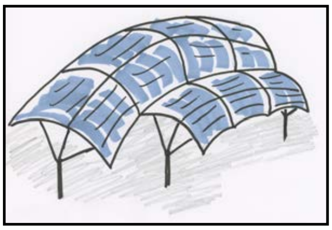


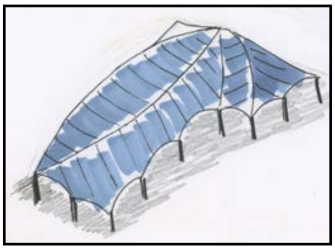
RIDGE & VALLEY

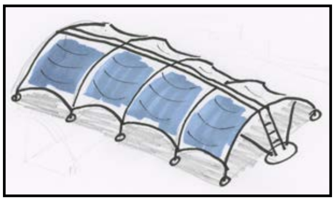


SADDLE

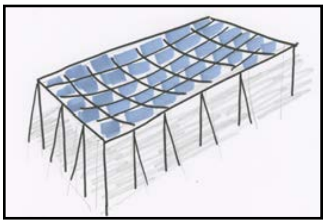








CABLE NET



4.2 Case Studies

All following case studies are designed with following parameters:

Hand Free drawing

3D drawing of the membrane boundary in Rhino program

3D form Finding of the membrane in Easy program

Steel structure drawing in Rhino

Statical Analysis in Easy

Steel structure calculation in EASY + RSTAB program.

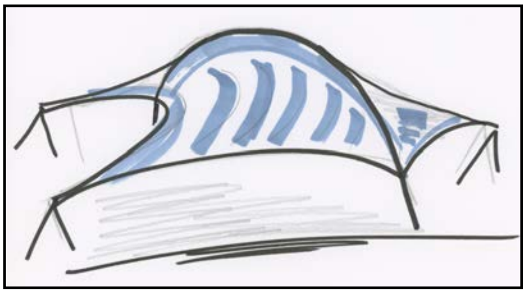
Rendering of the membrane and structure in Rhino

Criteria:
Wind pressure taking in consideration: 95 daN/ m^2
CP value: average cp value = 1

CASE STUDY n°01

Arch-supported Tent

The Central Arch is asymmetric and consist of a long curved tube.



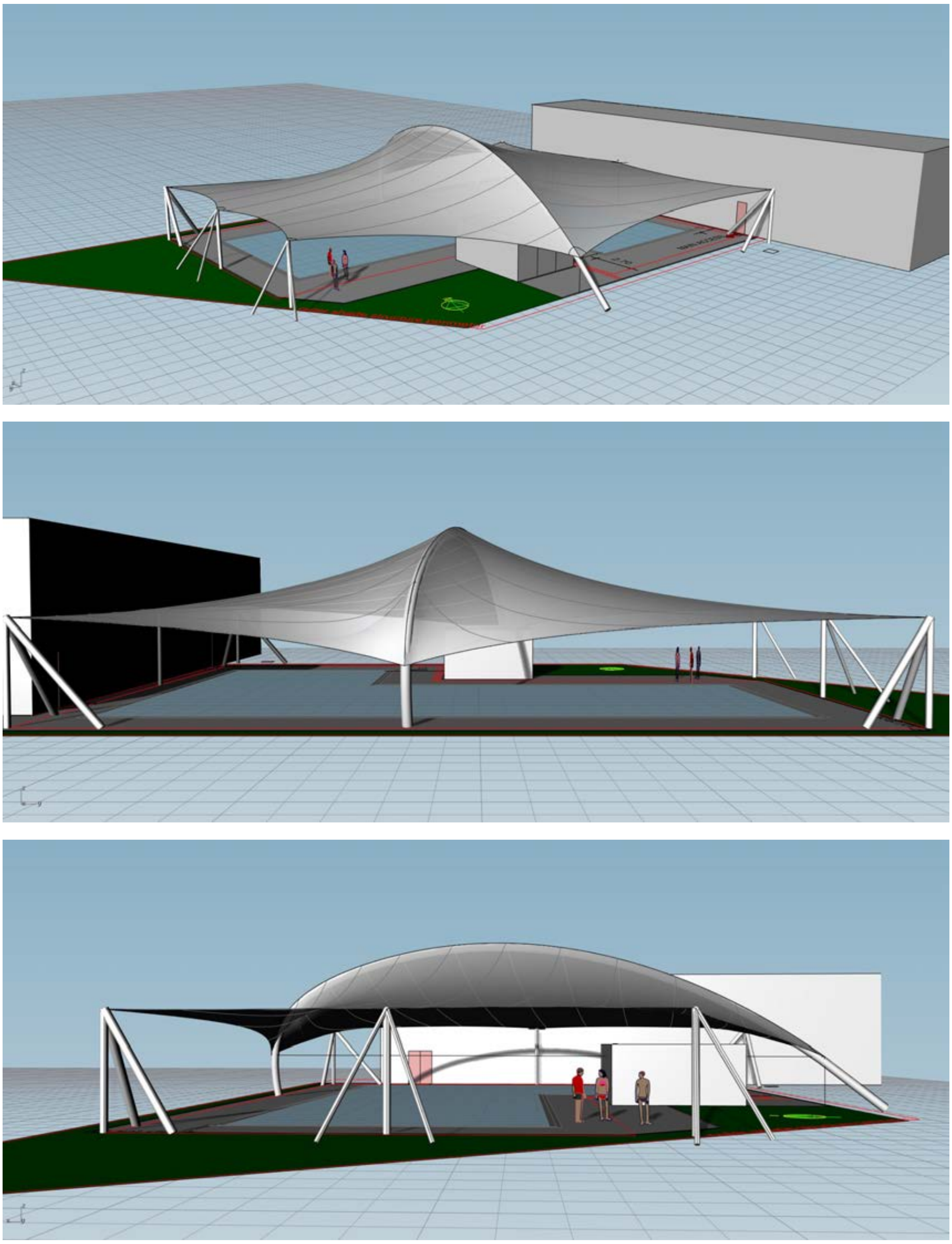


Figure 31: Arch Supported Tent, 3 views

CASE STUDY n°02

Arch-supported Tent Option 2

The Central Arch is a curved steel tube symmetric in shape and supported on 2 reinforced concrete cone.

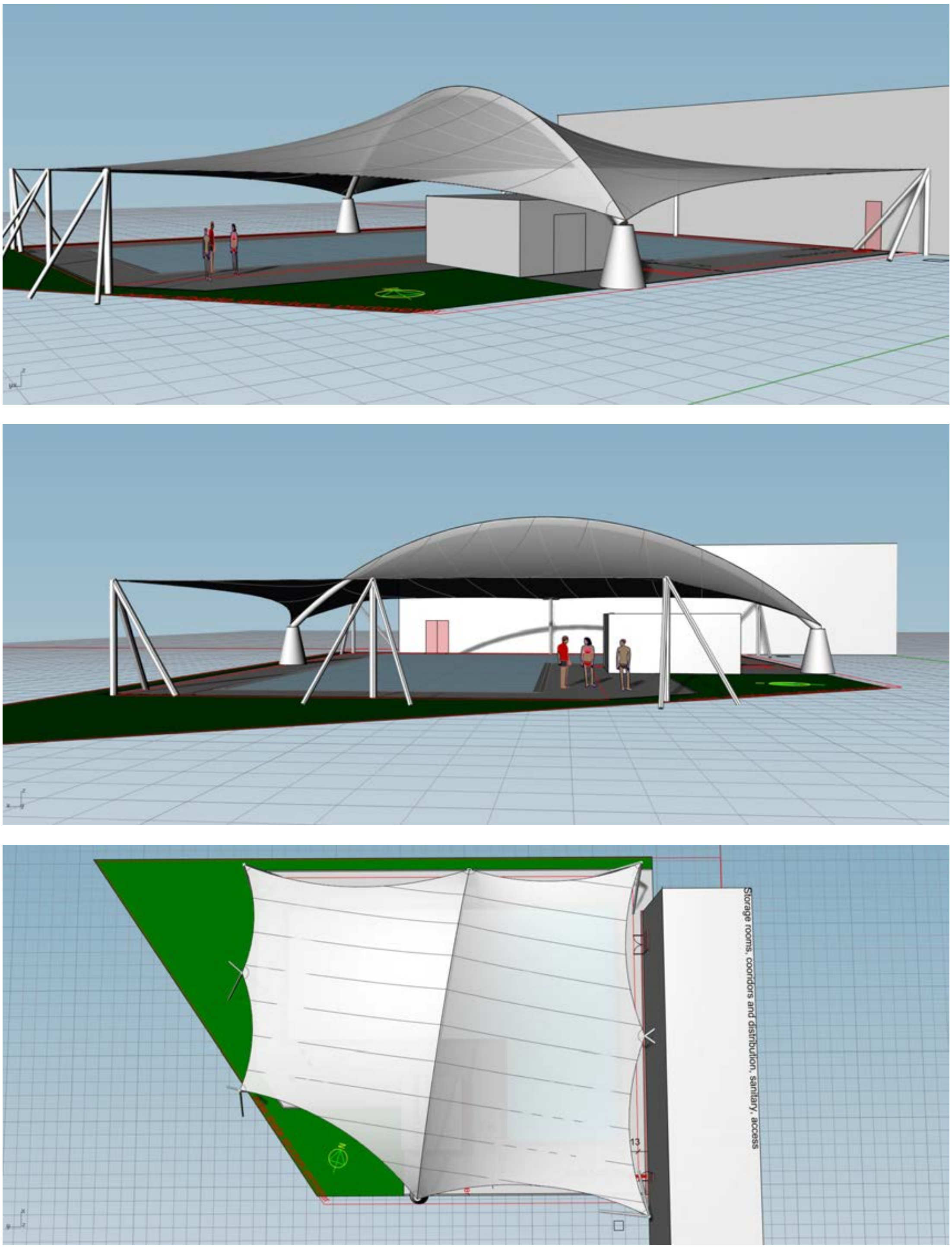
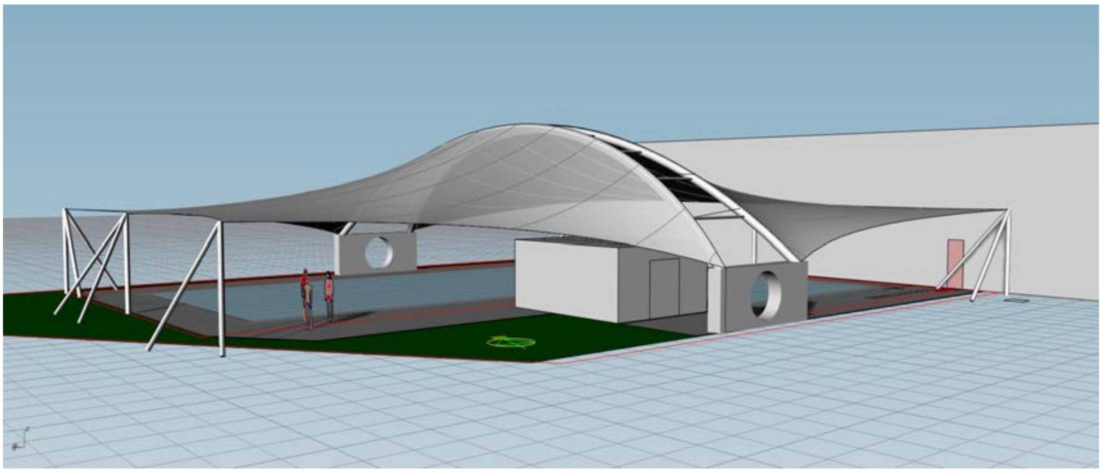


Figure 32: Arch Supported Tent, option 2, 3 views

CASE STUDY n° 03

Arch-supported Tent Option 3

The ridge is a separated double curve tube giving natural ventilation to this membrane roofing



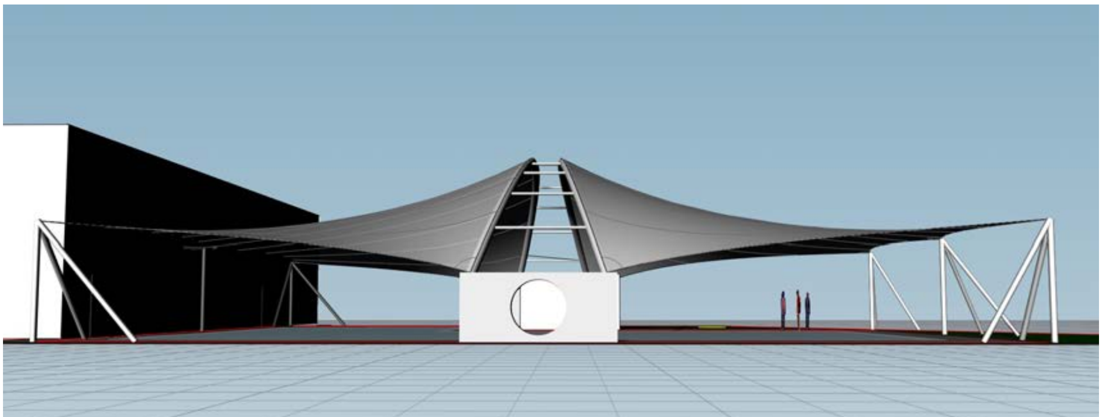


Figure 33: Double Arch Supported Tent, option 3, 2 views

CASE STUDY n° 04

The tent is similar to option 2 using a symmetric central arch, but supported by 2 CORTEN steel elements

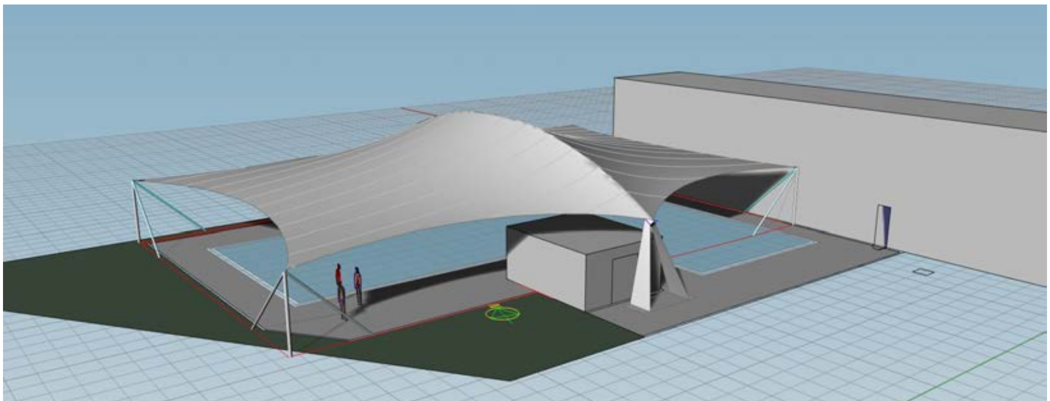
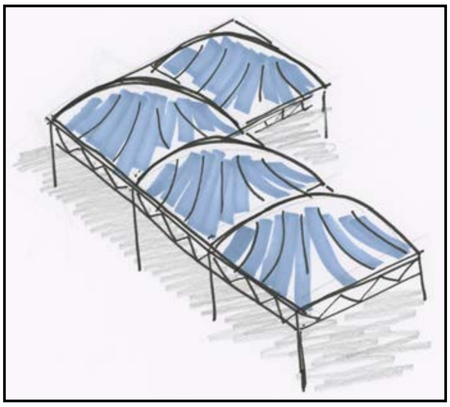
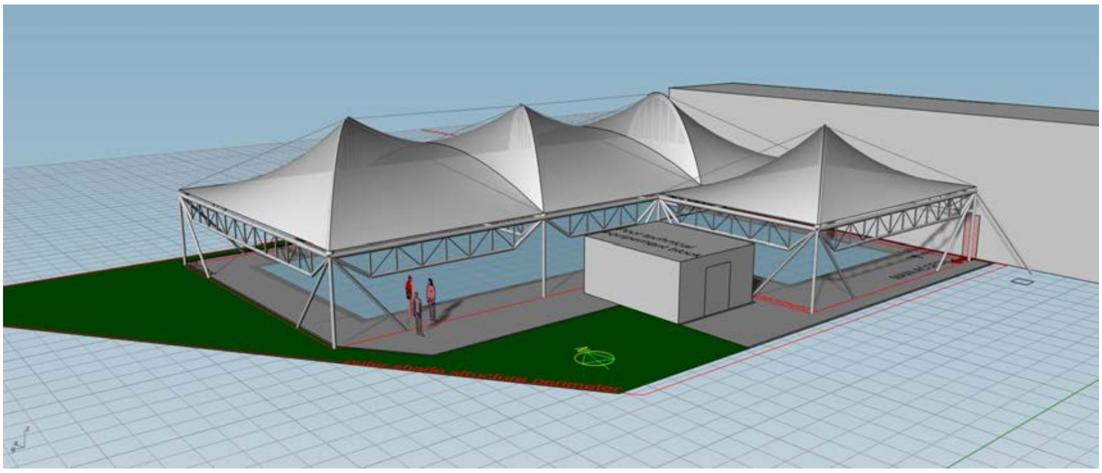


Figure 34: Arch Supported Tent, option 4, 1 view

CASE STUDY n° 05

Inclined Interconnected Arches supporting 4 membranes, 3 over the large pool and 1 to cover the small pool and entrance.





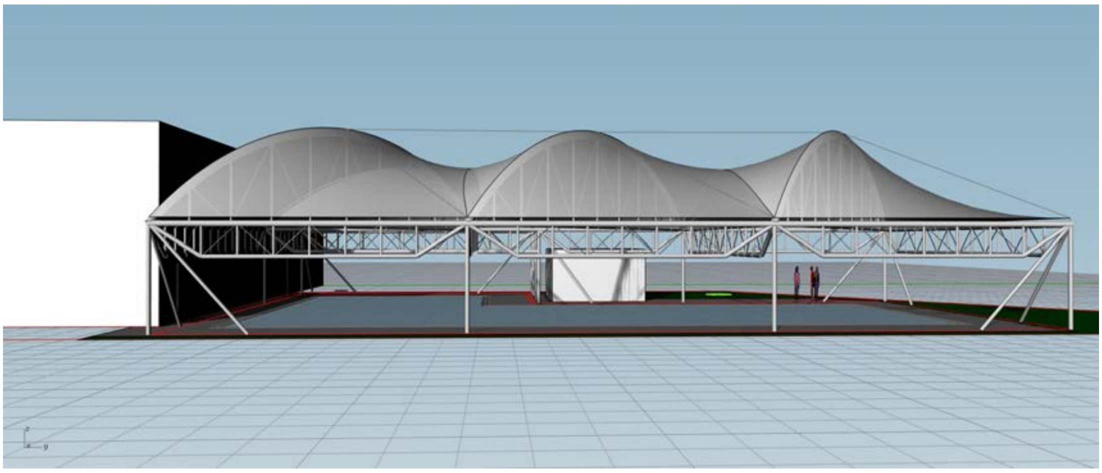


Figure 35: Inclined Interconnected Arches, 2 views

CASE STUDY n° 06

Long Ridge
3D Truss Beam at ridge

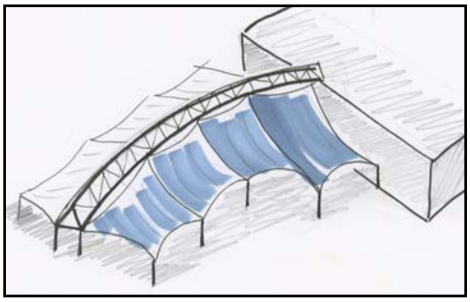
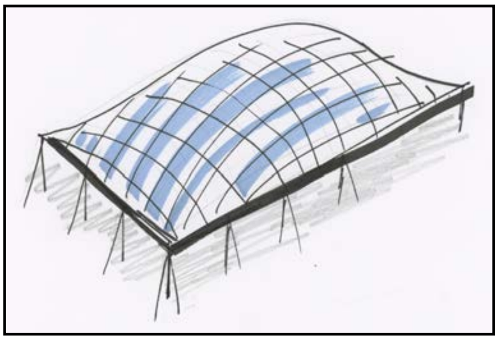
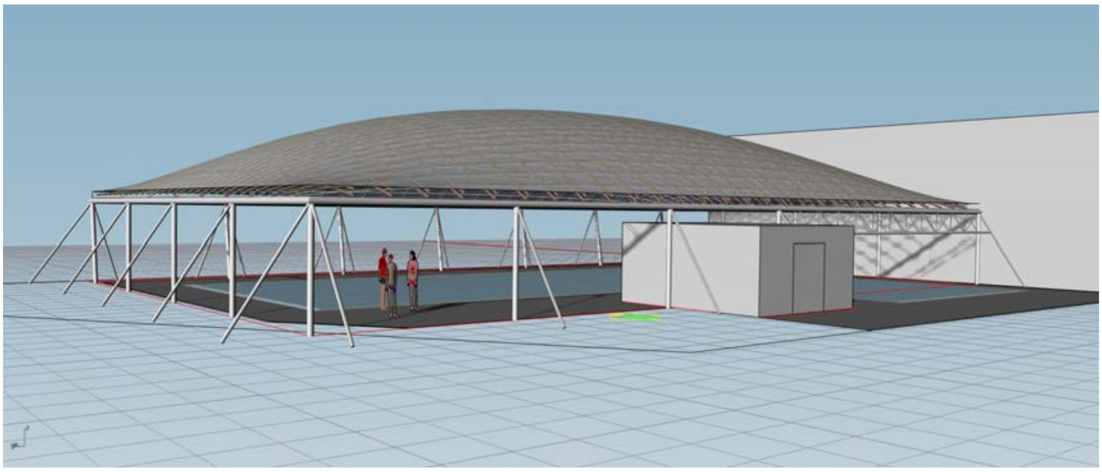


Figure 36: Long 3D Truss Beam, 3 views

CASE STUDY n° 07

Grid-Shell to cover the large pool, area A





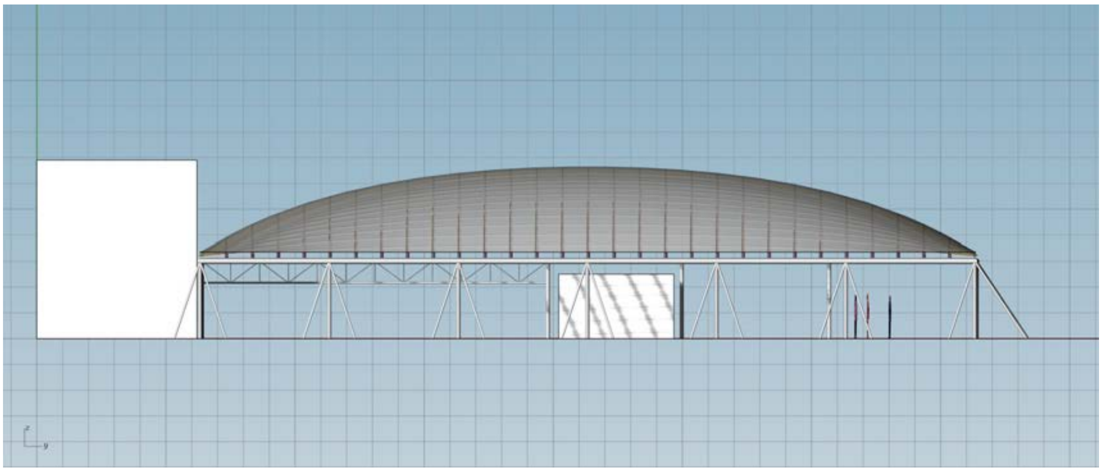
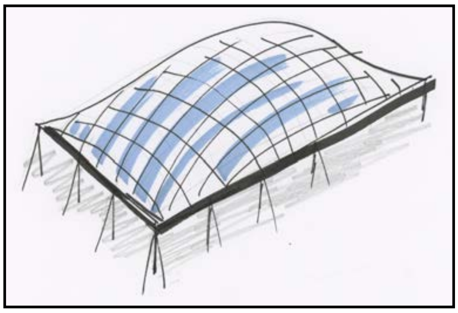


Figure 37: Grid Shell Dome A, 2 views

CASE STUDY n° 07 B



Grid-Shell to cover the total area:

- Large pool
- Small pool area
- side deck area

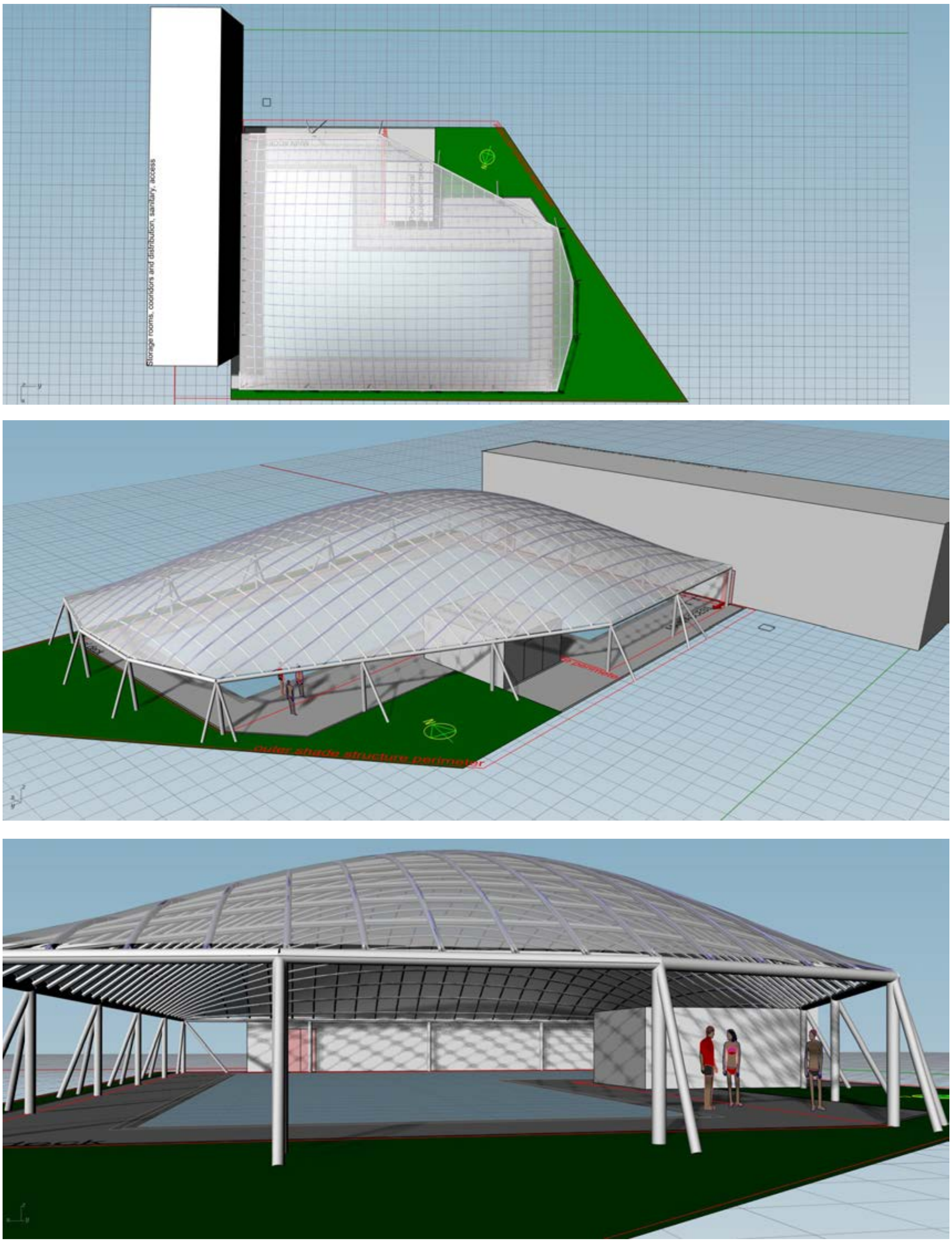
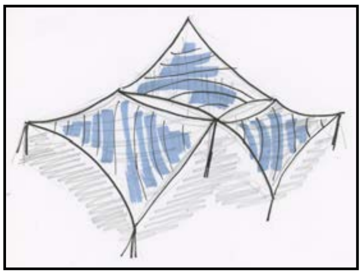


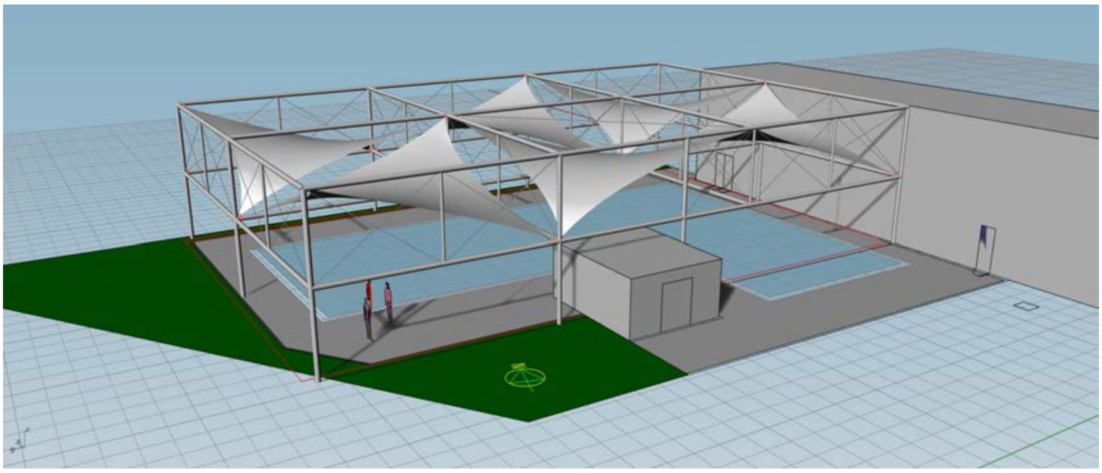
Figure 38: Large Grid Shell Dome, 3 views

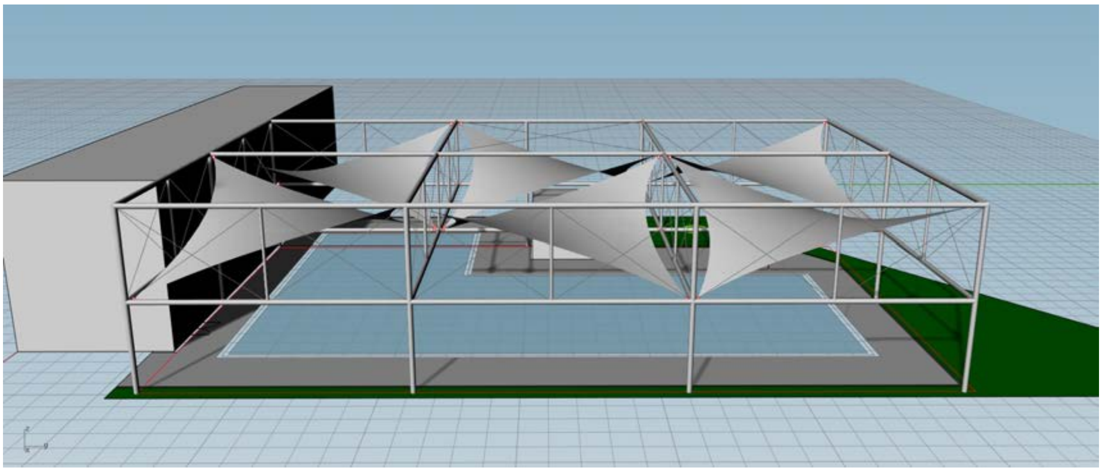
CASE STUDY n° 08

Group of Four-point Tent suspended in a steel tube frame.



The 6 membrane elements are similar and tensioned in a steel fame structure





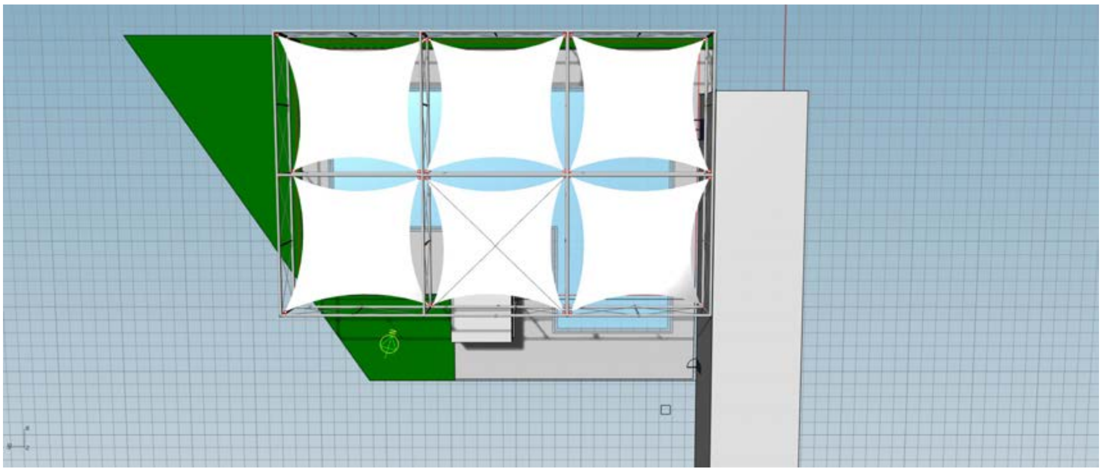


Figure 39: Group of six Hypar sails, 3 views

CASE STUDY n° 09

Group of Four-point Tent

The high and low points are supported by steel tube masts, and the membrane tensioned by means of edge cables and guying tube and cables.

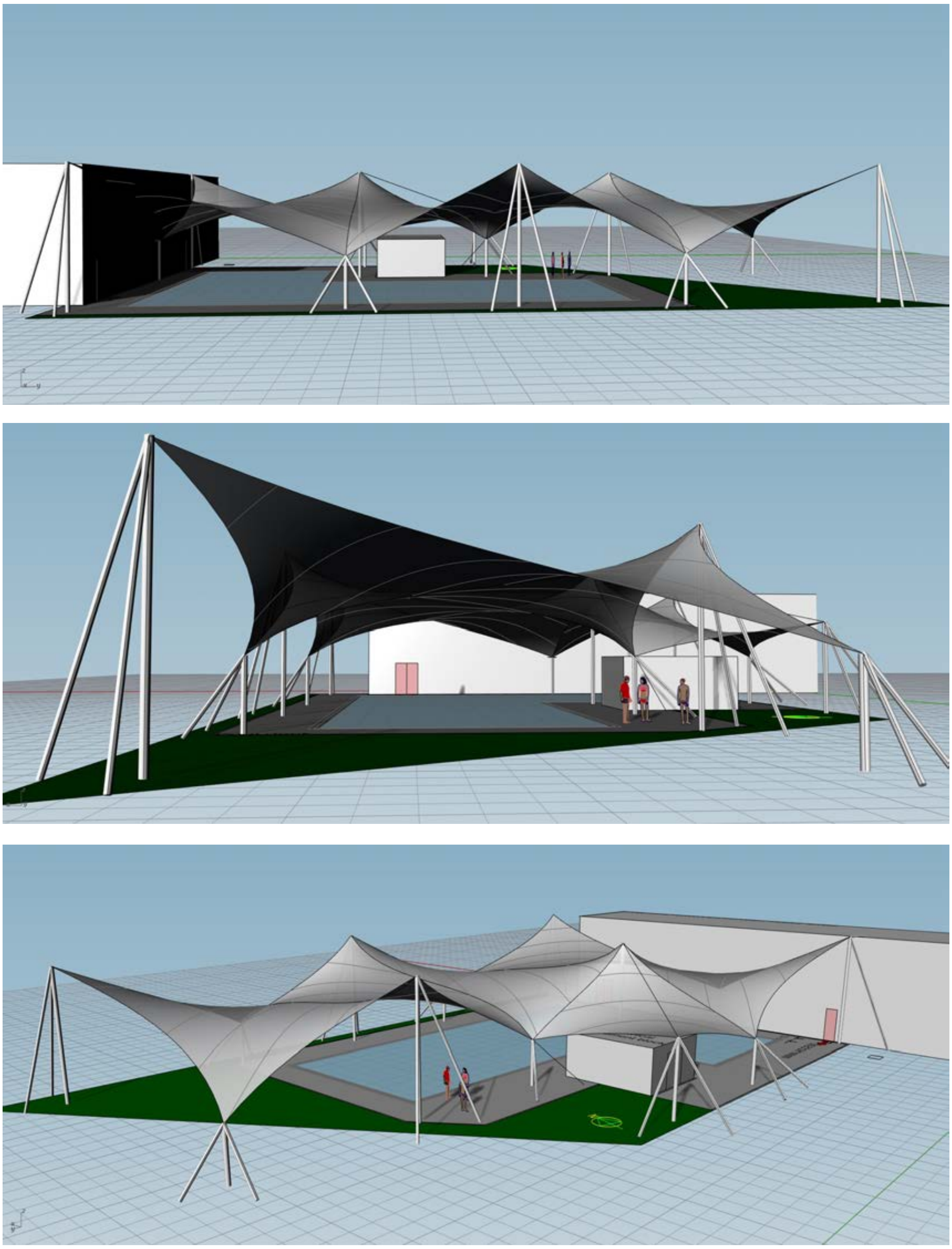


Figure 40: Group of Four-Point tents, 3 views

CASE STUDY n° 10

Group of three Four-point Tent

The membrane boundary system is made of rigid steel trusses, self-supported by columns disposed in zigzag way.

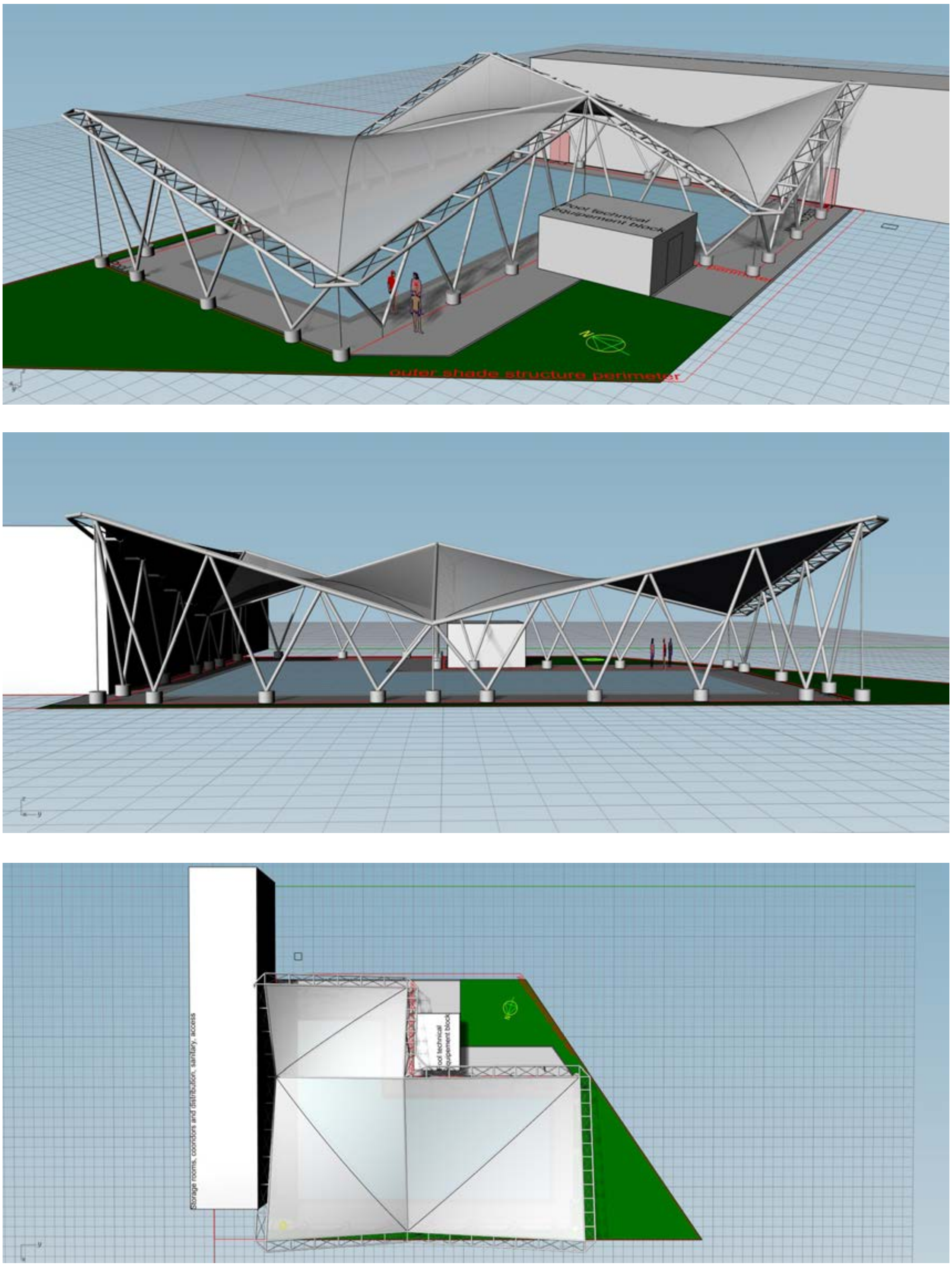
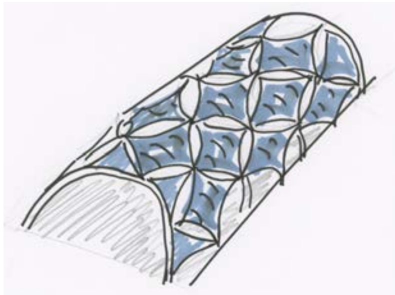


Figure 41: Group of three Four-Point tents, 3 views

CASE STUDY n° 11



Flying Hypar’s

Small hypars sails « flying » between steel arches structure

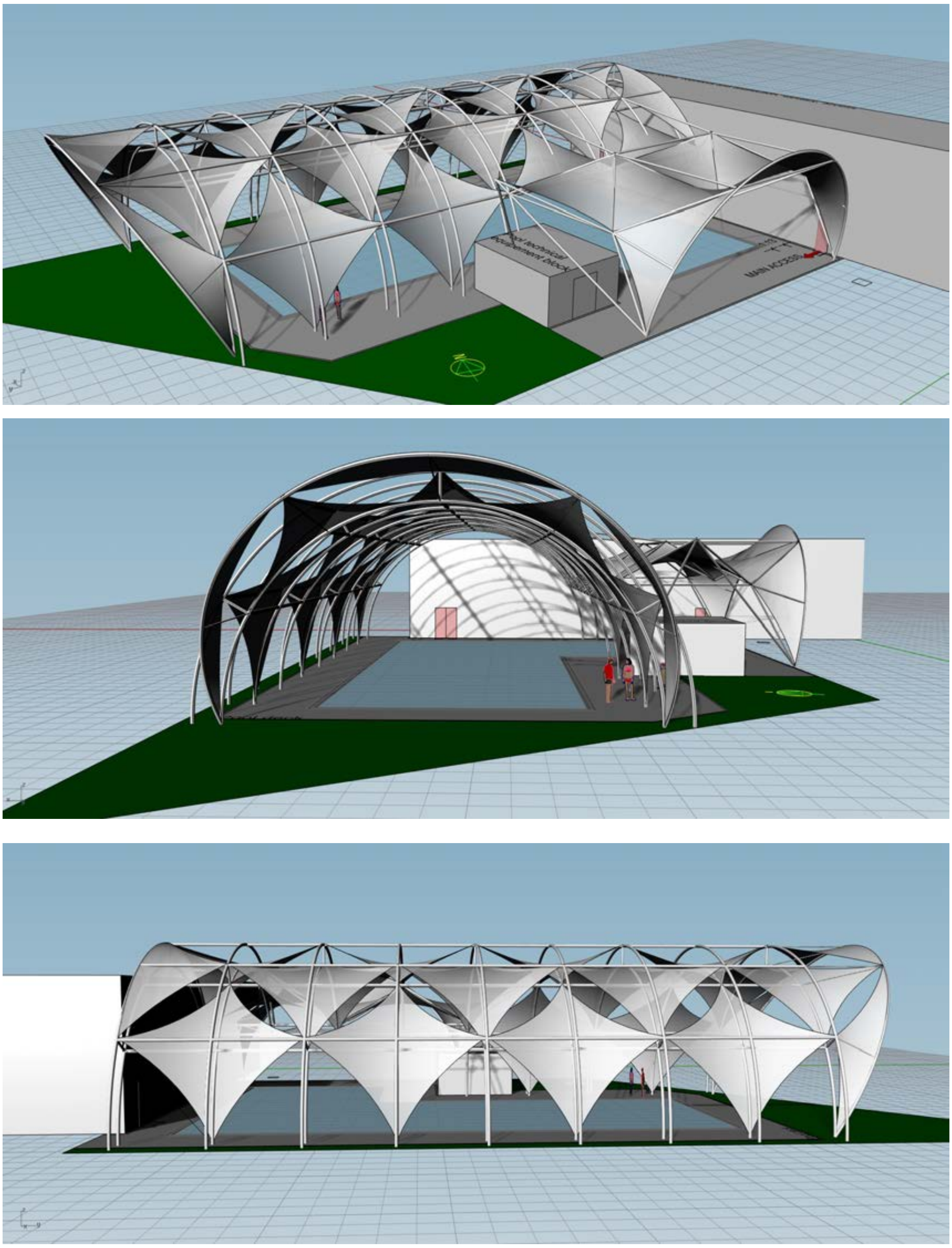
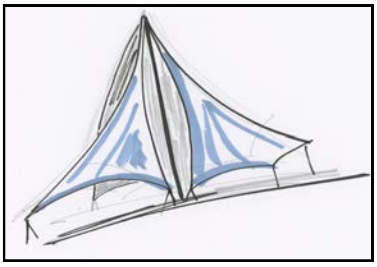


Figure 42: « flying » Hypar sails, 3 views

CASE STUDY n° 12

PEAK HIGH POINT TENT



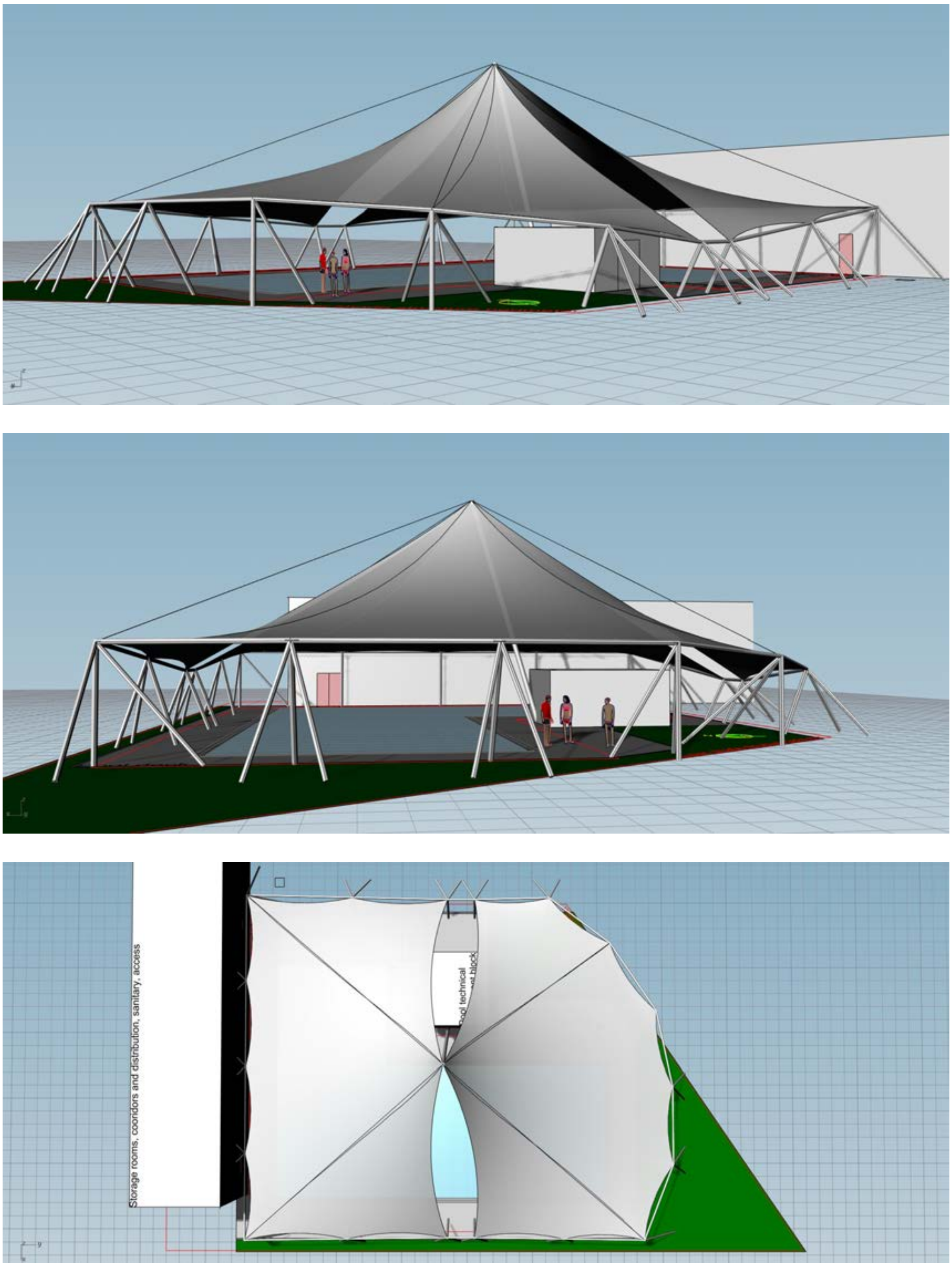
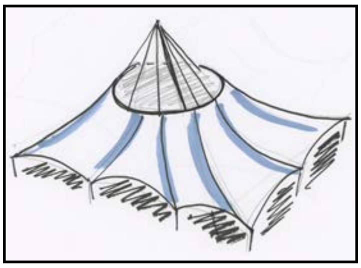


Figure 43: Peak High Point Tent, 3 views

CASE STUDY n° 13

RING HIGH POINT TENT



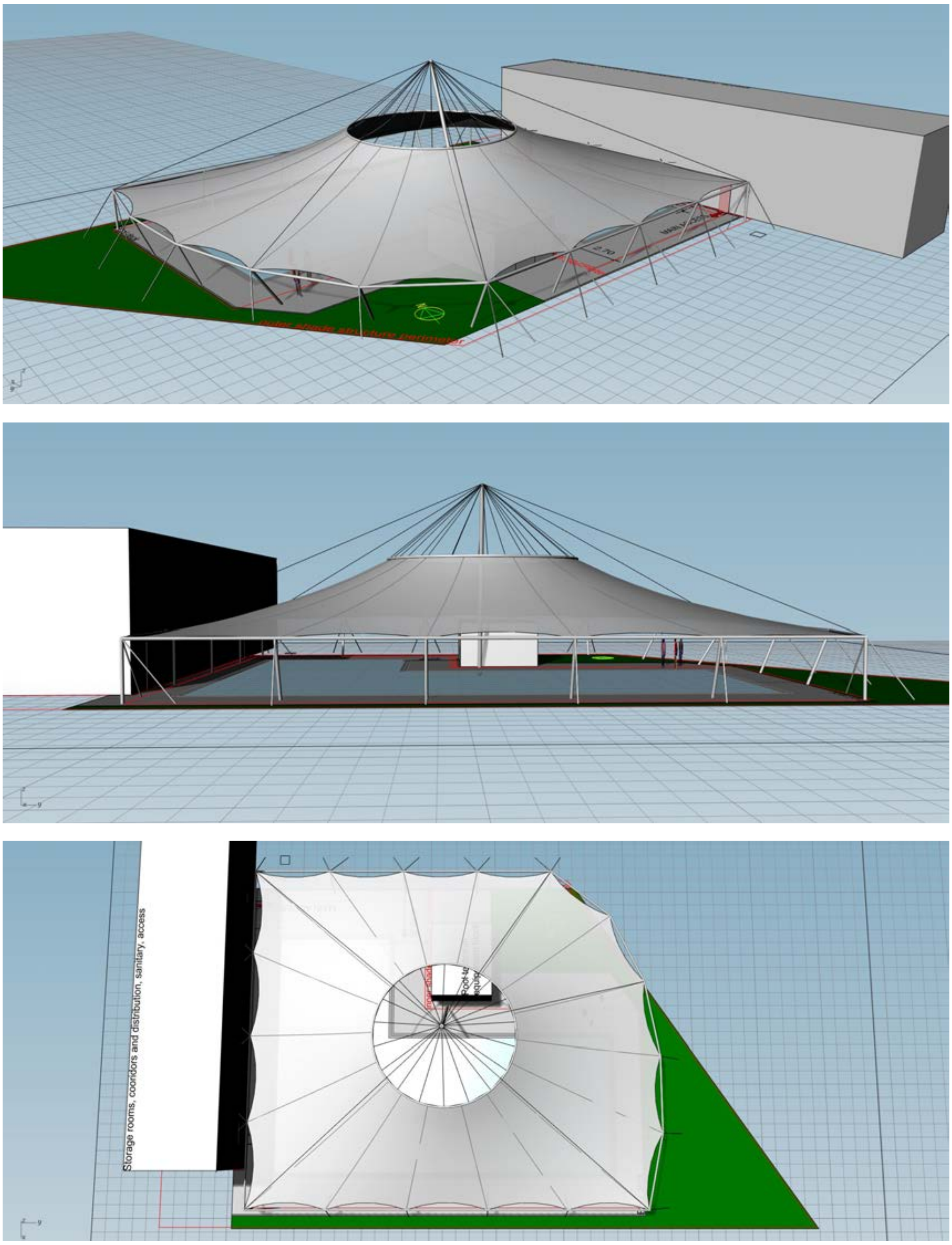
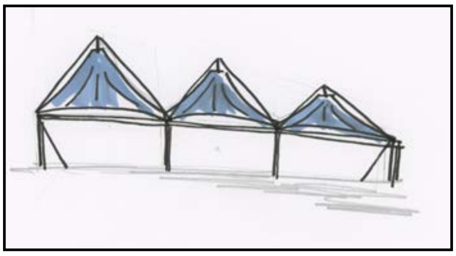


Figure 44: Peak High Point Tent, 3 views

CASE STUDY n° 14

HIGH POINT TENTS

Four elements Supported
by pyramidal trusses



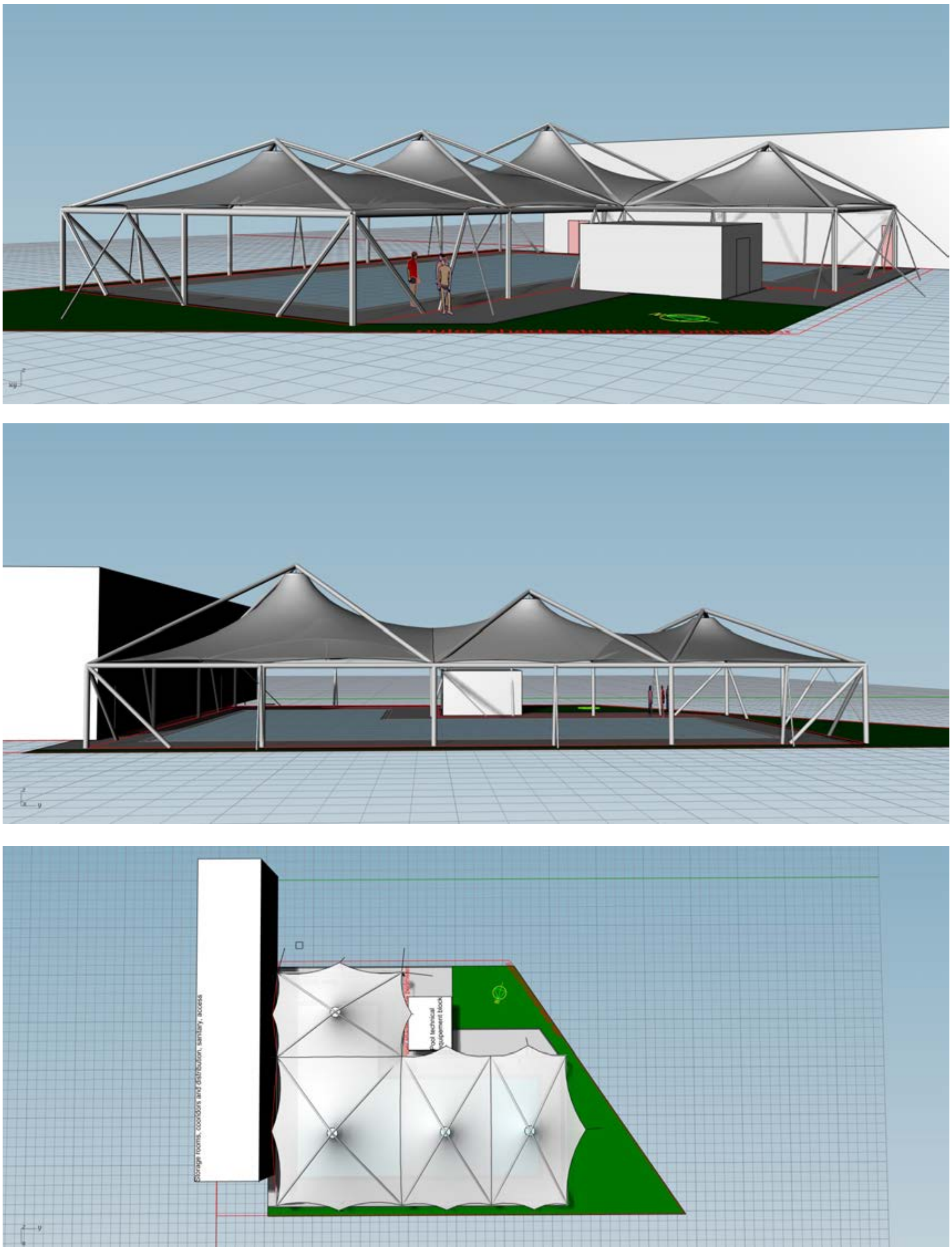
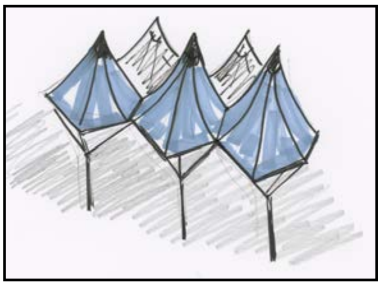


Figure 45: High Point Tents, 3 views

CASE STUDY n° 15

HEXAGONAL UMBRELLAS



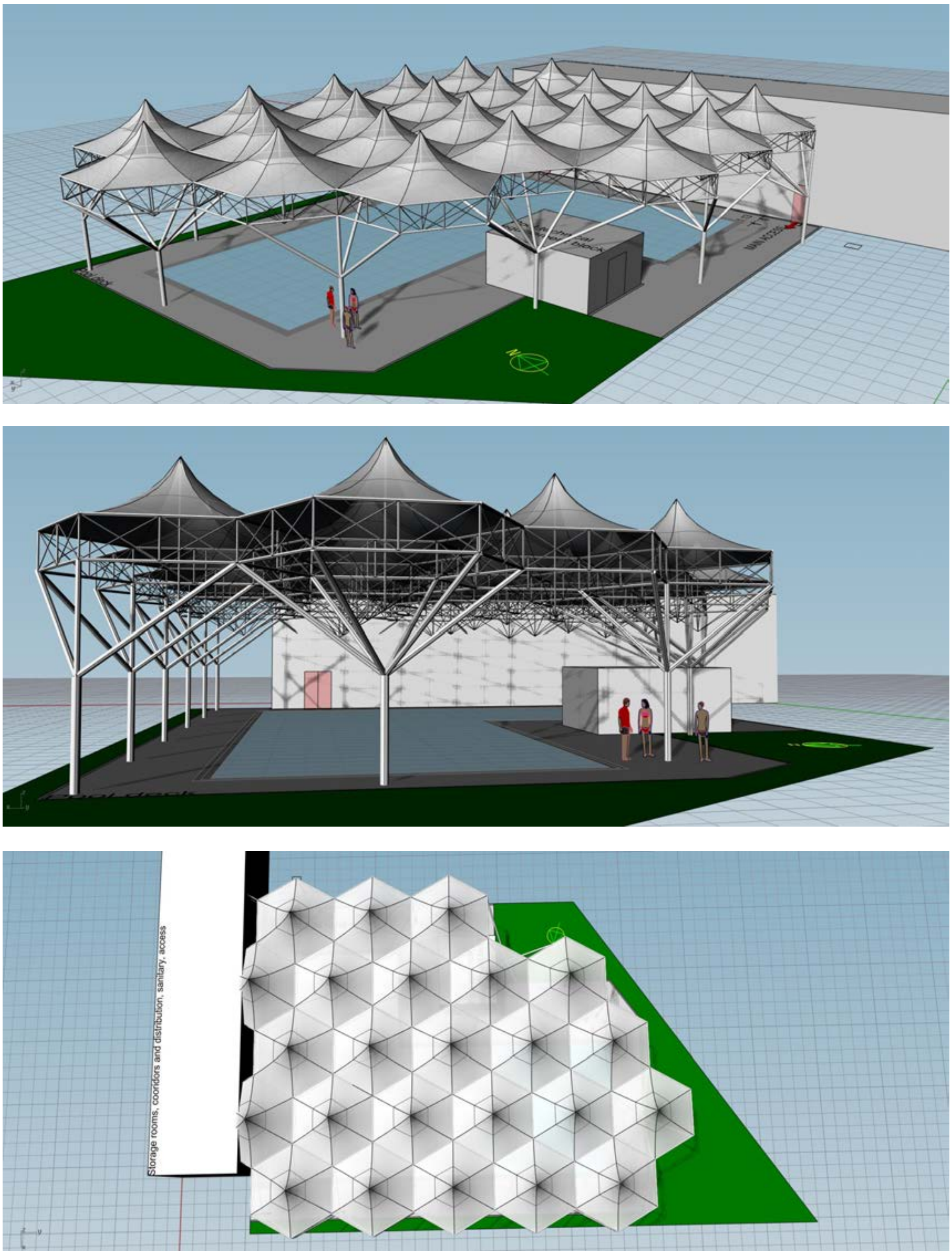
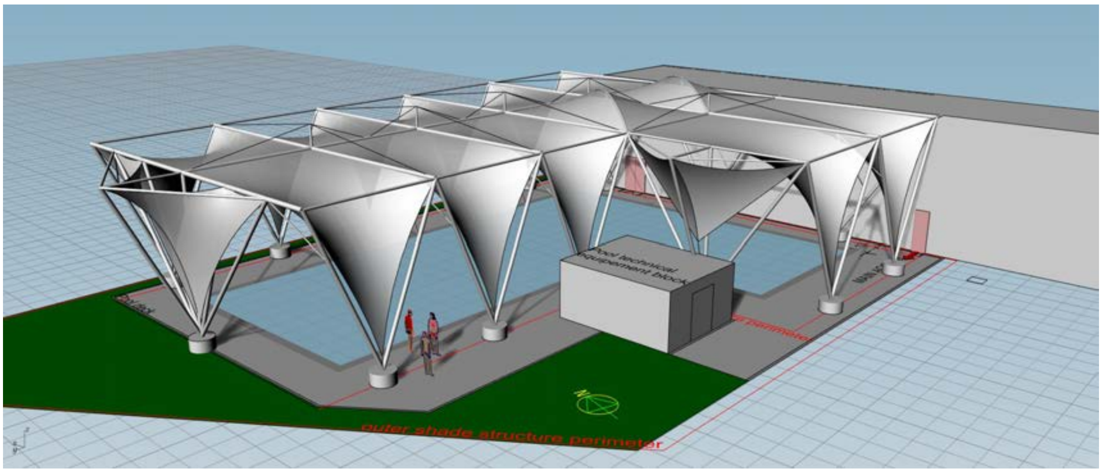


Figure 46: Hexagonal umbrellas, 3 views

CASE STUDY n° 16

« CANOPEE »



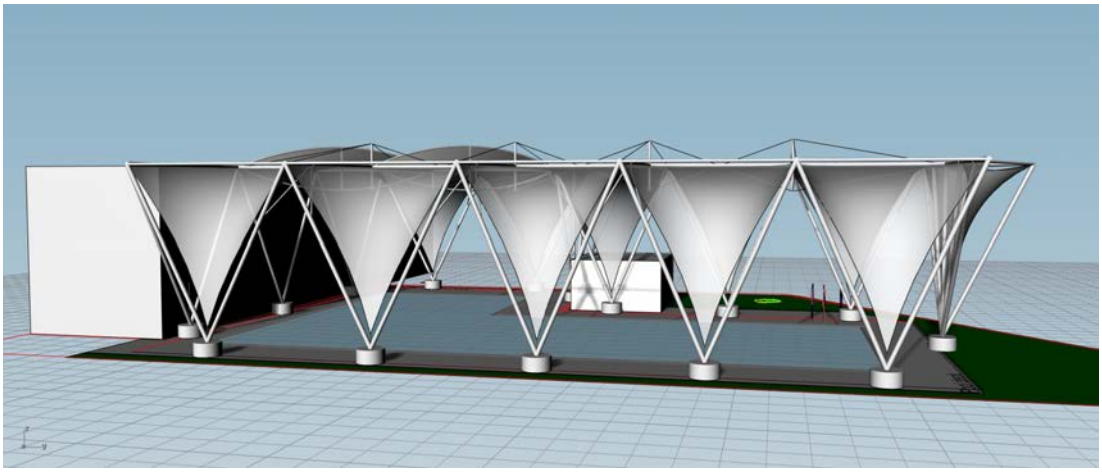
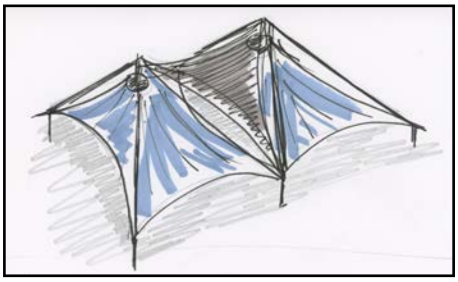


Figure 47: « Canopee », 2 views

CASE STUDY n° 17

Four-Point & High Point Tent

The high points of both the conical elements and the Hypar tents are supported by steel beams sited <u>on reinforced concrete wall element</u>



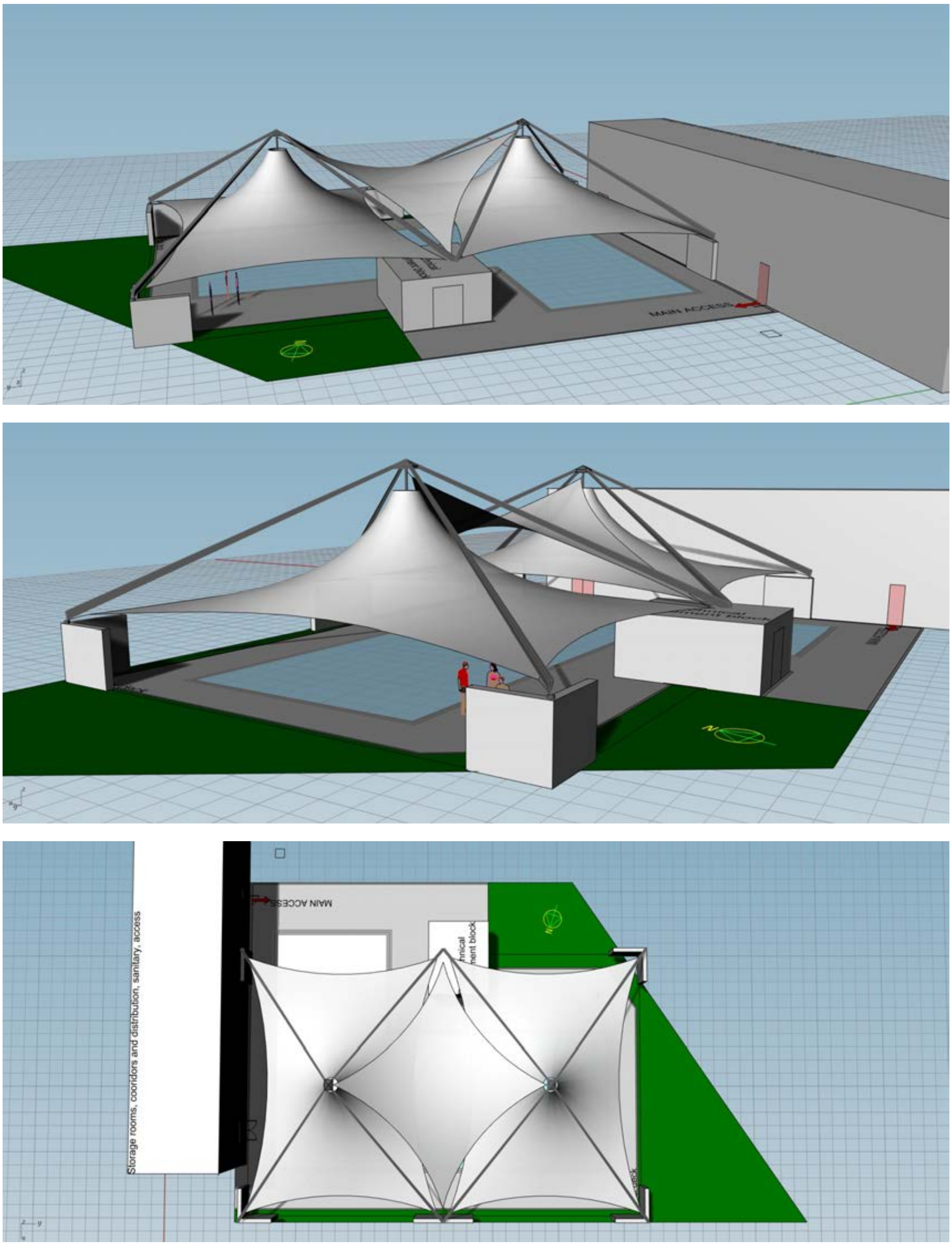
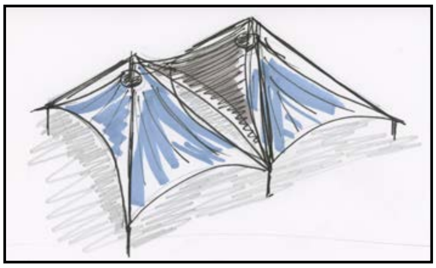


Figure 48: Four-Point & Hypar Tent, on concrete walls, 3 views

CASE STUDY n° 18

Four-Point & Hypar Tent

The high points of both the conical elements and the Hypar tent are supported by steel beams sited on Steel structure.



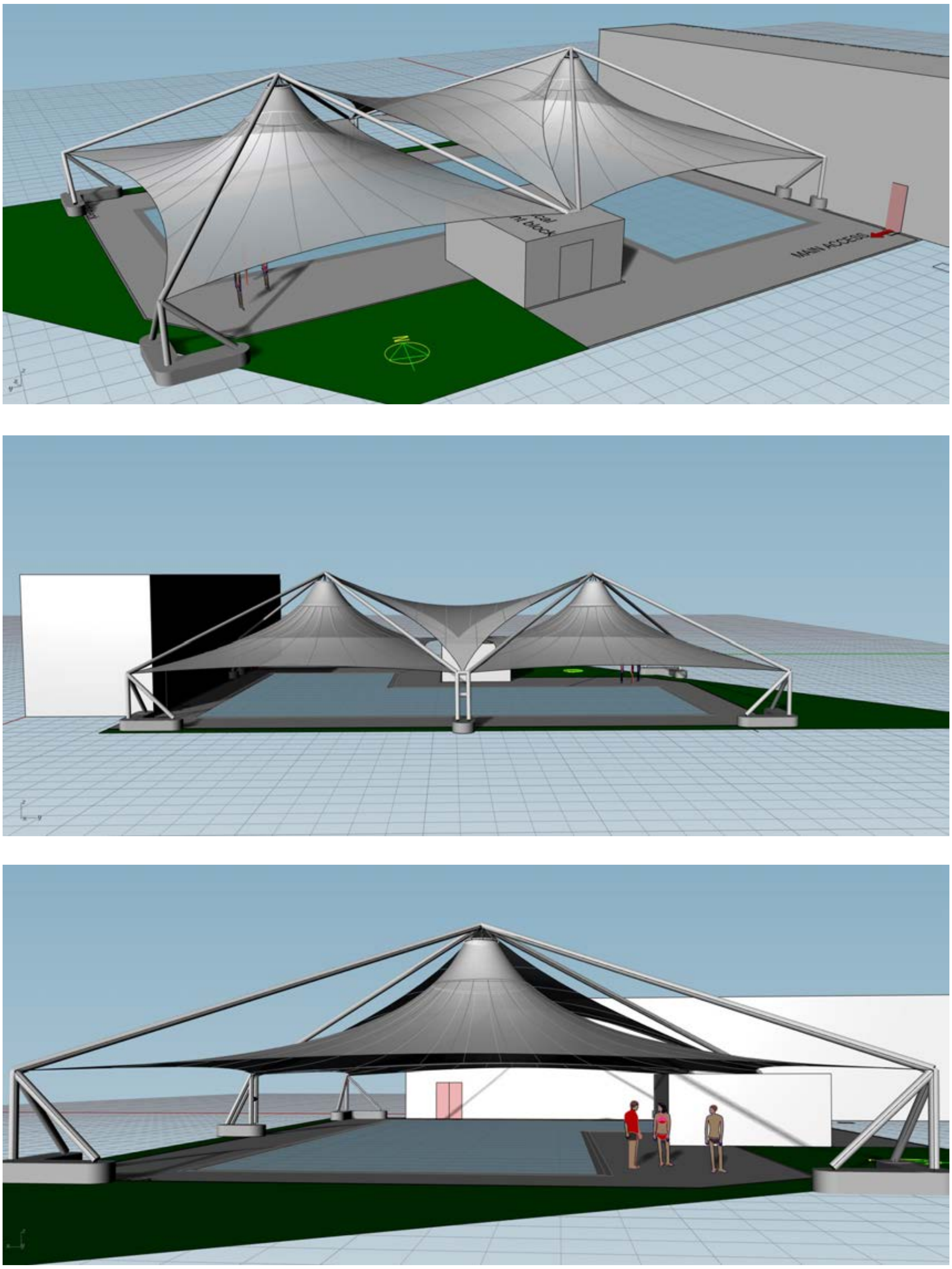
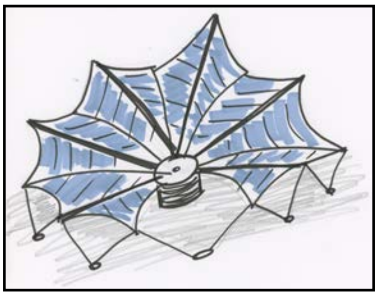


Figure 49: Four-Point & Hypar Tent, on steel structure, 3 views

CASE STUDY n° 19

Radial Ridge & Valley Tent



Like a Fan, the structure is radially organized. The central point is the new technical room, rebuilt with reinforced concrete serving as a strong support.

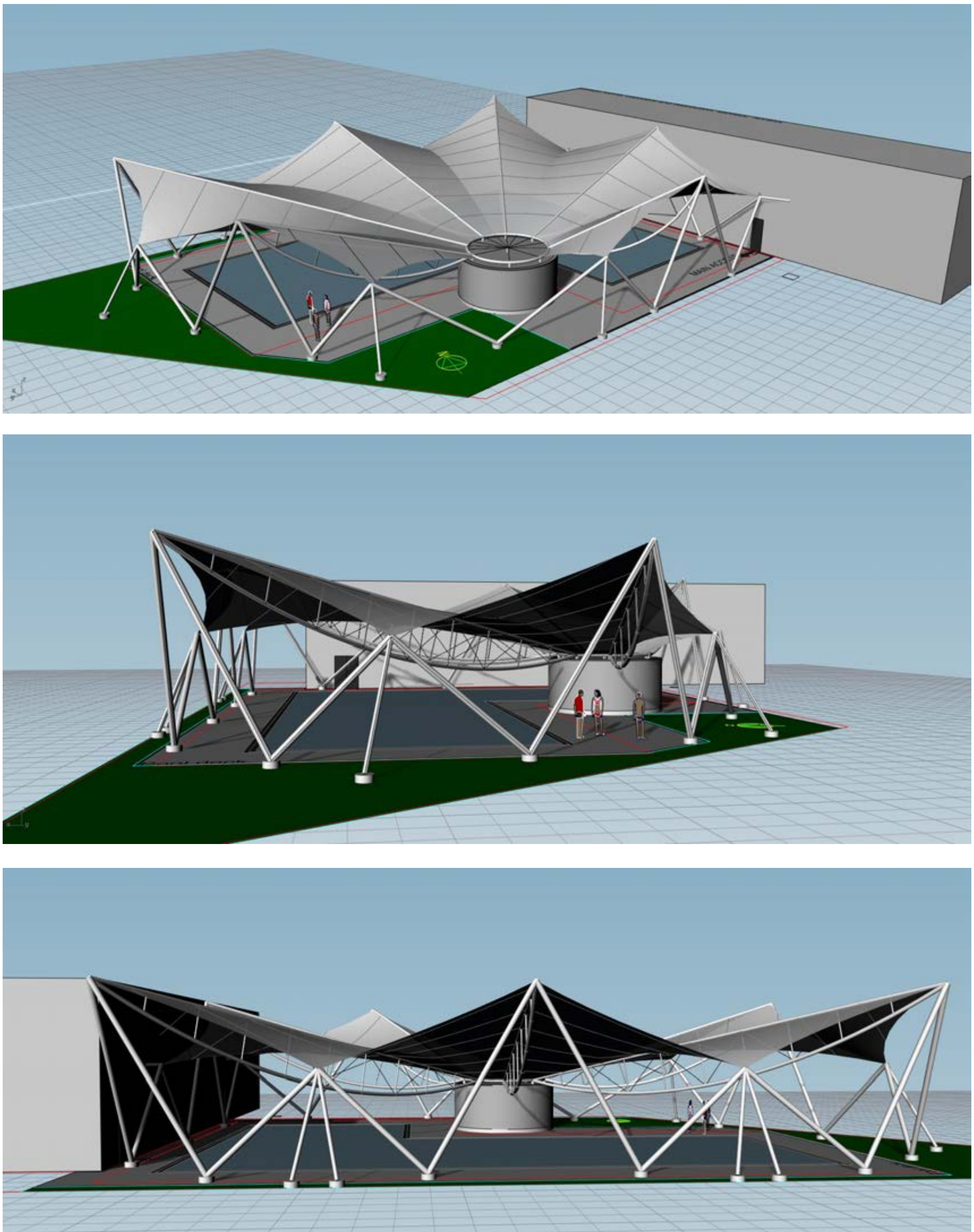
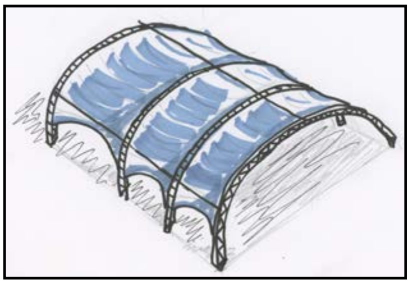


Figure 50: Radial Ridge & Valley Tent, 3 views

CASE STUDY n° 20

Saddle Tent

The 3 membrane elements are tensioned between 3D truss beam curved with a 20 m span and 7 meters high at ridge.



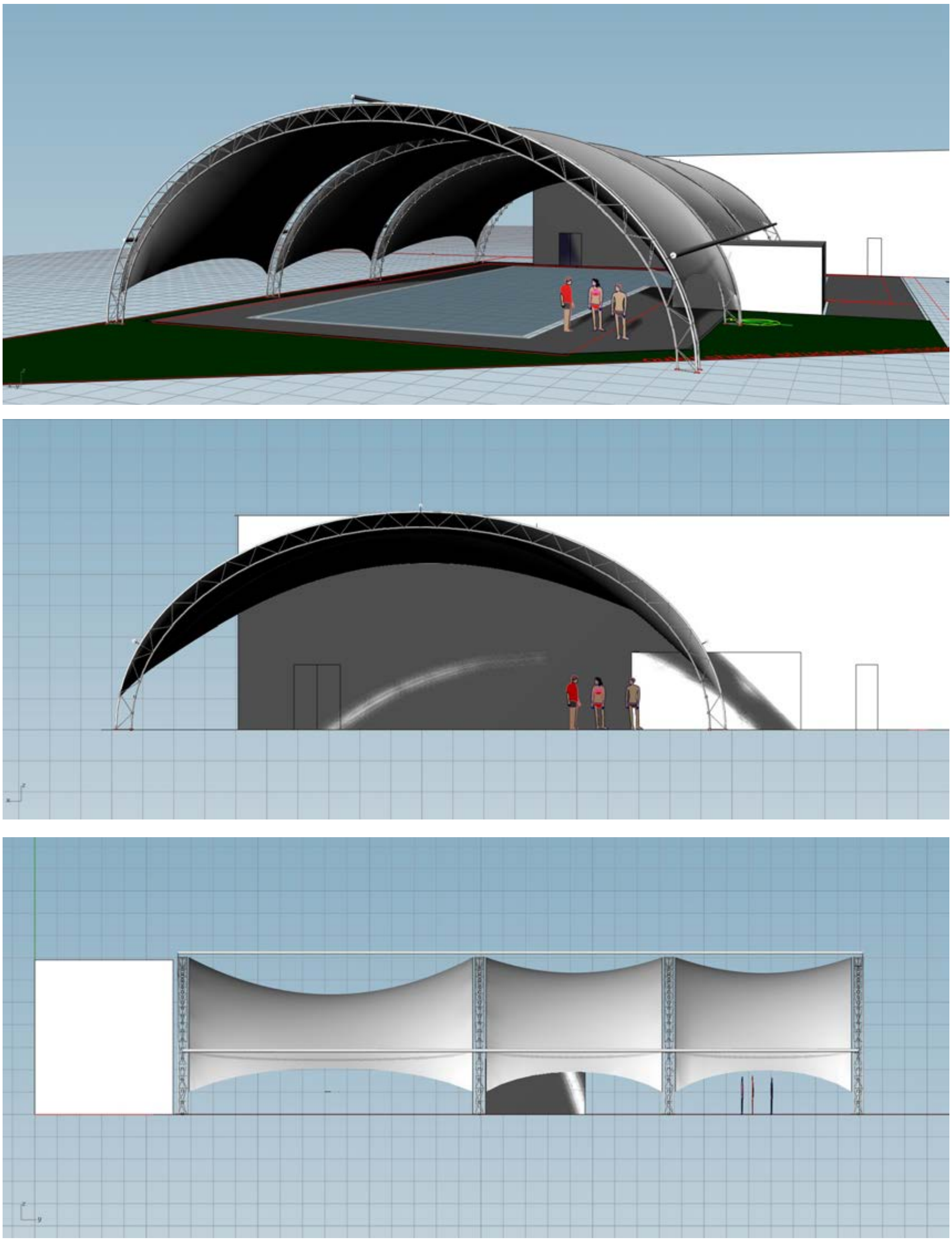
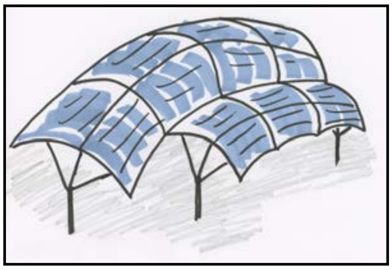


Figure 51: Saddle Tent, 3 units, 3 views

CASE STUDY n° 21

Axial 3D Truss beam
to support 2 membrane elements



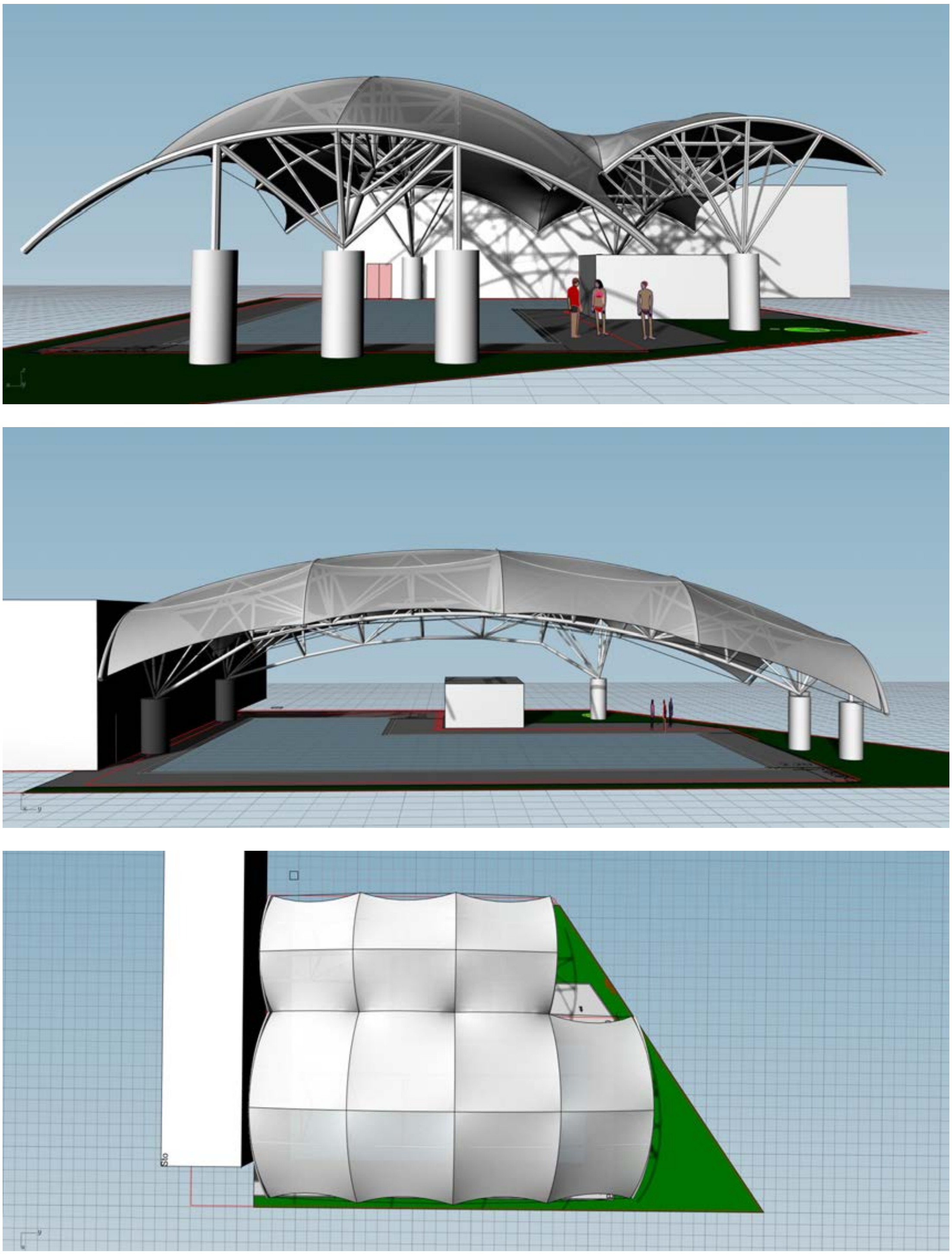
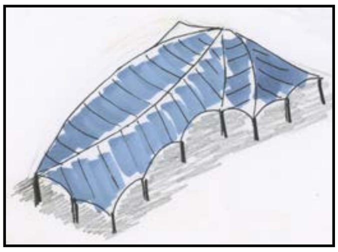


Figure 52: Axial 3D Truss Beam Tent, 3 views

CASE STUDY n° 22

Diagonal central arches

supporting a Like Reverted Hull
including saddle shape membrane
elements



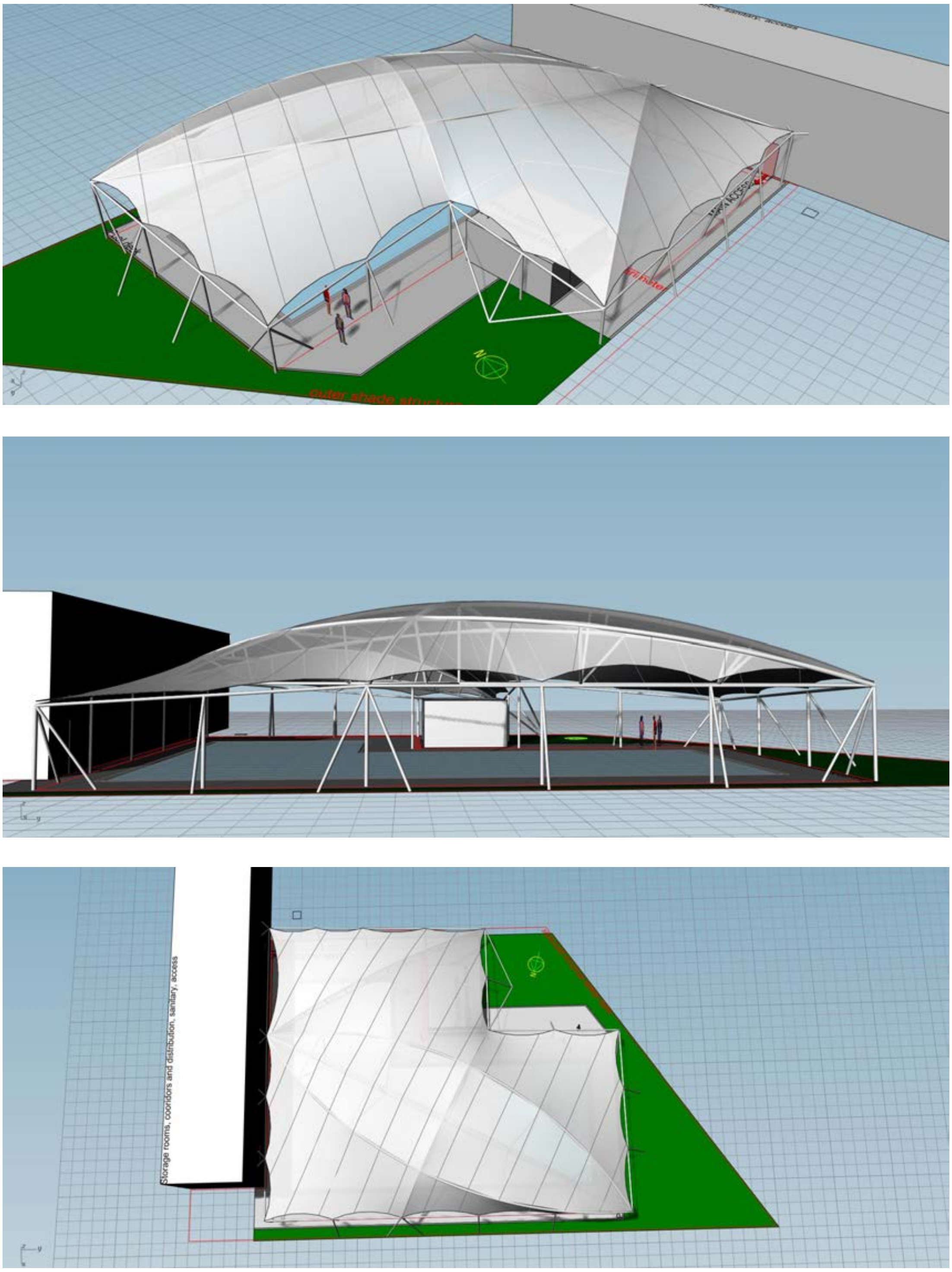
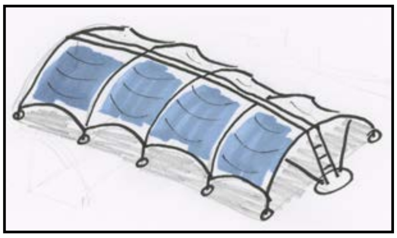


Figure 53: Diagonal Central Arches Tent, 3 views

CASE STUDY n° 23

Saddle Tent

Two areas (access small pool and main pool) are covered. The steel structure of the main membrane is ventilated at ridge.



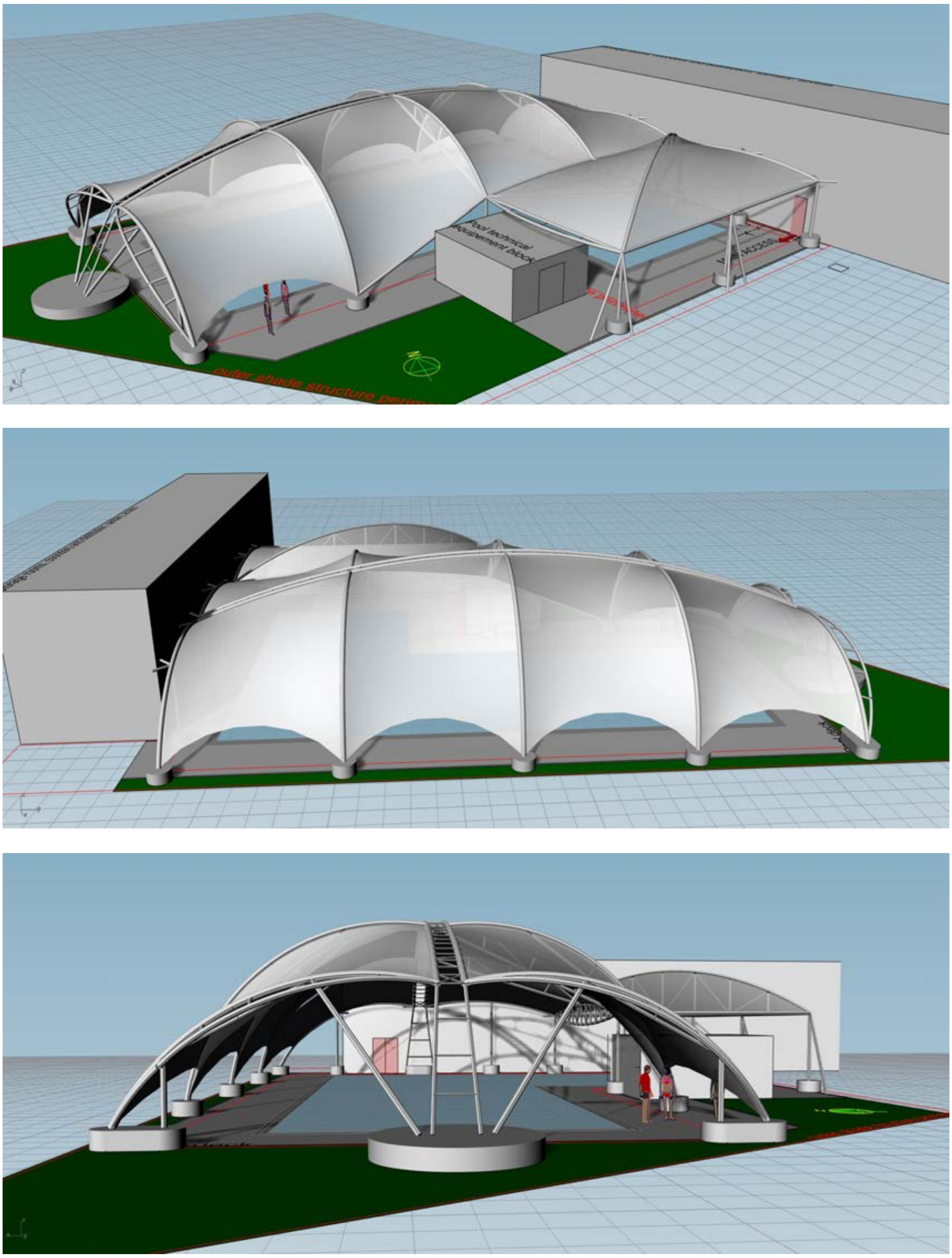
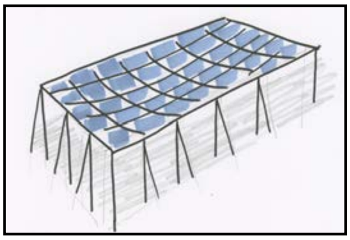


Figure 54: Saddle shape Tent, 3 views

CASE STUDY n° 24

Prestressed Cable Net



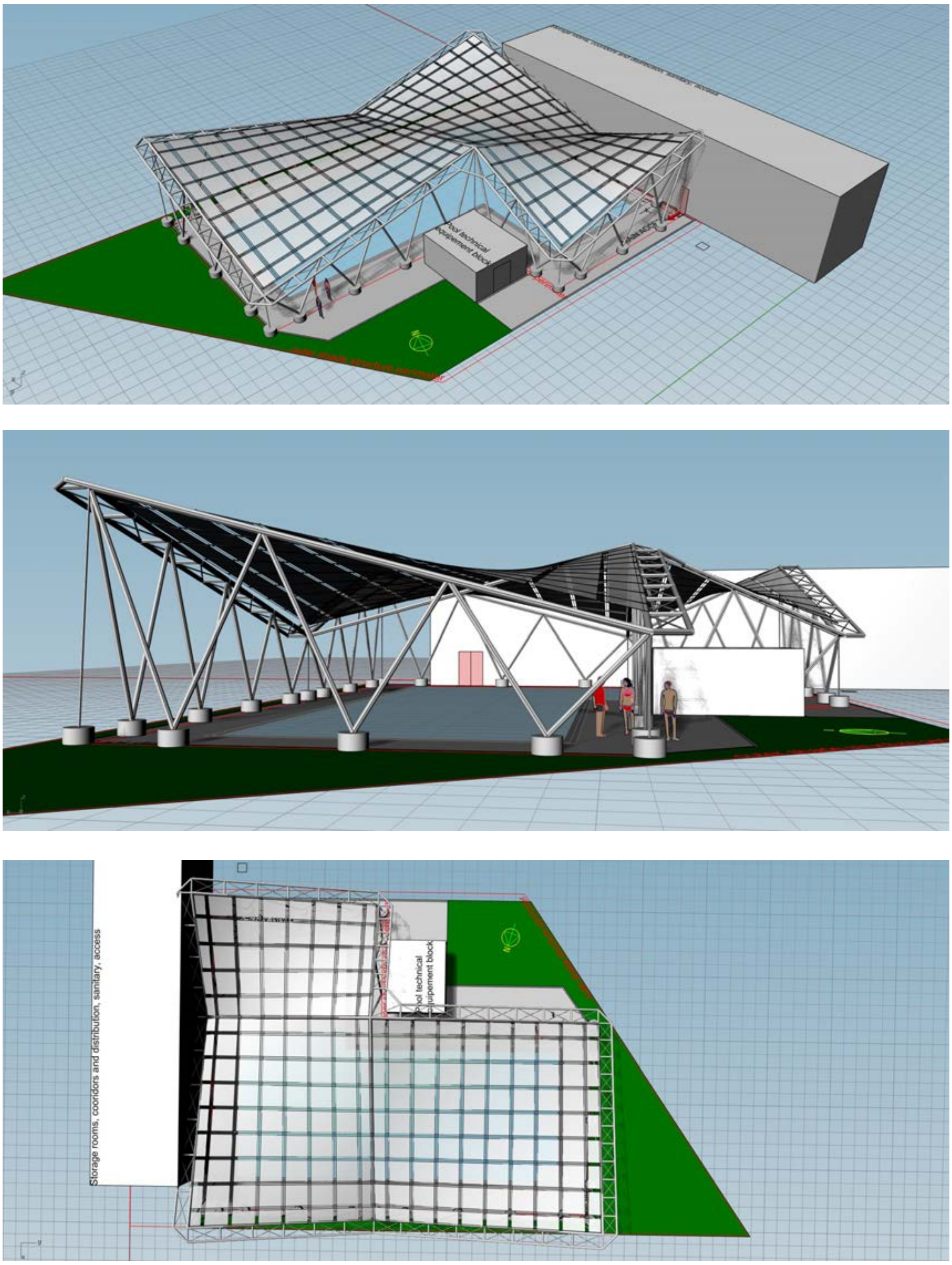


Figure 55: Prestressed cable net Tent, 3 views

5. PROPOSED CASE STUDIES CRITICAL APPRAISAL

The various case studies present a large variety of forms. They are by no way the only solutions, an infinity of other possibilities exist. This gives the architect a large liberty to express his creativity.

In all cases studied, the main function is to shade the pool area, and this is achieved by all designs; yet some propositions cover the area more effectively than others. The dilemma is now to balance solar protection vs. aesthetics.

The membranes appropriate to the various proposals are equally varied. Depending on membrane size, forces and stress which must be sustained, various types are available to the architect: micro-structured, mesh, solid membranes... these different fabrics feature translucency from 1 to 38% adding another degree of flexibility. They can block all light transmission or attenuate it. Chapter Appendix provides a list of fabrics.

The covered area varies with each proposal

- Covering the large bassin and its deck (the school management, elementary demand): Case Study n°07A, 08, 17, 18, 20.
- Covering the large and small basins plus the access to the: Case Study n°05, 06, 10, 11, 14, 16, 19, 22, 23, 24.
- Covering the two bassins, access to the pool plus the adjacent outer area to be used for circulation or relaxation: Case Study n°: 01, 02, 03, 04, 07B, 09, 12, 13, 15, 21.

5.1 Case studies comparison, by criteria

Data from calculation by hand and using EASY software
Presentation of data for each 24 Case Studies
Comparison of the results showing impact on steel material, cables and membrane.
Presentation of the result

Charts

The following tables present the material quantity and type.

5.1.1 Chart 1

Membrane type and quantity
Consomption ratio m^2 membrane / covered surface

5.1.2. Chart 2

Accessories Bill of Quantity :

- Edge cable
- Clamping
- Fittings

5.1.3. Chart 3

Steel Structure and Stabilisation cables Bill of Quantity

- Total steel quantity in Kg
- Ratio steel quantity in Kg / m^2 of covered surface
- Stabilization cable

5.1.1. Membrane / Bill of Quantity

Reference	Covered area in plan projection unit in m2	Membrane Type I, II, III	Total Membrane consumption unit in m2	Multiplying factor for material per covered surface
CASE STUDY 01	657	III	900	1,37
CASE STUDY 02	657	III	900	1,37
CASE STUDY 03	657	III	900	1,37
CASE STUDY 04	657	III	900	1,37
CASE STUDY 05	545	II & III	930	1,71
CASE STUDY 06	545	III	710	1,30
CASE STUDY 07A	585	I & II	930	1,59
CASE STUDY 07B	657	I & II	800	1,22
CASE STUDY 08	550	III	550	1,00
CASE STUDY 09	760	I & II	800	
CASE STUDY 10	580	III	720	1,24
CASE STUDY 11	600	I & II	1150	1,92
CASE STUDY 12	658	III	900	1,37
CASE STUDY 13	658	III	1000	1,52
CASE STUDY 14	550	II	1000	1,82
CASE STUDY 15	750	I & II	1200	1,60
CASE STUDY 16	550	II	1300	2,36
CASE STUDY 17	550	III	950	1,73
CASE STUDY 18	550	III	950	1,73
CASE STUDY 19	640	II	850	1,33
CASE STUDY 20	570	II & III	850	1,49
CASE STUDY 21	678	II & III	1000	1,47
CASE STUDY 22	610	II & III	900	1,48
CASE STUDY 23	600	II & III	1000	1,67
CASE STUDY 24	580	I & II	700	

Figure 56: Membrane Bill of Quantity chart

5.1.2. Edge cable, Clamping, Fittings / Bill of Quantity

Reference	Covered area in plan projection unit in m2	Cable Total weight Kg	Angle plate Units	Clamping, Linear meters	Fittings, Units
CASE STUDY 01	657	249	8	54	8
CASE STUDY 02	657	249	8	54	8
CASE STUDY 03	657	242	10	54	10
CASE STUDY 04	657	249	8	54	8
CASE STUDY 05	545	0	8	118	8
CASE STUDY 06	545	392	21		21
CASE STUDY 07A	585	0	8	150	8
CASE STUDY 07B	657	0	8	200	0
CASE STUDY 08	550	301	24	0	24
CASE STUDY 09	760	758	24	0	24
CASE STUDY 10	580	58	12	140	12
CASE STUDY 11	600	449	128	50	128
CASE STUDY 12	658	571	8	0	8
CASE STUDY 13	658	571	18	31	18
CASE STUDY 14	550	200	8	12	8
CASE STUDY 15	750	246	22	296	22
CASE STUDY 16	550	74	18	268	18
CASE STUDY 17	550	242	12	6	12
CASE STUDY 18	550	320	12	6	12
CASE STUDY 19	640	224	8	10	8
CASE STUDY 20	570	90	12	0	12
CASE STUDY 21	678	106	28	180	28
CASE STUDY 22	610	132	8	0	8
CASE STUDY 23	600	132	8	272	8
CASE STUDY 24	580				

Figure 57: Edge cable, Fittings, Bill of Quantity chart

5.1.3. Steel Structure, Stabilization cable / Bill of Quantity

Reference	Covered area in plan projection unit in m2	Steel Total weight Kg	Steel ratio, Kg / m2	Stabilization cable Kg	Members Numbers
CASE STUDY 01	657	6000	9,20	249	20
CASE STUDY 02	657	6000	9,20	249	20
CASE STUDY 03	657	14000	21,30	0	32
CASE STUDY 04	657	6000	9,20	249	23
CASE STUDY 05	545	12900	23,70	66	225
CASE STUDY 06	545	7600	14,00	0	140
CASE STUDY 07A	585	14000	24	0	200 +
CASE STUDY 07B	657	15000	24,00	0	200 +
CASE STUDY 08	550	7000	12,70	0	120
CASE STUDY 09	760	4000	5,30	0	40
CASE STUDY 10	580	13000	22,40	0	280
CASE STUDY 11	600	14000	23,30	70	100
CASE STUDY 12	658	7000	10,70	249	60
CASE STUDY 13	658	7000	10,70	0	40
CASE STUDY 14	550	3600	6,60	12	80
CASE STUDY 15	750	18000	24	60	200
CASE STUDY 16	550	10000	18,20	157	70
CASE STUDY 17	550	5000	9,10	0	34
CASE STUDY 18	550	5000	9,10	0	10
CASE STUDY 19	640	9000	14,10	0	100
CASE STUDY 20	570	7600	13,40	0	680
CASE STUDY 21	678	7000	10,30	180	120
CASE STUDY 22	610	12000	19,70	0	130
CASE STUDY 23	600	6700	11,20	0	180
CASE STUDY 24	580	13000	22,40	0	280

Figure 58: Steel, Bill of Quantity chart

5.2. Comments about quantitative tables

5.2.1. Membrane:

From the membrane surface requirement standpoint, and its economical impact, all case studies exhibit a good usage/coverage/quantity ratio with values in the 1-to-1.49 range.

Usage/coverage/quantity ratio varying in range 1-to-1.49 mean 1-to-1.49 m2 is required to cover 1 m2 of ground. The following cases are in this range:

Case Study 08 / Group of Four Point Tent	Ratio 1,00	p. 36
Case Study 10 / Group of 3 four Point Tent	Ratio 1,24	p. 38
Case Study 06 / Long Ridge 3D Truss Beam	Ratio 1,30	p. 33
Case Study 19 / Radial Ridge & Valley	Ratio 1,33	p. 47
Case Study 01 / Arch Supported Tent, Opt. 1	Ratio 1,37	p. 29
Case Study 02 / Arch Supported Tent, Opt. 2	Ratio 1,37	p. 30
Case Study 03 / Arch Supported Tent, Opt. 3	Ratio 1,37	p. 31
Case Study 04 / Arch Supported Tent, Opt. 4	Ratio 1,37	p. 31
Case Study 21 / Axial 3D Truss Beam	Ratio 1,47	p. 49
Case Study 22 / Diagonal Central Arch	Ratio 1,48	p. 50
Case Study 20 / Saddle Tent	Ratio 1,49	p. 48

Others case studies show a higher material ratio but can be chosen for architectural reason:

Case Study 13 / Ring High Point	Ratio 1,52	p. 41
Case Study 07A / Grid Shell	Ratio 1,59	p. 34
Case Study 15 / Hexagonal Umbrellas	Ratio 1,60	p. 43
Case Study 23 / Saddle Tent	Ratio 1,24	p. 51
Case Study 05 / Inclined Interconnected Arches	Ratio 1,71	p. 32
Case Study 17 / Four Point Tent & Hypar	Ratio 1,73	p. 45
Case Study 18 / Four Point Tent & Hypar, opt. 2	Ratio 1,73	p. 46
Case Study 14 / High Point Tent	Ratio 1,82	p. 42
Case Study 11 / Flying Hypar’s	Ratio 1,92	p. 39
Case Study 16 / Canopee	Ratio 2,36	p. 44

5.2.2. Steel structure ratio:

From the steel requirement standpoint, and its economical impact, the following studies exhibit a good steel mass-to-shaded area ratio

Case Study 09 / Group of Four Point Tent	Ratio: 5,30 Kg/ m²	p. 37
Case Study 14 / High Point Tent	Ratio: 6,60 Kg/ m²	p. 42
Case Study 17 / Four Point Tent & Hypar	Ratio: 9,10 Kg/ m²	p. 45
Case Study 18 / Four Point Tent & Hypar, 02	Ratio: 9,10 Kg/ m²	p. 46
Case Study 09 / Group of Four Point Tent	Ratio: 9,20 Kg/ m²	p. 37
Case Study 02 / Arch Supported Tent, Opt. 2	Ratio: 9,20 Kg/ m²	p. 30
Case Study 04 / Arch Supported Tent, Opt. 4	Ratio: 9,20 Kg/ m²	p. 31
Case Study 21 / Axial 3D Truss Beam	Ratio: 10,30 Kg/ m²	p. 49
Case Study 12 / Peak High Point	Ratio: 10,70 Kg/ m²	p. 40
Case Study 13 / Ring High Point	Ratio: 11,70 Kg/ m²	p. 41
Case Study 23 / Saddle Tent	Ratio: 11,20 Kg/ m²	p. 51
Case Study 20 / Saddle Tent	Ratio: 13,40 Kg/ m²	p. 48
Case Study 06 / Long Ridge 3D Truss Beam	Ratio: 14,00 Kg/ m²	p. 33
Case Study 19 / Radial Ridge & Valley	Ratio: 14,10 Kg/ m²	p. 47

Others case studies show a higher material ratio but can be chosen for architectural reason:

Case Study 16 / Canopee	Ratio: 18,20 Kg/ m²	p. 44
Case Study 22 / Diagonal Central Arch	Ratio: 19,70 Kg/ m²	p. 50
Case Study 03 / Arch Supported Tent, Opt. 3	Ratio: 21,30 Kg/ m²	p. 31
Case Study 10 / Group of Four Point Tent	Ratio: 22,40 Kg/ m²	p. 38
Case Study 24 / Cable Net	Ratio: 22,40 Kg/ m²	p. 52
Case Study 11 / Flying Hypar’s	Ratio: 23,30 Kg/ m²	p. 39
Case Study 05 / Inclined Interconnect. Arches	Ratio: 23,70 Kg/ m²	p. 32
Case Study 07A / Grid Shell	Ratio: 24,00 Kg/ m²	p. 34
Case Study 07B / Grid Shell Large	Ratio: 24,00 Kg/ m²	p. 35
Case Study 15 / Hexagonal Umbrellas	Ratio: 24,00 Kg/ m²	p. 43

5.3 Final Choice.

Textile architecture selected for this project

Comparing the merits of the various Case Studies, it was decided to retain

CASE STUDY N°01.

Why:

From an aesthetic stand point, it appears at first glance as simple, original and evident. The large asymmetrical arch projects elegance and modernity.
Solar protection is all-inclusive. The membrane will be Type III in consideration of the forces it must sustain; it will be white with a translucency about 10%. This is sufficient under day light to offer visual comfort; UV protection is optimum.

The membrane type chosen offers the best durability.

The covered area is wide. It allows to use Zone-C, the triangle around the technical building, for relaxation.

The fabric quantity required presents a good ratio. Steel elements required by the structure have a reasonable mass of 6 tons for 657 m2 of covered area.

Edge cables are in significant numbers, 249 kg of stainless steel cable, however the other fitting elements are few:
8 angle plates, 8 turnbuckles, Along arch membrane reinforcement plus anti-lift lacing or optional a 54 m of clamping to secure the membrane on either side of the central arch.

Further, this design is in full agreement with the architect and master of this trade. Frei Otto words will be the guide line:

« It's quite simple: find the form and the smallest requirement for materials - not for money! This is extremely important. »

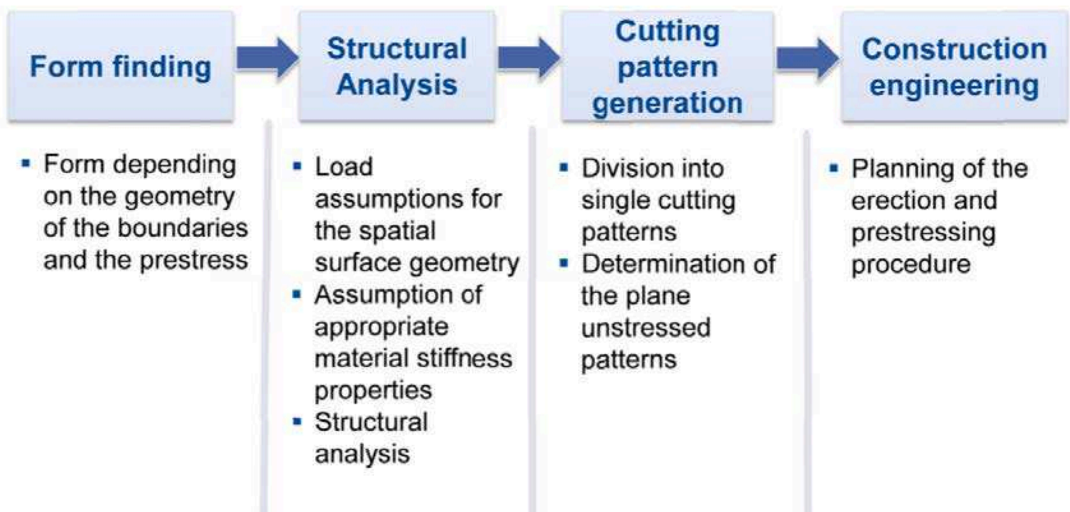
The complete study for this retained solution is described there after.

6. CASE STUDY CS 01
Complete Development

Description: The proposal is a Central Arch Tent. The Arch is positioned lightly in diagonal comparing to the pool plan area. the Arch curvature is asymmetric to give an architectural signature to the project. The two membrane slopes falling both side of the central arch cover the whole large area. The part I (left) to the arch seeing from top come along the adjacent service building and the the part II (right) to the central arch cover the 15 meters of pool and deck with a triangle shape at front in order to follow the land.

The part I is 418 m² in plan projection and the part II is 250 m². The totale covered area is 668 m².

The complete development process include:



6.1 Form Finding

6.1.1 Boundary creation and stressed surface evaluation

The membrane boundary is exported to the form finding module in Easy program. the membrane net is calculated with basic prestress value

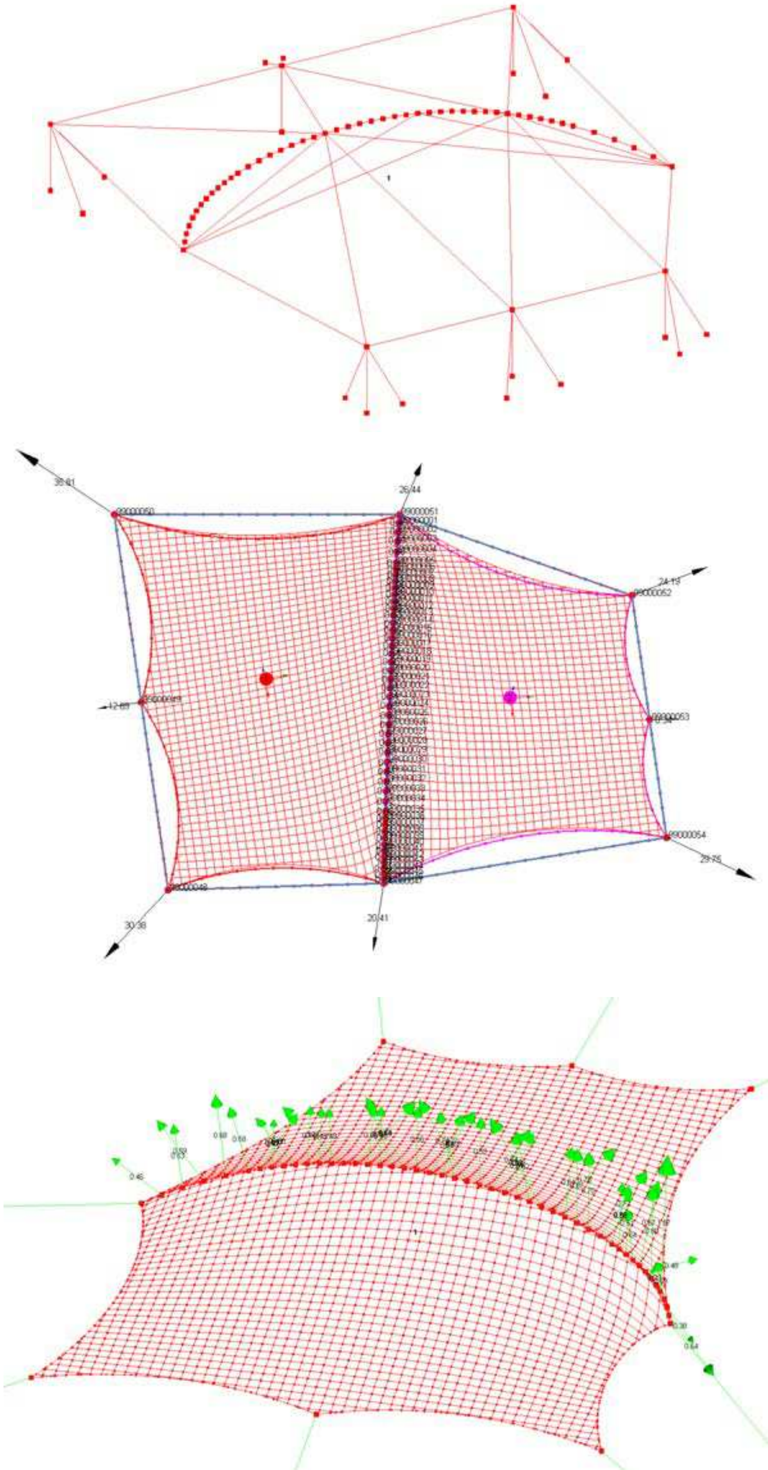


Figure 59: Form Finding CS 01, 3 drawings

6.1.2 Rendering :

Back to Rhino program, the three dimensional membrane net is connected to the building and steel structure environment, then « patch » fonction create a mesh plain surface over the net for a realistic membrane rendering.

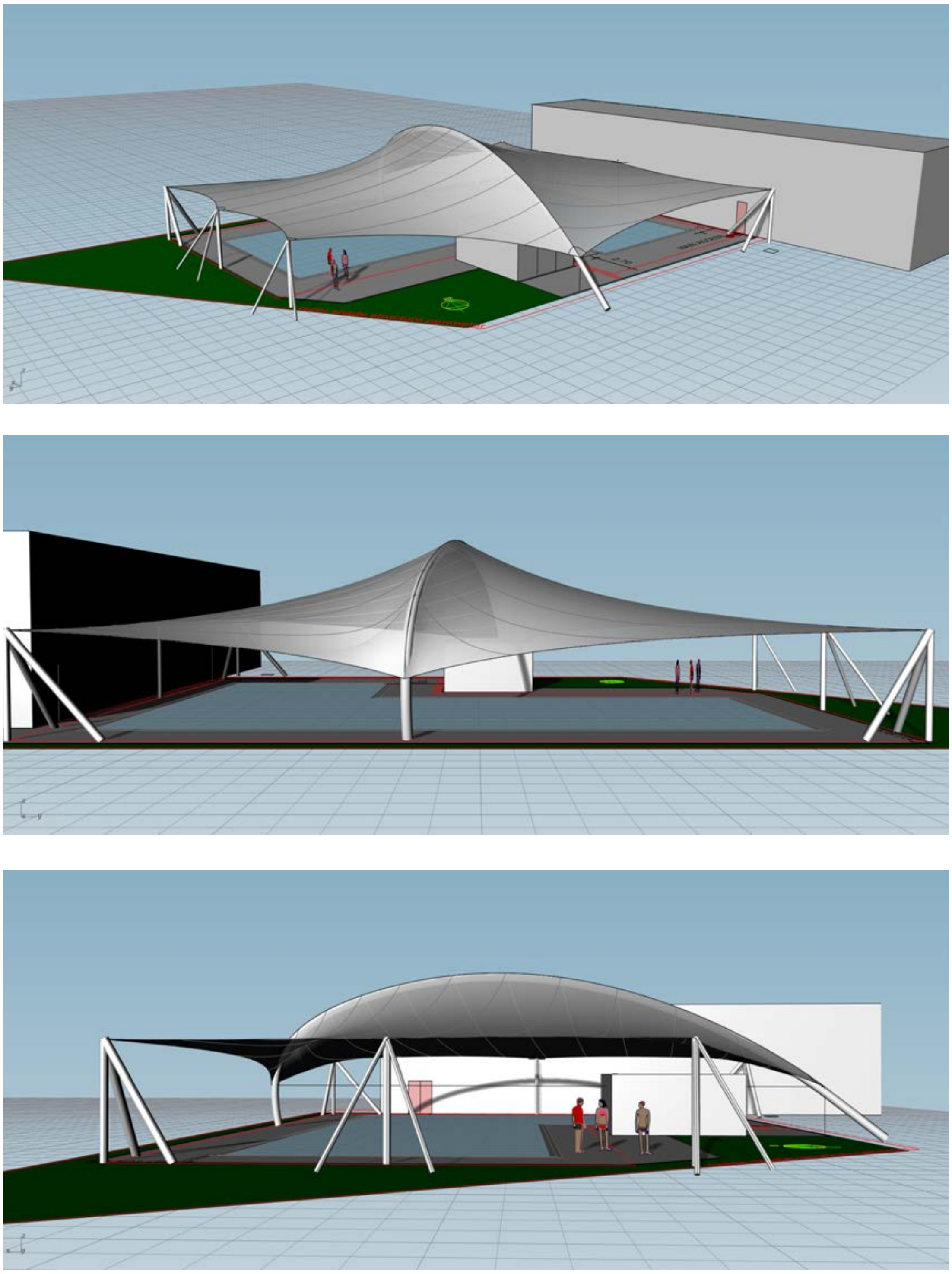
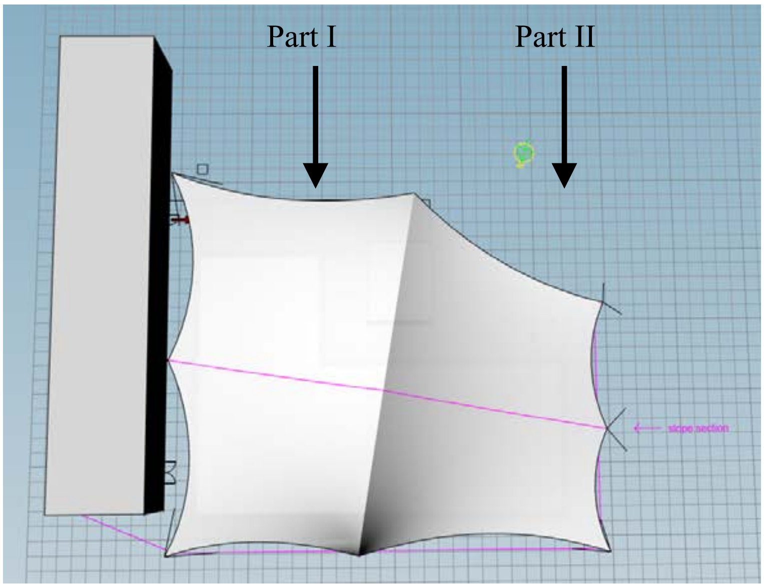
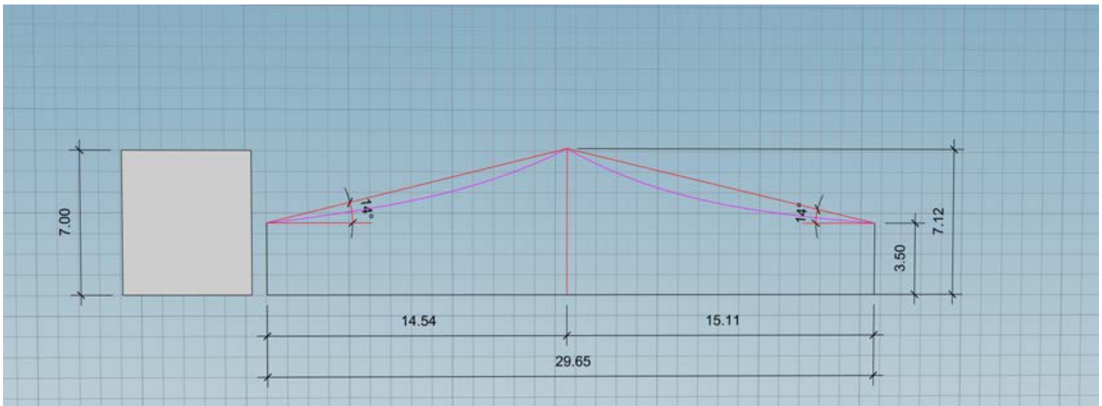


Figure 60: Form Finding CS 01, rendering, 3 drawings

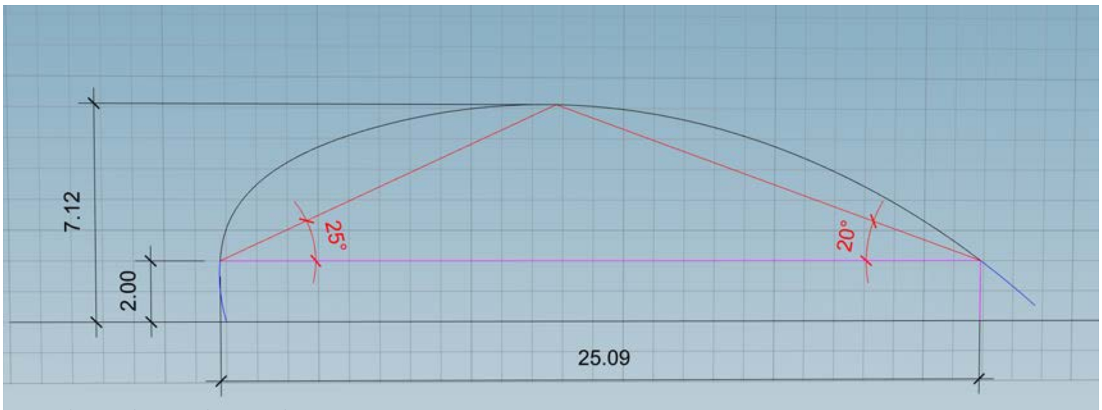
6.1.3 Verification of curvature along the covering membrane



Top view of the membrane including the axis for section (pink color), on the 2 slopes part I and part II



Section cross to the arch plan



Section along the arch

Figure 61: CS01, Membrane curvature, 3 drawings

On an aesthetically point of view the result is close to expectation. It is then decided to follow the development with this central arch project.

6.1.4 Main parameters check list

On a Technically point of vue, it is important to have confirmation that the main parameters are in conformity with the basic before to pursue the development:

Check list of essential parameters: Figure 62: CS01, parameters check list

Items	State of the art required parameters	Is the situation fulfill with?
1	**Membrane and associated curvature.** Under stress, the membrane chord-to-Sag ratio is staying within the limits: chord/sag ratio ≤ < 20	True on most areas. Nearly flat on corners
2	**Pre-constraint** A tensile force to be applied to textile membranes at an average value of ≥ 15 kN/ml?	Yes on all edges
3	**Slope and edges** The slope at the edges must allow the rain water to fall when the tensile forces are applied.	close to « 0 » at 4 corners
4	**Splitting** No single membrane element - as delimitated by its edges or lacings - must exceed 500 m2 in 2D projection, unless special reinforcements are designed-in.	Can be an alternative. Splitting areas I and II with 2 cables perpendicular to the arch can be tried.
5	**Membrane / Membrane area limits by membrane type** Types II, III or IV PVC-coated polyester fabric are mandatory for covered elementary area > 30 m² of 2D-projection.	First numbers shows the membrane stress will be in the level of 20 KN, which require membrane type III.
6	**Fittings** The radius of curvature of the bolt ropes must not exceed 25 m.	
7	**Sustaining structure** The supporting structure must be stable in the absence of the covering membrane.	to be included in the steel structure design

Above remarks show that some modifications are to be applied to the design.

Parameters on witch we can act in order to increase the curvature and slope:

- increase the arch hight
- increase and decrease the membrane corners hight
- Increase the membrane Tension on its Y axis
- Splitting the 2 areas I and II.

6.1.5 Modifications in Easy module Form finding:

- Part I and II are divided and a tensioned cable place in pocket between the 2 new areas both sides of the arch.
- The arch highest level increase from 7 to 9 meters.
- Cables are installed in to prestress the arch

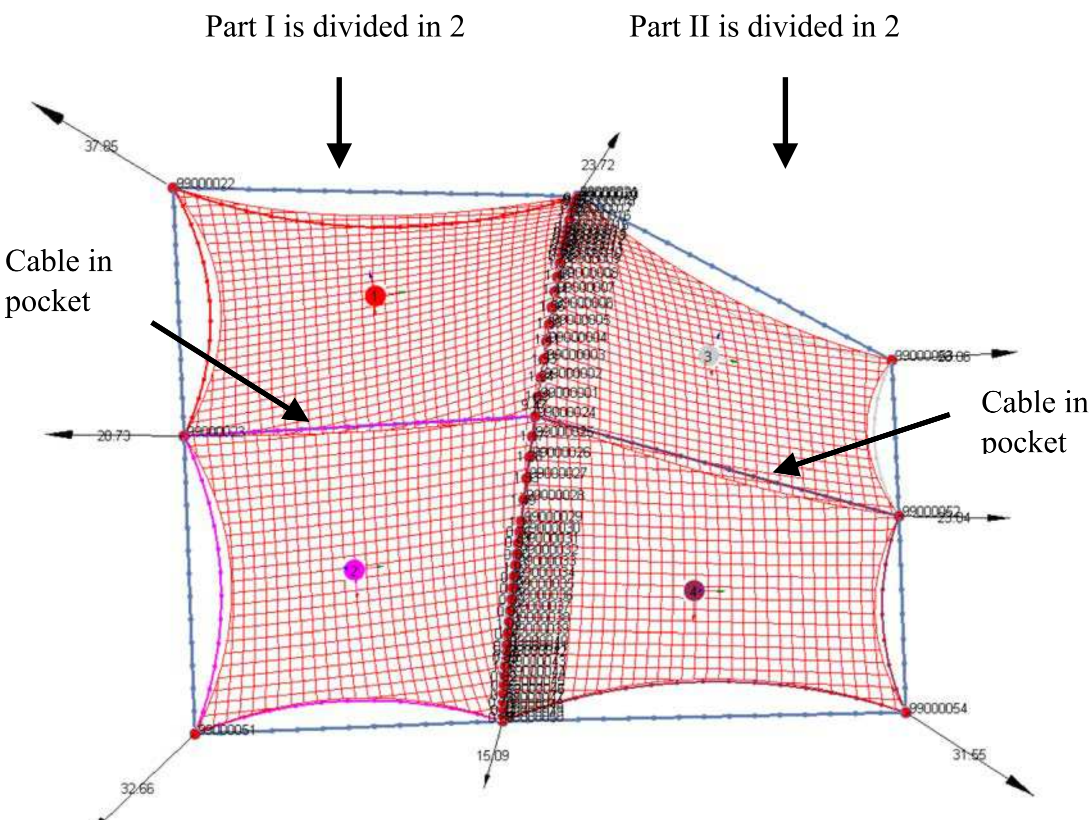
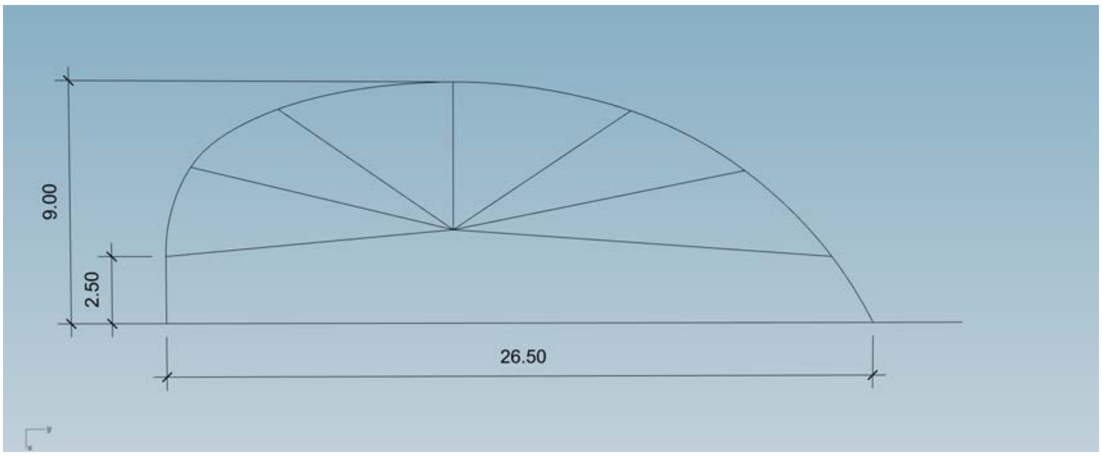


Figure 63: CS01, modified membrane

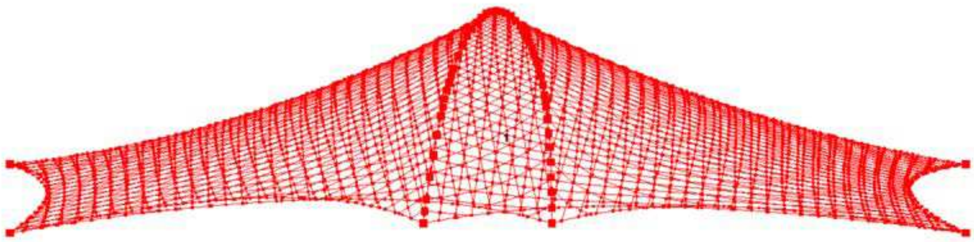


The new arch section after modification of the height

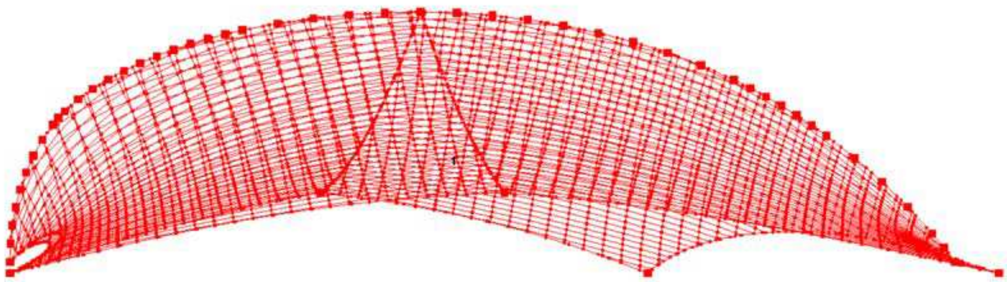
Figure 64: CS01, modified Arch

6.1.6 Final Drawings

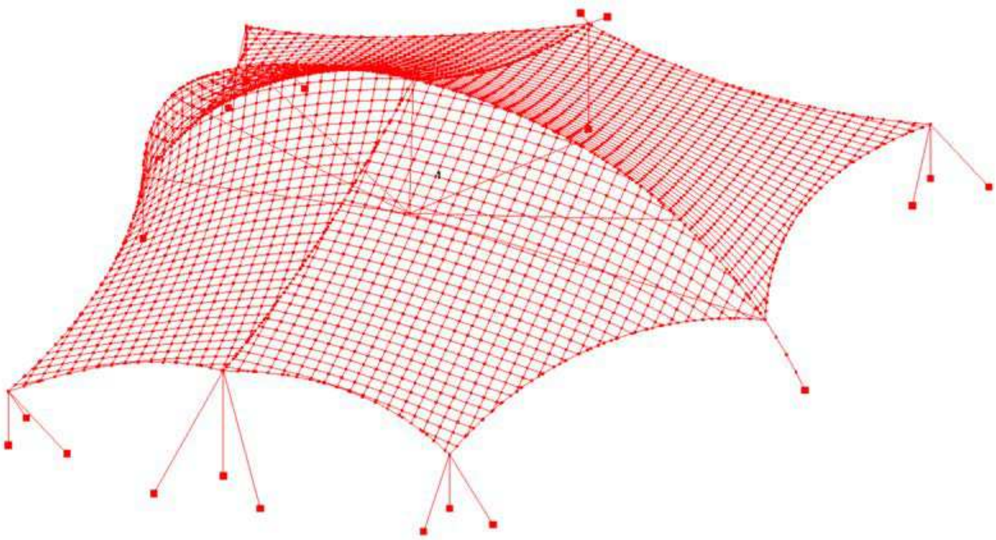
The front view of the modified membrane show the slope both sides of the arch.



Front view



Side view

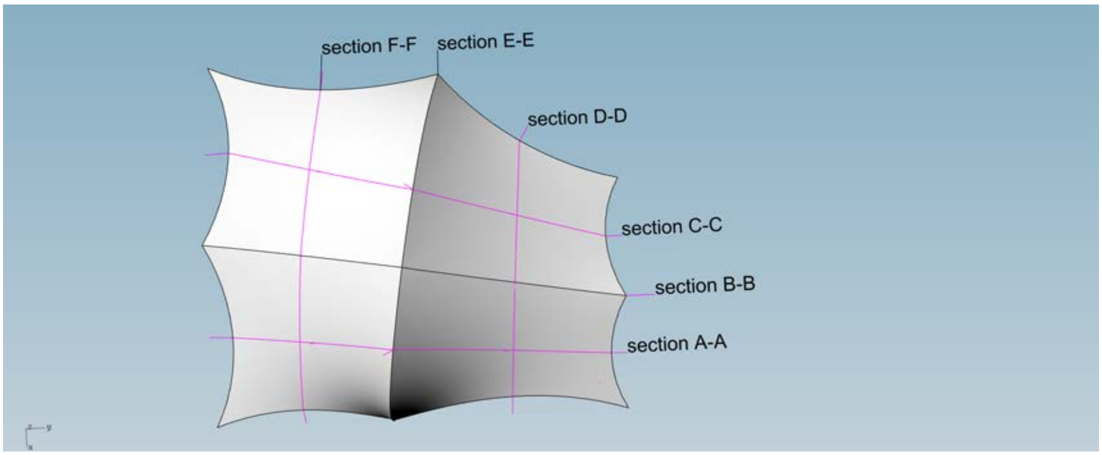


The complete membrane system including, membrane, edge cables, arch, columns, guying cable and arch cable prestressed.

Figure 65: CS01, modified membrane and structure, 3 drawings

6.1.7 Vérification of the membrane curvature after modifications

The new plan view design with section references



The membrane curvature along different sections

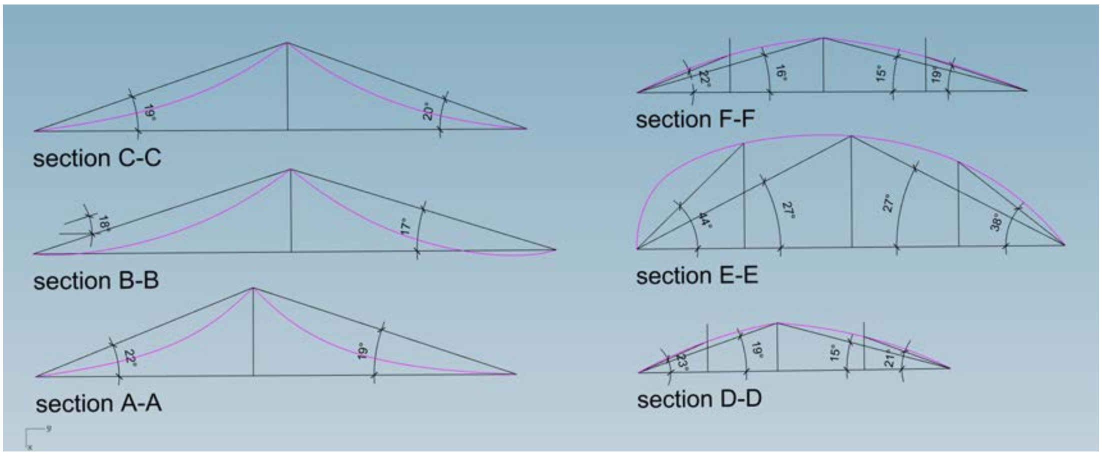


Figure 66: CS01, membrane curvature, 2 drawings

Section A-A: perpendicular the the arch, 1/4 distance; angle: 19°- 22°
Section B-B: perpendicular the the arch, 1/2 distance: angle 17° - 18°
Section C-C: perpendicular the the arch, 1/4 distance, angle: 19° - 20°
Section D-D:parallel to the arch, middle of area II, angle 15° - 19°
Section E-E: in the plan of the arch. Angle from horizontal to high point: 27°
Section F-F: parallel to the arch, middle of area I, angle 15° - 16°

6.1.8 Final Form Finding and rendering

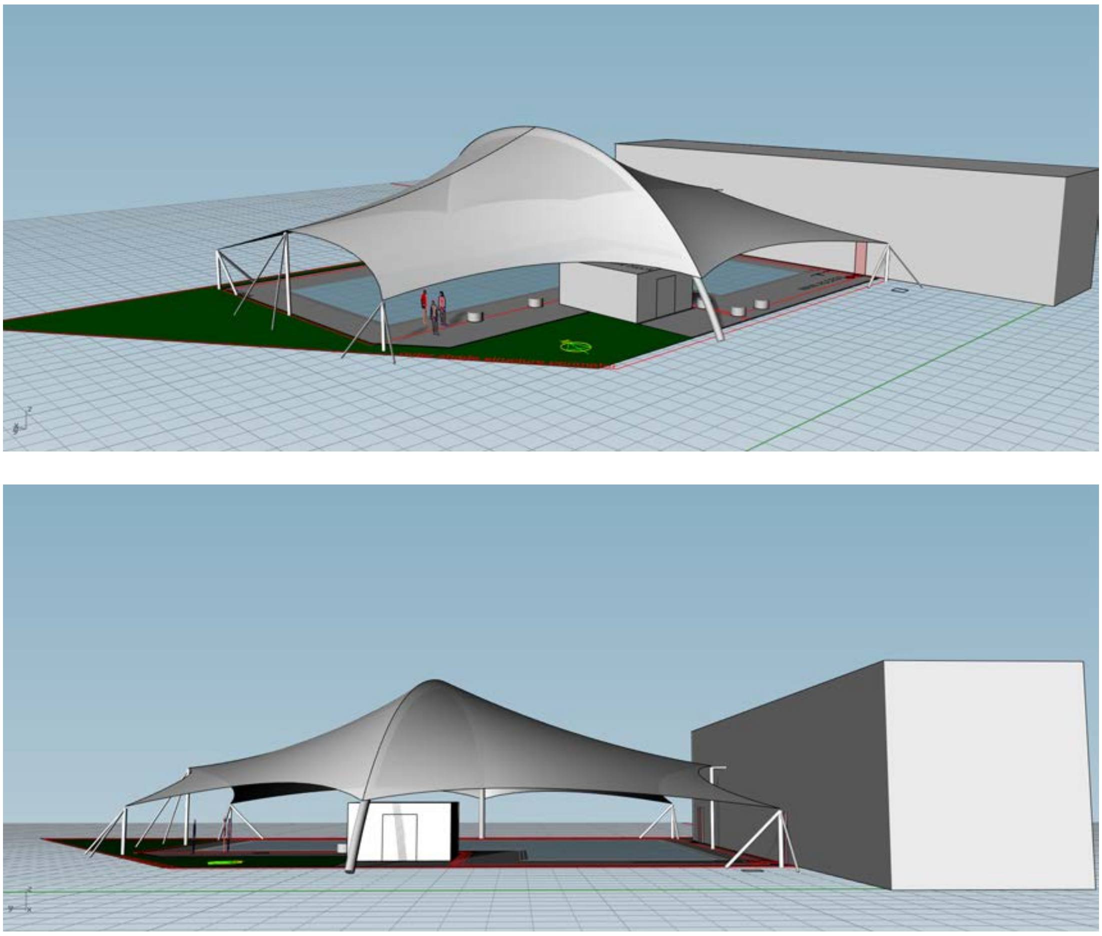


Figure 67: CS01, Final Form Finding & Rendering, 2 views

The shape is slightly modified, showing a higher arch level and more slope falling to peripheral masts.

6.2 Statical Analysis

6.2.1 Loads Hypothesis

6.2.1.1. Permanent loads

Own weight fabric Ferrari 1202 : 1050 g/m2, Own weight steel : 10 daN/m2

Prestress : included
Prestress vectors without external load

6.2.1.2. Climatic loads

Permanent loads: Climatic loads

6.2.1.3. Extreme rain

Extreme Rain
Uniform load : 10 daN/m2 (1cm of water) => useful to ensure the absence of water pounding

6.2.1.4. Wind speeds

Wind speed adopted in this calculations : 100 km/h

Determination of Basic wind velocity pressure and Dynamic velocity pressure.

Wind speed of 100 km/h,
or, V =100/3.6 = 27.7 m/sec
Basic velocity pressure: $q_{ref} = V^2/1600$
$= 27.7^2/1600 = 0.480$ kN/m²

Dynamic velocity pressure:
$q = 1.7 \times q_{ref} \times (h/10)^{0.37}$
$q = 1.7 \times 0.480 \times 1 = 0.82$ kN/m²
This value is in accordance with the local regulation for area category IIA and a given value of: **83 daN/m²**

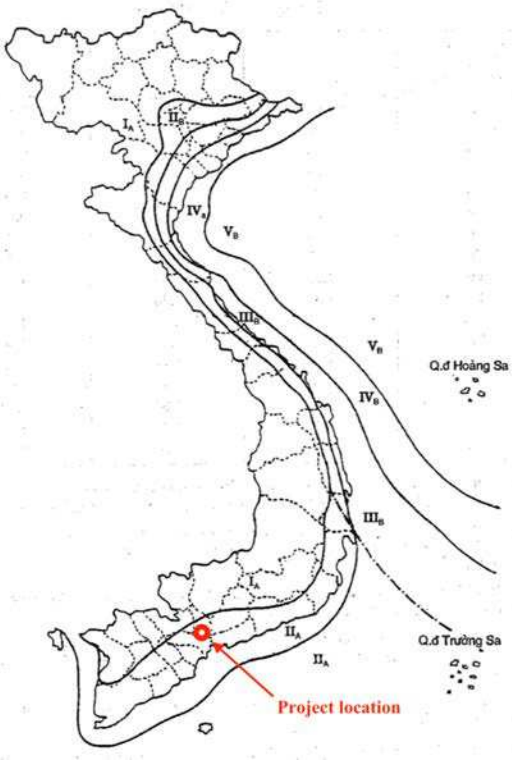


Figure 68: Vietnam wind areas

6.2.2. Cp value: shape coefficient

The term Cp refers to the wind pressure coefficient that multiplies the site wind pressure to give the wind loading pressure. Therefore it is essential to evaluate the Cp as realistically as possible.

Cp estimation can be done by following analysis method:

- Wind tunnel test on physical models
- CFD analysis
- Existing tensile case study document
- Norms as Eurocode and ASTM.

Wind tunnel test and CFD are out of reach during this thesis works, I then propose to work accordingly to well known case studies and norms, which is usually enough for statical analysis at pre-design stage and for full study of reasonable size project.

I propose to look at some typical external Cp values for simple membrane structures and see if some similarities can be found and adapted to the Arch Tent project.

Case studies documents taken as model:

- Cone
- Ridge and valley
- Hypar, Saddle
- Saddle
- Eurocode

All Cp values given in original following tables are for open sided structure, except the hypar which is a closed structure.

The following table proposals consider 2 wind load cases, WIND 1 for wind South-North direction, along arch axis and WIND 4 for wind West-East direction perpendicular to the arch plan according to this studied project.

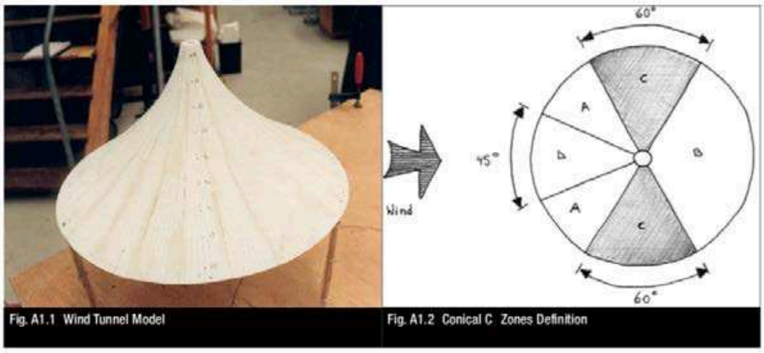
Case WIND 1: normal inside Cpi value is added to the external value considering the air can flow freely through the tent.

Case WIND 4: an augmented additional Cpi (internal Cp value) is added to the external value considering that the nearby building along the East side obstructed the air flow, increasing the inside pressure toward the membrane. The Cpi values are estimated by feeling based on existing studied cases and are not calculated by a scientific method.

During following Form cases study the goal is to find similarity with the studied central arch project in order to deduct, if possible, realistic Cp values.

Cone

Figure 69: Cone, wind tunnel model



Shape parameters:
a) The angle of slope of the membrane
b) Open or closed sides.

The angle of slope of the membrane is based on the elevational angle from horizontal to a straight line drawn from the structure perimeter to the apex. Due to the concave nature of the external surface, the angle to horizontal of the fabric at the perimeter will be less than this defined angle. Similarly the angle of the fabric near the apex of the structure will be greater.

External C_p Values for Conical Structures		Zones			
	Angle of slope of membrane to horizontal /deg.	A	B	C	D
Open sided structure	40	-0.15	-0.6	-1.0	+0.4/-0.2
Closed structure	40	-0.41	-0.7	-1.0	+0.75/-0.6

Table 1 External C_p Values for Conical Structures

Is this proposal based on conical shape similarities a possible Cp value model?

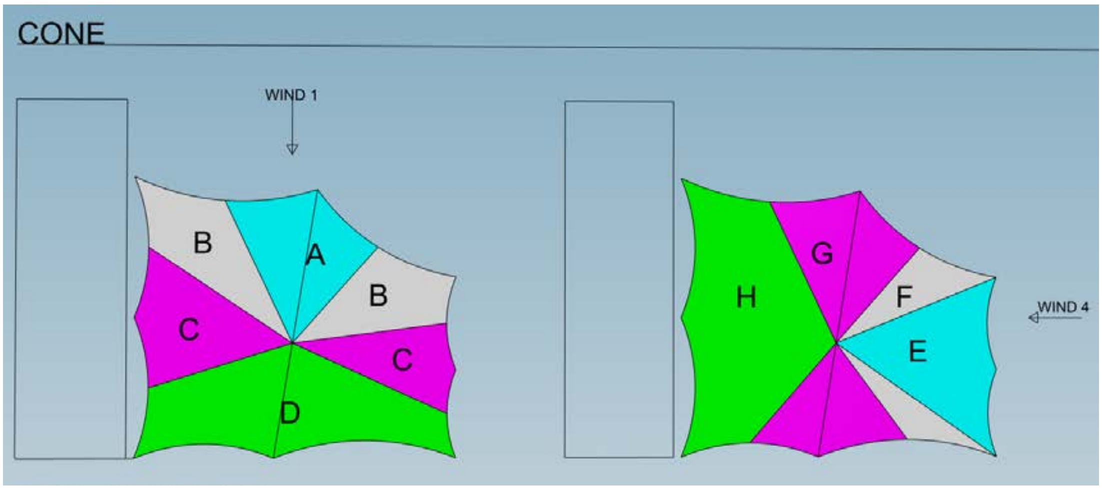


Figure 70: Central Arch, wind zone definition, cone type

Cp proposal in similarity								
	A	B	C	D	E	F	G	H
Cpe	-0,20	-0,15	-1,00	-0,60	-0,20	-0,15	-1,00	-0,60
Cpi					0,30	0,30	0,40	0,80
Cptot	-0,20	-0,15	-1,00	-0,60	-0,50	-0,45	-1,40	-1,40

Ridge & Valley

Shape parameters:
The defining shape parameters for this type of structure are

a) Ratio: $\frac{\text{valley width}}{\text{valley depth}}$

b) Open or closed sides.

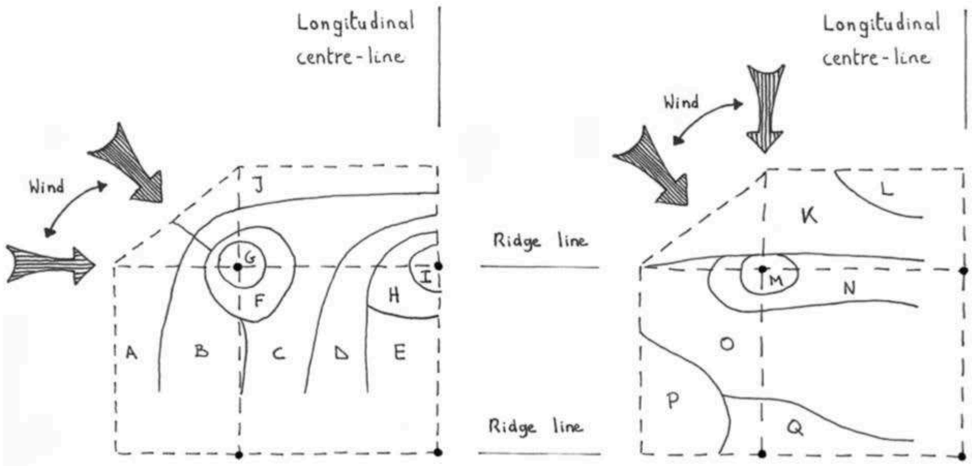


Fig. A1.4 Ridge and Valley C Zone Definition

Figure 71: Ridge and Valley Zone Definition

External C_p Values	Sides	Open	Closed
for Ridge/Valley	Ratio of Valley Width to Valley Depth	2.5	4
Type Structures	Approximate slope of membrane /deg	39	26
C_p zones	A	+0.6 -0.39	+0.3
	B	+0.23 -0.33	+0.25
	C	-0.41	-0.2
	D	-0.2	-0.3
	E	-0.11	-0.45
	F	-0.38	-0.35
	G	-0.38	-0.8
	H	-0.33	-0.5
	I	-0.33	-0.9
	J	+0.14 -0.3	+0.35 -0.3
	K	+0.58 -0.29	0.3
	L	+0.38 -0.42	+0.3 -0.2
	M	-0.38	-1.2
	N	-0.38	-0.6
	O	+0.38 -0.37	-0.4
	P	+0.45 -0.46	+0.2 -0.2
	Q	+0.12 -0.27	+0.3 -0.3

Table 2 External C_p Values for "Ridge and Valley" Type Structures

The Arch tent project can be seen as a ridge and valley shape as well

Is this proposal based on ridge & valley shape similarities a possible Cp value model?

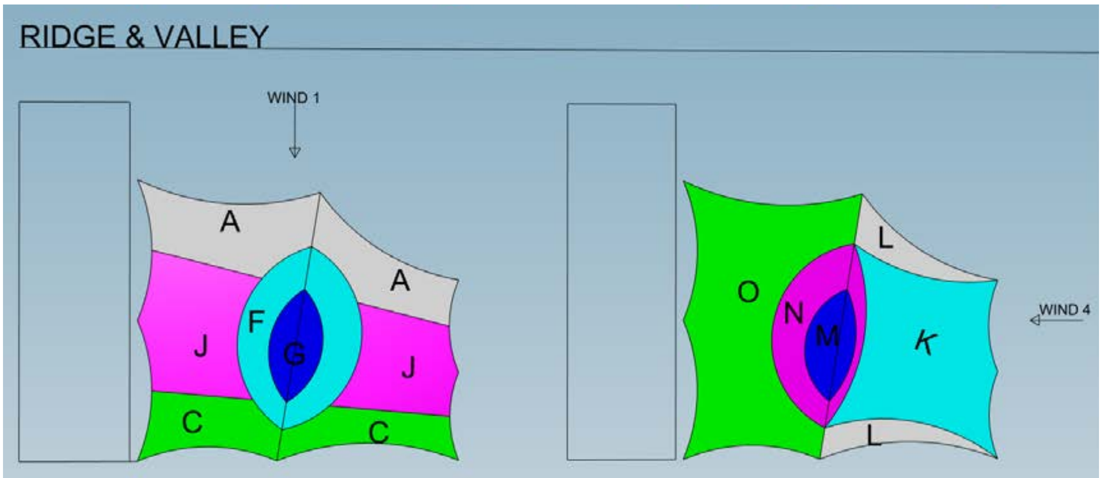


Figure 72: Central Arch zone definition, Ridge and Valley Zone type

Simulation			
	Cpe	Cpi	Cp tot
A	+0,6 -0,39		+0,6 -0,39
C	-0,41		-0,41
F	-0,38		-0,38
G	-0,38		-0,38
J	+0,14 -0,3		+0,14 -0,3
K	+0,58 -0,29	0,30	+0,88 -0,59
L	+0,38 -0,42	0,30	+0,68 -0,72
M	-0,38	0,40	-0,78
N	-0,38	0,50	-0,88
O	+0,38 -0,37	0,80	+1,18 -1,17

Hypar, Saddle

Figure 73: Hypar Cp zone definition

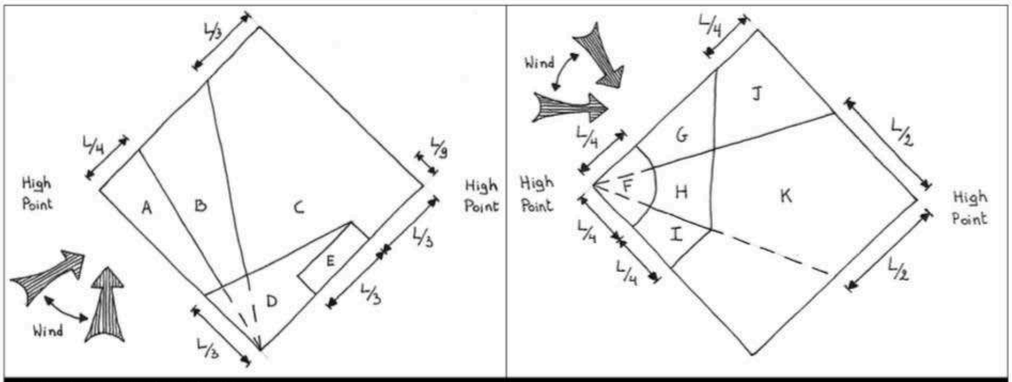


Fig. A1.6 Hypar C_p Zone Definition

External C_p Values	Zones										
	A	B	C	D	E	F	G	H	I	J	K
positive	+0	+0	+0.3	+0.3	+0.3	+0	+0	+0.2	+0	+0	+0.2
negative	-1.45	-0.9	-0.65	-0.70	-1.20	-1.80	-1.20	-0.90	-1.20	-0.65	-0.65

Table 3 External C_p Values for hypar / saddle structures

Data based on a closed sided structure with a shape ratio of 4.7

Is this proposal based on Hypar, saddle shape similarities a possible Cp value model?

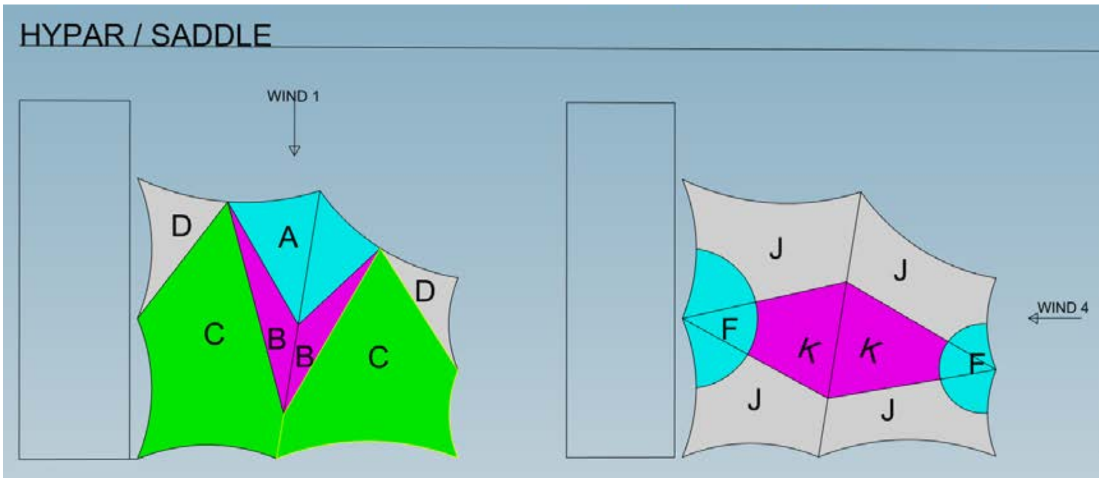


Figure 74: Central Arch, Cp zone definition, Hypar type

	A	B	C	D	F	J	K
Cpe	-1,45	-0,90	-0,65	-0,70	-1.80	-0,65	-0,65
Cpi					0,50	0,30	0,40
Cptot	-1,45	-0,90	-0,65	-0,70	-2,30	-0,95	-1,05

Saddle

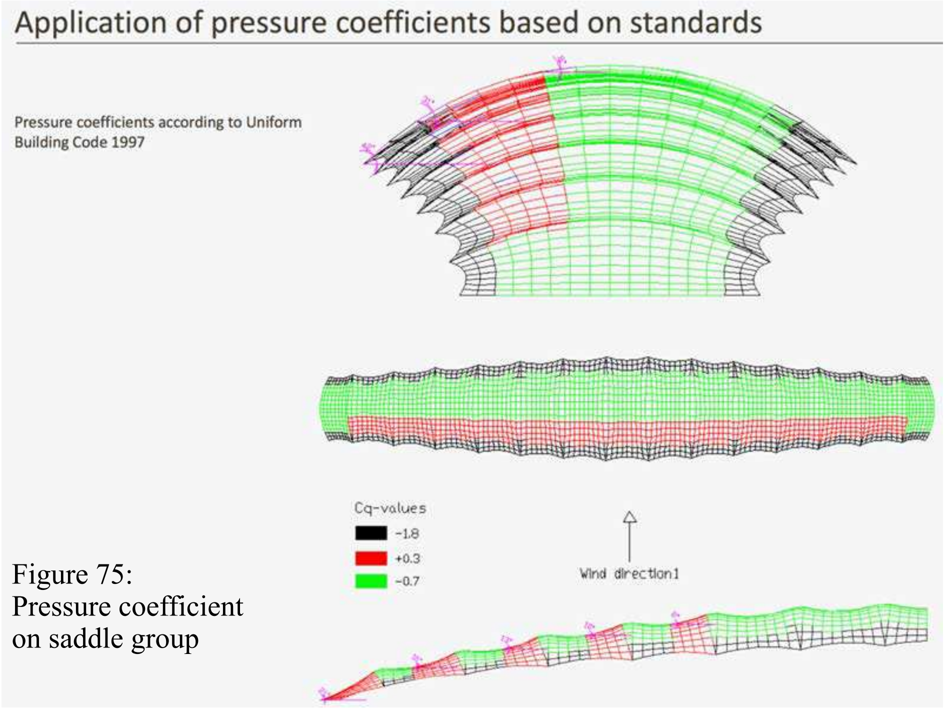


Figure 75: Pressure coefficient on saddle group

Is this proposal based on saddle shape similarities a possible Cp value model?

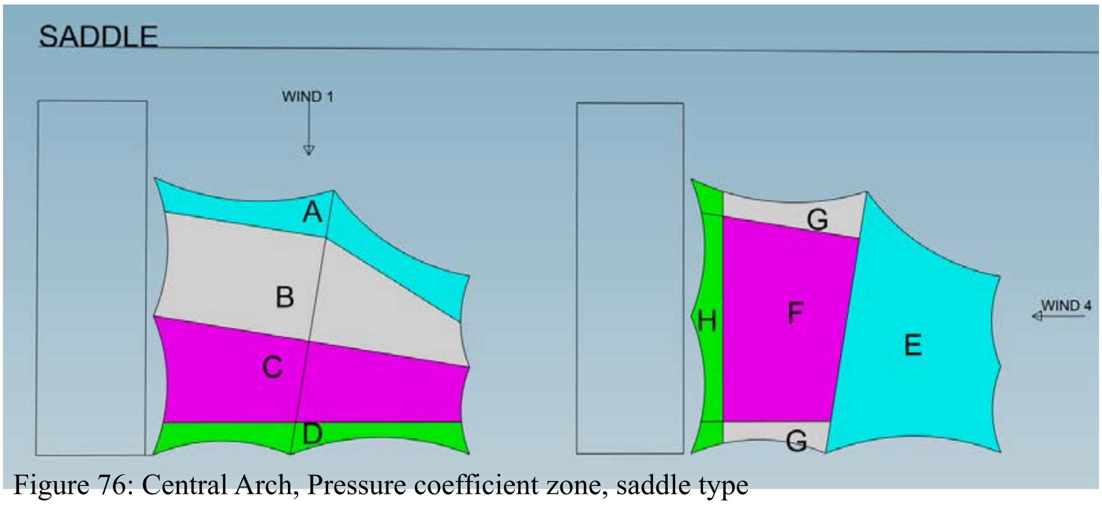


Figure 76: Central Arch, Pressure coefficient zone, saddle type

	A	B	C	D	E	F	G	H
Cpe	-1,80	0,30	-0,70	-1,80	+0,30 -0,30	-0,70	-1,80	-1,80
Cpi					+0,00 -0,30	-0,80	-0,60	-1,00
Cptot	-1,80	0,30	-0,70	-1,80	+0,30 -0,60	-1,50	-2,40	-2,80

6.2.3. EUROCODE

Extract from EUROPEAN STANDARD EN 1991-1-4

7.3. Canopy roofs
(1) A canopy roof is defined as the roof of a structure that does not have permanent walls.
(2) The degree of blockage under a canopy roof shown in figure 7.15. it depends on the blockage φ, which is the ratio of the area of feasible, actual obstructions under the canopy divided by the cross sectional area under the canopy, both areas being normal to the wind direction.

Note: φ=0 represents and empty canopy, and φ=1 represents the canopy fully blocked with contents to the down wind eaves only (this is not a closed building).

(3) The overall force coefficients, Cf, and net pressure coefficients Cpnet, given in tables 7.6 to 7.8 for φ=0 and φ=1 take account of the combined effect of wind acting on both the upper and lower surfaces of the canopies for all wind directions. Intermediate -values may be found by linear interpolation.

(4) Downwind of the position of maximum blockage, Cpnet values for φ=0 should be used.

(5) The overall coefficient represents the resulting force. The net pressure coefficient represents the maximum local pressure for all wind directions. It should be used in the design of the roofing element and fixings.

(6) Each canopy must be able to support the load cases as defined below:
For a duo pitch canopy (table 7.7) the center of pressure should be taken at the center of each slope (figure 7.17). In addition a duo pitch canopy should be able to support one pitch with the maximum or minimum load, the other pitch being unloaded.

EN 1991-1-4:2005 (E)

Figure 77: Eurocode EN 1991-1-4: 2005

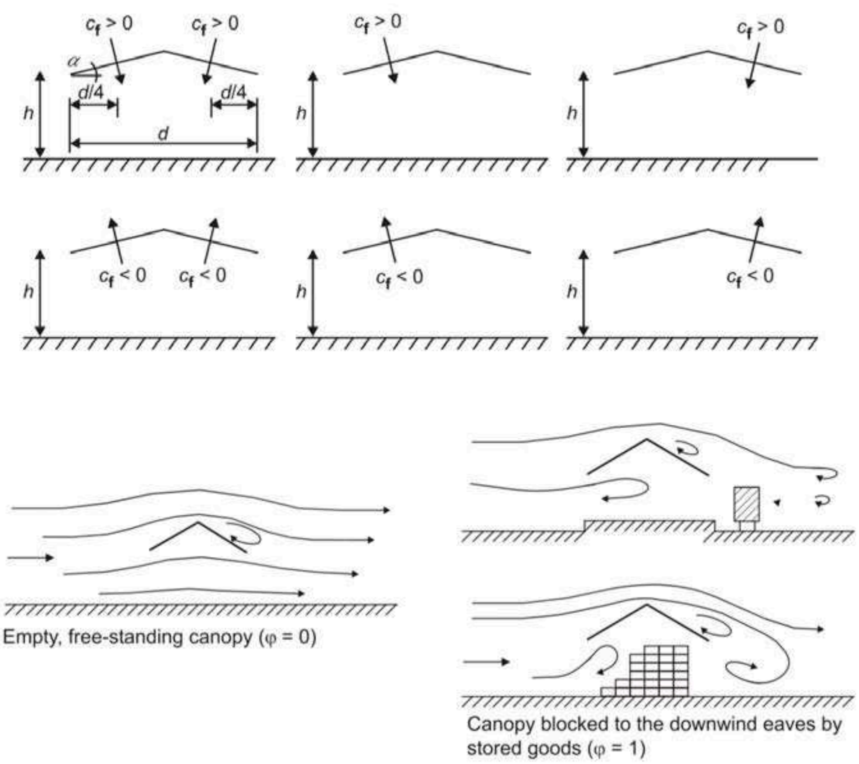


Figure 7.15 — Airflow over canopy roofs

6.2.4 Cp values for duo pitch canopies, Key Plan, Values for 20° angle roof slope adapted to selected central arch project

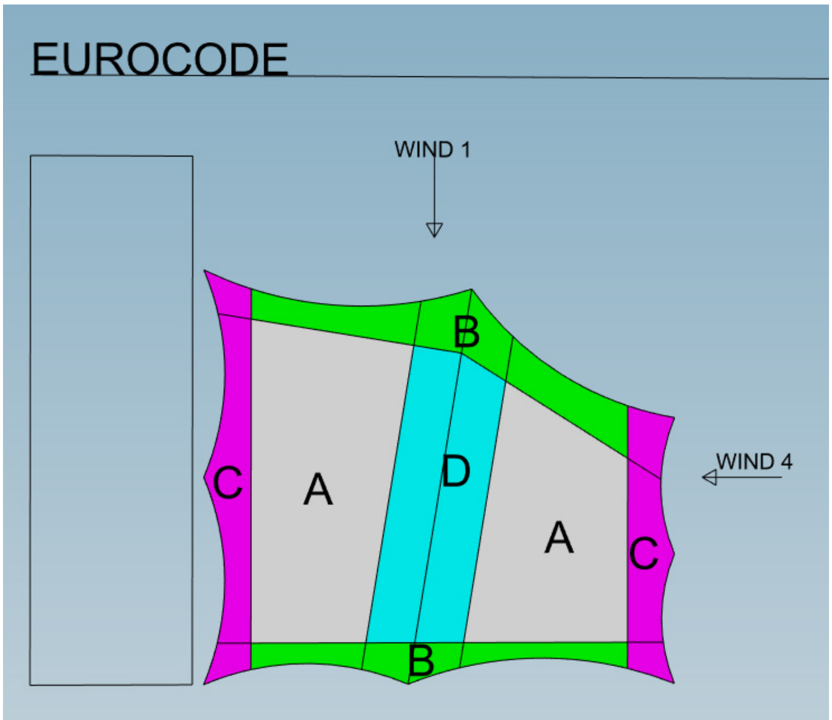
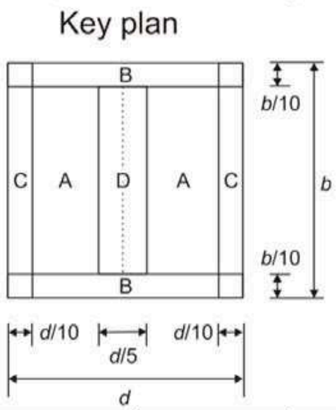


Figure 78: Central Arch zone definition, Eurocode partition type

EN 1991-1-4:2005 (E)

Table 7.7 — $c_{p,net}$ and c_f values for duopitch canopies

Net pressure coefficients $c_{p,net}$



Roof angle α [°]	Blockage φ	Overall Force Coefficient c_f	Zone A	Zone B	Zone C	Zone D
+ 20	Maximum all φ	+ 0,6	+ 1,1	+ 1,9	+ 1,5	+ 0,4
	Minimum $\varphi = 0$	- 0,9	- 1,2	- 1,8	- 1,4	- 2,0
	Minimum $\varphi = 1$	- 1,3	- 1,4	- 2,2	- 1,6	- 2,1

6.2.5. ABSTRACT / Cp Value

After to have studied in detail the different shape models; Cone, Ride Valley, Hypar Saddle, and Saddle it appears some similarities in the values. Generally, the load applied to the membrane is by succion and the value including in the range of - 0,30 to - 2,40. These values can be taken for calculation with some reservation before a complete wind tunnel test of CFD can be made.

The EUROCODE cover all situations and will be used for final statical analysis.

6.2.6 Statical Analysis Based on Eurocode

Following calculation are done using EASY PROGRAM

Different case studies will be calculated following Eurocode procedure:

3 situations using Overall coefficients apply downward, true for all φ
3 situations using Overall coefficients apply uplift, true with $\varphi = 1$ (as 1 project side is obstructed by adjacent building)
1 situation using Net coefficients apply downward on 4 membrane zones, true for all φ
1 situation using Net coefficients apply uplift on 4 membrane zones, true for φ=1

Calculation will be done using EASY program. This is the same program used for FormFinding.

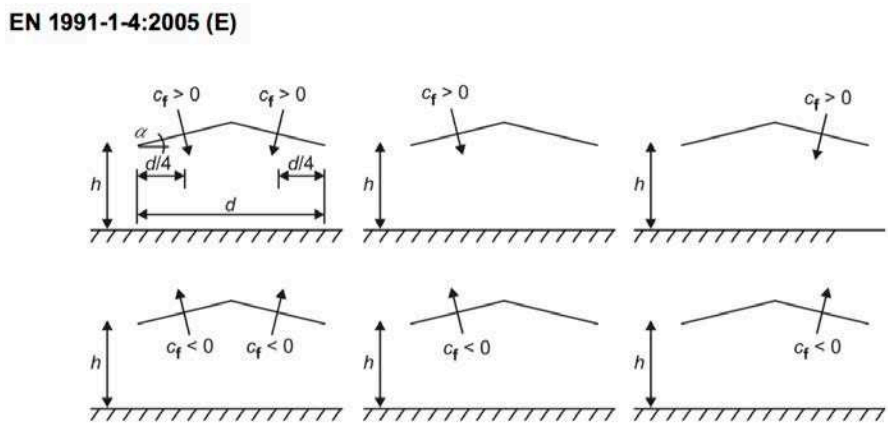
The program EASY will be loaded with following data:

- Wind Velocity Pressure for all case studies: 0.83 kN/m^2
- Membrane Zone I and Zone 2 when Overall coefficient are applied in middle of each zone
- Membrane 4 Zones, when Net pressure coefficient are applied to 4 Zones
- Cp values applied in different case studies are; 0.6, -1.3, +1.1, +1.9, +1.5, +0.4, -1.4, -2.2, -1.6, -2.1

6.2.6.1 Statical Analysis / Overall force coefficient:

Cf Maximum all φ, Load applied downward
Cf Minimum φ = 1, Load applied uplift

6 case studies are calculated. The wind load is applied on roof as described on following pictograms



The membrane is shared in 2 areas; left and right beside the central arch.

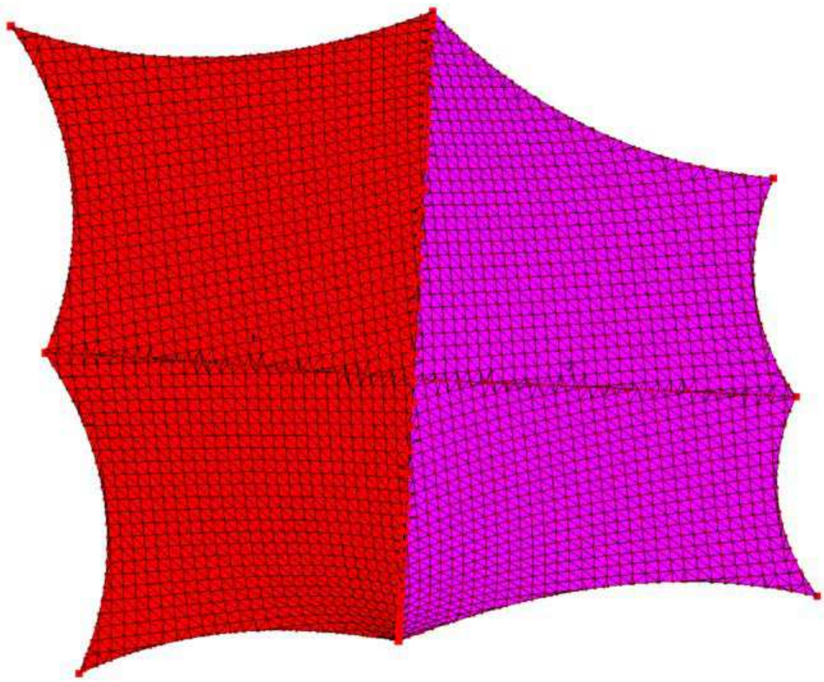


Figure 79: Central Arch Zone 1 & II drawn in Easy program

CS 1: Cf Maximum all φ

Area I and Area II, loaded
cf value: + 0.6
Membrane stress, max: 16.99 kN
Cable Force, max.: 132.42 kN

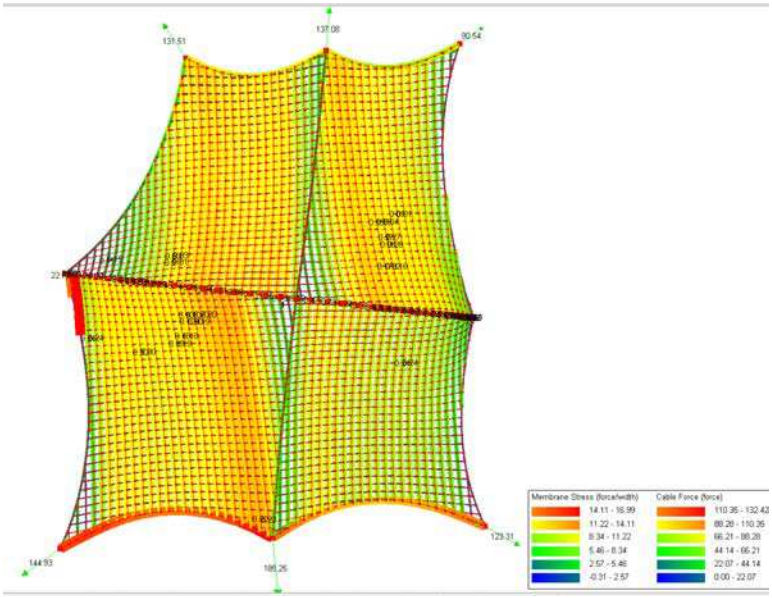


Figure 80:
Statical Analysis,
CS1, Easy

CS 2: Cf Maximum all φ

Area I loaded, Area II prestress load only
Cf Value: +0.6
Membrane stress, max: 16.99 kN
Cable Force, max.: 132.42 kN

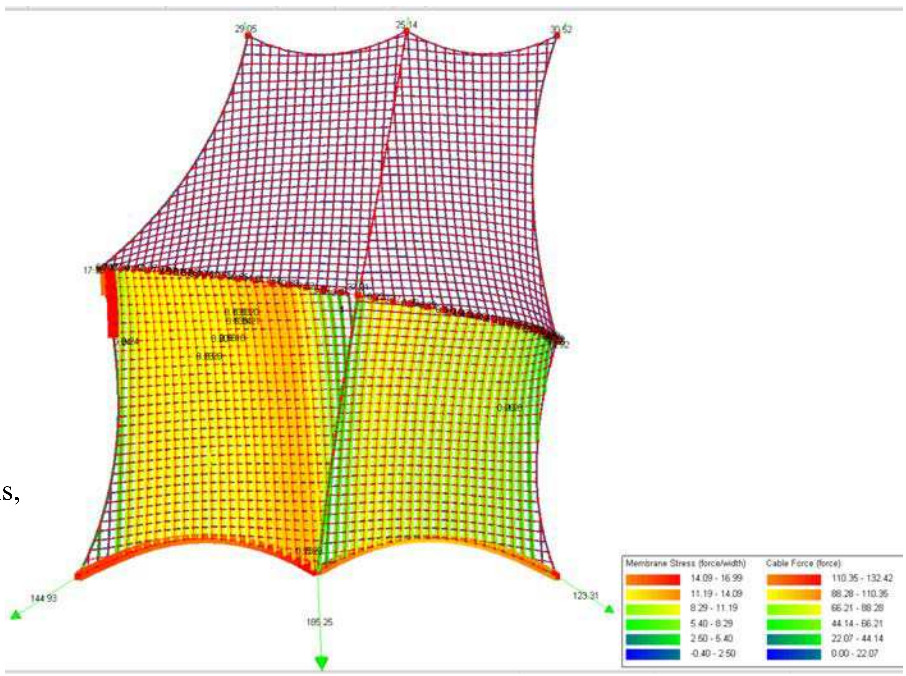


Figure 81:
Statical Analysis,
CS2, Easy

CS 3: Cf Maximum all φ

Area II loaded, Area I prestress load only

Cf value: + 0.6

Membrane stress, max: 12.15 kN

Cable Force, max.: 91.78 kN

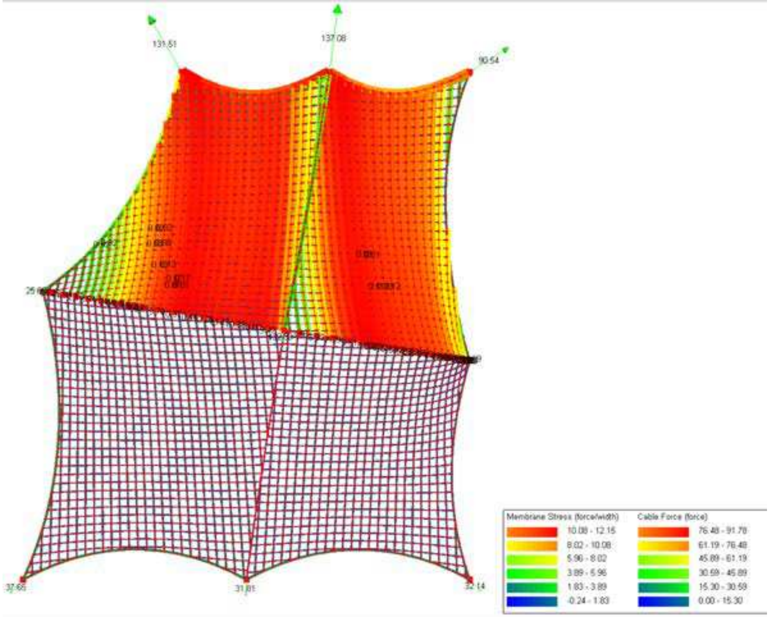


Figure 82:
Statical Analysis,
CS3, Easy

CS 4: Cf Minimum, φ=1

Area I loaded, Area II loaded

Cf value: -1.3

Membrane stress, max: 21.02 kN

Cable Force, max.: 264.23 kN

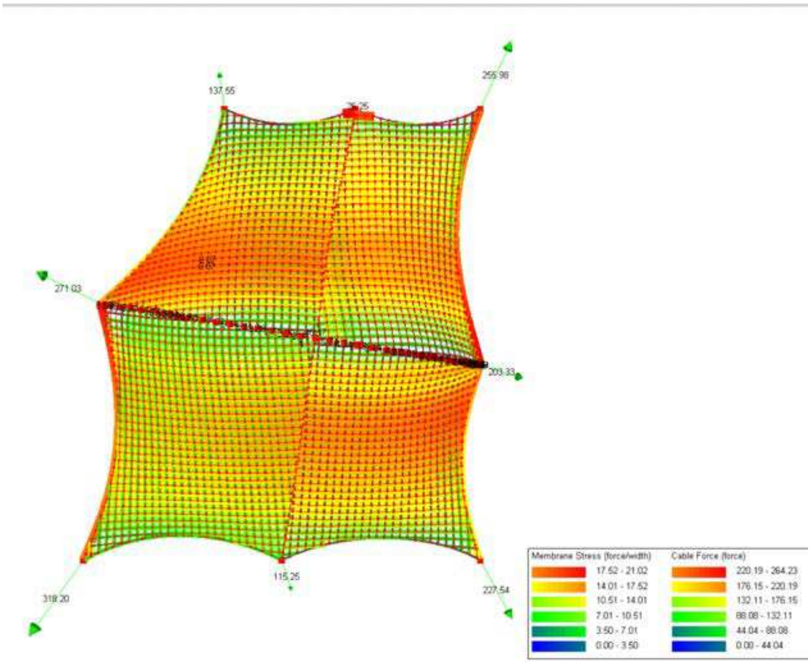


Figure 83:
Statical Analysis,
CS4, Easy

CS 5: Cf Minimum, φ=1

Area I loaded, Area II loaded with prestress only
Cf value: -1.3
Membrane stress, max: 18.57 kN
Cable Force, max.: 251.50 kN

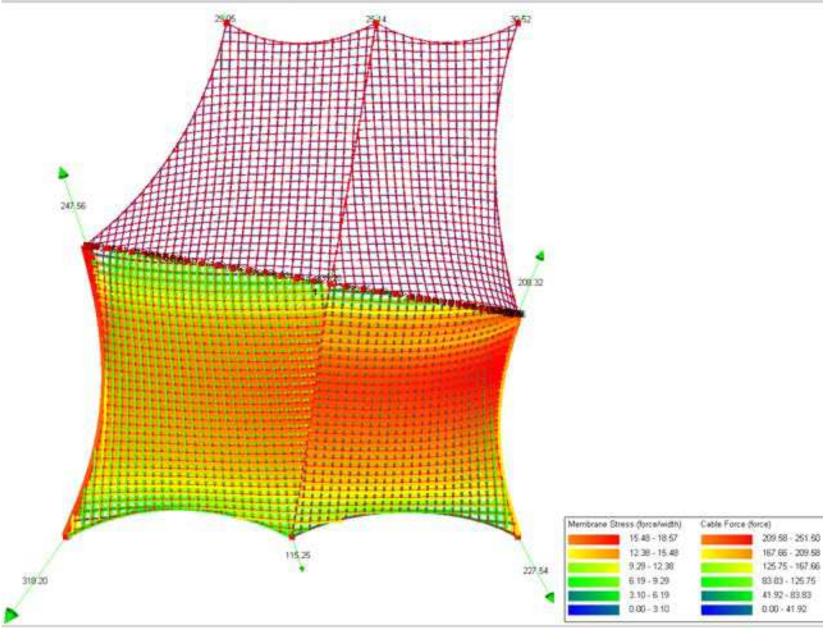


Figure 84:
Statical Analysis,
CS5, Easy

CS 6: Cf Minimum, φ=1

Area I loaded with prestress only, Area II loaded
Cf value: -1.3
Membrane stress, max: 21.02 kN
Cable Force, max.: 264.23 kN

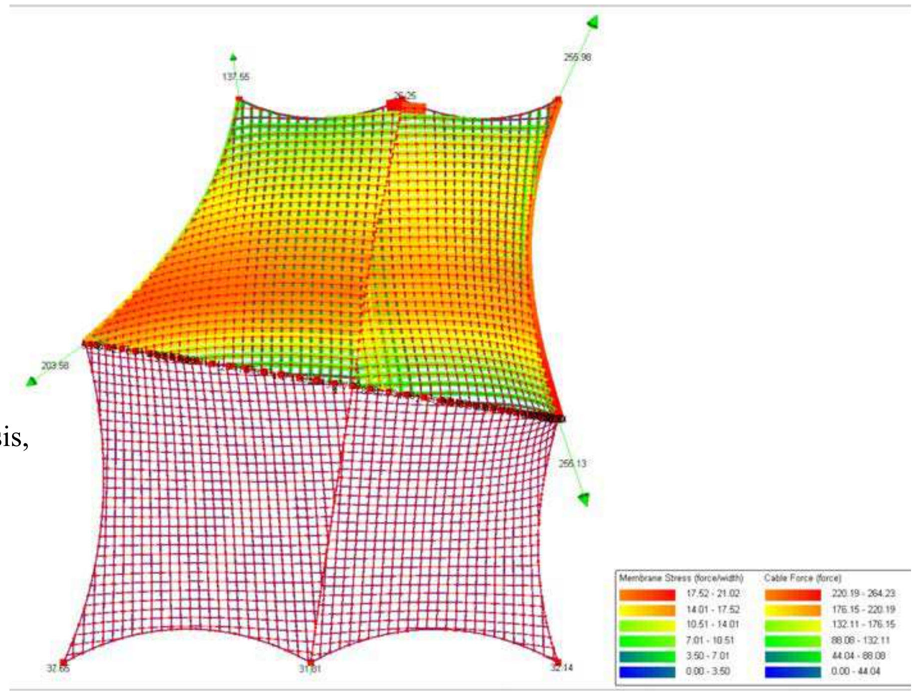
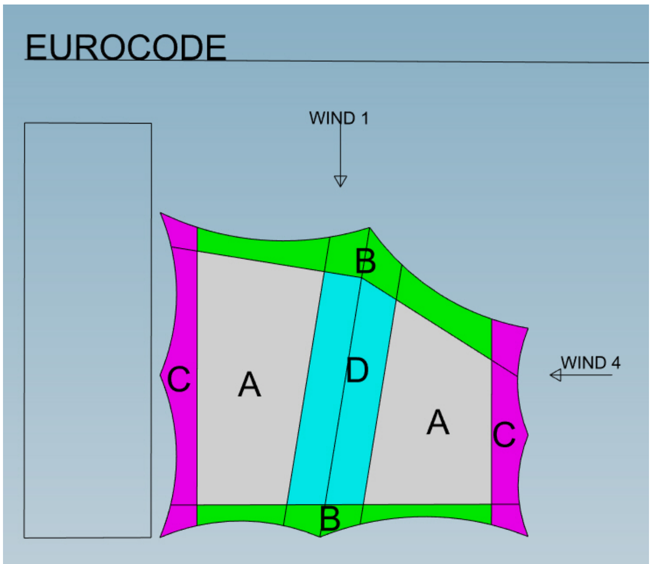


Figure 85:
Statical Analysis,
CS6, Easy

6.2.6.2 Statical Analysis / Net Pressure coefficient:

Cpnet Maximum all φ, Load applied downward
Cpnet Minimum $\varphi = 1$, Load applied uplift



Case Study Max, all φ:
Zone A: Cp net +1.1
Zone B: Cp net +1.9
Zone C: Cp net +1.5
Zone D: Cp net +0.4

Case Study Min, φ=1:
Zone A: Cp net -1.4
Zone B: Cp net -2.2
Zone C: Cp net -1.6
Zone D: Cp net -2.1

4 zones load repartition on the membrane 3D shape in Easy program.
To be in accordance with Eurocode

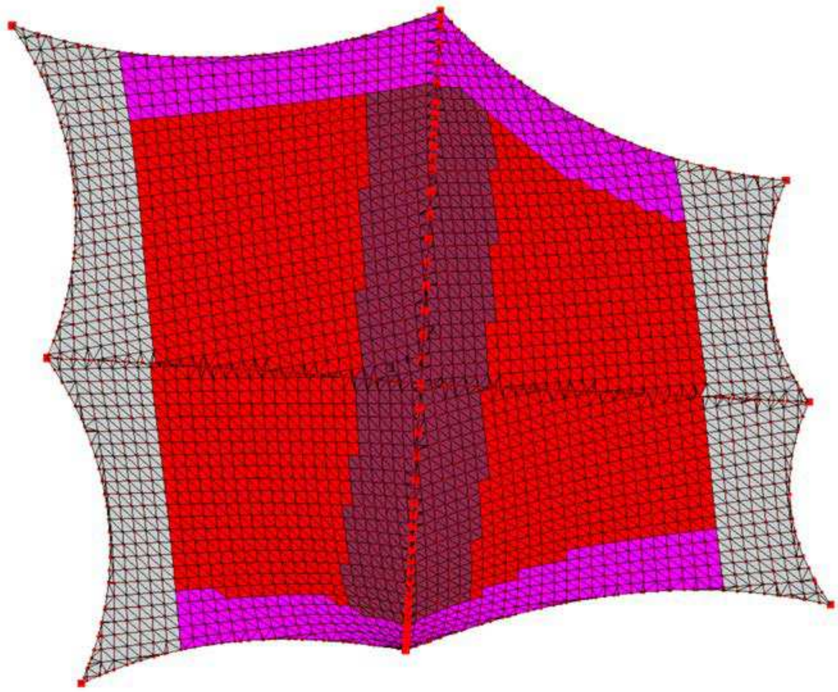


Figure 86: Net pressure, 4 zones partition

CS 7: Cp net Maximum, All φ

Zone A loaded (Cp net +1.1), Zone B loaded (Cp net +1.9),
Zone C loaded (Cp net +1.5), Zone D loaded (Cp net +0.4)

Membrane stress, max: 30.45 kN
Cable Force, max.: 203.04 kN

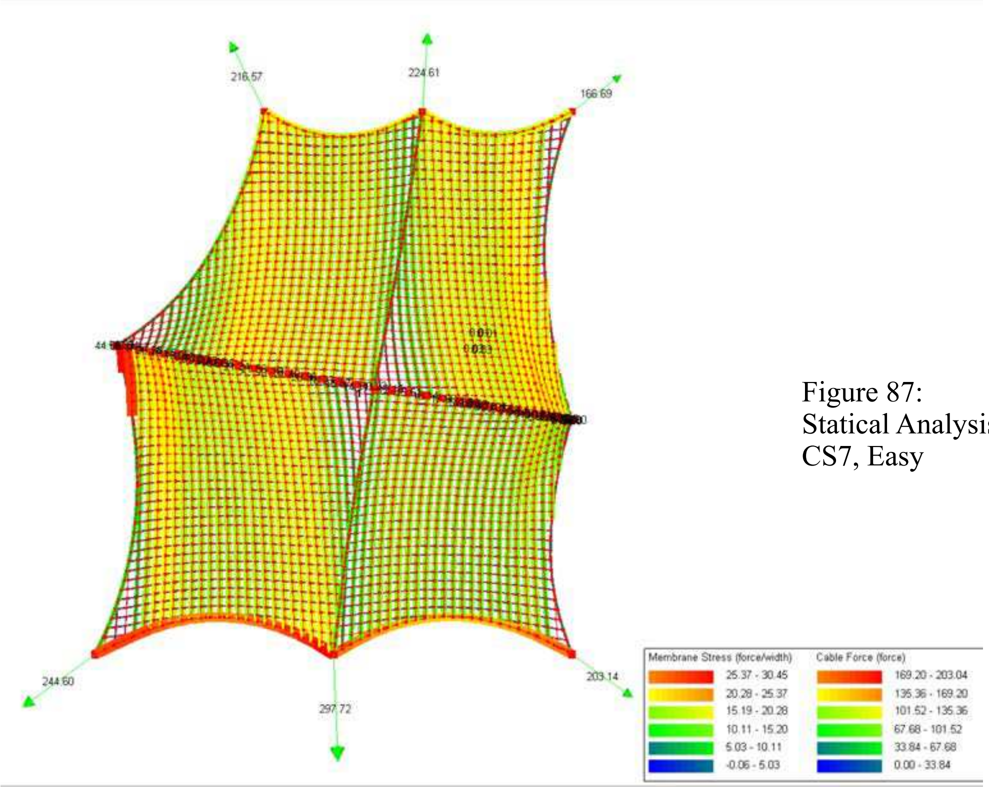


Figure 87:
Statical Analysis
CS7, Easy

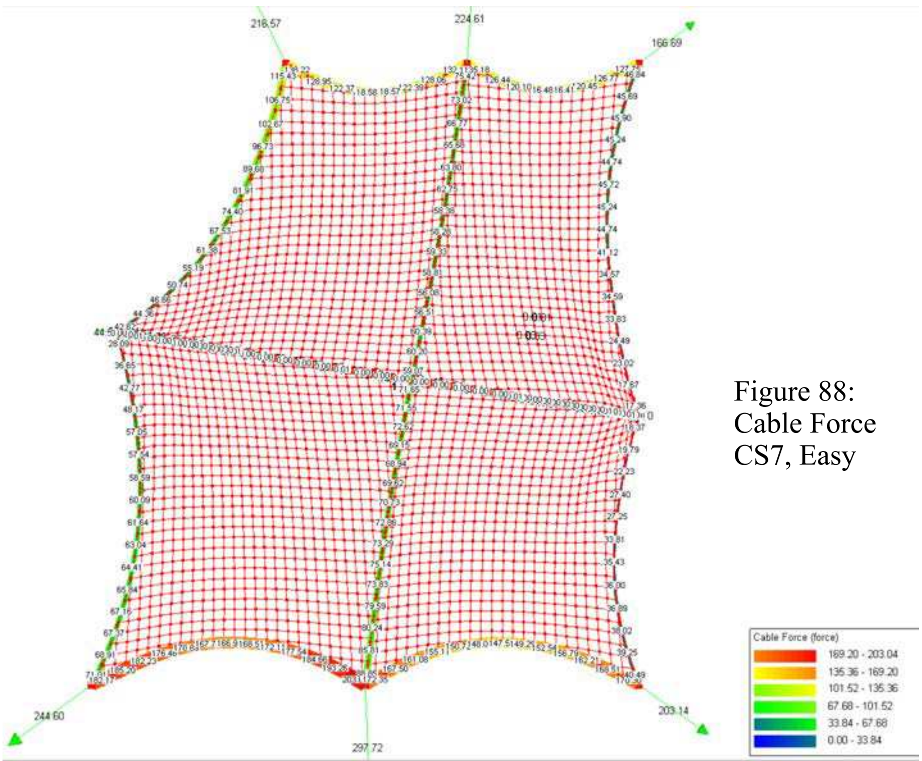


Figure 88:
Cable Force
CS7, Easy

CS 8: Cp net Minimum, φ=1

Zone A loaded (Cp net -1.4), Zone B loaded (Cp net -2.2),
Zone C loaded (Cp net -1.6), Zone D loaded (Cp net -2.1)

Membrane stress, max: 23.07 kN
Cable Force, max.: 307.31 kN

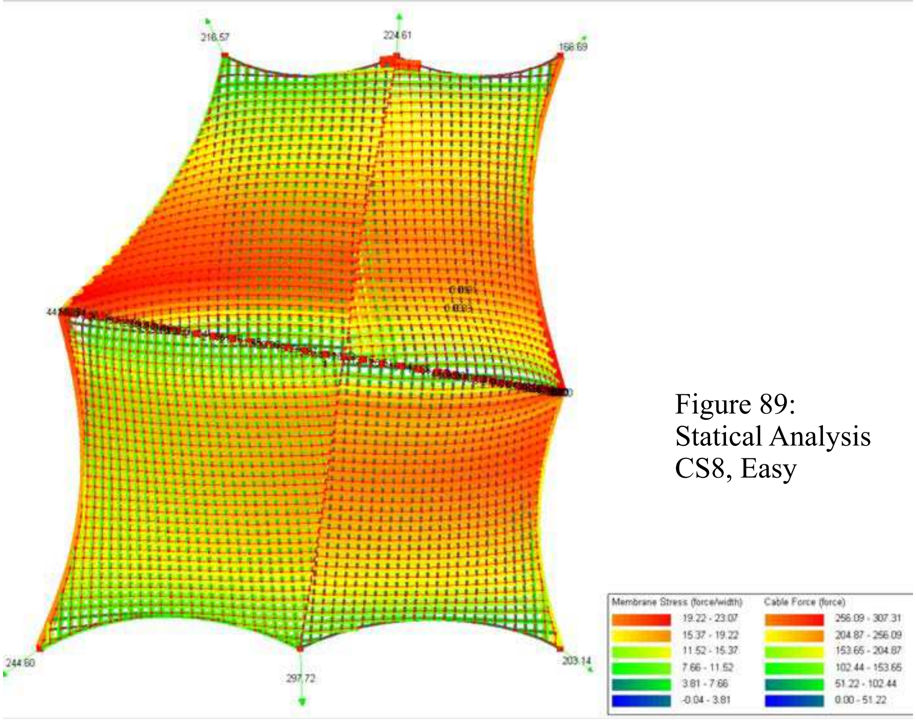


Figure 89:
Statical Analysis
CS8, Easy

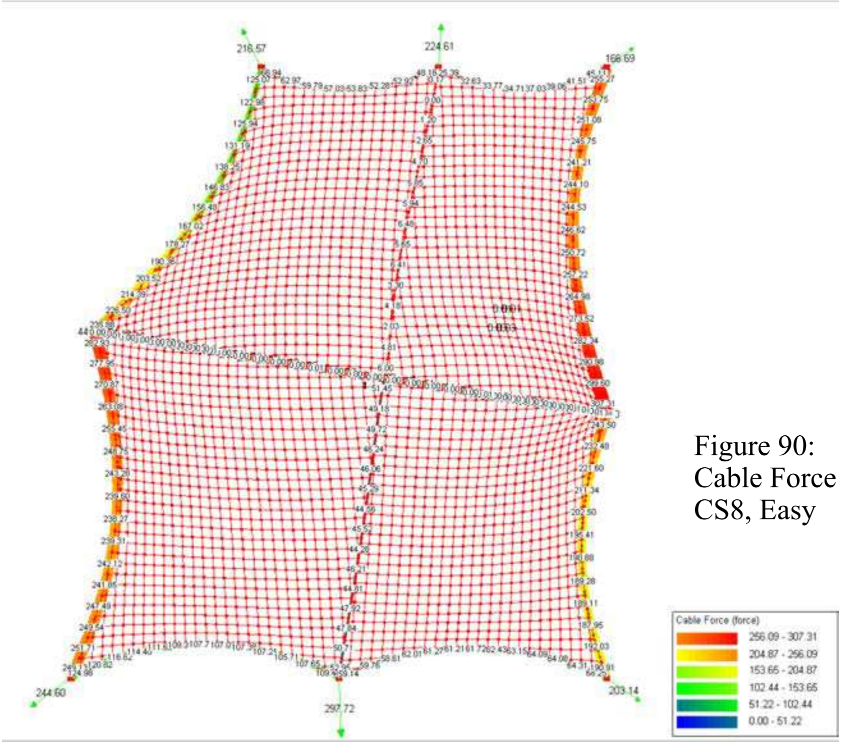


Figure 90:
Cable Force
CS8, Easy

6.2.7 Looking in detail membrane areas showing maximum stress values

Wind Load Case, CS 7, Cp net Max

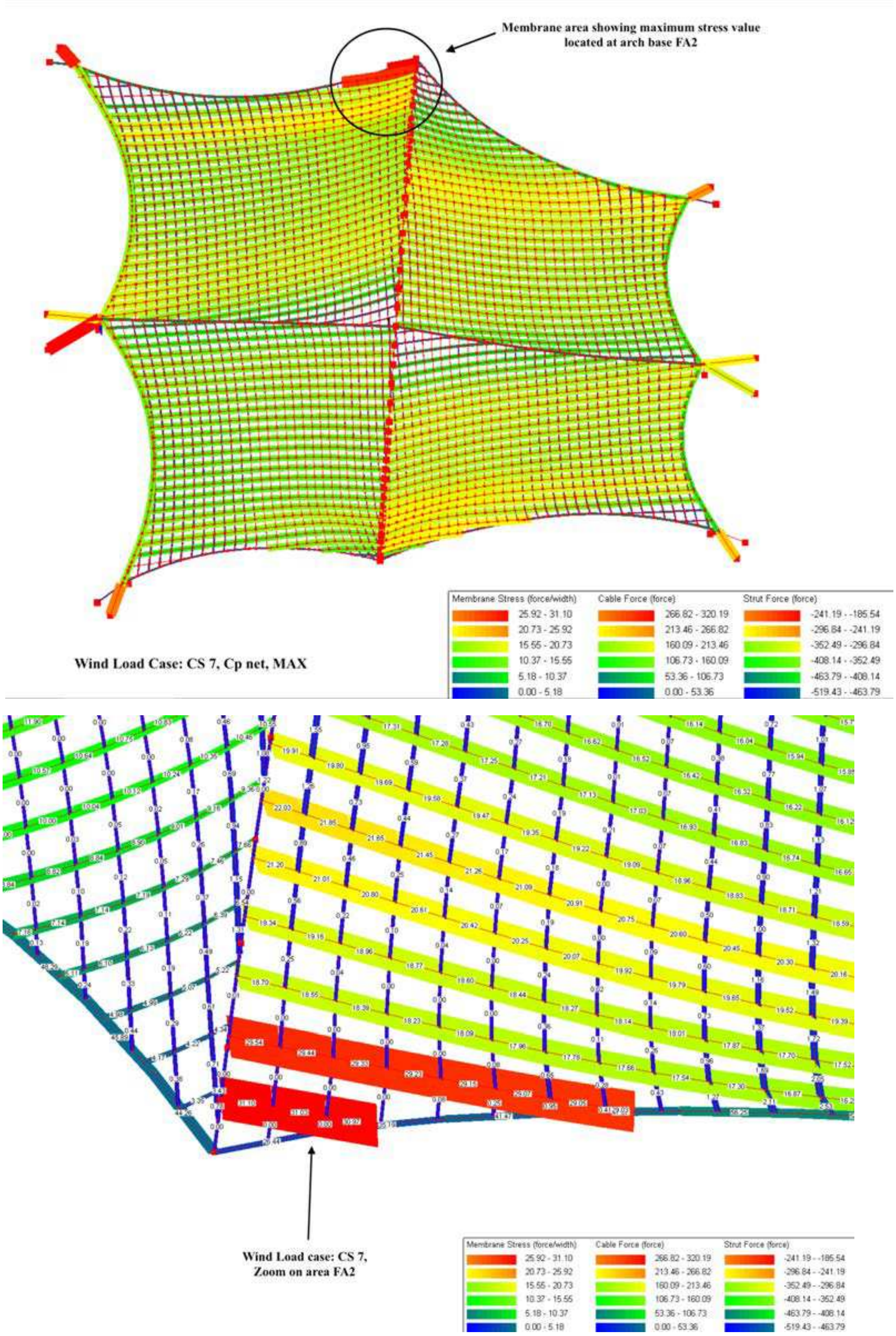


Figure 91: CS7, Membrane Stress Max

WIND LOAD CASE STUDY, CS 8, Cp net Min

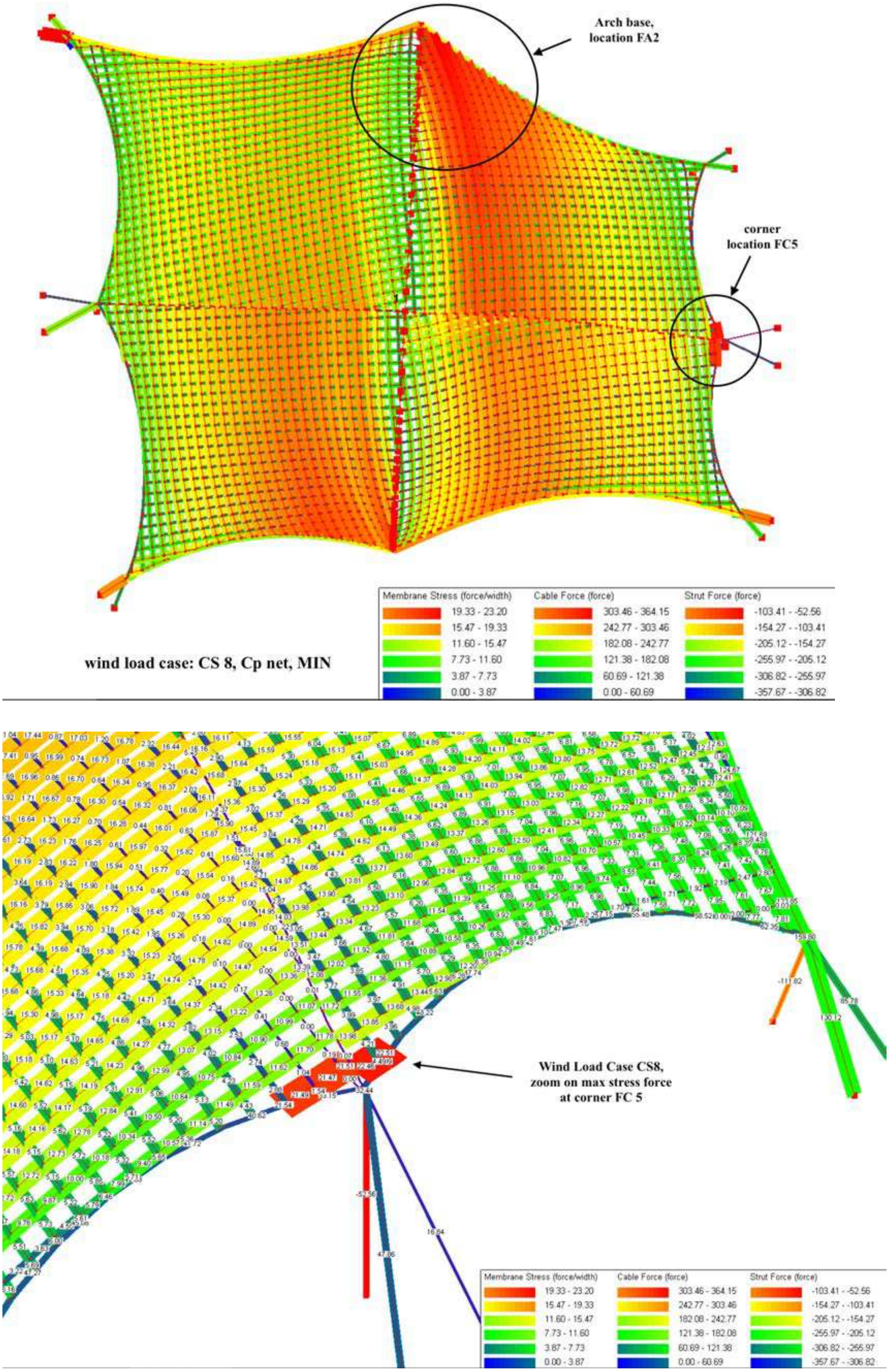


Figure 92: CS8, Membrane Stress Max

6.2.8 Summary of all statical analysis wind load case studies Membrane Stress

case studies	membrane stress max, kN
Overall Force coefficient, Download Force	
Zone I & II loaded, Cf Max +0.6	16.99
Zone I loaded, Cf Max +0.6	12.15
Zone II loaded, Cf Max +0.6	16.99
Overall Force coefficient, Uplift Force	
Zone I & II loaded, Cf Min -1.3	21.02
Zone I loaded, Cf Min -1.3	18.57
Zone II loaded, Cf Min -1.3	21.02
Net pressure coefficient, 4 zones	
Cpnet Max, Zone A (Cp +1.1), Zone B (Cp +1.9), Zone C (Cp +1.5), Zone D (Cp +0.4)	30.45
Cpnet Min, Zone A (Cp -1.4), ZoneB (Cp -2.2), Zone C (Cp -1.6), Zone D (Cp -2.1)	23.07

Figure 93: Summary of statical analysis wind load chart

Remarks:
The maximum stress membrane values of 23.07 and 30.45 kN are located at 2 angles FA2 and CF5 where the membrane will be doubled.

All other values are within minimum and maximum values 12.15 and 21.02 kN./m2

The Maximum value to be considered is: 21.01 kN; after application of factor 5 for safety, the necessary membrane Tensile Strength to be selected is 21 x 5 = 105 kN/m or 525 daN/5cm (5 cm strip being usually given in materials data sheet).

6.2.9 Summary of all case studies edge cable loads

	E.C.1	E.C.2	E.C.3	E.C.4	E.C.5	E.C.6	E.C.7	E.C.8
CS 1	17	112	132	27	62	91	81	15
CS 2	17	112	132	27	20	13	12	19
CS 3	15	19	20	19	62	91	81	15
CS 4	217	59	106	251	205	50	35	264
CS 5	217	59	106	251	20	13	12	19
CS 6	15	19	20	19	205	50	35	264
CS 7	40	172	203	71	115	138	127	46
CS 8	243	66	124	282	235	66	45	307

Values in this table are in kN Figure 94: Summary of case studies edge cable loads chart

CS = Case study
CS1: Cf Max All φ, Zone I loaded Cf + 0.6, Zone II loaded Cf + 0.6,
CS2: Cf Max All φ, Zone I loaded Cf + 0.6, Zone II prestress only
CS3: Cf Max All φ, Zone I prestress only, Zone II loaded Cf + 0.6,
CS4: Cf Min φ=1, Cp -1.3 (uplift) applied (downward) on Zone I and II
CS5: Cf Min φ=1, Cp -1.3 (uplift) applied (downward) on Zone I
CS6: Cf Min φ=1, Cp -1.3 (uplift) applied (downward) on Zone II
CS7: Cpnet Max All φ, Zone 1 (Cp 1.1), Zone 2 (Cp 1.9), Zone 3 (Cp 1.5), Zone 4 (Cp 0.4)
CS8: Cpnet Min φ=1, Zone 1 (Cp -1.4), Zone 2 (Cp -2.2), Zone 3 (Cp -1.6), Zone 4 (Cp -2.1)

E.C. = Edge Cable
Median cable (separation zone I and II)
Median cable 1: CS1 (54 kN), CS 2 (51 kN), CS3 (12 kN), CS5 (42 kN), CS6 (12 kN), CS 7 (88 kN), CS 8 (52 kN)
Median cable 2: CS1 (44 kN), CS 2 (11 kN), CS3 (44 kN), CS5 (30 kN), CS6 (2 kN), CS 7 (75 kN), CS 8 (6 kN)

Remarks:
the 2 wind load case studies, CS7 and CS8, where the Cp net values are applied download and uplift to the 4 membrane zones give the maximum force on edge cable.

To complete this study: can hand calculation using basic arithmetics be an option?

6.2.10 Hand Calculation as a method for Statical Analysis Force Calculation of Loads

We assume the wind load is acting UPLIFT to the membrane.

Project parameters:
Height over site: 9 meters
Wind Speed: V = 100 km/h. V = 100/3.6 = 27.7 m/sec
Basic Velocity Pressure: Qref = $V^2/1600 = 27{,}7^2/1600 = 0.480$ kN/m²
Peak Velocity Pressure or Dynamic Velocity Pressure:
Q = 1.7 x Qref x $(H/10)^{0.37}$ = 0.82 kN/m²
Where 1.7 is in relation with the terrain configuration and H/10 puissance 0.37 in relation with the project height.
The calculated Dynamic Velocity Pressure 0.82 is in the range of local regulation.

The value to be taken in consideration is given by local rule, **Q Value = 0.83 kN/m²**

Aerodynamic Pressure Coefficient:
The Cp value vary from area to area on membrane surface according to the position, the wind direction, and the angle between membrane surface and horizontal. In order to make the hand calculation possible we assume the Cp value: 1.6 (accepted value for this kind of shape).

Calculation of wind load pressure
Wind Load pressure: W = Q x Cp = 0.83 x 1.6 = 1.328 kN/m²

Dimensional parameters
Surface of project:
AREA 1: 418 m² + AREA 2: 250 m² = Total: 668 m²
Sum of: Border cable along area 1: 57 m + Border cable along area 2: 50 m =
Total border cable length: 107 m

Vertical Load calculation
In this simulation we assume that the central arch dont play an essential role in the load calculation. Due to uplift action on the wind to the membrane the central arch is indeed not loaded.
Total Vertical Load: V = A (m²) x W (kN/m²) = 668 x 1,328 = 887 kN
Vertical Load « v » per meter along border cable: v = 887 / 107 = 8.23 kN/m
Border cable loading

Determination of border cable loading, by trigonometry, the vector n: n = v . 1/sin α
The value is in Kn/m
α: angle in degree between horizontal and membrane along cable. α is directly measured on the CAD drawing.

Following table give the result for n

Edge Cable	**angle** α	**Sin** α	**1/sin**α	**v**	n
E.C.1	24.4°	-0.67	-1.49	8.23	-12.30
E.C.2	14°	0.99	1.01	8.23	8.31
E.C.3	8°	0.99	1.01	8.23	8.32
E.C.4	21.2°	0.71	1.41	8.23	11.57
E.C.5	20.5°	0.99	1.0	8.23	8.26
E.C.6	14.2°	0.99	1.0	8.23	8.25
E.C.7	7.5°	0.93	1.07	8.23	8.77
E.C.8	26°	0.76	1.31	8.23	10.79

Figure 95: edge cable n chart

The radius of each edge cable is calculated following:
r = 4 $f^2 + l^2$: 8f
r: radius, f: sag, l: rope length
to simplify, when f=l/10, r = 1.3 x l

Calculate the radius for all edge cables and the tension Force
The tension Force is given by the formula: S = n x r
S in kN
l is measured on the CAD drawing, the value is in meter
Determination of the design cable load S in kN

After to have done a first simulation by theory it is decided to measure the radius directly on the drawing, on the net membrane drawing given by the form finding program.

…/…

…/…

Cable Force Calculation:

Edge Cable	Cable lenght	Rope	Radius l.1.3	Measured on drawing	n	S (force) kN
E.C.1	13.00	12.70	16.51	15.60	-12.30	-191
E.C.2	13.70	13.00	16.90	17.00	8.31	141
E.C.3	13.65	13.00	16.90	16.30	8.32	135
E.C.4	17.00	16.70	21.71	21.60	11.57	249
E.C.5	15.44	15.00	19.50	19.00	8.26	156
E.C.6	9.20	8.80	11.44	15.50	8.25	127
E.C.7	8.76	8.40	10.92	10.70	8.77	93
E.C.8	17.00	16.60	21.58	20.80	10.79	224

Figure 96: cable Force calculation chart

As a matter of comparaison, and in order to validate this calculation I propose to use the Easy Statical analysis program. The parameters for Wind Velocity Pressure 0.83 kN/m² and Cp 1.6 are used in the wind load module with uplift load direction on the membrane;

The result for edge cable Force given by Easy Statical Analysis module is:

E.C. 1: 187 - 253 kN (in middle 200 kN)
E.C. 2: 72 - 75 kN (in middle 70 kN)
E.C. 3: 103 - 116 kN (in middle 100 kN)
E.C. 4: 252 - 314 kN (in middle 250 kN)
E.C. 5: 108 - 228 kN (in middle 145 kN)
E.C. 6: 64 - 81 kN (in middle 70 kN)
E.C. 7: 39 - 50 kN (in middle 45 kN)
E.C. 8: 238 - 304 kN (in middle 230 kN)

Illustration in following drawing:

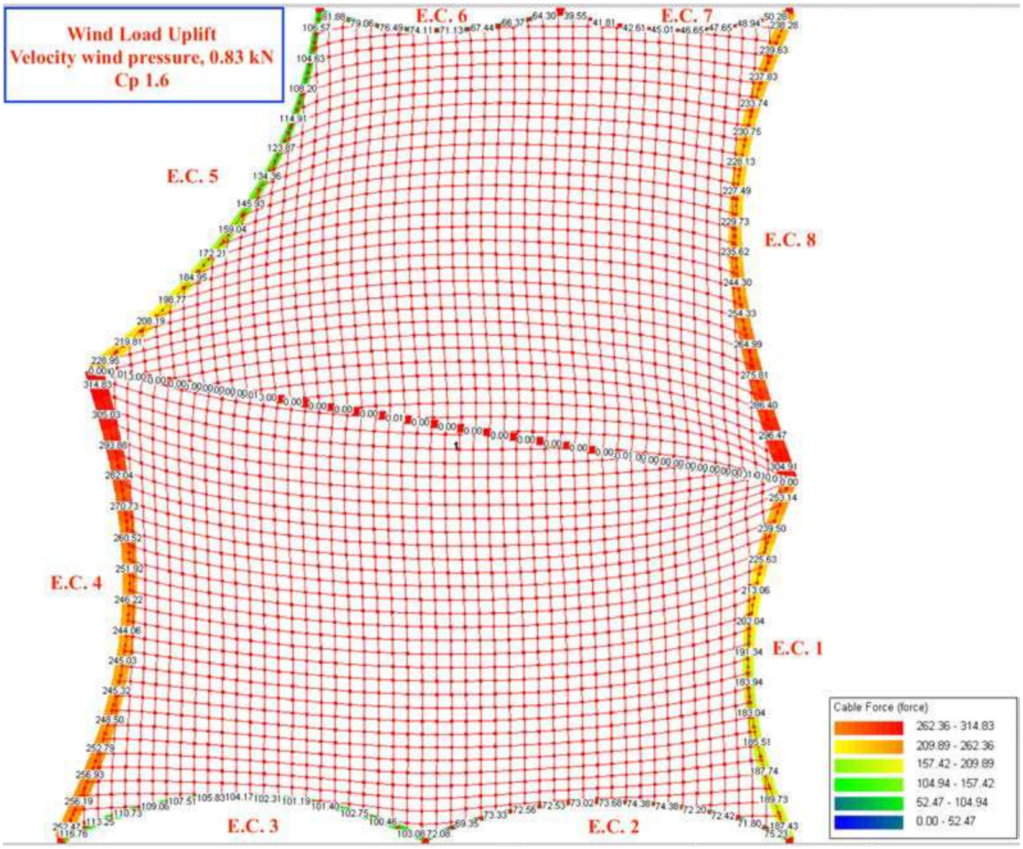


Figure 97: Wind Load, Uplift

Remarks:
Cable Force appear to be in same range, yet some differences. It is to be noted that the measurement of angle α on the drawing is not evident, the measured angle value is not so precise and the difficulty increase with the angle value witch changes all along the edge according to the non symmetry of this shape. As a direct effect, a small change in α can give very different value of SIN α and can induce big difference in the calculation tension Force value, since the Force is given by the formula: S = n x r .

Conclusion:

Therefore I consider the hand calculation as a possible method for a first approach only. This will give a figure for cable sections and then a first budget estimate.

The hand calculation give a maximum load of 249 kN. if a safety margin of 1.5 is taken, then the maximum cable service load will be 373 kN.

Possible cable choice for all edge cables:
Jakob 22 mm strand with a breaking load of 399 kN
Pfeifer 24,1 mm strand with a breaking load of 409 kN
Pfeifer 28,6 mm strand with a limit tension of 350 kN

6.2.11 Calculation of loads at corners for Dimensioning of structural elements

Resultant Forces at Membrane Corners

The following pictures come from Statical Analysis module of Easy program. The vectors at corners are in kN. They are the resultant force loads at membrane corners.

wind load case, CS Min, Velocity wind pressure 0.83 kN, Cp net Min apply to 5 zones
wind pressure is applied uplift to the membrane.

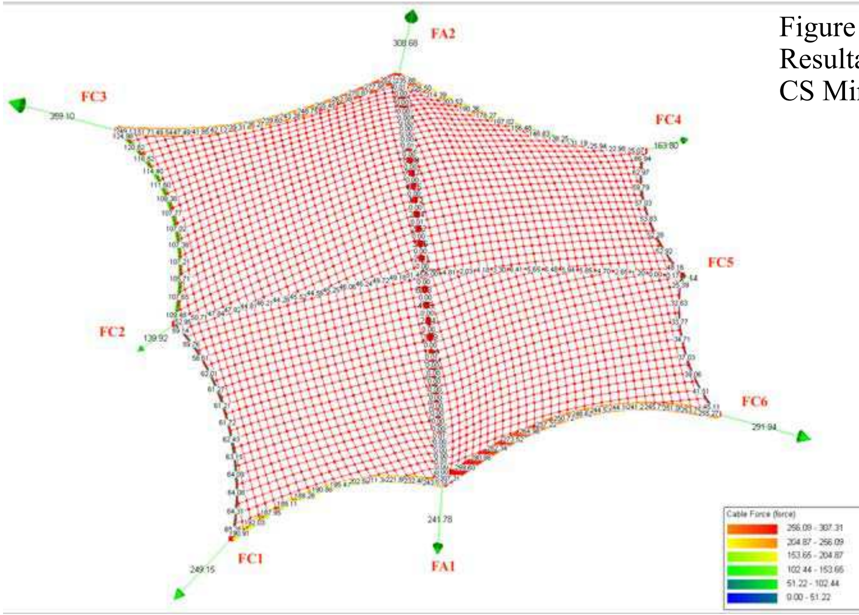


Figure 98: Resultant Force, CS Min

wind load case, CS Max, Velocity wind pressure 0.83 kN, Cp net Max apply to 5 zones
wind pressure is applied downward to the membrane

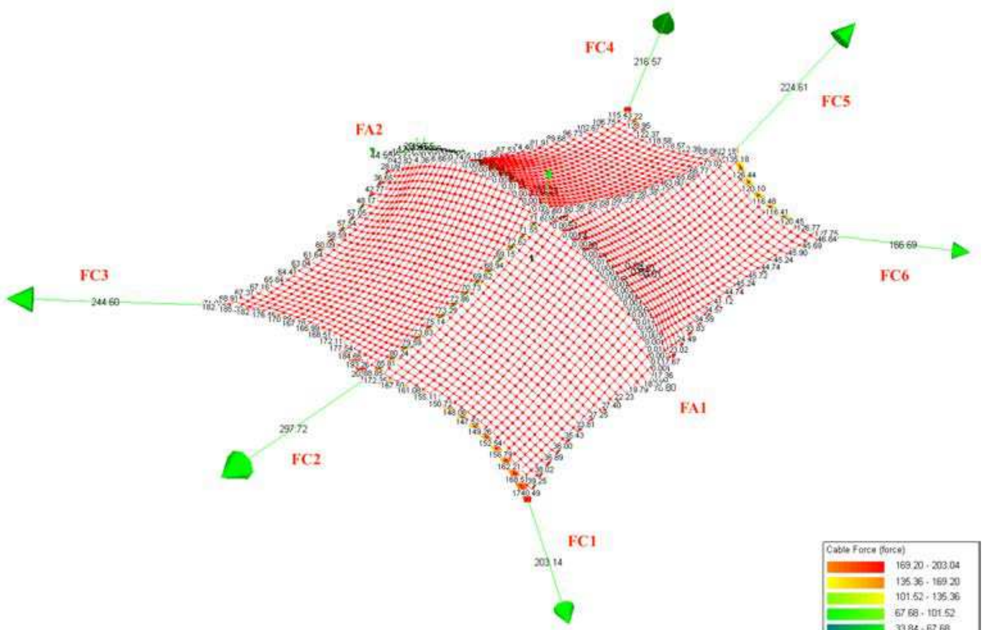


Figure 99: Resultant Force, CS Max

Prestress load case, Velocity wind pressure 0.83 kN

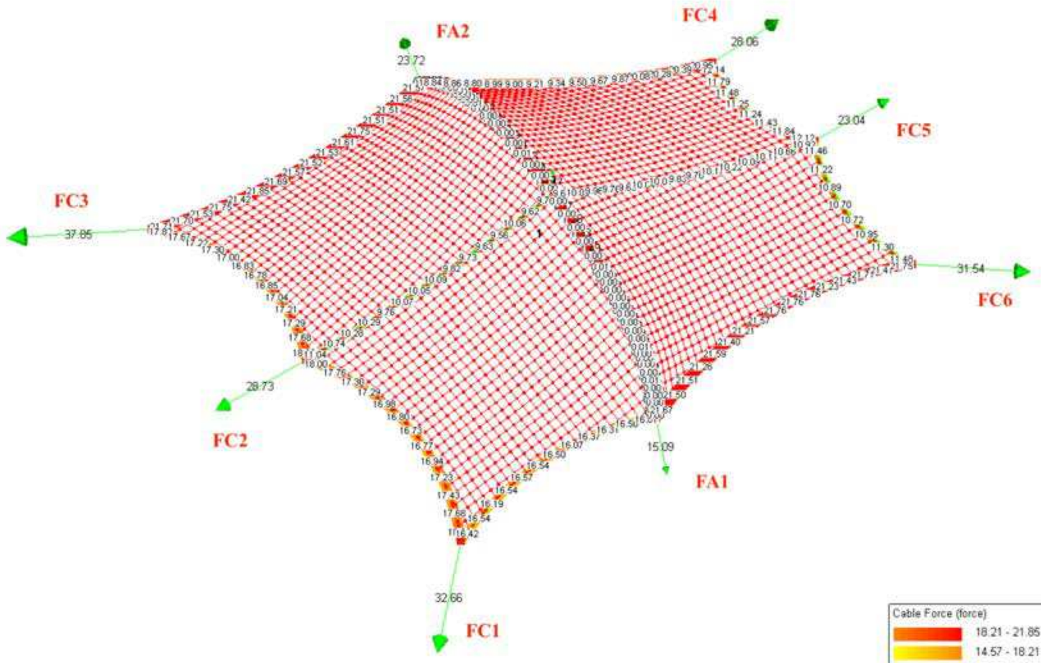


Figure 100: Prestress load case

Force Vectors at corners, under prestress and wind load cases, CS Max, CS Min			
Corners location	Prestress	CS Max	CS Min
FA1	15.09	16.80	241.78
FA2	23.72	44.50	308.68
FC1	32.66	203.14	249.15
FC2	28.73	297.72	139.92
FC3	37.85	244.60	359.10
FC4	28.06	216.57	163.80
FC5	23.04	224.61	
FC6	31.54	166.69	291.94

Values in this table are in kN

Figure 101: Force Vectors at corners

6.2.12 Down Load at Corners

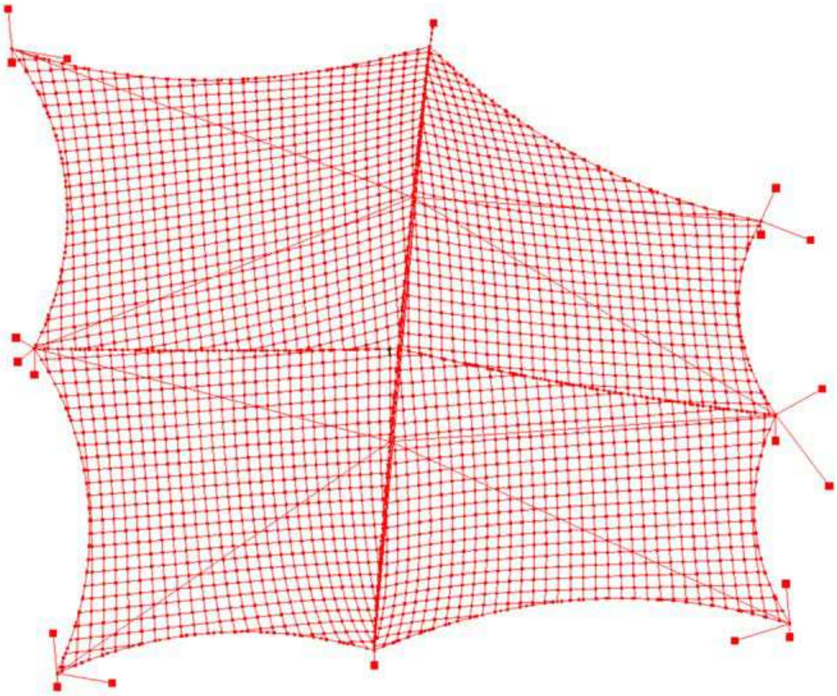


Figure 102: Down Load at Corners

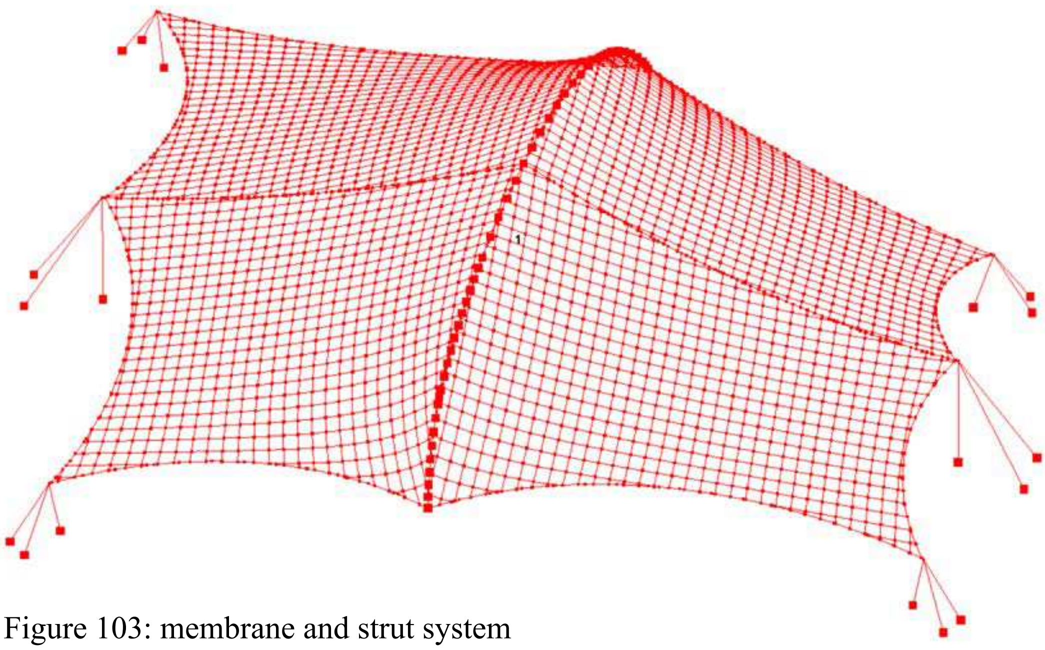


Figure 103: membrane and strut system

Down Load at Corners

Forces in Strut elements (Posts & Guying Cables)

Corner FC1 / wind load: CS Max (left), CS Min (right)

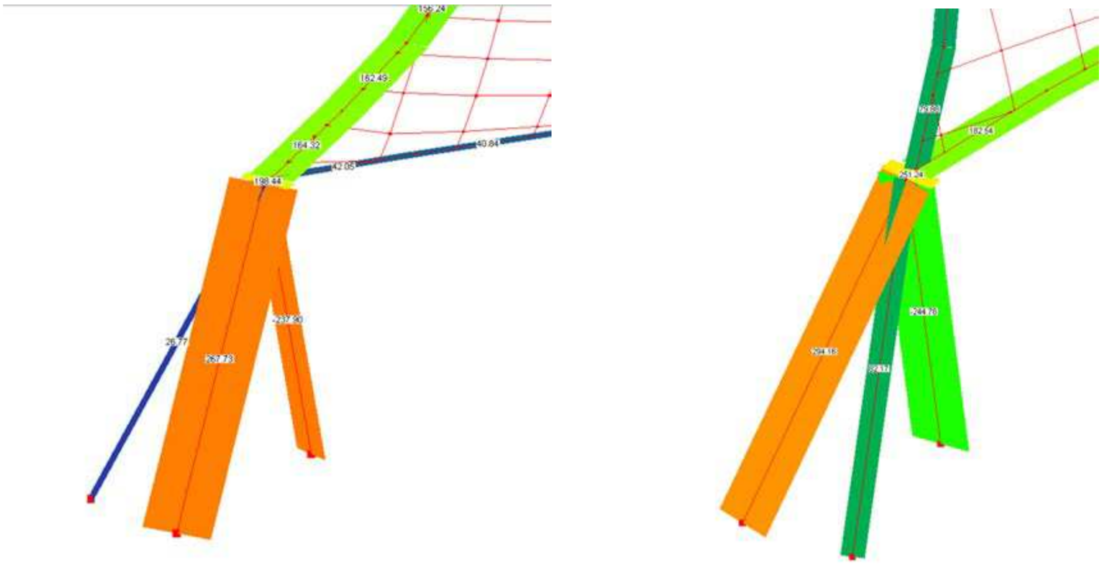


Figure 104: Forces in strut system at FC1

Corner FC2 / wind load: CS Max (left), CS Min (right)

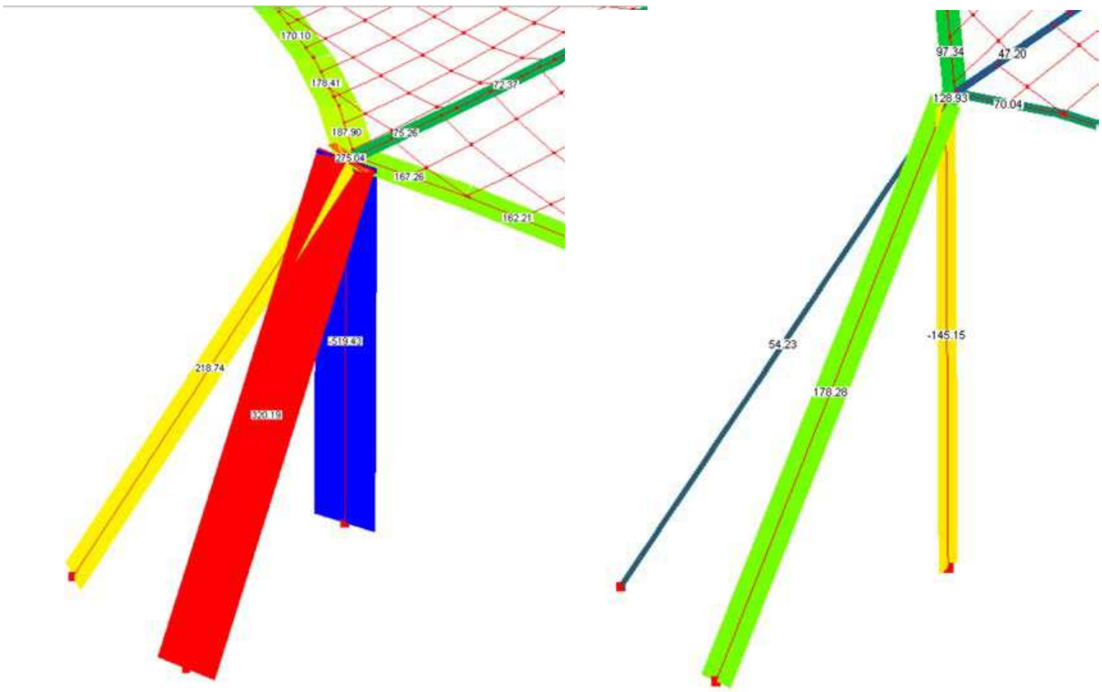


Figure 105: Forces in strut system at FC2

Corner FC 3 / wind load: CS Max (left), CS Min (right)

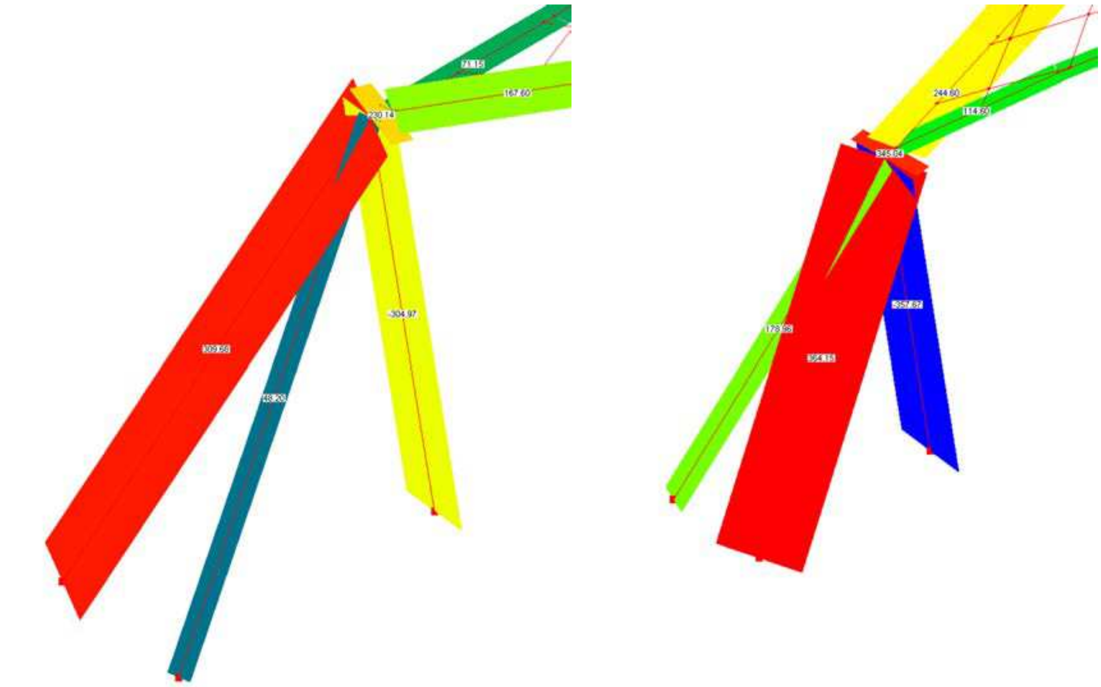


Figure 106: Forces in strut system at FC3

Corner FC4 / wind load: CS Max (left), CS Min (right)

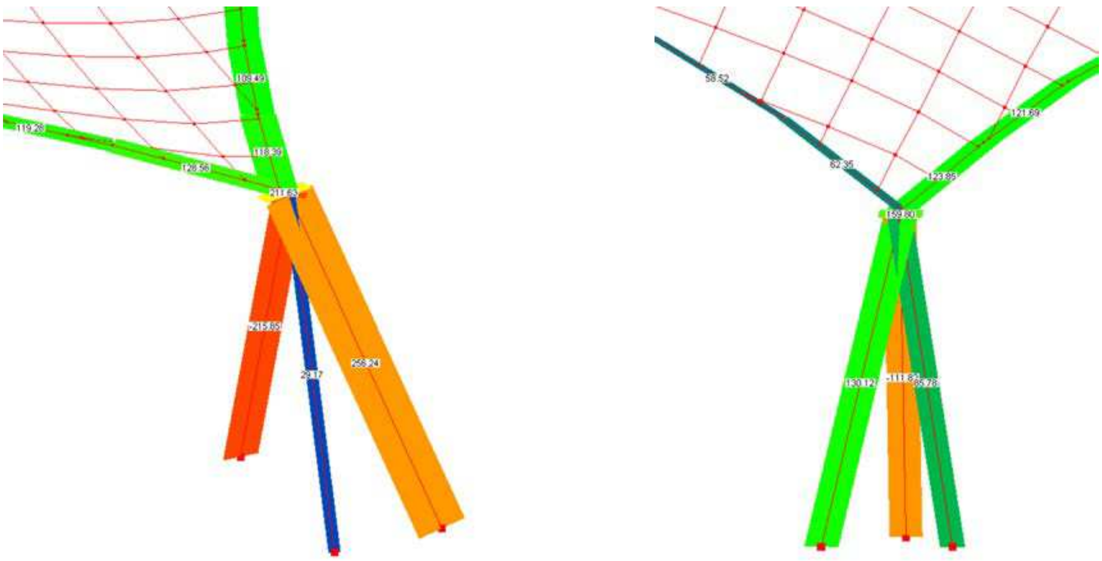


Figure 107: forces in strut system at FC4

Corner FC5 / wind load: CS Max (left), CS Min (right)

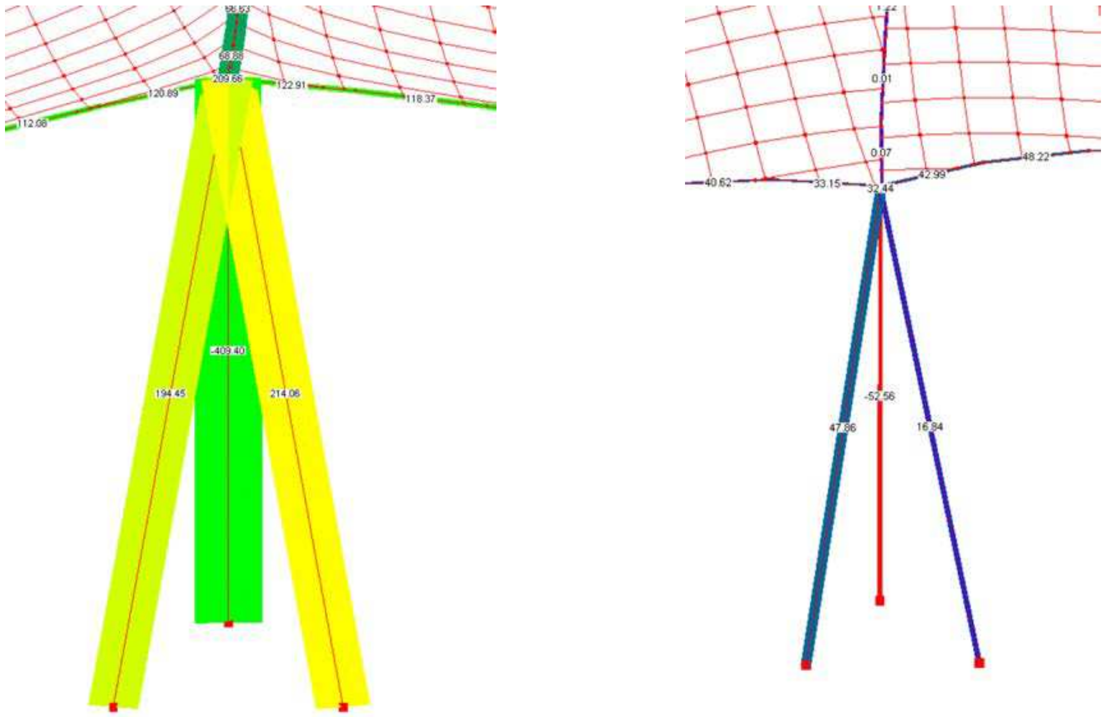


Figure 108: Forces in strut system at FC5

Corner FC6 / wind load: CS Max (left), CS Min (right)

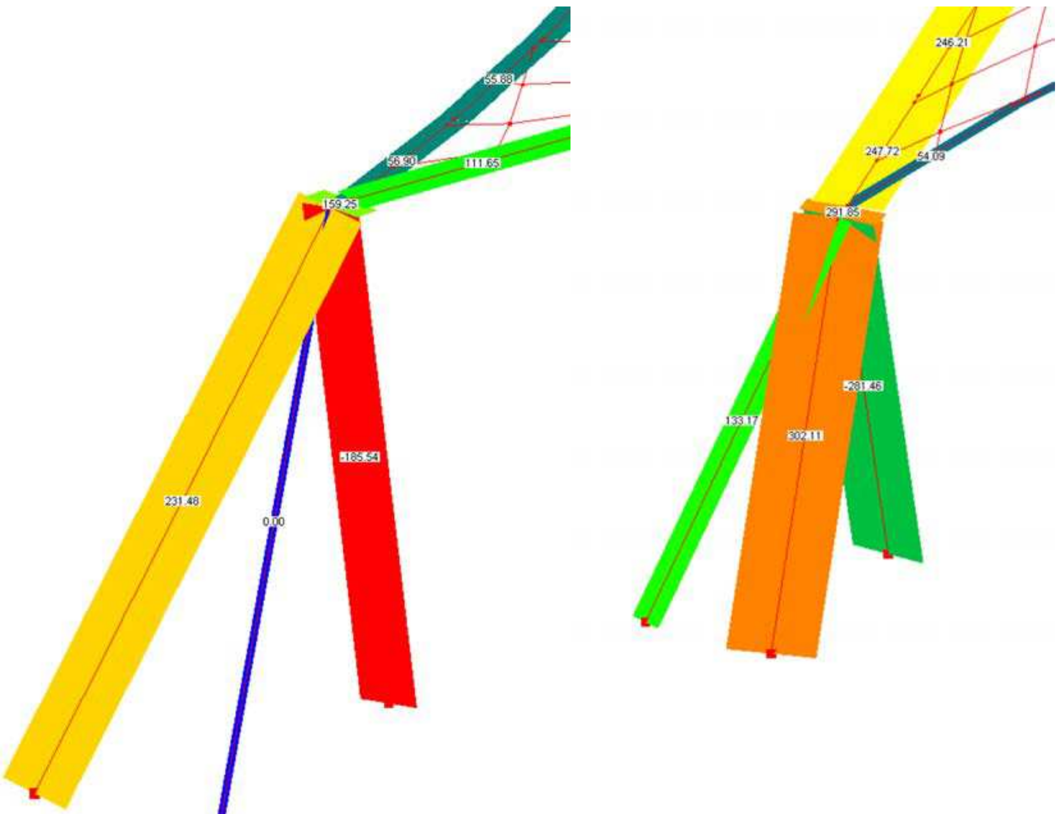


Figure 109: Forces in strut system at FC6

6.2.13 Summary of Forces Values in Posts and Guying Cables at the 6 Membrane Corners

Force values in corner posts and guying cables. Values in kN.			
Location	POST	Tension Rod system Element 1	Tension Rod System Element 2
FC1, CS Max	**-297,90**	26,77	**267,73**
FC1, CS Min	-244,76	**294,16**	82,17
FC2, CS Max	**-519,43**	**218,74**	**320,19**
FC2, CS Min	-145,15	54,23	178,28
FC3, CS Max	-304,97	**309,68**	48,20
FC3, CS Min	**-357,67**	178,96	**364,15**
FC4, CS Max	**-215,85**	29,17	**256,24**
FC4, CS Min	-111,82	**130,12**	85,78
FC5, CS Max	**-409,40**	**194,45**	**214,06**
FC5, CS Min	-52,56	47,86	16,84
FC6, CS Max	-185,54	**231,48**	0,00
FC6, CS Min	**-281,46**	133,17	**302,11**

Figure 110: Forces values in post and guying cables chart

Values calculated with Easy Statical analysis module

The higher values for each elements (post and guying cables) are marked in red color. Such maximum values will be the taken in consideration for maximum forces reference at the moment of material choice.

At corner FC2, the download force value is important. An other alternative is to connect the corner directly to the façade concrete reinforced structure with possibly some inner additional armature in building concrete structure. Following graphical force estimation give a lower value for 2 horizontal brackets.

6.2.14 Down Load at Corners / Option 2: Columns & Compression tubes

Forces in Strut elements (Posts & Compression Tubes)

Corner FC1 / wind load: CS Max (left), CS Min (right)
At Position: FC1, FC2, FC3, FC6, possibility to use compressive elements instead of going cables.

Force values in corner posts and guying cables. Values in kN.			
Location	POST	Tensions-Compression ELEMENT 1	Tension-Compression ELEMENT 2
FC1, CS Max	282,00	166	**232**
FC1, CS Min	**322**	**293**	207
FC2, CS Max	**-62**	**188**	**169**
FC2, CS Min	56	108	43
FC3, CS Max	341	203	**279**
FC3, CS Min	**477**	**392**	277
FC6, CS Max	231	140	**187**
FC6, CS Min	**368**	**354**	167

Calculation done by vectors graphical method
Angle force vectors are taken from Easy statical analysis module
Down load forces are calculated by graphic method.

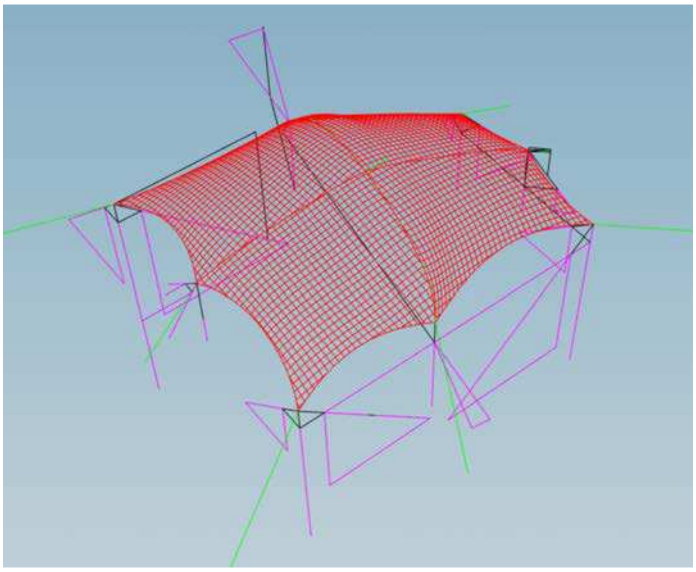


Figure 111:
Forces calculated
by graphical method

6.3 Material Dimensioning

6.3.1. Membrane dimensioning and selection

Remarks:

The maximum stress membrane values of 23.07 and 30.45 kN are located at 2 angles FA2 and CF5 where the membrane will be doubled.

All other values are within minimum and maximum values 12.15 to 21.02 kN./m2

The Maximum value to be considered is: 21.01 kN, and after applying a safety factor of 5, the necessary membrane Tensile Strength to be selected is 21 x 5 = 105 kN/m or 525 daN/5cm (5 cm strip as usually given in material data sheet).

Membrane selection

Serge Ferrari catalogue, the specialist manufacturer for Precontraint POLYESTER/PVC membrane, specifies:
the membrane range type III, features a warp and weft Tensile Strength of 560 daN/m, which would fulfill our requirements
This is the case for models:

- Flexlight Advanced 1202 S2 (see following data)
- Flexlight Xtrem TX 30 Type III (see following data)

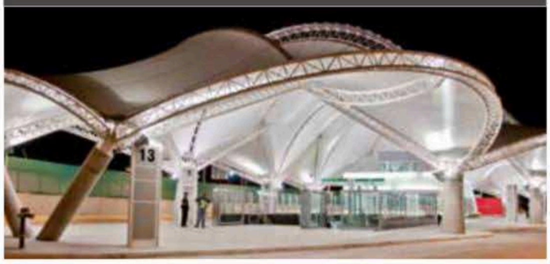
SERGE FERRARI data: Flexlight advanced

Tensile architecture

Serge Ferrari | **Flexlight** Advanced

Main applications

Covered outdoor
Sports hall roofs
Shading structures



Longevity & Easy cleaning

Long lasting, consistent color per translucency and easy maintenance

Major advantages

- Long lasting & maintenance
- Improved aesthetic thanks to controled color per translucency (VISU)
- High dimensional stability due to Precontraint® technology
- Recyclable via Texyloop process

Technical specifications

	Flexlight Advanced 902 S2	Advanced 1002 S2	Advanced 1202 S2	Advanced 1302 S2	Advanced 1502 S2
Base fabric	Anticapilarity low wick yarn treatment				
Weight - EN ISO 2286-2	950 g/m²	1050 g/m²	1050 g/m²	1350 g/m²	1500 g/m²
Standard format length	220 lm	175 lm	175 lm	150 lm	200 lm
Tensile strength (warp/weft) EN ISO 1421 ASTM D 751-00 Cut Strip	420/400 daN/5 cm	420/400 daN/5 cm	560/560 daN/5 cm	800/700 daN/5 cm	1000/800 daN/5 cm
Tear strength (warp/weft) DIN 53.363 ASTM D 751-00 Trapezoid	55/50 daN	55/50 daN	80/65 daN	120/110 daN	160/140 daN
Flame retardancy	**B-s2, d0**	**B-s2, d0**	**C-s2, d0**	**C-s2, d0**	**C-s2, d0**
Warranty*	15 years	15 years	15 years	15 years	15 years
MOQ**	1500 lm for 180 cm width - 3500 lm for 267 cm width				
Maximum delivery time	In stock (excepted 1502 S2 with delivery time of 4 working weeks)				
Provided services	Control of consistent color per translucency (VISU service) Special production & colours - Short productions runs Possibility to order rolls 50 lm - Promissed delivery garanted up to 2000 lm				

* Please refer to the text of our warranty. The warranty is valid only after confirmation on a case-by-case basis of warranty application. The warranty will not apply to mobile structures. The buyer of our products is fully responsible for their application or their transformation concerning any possible third party. The buyer of our products is responsible for their implementation and installation according to the standards, use and customs and safety rules of the countries where they are used.

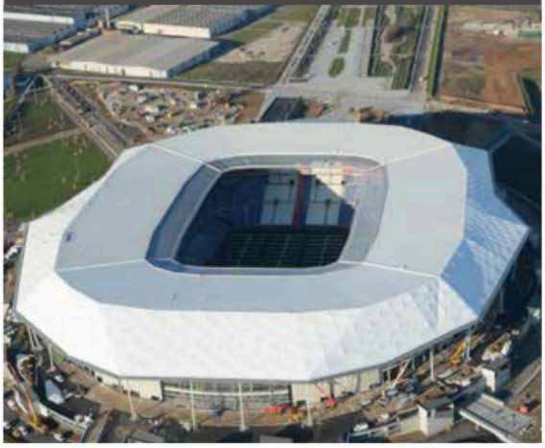
** this MOQ is for category C products (Custom made)

Precontraint® Technology

SERGE FERRARI data: Flexlight Xtrem TX 30 Type III

Serge Ferrari | **Flexlight** Xtrem TX30

Main applications
High-end and large roofs
Stadium roofs
Sport hall covers



Superior Service Life and Aesthetics

Long term service life and durable aesthetics for demanding translucent roofs

Major advantages

- Proven design life >30 years
- Durably clean & easy maintenance
- High translucency & consistent colour (VISU)
- High dimensional stability due to Precontraint® technology

Other applications

- Shading structures
- Awning & walkway covers

Technical specifications

	Flexlight			
	Xtrem TX30-II	**Xtrem TX30-III**	**Xtrem TX30-IV**	**Xtrem TX30-V**
Base fabric	Anticapilarity low wick yarn treatment			
Weight - EN ISO 2286-2	1050 g/m²	1050 g/m²	1350 g/m²	1500 g/m²
Standard format length	250 lm	250 lm	250 lm	200 lm
Tensile strength (warp/weft) EN ISO 1421	430/430 daN/5 cm	560/560 daN/5 cm	800/700 daN/5 cm	1000/800 daN/5 cm
Tear strength (warp/weft) DIN 53.363	55/50 daN	80/65 daN	120/110 daN	160/140 daN
Flame retardancy	**B-s2, d0**	**C-s2, d0**	**C-s2, d0**	**C-s2, d0**
Warranty*	20 years	20 years	20 years	20 years
MOQ**	2500 lm			
Maximum delivery time	4 working weeks			
Provided services	Special colours (limited) Promised delivery guaranteed up to 2 000 lm			

HANDLING & FABRICATION PRECAUTIONS:
TX30 shall be abraded before welding. Please refer to the TX30 handling and fabrication recommandations.

6.3.2. Edge cable choice according to maximum service load.

Service load = design load x safety factor.
Safety factor of 1.5

Cable position	Design Load	Safety factor	Service load	Cable type
Edge cable 1	243	1,5	364,5	spiral strand, stainless steel, limit tension 350kN, ∅ 28,6
Edge cable 2	172	1,5	258	spiral strand, stainless steel, limit tension 248kN, ∅ 24,1
Edge cable 3	203	1,5	304,5	spiral strand, stainless steel, limit tension 350kN, ∅ 28,6
Edge cable 4	282	1,5	423	spiral strand, stainless steel, limit tension 442kN, ∅ 32,1
Edge cable 5	235	1,5	352,5	spiral strand, stainless steel, limit tension 350kN, ∅ 28,6
Edge cable 6	138	1,5	207	spiral strand, stainless steel, limit tension 248kN, ∅ 24,1
Edge cable 7	127	1,5	190,5	spiral strand, stainless steel, limit tension 350kN, ∅ 28,6
Edge cable 8	307	1,5	460,5	spiral strand, stainless steel, limit tension 248kN, ∅ 24,1
Tension cable, Middle area 1	88	1,5	132	spiral strand, stainless steel, limit tension 160kN, ∅ 16,6
Tensin cable, middle area 2	75	1,5	112,5	spiral strand, stainless steel, limit tension 160kN, ∅ 16,6

Figure 112: Edge cable choice chart

Cable in above table are from Pfeiffer company
Characteristics:
DIN EN 12385 - Stainless Steel
Limit tension in kN (breaking load are much more higher in value)

Alternative with other supplier / JAKOB:
Cable Strand / breaking load 544 kN, ∅ 26 mm
Cable Strand / breaking load 211 kN, ∅ 16 mm

According to budget possibility the choice can be made from very safe alternative with Pfeiffer and tension limit value or breaking load value as a guide.

6.3.3. Structural Cable and Masts Dimensioning at Corners

Base on previous force calculation from Statical Analysis Easy module and graphic method.

MASTS

According to the STRUT system; 1 post working in compression and 2 cables working in tension (true for corners; FC1, FC3, FC4, FC5, FC6).

According to previous wind load case studies all in accordance with Eurocode and a dynamic velocity pressure of 0.83 kN/m2, the maximum Force in posts is 477 kN located at corner n° 3 of the project.

Easy Beam and Rstab calculate the section of the post: ∅ 193 and 219 mm for a tube wall thickness 6.3 mm.

An Excel Buckling calculation program give:
Post ∅ 193,7 x 4 mm, with a safety factor of 1,13 and working rate of 0,83
Post ∅ 219 x 6,3 mm, with a safety factor of 2,01 and a working rate of 0,50

A steel tube of ∅ 210 x 6,3 mm is therefore chosen for the whole 6 posts of the project.

TENSION ROD SYSTEM


Figure 113: Tension Rod

To keep structural integrity in case of no membrane on the project, the tension members will be rigid elements.

The tension elements are, Pfeiffer;
Tension Rod type 860 + Fork Connectors Type 860

Maximum load in tension is at corner n°3: 364 kN

If safety factor is 1.5, the maximum Force load in Tension is: 546 kN

Pfeiffer Rod type 860 will be M 42 for F 504,2 kN or M 48 for F 658,6 kN

Except one position at angle C3, other tension values are all under 320 kN (with safety factor 1.5 = 480 kN), then we chose Tension Rod M 42.

Buckling calculation

Mast tube section 196,7 x 4 mm
Mast tube section 219 x 6,3 mm

Buckling Calculation table, (table from Nicolas Pauli / ABACA)

14-févr-19

Dimensionnement au flambement
de profils Rond
selon le règlement "Construction métalliques CM66"

Commentaires	

Données

Profil rond		
Diamètre	**196,7**	mm
Epaisseur	**4**	mm
Type de profil	**ROND**	
Effort de compression	47700	daN
Longueur de flambement	**2**	m
Moment de flexion associé	3082	daN.m
Matériau	**ACIER**	
Module d'élasticité	21000	daN/mm²
Limite élastique σ_{el}	23,5	daN/mm²

< >

Poids	18,89 daN/ml

Remplir la case par **ALU** ou **ACIER**
Pour mémoire
Alu 6060 : E=6950 et sigma=18 (19) daN/mm²
Alu 6061 : E=6950 et sigma=25 daN/mm²

Résultats

CALCUL OK

Caractéristiques profil rond		
Section matière	24,215	cm2
Moment d'inertie	1124,481	cm4
Module de flexion	114,335	cm3
Rayon de giration	6,814	cm

Résultats intermédiaires		
Elancement Lambda	29,35	
Contrainte critique d'Euler	240,61	daN/mm²
Eloignement de l'état critique μ	12,21	Tjrs > 1.3
Coefficient k1	1,03	
Coefficient k	1,03	

Vérification normale	**Profil**	**ROND**
Contrainte critique	**22,76**	daN/mm²
Contrainte réelle	**19,70**	daN/mm²
Sécurité	**1,16**	> 1
Taux de travail	0,87	< 1

Vérification flexion composée		
Contrainte normale	**19,70**	daN/mm²
Contrainte flexion	**26,96**	daN/mm²
Coefficient k1	1,03	
Coefficient kf	1,12	
Contrainte réelle amplifiée	**50,48**	< σ_{el}
Sécurité	**0,47**	> 1
Taux de travail	2,15	< 1

14-févr-19

Dimensionnement au flambement
de profils Rond
selon le règlement "Construction métalliques CM66"

Commentaires	

Données

Profil rond		
Diamètre	**219**	mm
Epaisseur	**6,3**	mm
Type de profil	**ROND**	
Effort de compression	47700	daN
Longueur de flambement	**2**	m
Moment de flexion associé	3082	daN.m
Matériau	**ACIER**	
Module d'élasticité	21000	daN/mm²
Limite élastique σ_{el}	23,5	daN/mm²

< >

Poids	32,84 daN/ml

Remplir la case par **ALU** ou **ACIER**
Pour mémoire
Alu 6060 : E=6950 et sigma=18 (19) daN/mm²
Alu 6061 : E=6950 et sigma=25 daN/mm²

Résultats

CALCUL OK

Caractéristiques profil rond		
Section matière	42,098	cm2
Moment d'inertie	2382,779	cm4
Module de flexion	217,605	cm3
Rayon de giration	7,523	cm

Résultats intermédiaires		
Elancement Lambda	26,58	
Contrainte critique d'Euler	293,28	daN/mm²
Eloignement de l'état critique μ	25,88	Tjrs > 1.3
Coefficient k1	1,01	
Coefficient k	1,03	

Vérification normale	**Profil**	**ROND**
Contrainte critique	**22,90**	daN/mm²
Contrainte réelle	**11,33**	daN/mm²
Sécurité	**2,02**	> 1
Taux de travail	0,49	< 1

Vérification flexion composée		
Contrainte normale	**11,33**	daN/mm²
Contrainte flexion	**14,16**	daN/mm²
Coefficient k1	1,01	
Coefficient kf	1,05	
Contrainte réelle amplifiée	**26,40**	< σ_{el}
Sécurité	**0,89**	> 1
Taux de travail	1,12	< 1

6.3.4. Masts Design at Corners

Mast design at corners; FC2, FC5

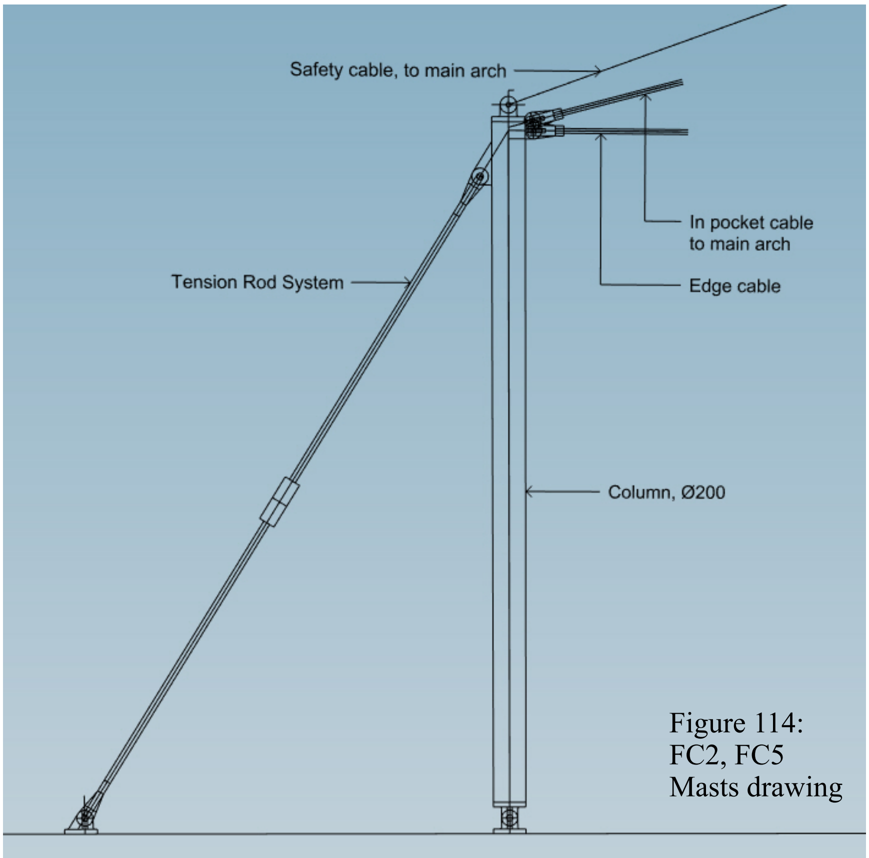


Figure 114:
FC2, FC5
Masts drawing

Mast design at corners; FC1, FC3, FC4, FC6

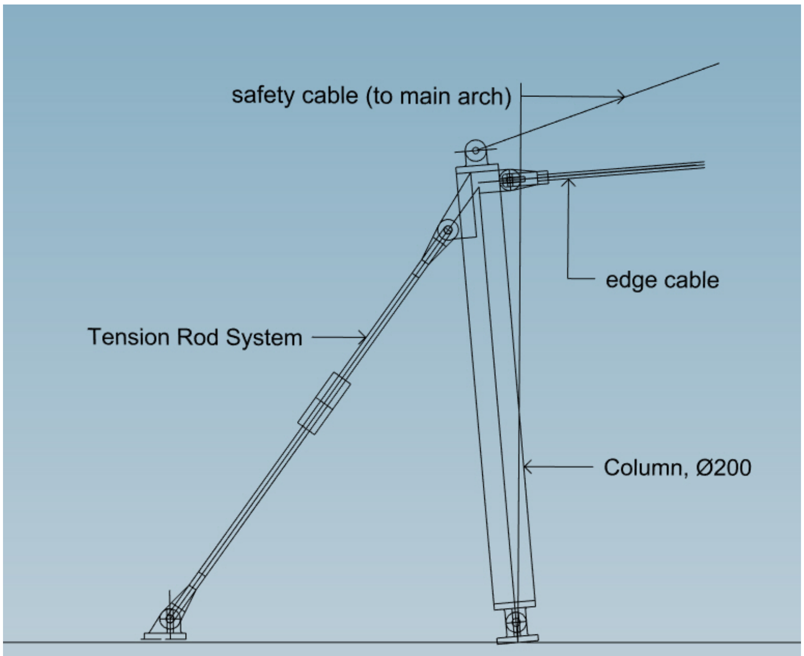


Figure 115: FC1, FC3, FC4, FC6, Masts drawing

6.3.5. Structural dimensioning for the masts and central arch using programs EasyBeam module and RSTAB.

EASY BEAM is in charge of force calculation
RSTAB give detailed steel members dimensioning

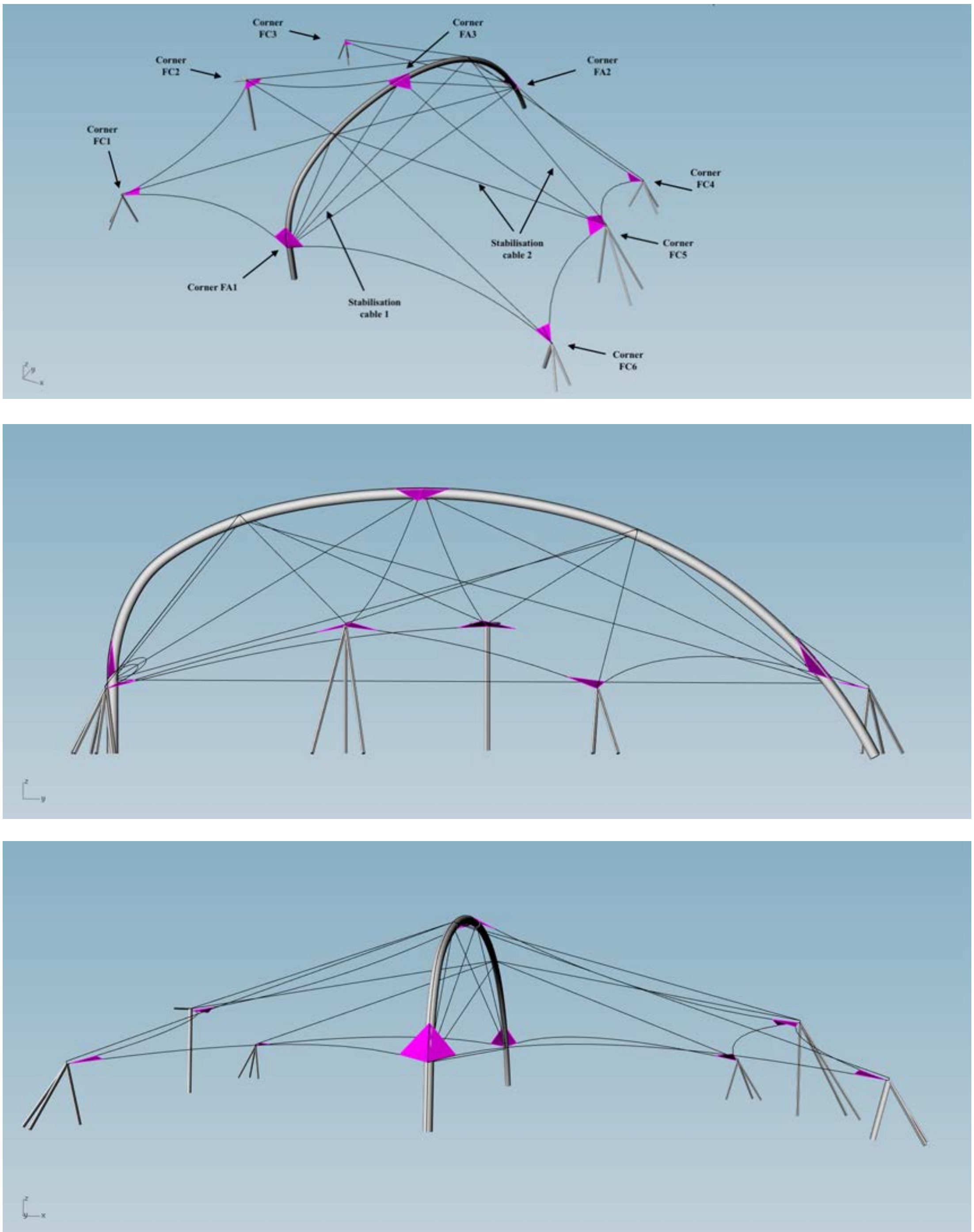


Figure 116: Steel structure, 3D drawings

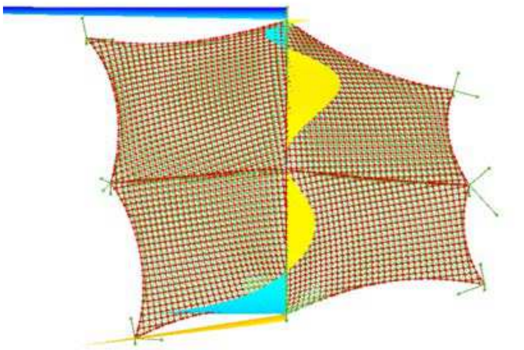
Dimensioning of the Steel Members using Computer Programs: BEAM module in EASY and RSTAB

BEAM module in EASY:
The design, including; membrane in tension, wind load cases and structural tension elements (cables), tension and compression elements (steel members), is transferred in Beam module for future analysis.

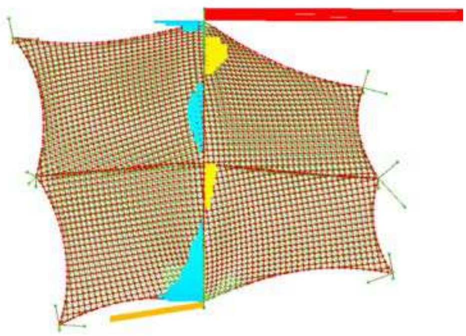
Steel cable and other tension and compression elements are designed in RSTAB, then transferred in BEAM. Beam then proceed with calculation and re-send all values in RSTAB for steel structure dimensioning.

Visualisation of the CENTRAL ARCH SOLICITATION in EASY program

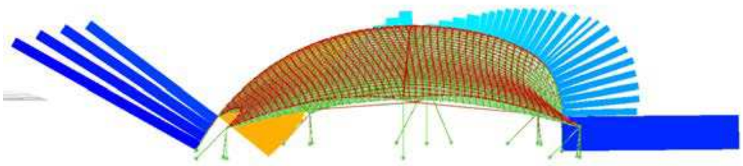
Visualisation of Bend moment, Shear Force, Torsional moment along the arch.



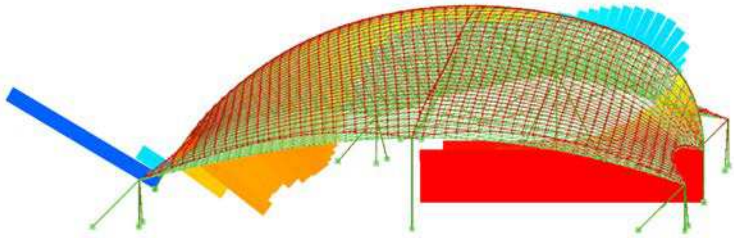
Bend Moment around W



Shear Force in V



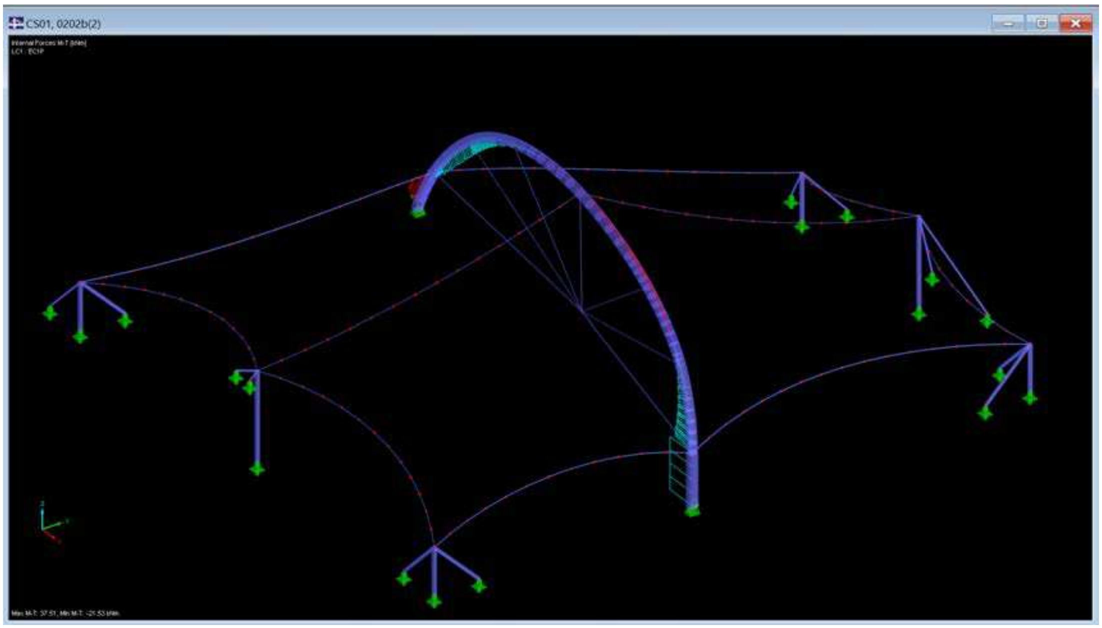
Shear Force in W



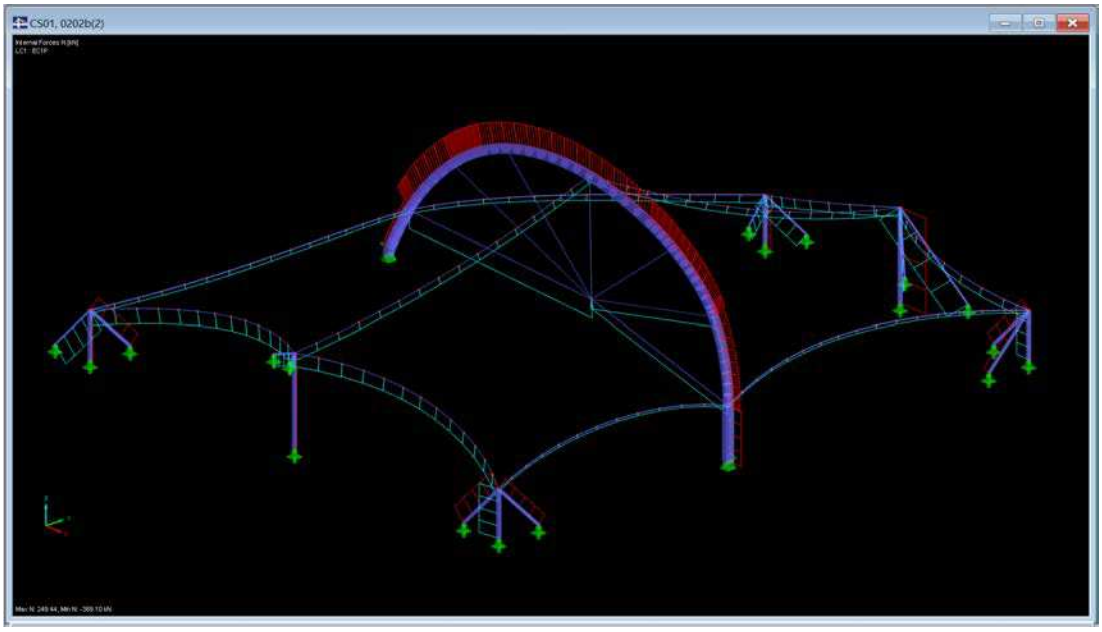
Bend Moment around W

Figure 117: Central Arch solicitation

OPTION 1
Visualisation of forces on the steel structure (RSTAB program):



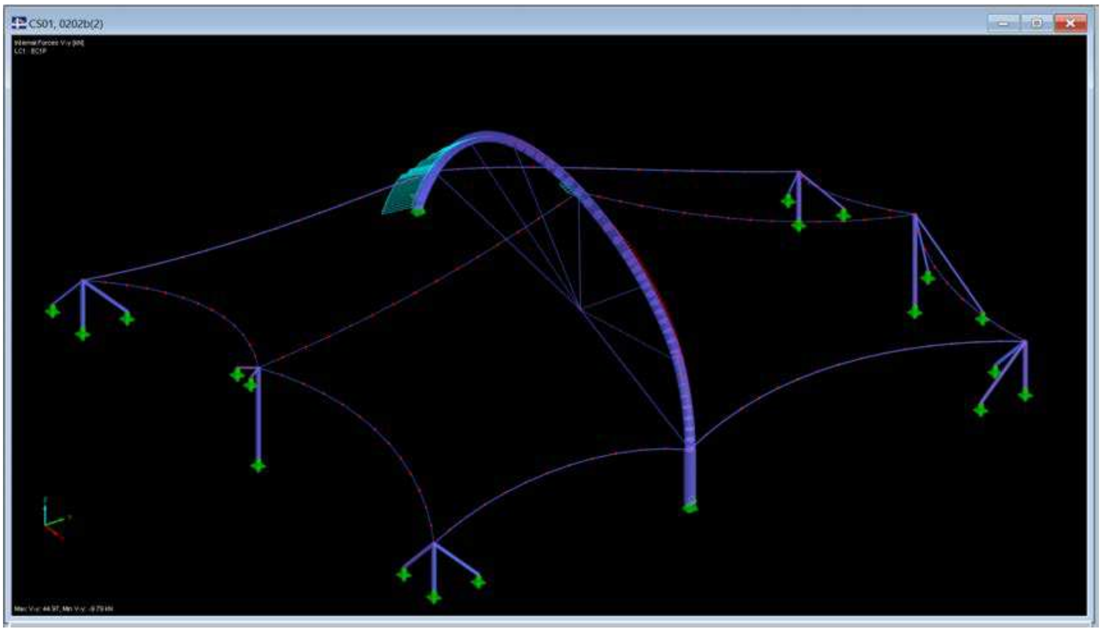
Internal Force M



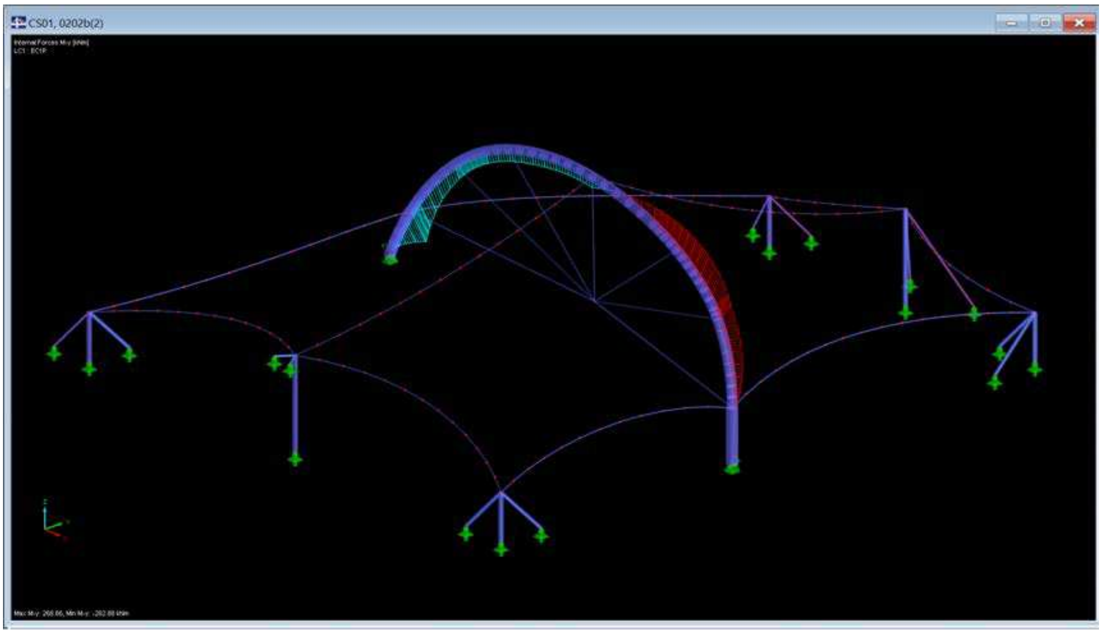
Internal Force N

Figure 118: Central Arch solicitation, Internal Force, M, N, 2 screen copies, RSTAB

Internal Force V and Force M (RSTAB):



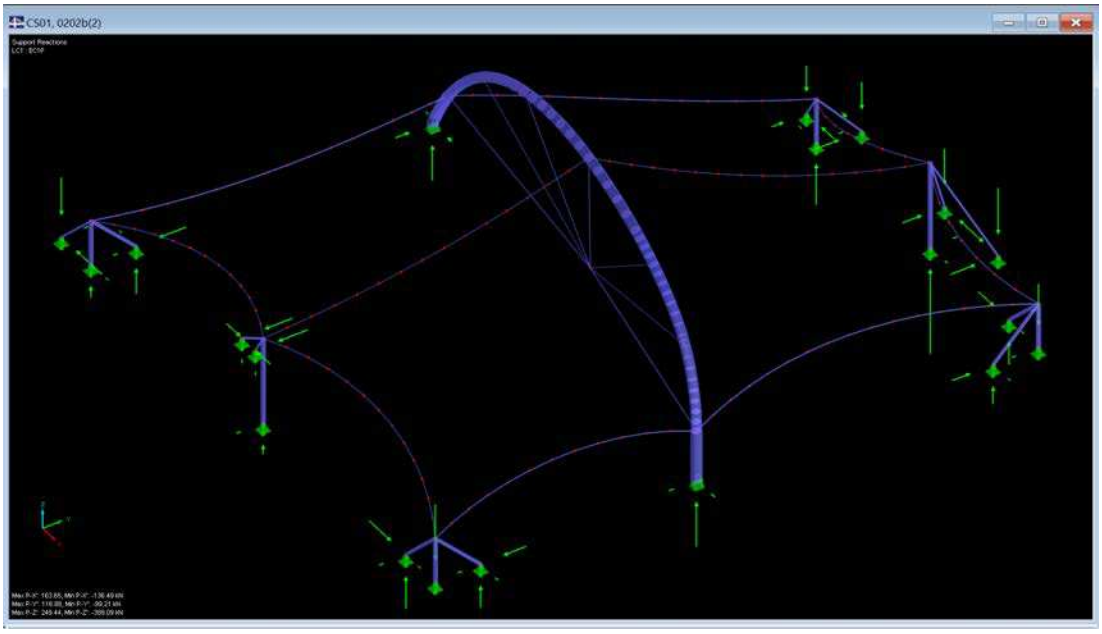
Internal Force V



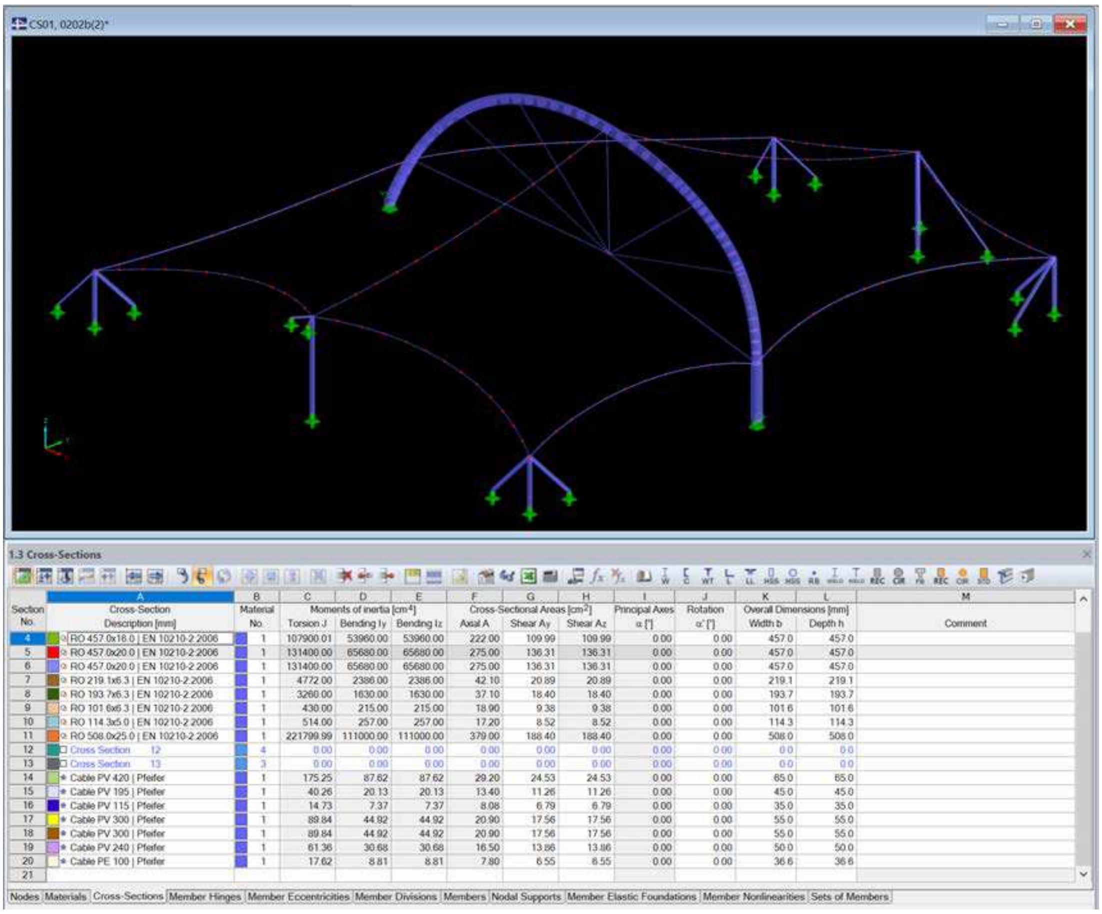
Internal Force M

Figure 119: Central Arch solicitation, Internal Force V, M, 2 screen copies, RSTAB

Support reaction and final calculation:



Support reaction



Section No.	A Cross-Section Description [mm]	B Material No.	C Moments of inertia [cm⁴] Torsion J	D Bending Iy	E Bending Iz	F Cross-Sectional Areas [cm²] Axial A	G Shear Ay	H Shear Az	I Principal Axes α [°]	J Rotation α' [°]	K Overall Dimensions [mm] Width b	L Depth h	M Comment
4	RO 457.0x16.0 | EN 10210-2:2006	1	107900.01	53960.00	53960.00	222.00	109.99	109.99	0.00	0.00	457.0	457.0	
5	RO 457.0x20.0 | EN 10210-2:2006	1	131400.00	65680.00	65680.00	275.00	136.31	136.31	0.00	0.00	457.0	457.0	
6	RO 457.0x20.0 | EN 10210-2:2006	1	131400.00	65680.00	65680.00	275.00	136.31	136.31	0.00	0.00	457.0	457.0	
7	RO 219.1x6.3 | EN 10210-2:2006	1	4772.00	2386.00	2386.00	42.10	20.89	20.89	0.00	0.00	219.1	219.1	
8	RO 193.7x6.3 | EN 10210-2:2006	1	3260.00	1630.00	1630.00	37.10	18.40	18.40	0.00	0.00	193.7	193.7	
9	RO 101.6x6.3 | EN 10210-2:2006	1	430.00	215.00	215.00	18.90	9.38	9.38	0.00	0.00	101.6	101.6	
10	RO 114.3x5.0 | EN 10210-2:2006	1	514.00	257.00	257.00	17.20	8.52	8.52	0.00	0.00	114.3	114.3	
11	RO 508.0x25.0 | EN 10210-2:2006	1	221799.99	111000.00	111000.00	379.00	188.40	188.40	0.00	0.00	508.0	508.0	
12	Cross Section 12	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	
13	Cross Section 13	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	
14	Cable PV 420 | Pfeifer	1	175.25	87.62	87.62	29.20	24.53	24.53	0.00	0.00	65.0	65.0	
15	Cable PV 195 | Pfeifer	1	40.26	20.13	20.13	13.40	11.26	11.26	0.00	0.00	45.0	45.0	
16	Cable PV 115 | Pfeifer	1	14.73	7.37	7.37	8.08	6.79	6.79	0.00	0.00	35.0	35.0	
17	Cable PV 300 | Pfeifer	1	89.84	44.92	44.92	20.90	17.56	17.56	0.00	0.00	55.0	55.0	
18	Cable PV 300 | Pfeifer	1	89.84	44.92	44.92	20.90	17.56	17.56	0.00	0.00	55.0	55.0	
19	Cable PV 240 | Pfeifer	1	61.36	30.68	30.68	16.50	13.86	13.86	0.00	0.00	50.0	50.0	
20	Cable PE 100 | Pfeifer	1	17.62	8.81	8.81	7.80	6.55	6.55	0.00	0.00	36.6	36.6	
21													

After Final calculation, all structural elements are described
Steel quantity is calculated.
Torsion, moment, shear, bending are calculated.

Figure 120: Central Arch solicitation, Structure calculation, 2 screen copies, RSTAB

Cross Section description:

Central Arch: Tube Φ 457 x 16, 20, 25 mm, by segments
Posts: Tube Diam. 219 mm x 6.3 mm
Compressive steel tube at all corners, 1, 3, 6, Φ 193 mm x 6.3 mm
Tension steel tube elements at corners 3, 4, 5, Φ 114 x 5 mm

Steel quantity, T: 5.0

OPTION 2:

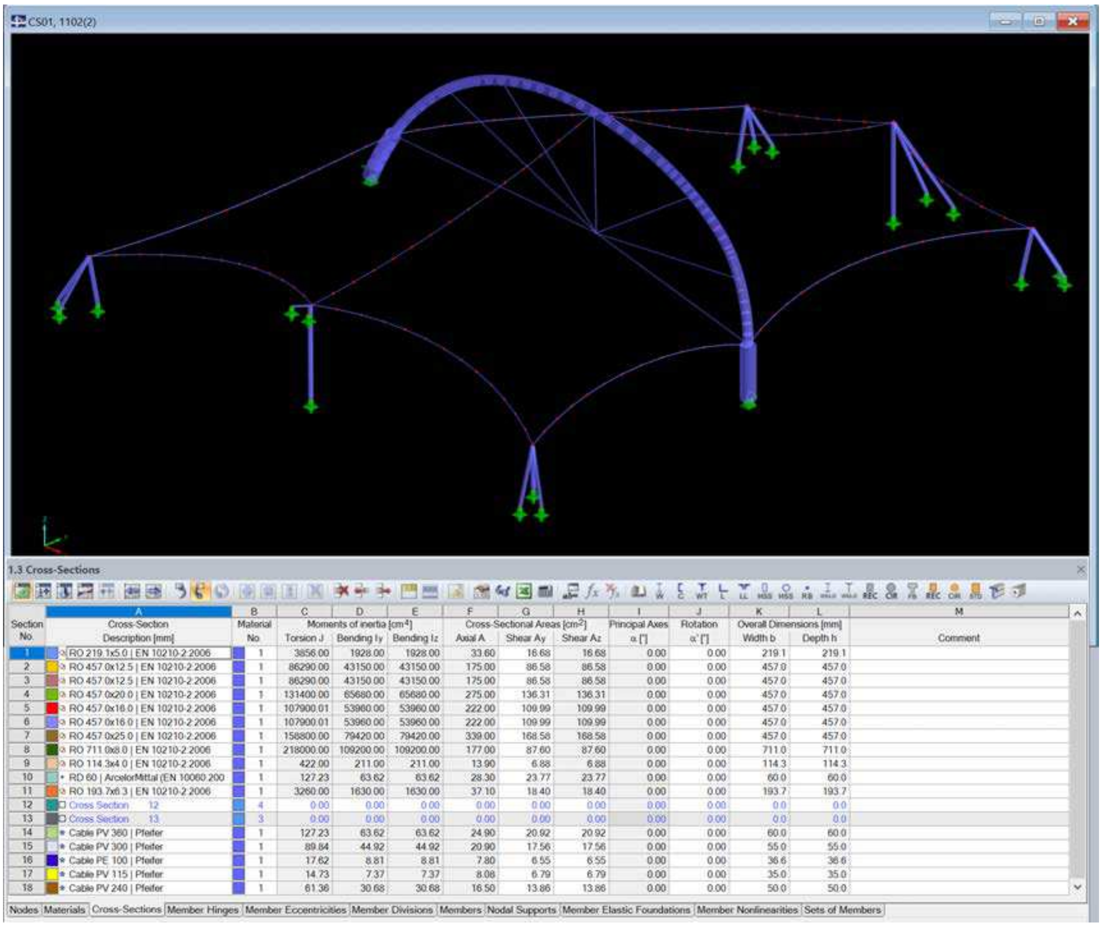


Figure 121: Steel Structure calculation, option 2, screen copies, RSTAB

Arch dimensioning is similar to option 1.: Φ 457 x 10, 16, 20, 25 mm
Columns (posts): Φ 193 x 6.3 mm
Guying tubes in tension: Φ 114 x 4 mm
Steel quantity, kg: 5’000

6.3.6 Central Arch Design and Dimensioning

As a rough estimation, the Old School rule of 1/50 can be use.

Projection steel member / 50 = first estimation of diameter.

In our case the projection is 25 m, and 25/50 = 0,50 m (tube diameter).

If Steel grade S 270, The Easy and Rstab calculation program give a diameter of 457 mm for a variable wall thickness from 6,3 to 20 mm along the different 6 meters tube segments.

If steel grade S 355, The Easy and Rstab calculation program give a diameter of 407 mm for a wall thickness from 6,3 to 20 mm along the different 6 meters tube segments.

This estimation give a steel quantity of 5 to 6 tons of steel for the project. This is enough for a budget estimation.

An other alternative will consist to install a 3D truss beam instead a single curved tube.

Final study, design and calculation, especially for the central arch will require a structural engineer expertise.

6.4 Cutting Pattern

6.4.1. Strip orientation

The strips are positioned perpendicular to the central arch. it is also the shortest distance following the geodesic line, longest line. The pattern is esthetically pleasant, with the strip orientation parallel to the main pool length.

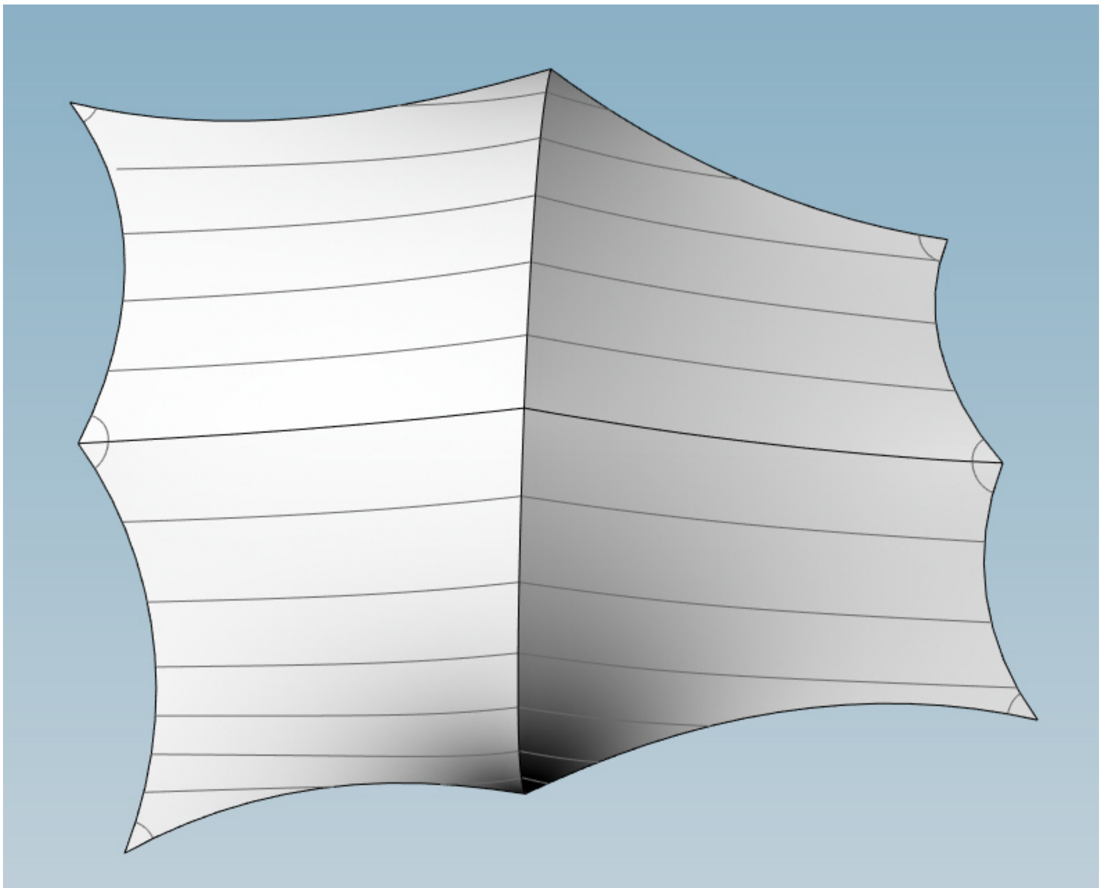


Figure 122: Membrane cutting pattern orientation

The membrane roof is made of 4 parts, then there are 4 cutting pattern groups. The Cutting Pattern module in Easy program is used to flatten each strip.

Chosen criteria:
Width of membrane strip on main area: 2.50 m
Width strip along arch edge: 1.30 m
Compensation: 0.4% in X and Y
Seam width: 50 mm

6.4.2. The three dimensional representation of the membrane with all strips areas

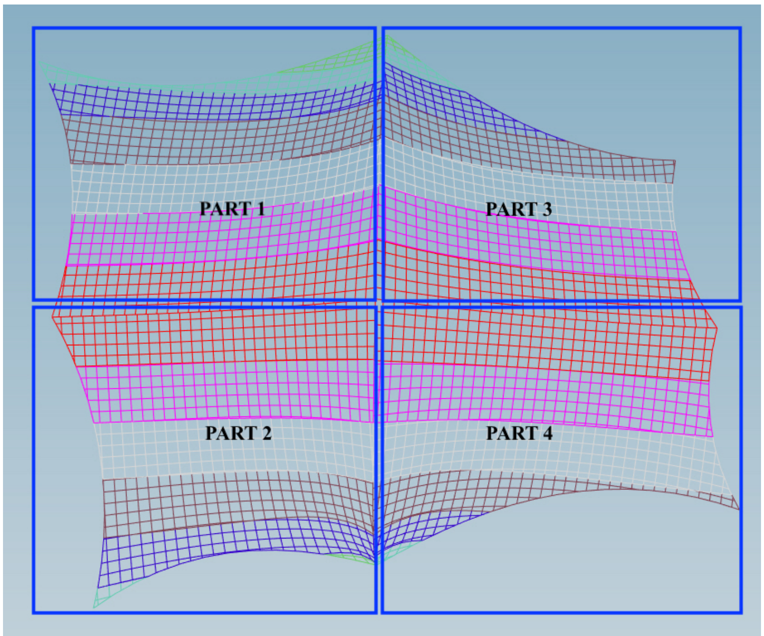


Figure 123: Membrane cutting pattern partition

6.4.3. All strip surface elements are flattened

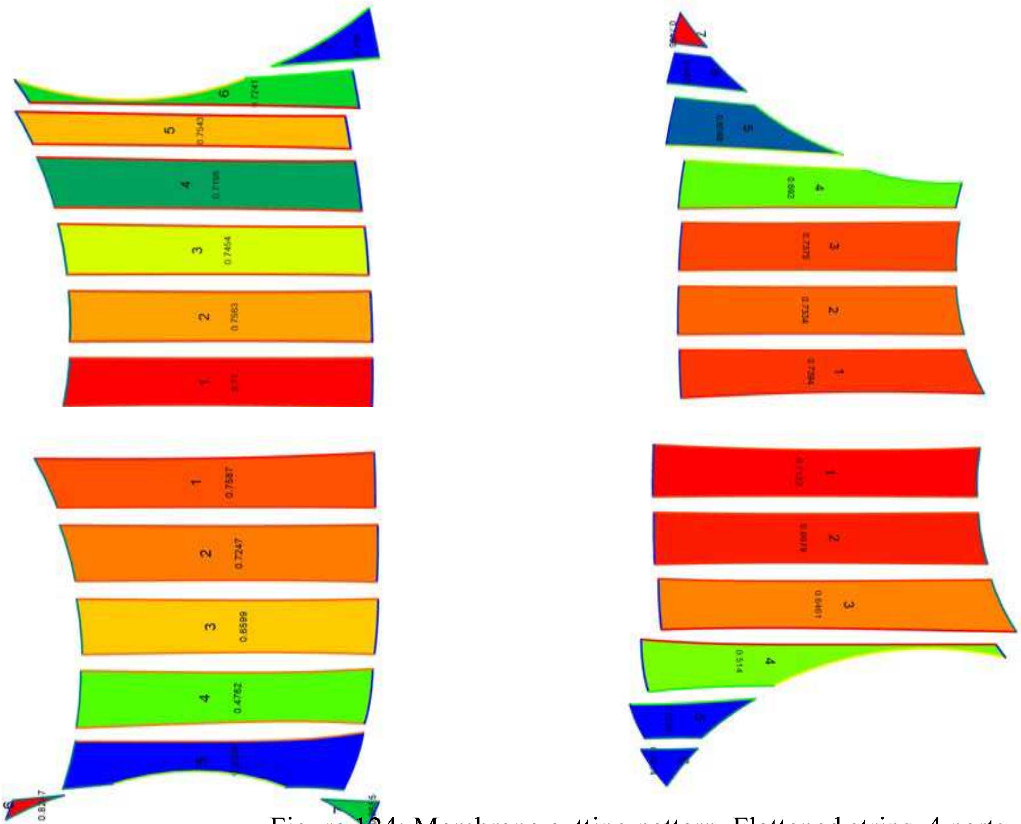
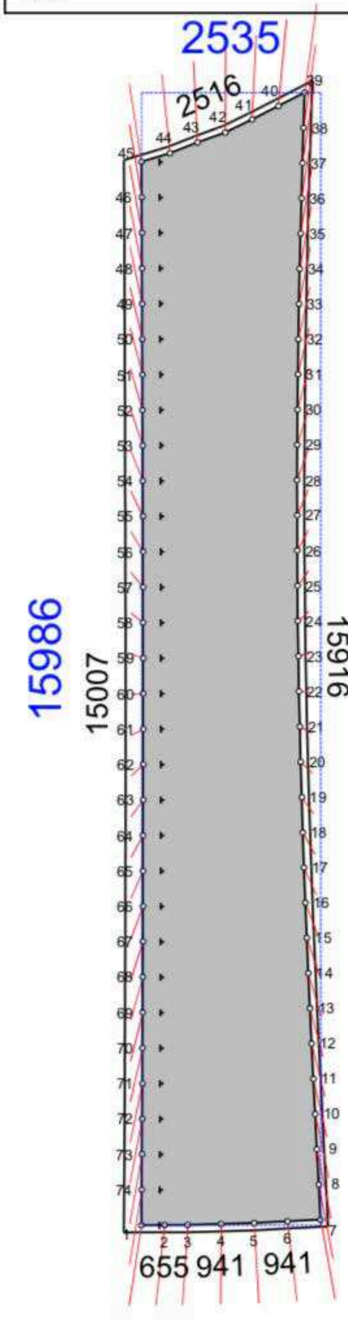


Figure 124: Membrane cutting pattern, Flattened strips, 4 parts

6.4.4. Exemple of final cutting pattern document

CUTTING PATTERN / STRIP N°1 / PART 3

scale	compensation K/S (%)	area (m²)	cutting pattern
1:80		41.05	Pattern 1



No.	X (mm)	Y (mm)	No.	X (mm)	Y (mm)
1	-1167	-7591	51	-1153	4414
2	-839	-7590	52	-1152	3914
3	-511	-7589	53	-1150	3414
4	-41	-7575	54	-1149	2914
5	429	-7562	55	-1148	2413
6	899	-7537	56	-1147	1913
7	1369	-7513	57	-1146	1413
8	1343	-7016	58	-1145	913
9	1317	-6519	59	-1145	413
10	1292	-6023	60	-1144	-88
11	1266	-5526	61	-1144	-588
12	1242	-5029	62	-1144	-1088
13	1218	-4532	63	-1144	-1588
14	1196	-4036	64	-1145	-2089
15	1174	-3539	65	-1146	-2589
16	1154	-3042	66	-1146	-3089
17	1135	-2545	67	-1148	-3589
18	1117	-2048	68	-1149	-4090
19	1102	-1550	69	-1150	-4590
20	1087	-1053	70	-1152	-5090
21	1075	-556	71	-1155	-5590
22	1063	-59	72	-1157	-6091
23	1055	439	73	-1160	-6591
24	1047	936	74	-1163	-7091
25	1043	1433			
26	1039	1931			
27	1038	2428			
28	1037	2925			
29	1040	3423			
30	1043	3920			
31	1049	4417			
32	1056	4915			
33	1064	5412			
34	1075	5909			
35	1086	6407			
36	1099	6904			
37	1113	7401			
38	1128	7898			
39	1144	8395			
40	771	8204			
41	397	8013			
42	20	7830			
43	-375	7689			
44	-765	7537			
45	-1167	7416			
46	-1164	6916			
47	-1161	6415			
48	-1159	5915			
49	-1157	5415			
50	-1155	4915			

job title	client	date: 15/02/2019		
		signed:		
engineering		project	draw	rev.

Figure 125: Membrane cutting pattern, strip 1, part 3

6.5. Membrane Fabrication

6.5.1. Membrane consumption according to cutting pattern:

Material: PVC POLYSTER type III
Roll width: 2.67 m
Total Length for the 4 parts: 337 linear meters
Quantity: 337 x 2.67 = 890 m2
Plus 15% Extra quantity for angle reinforcement and details: 133 m2
Total material: 1’023 m2

6.5.2. Fabrication

Marking and Cutting all strips and detail membrane elements
Welding seams and edge pockets
Welding membrane reinforcements
Punching holes at corners for accessories installation

Welding method: High Frequency welding machine, 12 KW at least.
Welding electrode width: 50 mm
Marking and Cutting: by hand or cutting table

Material & labour Bill of quantity for fabrication:

Membrane fabrication, bill of quantity		
Items	quantity	units
Material supply		
Membrane, Serge Ferrari, Flexlight 1202 S2	1100	m²
Fabrication		
Marking and cutting	520	m
Welding seam between strip	341	m
Welding edge and central pocket	179	m
Welding reinforcement at 6 corners	6	m²
Welding reinforcement at arch base and center	4	m²

6.6 Fittings at corners

6.6.1 Details Along ARCH

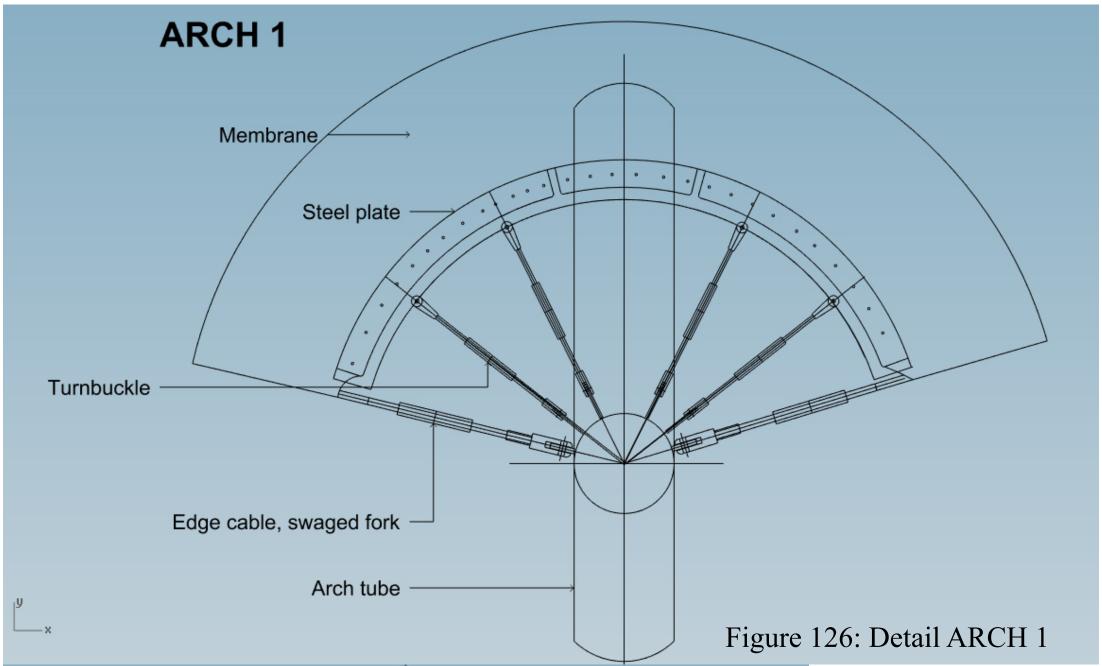


Figure 126: Detail ARCH 1

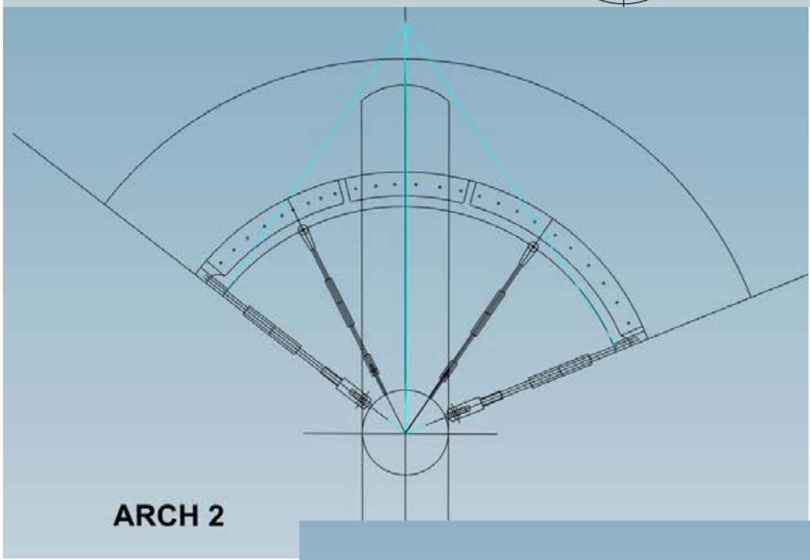


Figure 127:
Detail ARCH 2

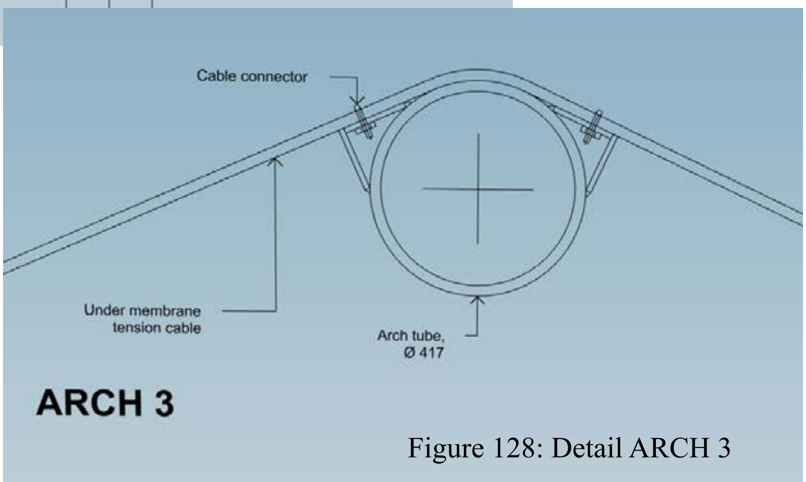


Figure 128: Detail ARCH 3

6.6.2 Details at Corners

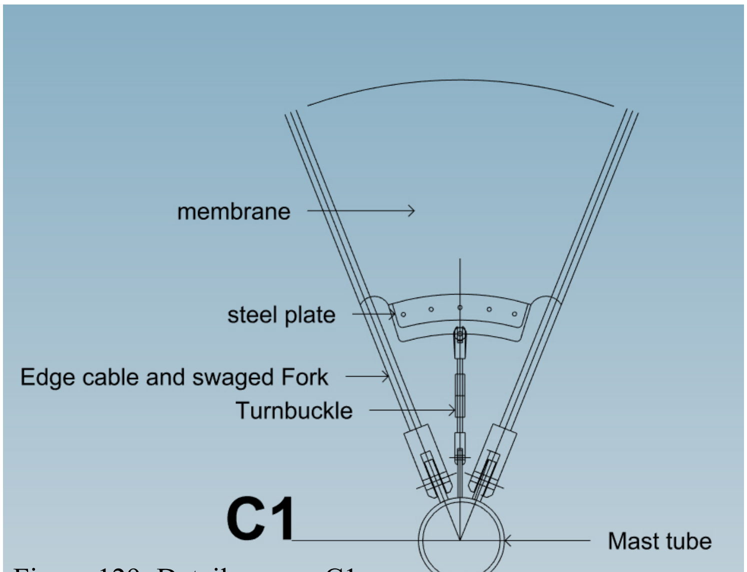


Figure 129: Detail corner, C1

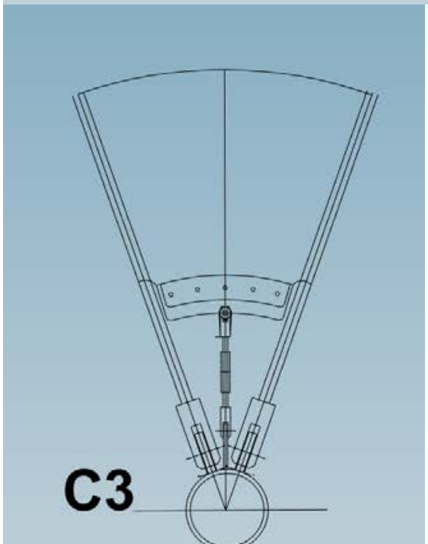


Figure 130: Detail corner, C3

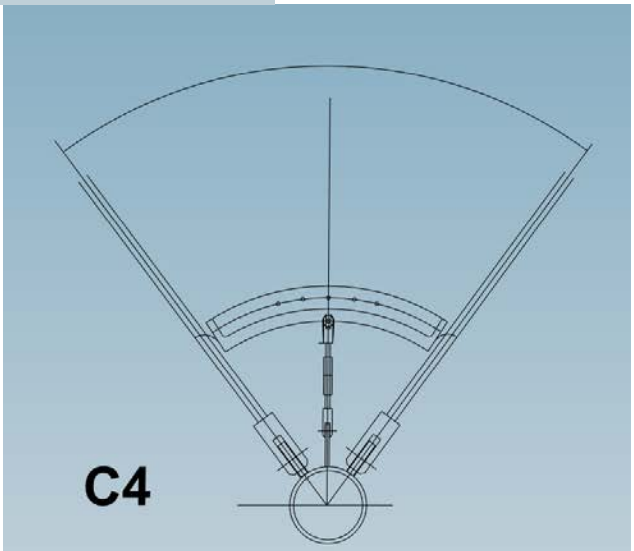


Figure 131: Detail corner, C4

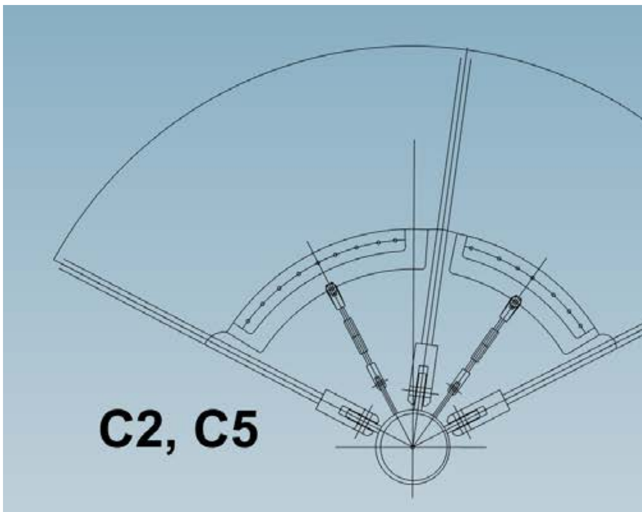


Figure 132: Detail corner, C2, C5

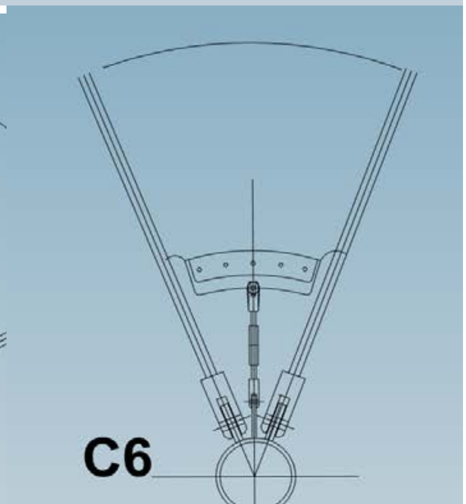


Figure 133: Detail corner, C6

6.7 Cable Bill of Quantity

BOQ: Cables and fittings				
Items	**Qty**	**length, m**	**weight /unit, kg**	**Total weigth, kg**
Edge cable (fork at both ends)				
EC1, PE60, spiral strand, stainless steel, limit tension 350kN, ∅ 28,6	1	13,00	3,700	48,100
EC2, PE45, spiral strand, stainless steel, limit tension 248kN, ∅ 24,1	1	13,65	2,700	36,855
EC3, PE60, spiral strand, stainless steel, limit tension 350kN, ∅ 28,6	1	13,80	3,700	51,060
EC4, PE75, spiral strand, stainless steel, limit tension 442kN, ∅ 32,1	1	17,00	4,700	79,900
EC5, PE60, spiral strand, stainless steel, limit tension 350kN, ∅ 28,6	1	15,40	3,700	56,980
EC6, PE45, spiral strand, stainless steel, limit tension 248kN, ∅ 24,1	1	9,20	2,700	24,840
EC7, PE60, spiral strand, stainless steel, limit tension 350kN, ∅ 28,6	1	8,70	3,700	32,190
EC8, PE45, spiral strand, stainless steel, limit tension 248kN, ∅ 24,1	1	17,00	2,700	45,900
Open swages fitting type PG981, PE45	6		5,600	33,600
Open swages fitting type PG981, PE60	8		8,000	64,000
Open swages fitting type PG981, PE 75	2		10,900	21,800
Tension cable in middle membrane pockets, fork at both ends, turnbuckle at 1 end				
TC 1, Pfeifer PE60, 350 kN, ∅ 28,6 mm		14,20	3,700	52,540
TC2, Pfeifer PE60, 350 kN, ∅ 28,6 mm		15,90	3,700	58,830
Open swages fitting type PG981, PE60	2		8,000	16,000
Turnbuckles with open socket type PG985, PE60	2		16,600	33,200
Arch prestress Stabilisation cable placed inside the arch curvature, fork at both ends, turnbuckle at 1 end				
STC 1, Pfeifer PG40, 367 kN, ∅ 20,1 mm		6,97	1,900	13,243
STC 2, Pfeifer PG40, 367 kN, ∅ 20,1 mm		12,35	1,900	23,465

BOQ: Cables and fittings				
STC 3, Pfeifer PG40, 367 kN, ∅ 20,1 mm		18,60	1,900	35,340
STC 4, Pfeifer PG40, 367 kN, ∅ 20,1 mm		24,54	1,900	46,626
STC 5, Pfeifer PG40, 367 kN, ∅ 20,1 mm		8,30	1,900	15,770
STC 6, Pfeifer PG40, 367 kN, ∅ 20,1 mm		15,33	1,900	29,127
STC 7, Pfeifer PG40, 367 kN, ∅ 20,1 mm		20,89	1,900	39,691
Open Swaged fitting, type 980, PG40	7		4,800	33,600
Turnbuckles with open socket type PG984, PG15	7		7,900	55,300
Angle tensioning fitting				
Cable 12 mm PE 10 + Fork + turnbuckle				
Rod M12 + swaged	8		2,300	18,400
Total stainless steel for cable and fitting			**kg**	**966,357**
Stabilisation and safety cable (from mast head to central arch)				
SC1, Pfeifer PG15, 81 kN, ∅ 12,2 mm		15,37	0,700	10,759
SC2, Pfeifer PG15, 81 kN, ∅ 12,2 mm		16,30	0,700	11,410
SC3, Pfeifer PG15, 81 kN, ∅ 12,2 mm		16,80	0,700	11,760
SC4, Pfeifer PG15, 81 kN, ∅ 12,2 mm		18,30	0,700	12,810
SC5, Pfeifer PG15, 81 kN, ∅ 12,2 mm		17,60	0,700	12,320
SC6, Pfeifer PG15, 81 kN, ∅ 12,2 mm		16,80	0,700	11,760
SC7, Pfeifer PG15, 81 kN, ∅ 12,2 mm		17,30	0,700	12,110
SC8, Pfeifer PG15, 81 kN, ∅ 12,2 mm		14,90	0,700	10,430
Open Swaged fitting, type 980, PG15	16		1,200	19,200
Turnbuckles with open socket type PG984, PG15	8		12,200	97,600
Tension Rod System with one coupleur				
Pfeifer, ref.				
Tension Rod type 860, M42	8	2,56	10,900	223,232
Tension Rod type 860, M27	2	0,9	4,500	8,100

BOQ: Cables and fittings				
Tension Rod type 860, M42	2	5,05	10,900	110,090
Fork connector type 860, M27	2		2,340	4,680
Fork connector type 860, M42	10		8,740	87,400
Take Ups coupler M27	2		1,510	3,020
Take Ups coupleur M42	10		5,740	57,400
Total Galfan steel fitting			**kg**	**704,081**

Figure 134: Cable bill of quantity chart

6.8 Steel Structure / Central Arch and Masts Bill of Quantity

BOQ: steel structure members				
	Qty	Length, m	Weigth/unit, kg	Total weight
Masts				
Masts column, steel, ∅ 219 x 6,3	4	2,2	33,000	290,400
Masts column, steel, ∅ 219 x 6,3	2	5	33,000	330,000
Mast footing	6		15,000	90,000
Mast heading	6		15,000	90,000
Connection of stay cable to foundation	10		11,000	110,000
Connection of stay cable to building	2		11,000	22,000
Central arch				
Base segment 1, ∅ 457 x 20	1	2,50	215,900	539,750
Segment 3, ∅ 457 x 6,3	1	7,80	70,000	546,000
Segment 4, ∅ 457 x 10	1	6,30	109,900	692,370
Segment 5, ∅ 457 x 10	1	7,56	109,900	830,844
Segment 6, ∅ 457 x 6,3	1	8,50	70,000	595,000
Base segment 7, ∅ 457 x 20	1	2,90	215,900	626,110

BOQ: steel structure members				
TOTAL STEEL			**kg**	**4762,474**

Figure 135: Steel structure bill of quantity chart

6.9 Steel Material Summary

Cable and fittings for membrane tensioning, Stainless steel grade	kg	966
Structural steel cable and tensioning rod system Galfan grade	kg	704
Structural Steel tube and plate elements Steel grade S270 or optional S355	kg	4800

6.10 Foundations

Reminder of the Download forces

Force values in corner posts and guying cables. Values in kN.			
Location	POST	Tension Rod system Element 1	Tension Rod System Element 2
FC1, CS Max	**-297,90**	26,77	**267,73**
FC1, CS Min	-244,76	**294,16**	82,17
FC2, CS Max	**-519,43**	**218,74**	**320,19**
FC2, CS Min	-145,15	54,23	178,28
FC3, CS Max	-304,97	**309,68**	48,20
FC3, CS Min	**-357,67**	178,96	**364,15**
FC4, CS Max	**-215,85**	29,17	**256,24**
FC4, CS Min	-111,82	**130,12**	85,78
FC5, CS Max	**-409,40**	**194,45**	**214,06**
FC5, CS Min	-52,56	47,86	16,84
FC6, CS Max	-185,54	**231,48**	0,00
FC6, CS Min	**-281,46**	133,17	**302,11**

Soil situation on site

The soil section includes on surface a 5 meters backfill layer and 20 meters layer of Hard material underneath.

Foundation principal:

<u>Columns and arch</u>
Columns and arch will sit on concrete piling system.
The compression Force, max value is 400 kN.
The piling, is 600 mm diameter, 15 meters long and include a steel cage embedded in concrete. The length of the piling system will be adjusted after soil investigation.

<u>Tension Rod System</u>
The Tension in the tension rod systems will be supported by anchoring system.
The max tension Forces is 360 kN.
The concrete anchoring system will be drilled at a depth of 15 meters around (design to be adjusted after soil investigation).

The 2 anchoring systems and the piling will be connected by a 800 mm thick concrete slab. A steel buckle or hook will also be connected to the embedded steel structure reinforcement of the piling and anchors to serve as connection point during installation.

Column FC 1, FC3, FC4, FC6 on concrete slab, piling and anchor

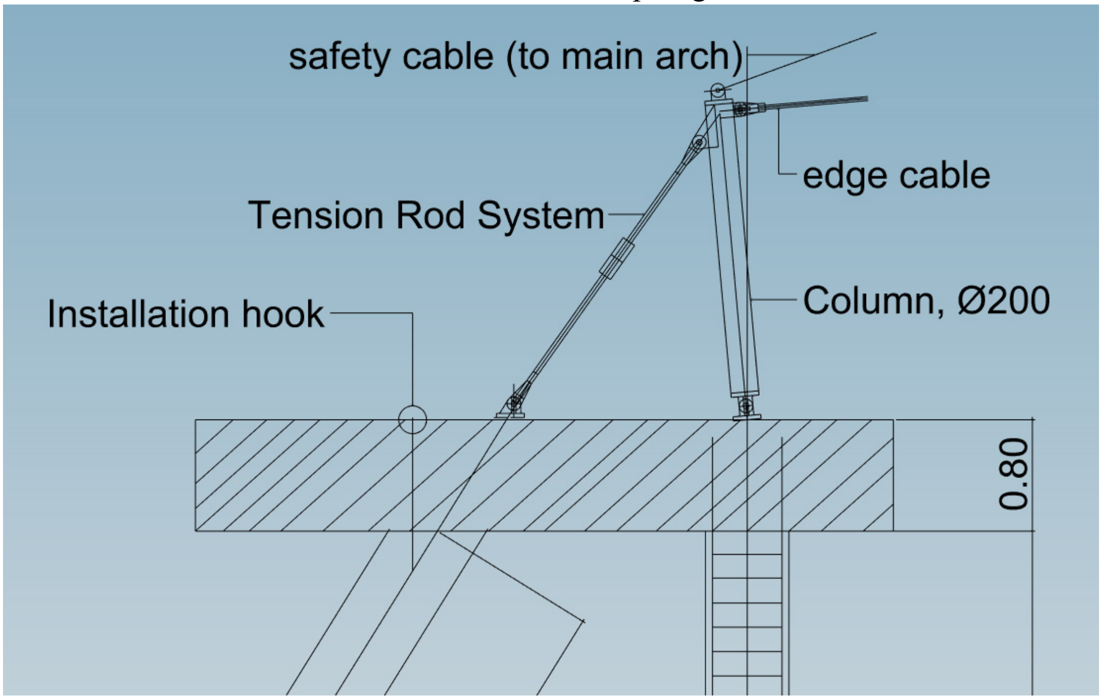


Figure 136: foundation slab at columns FC1, FC3, FC4, FC

Foundations

section at columns FC1, FC3, FC4, FC6

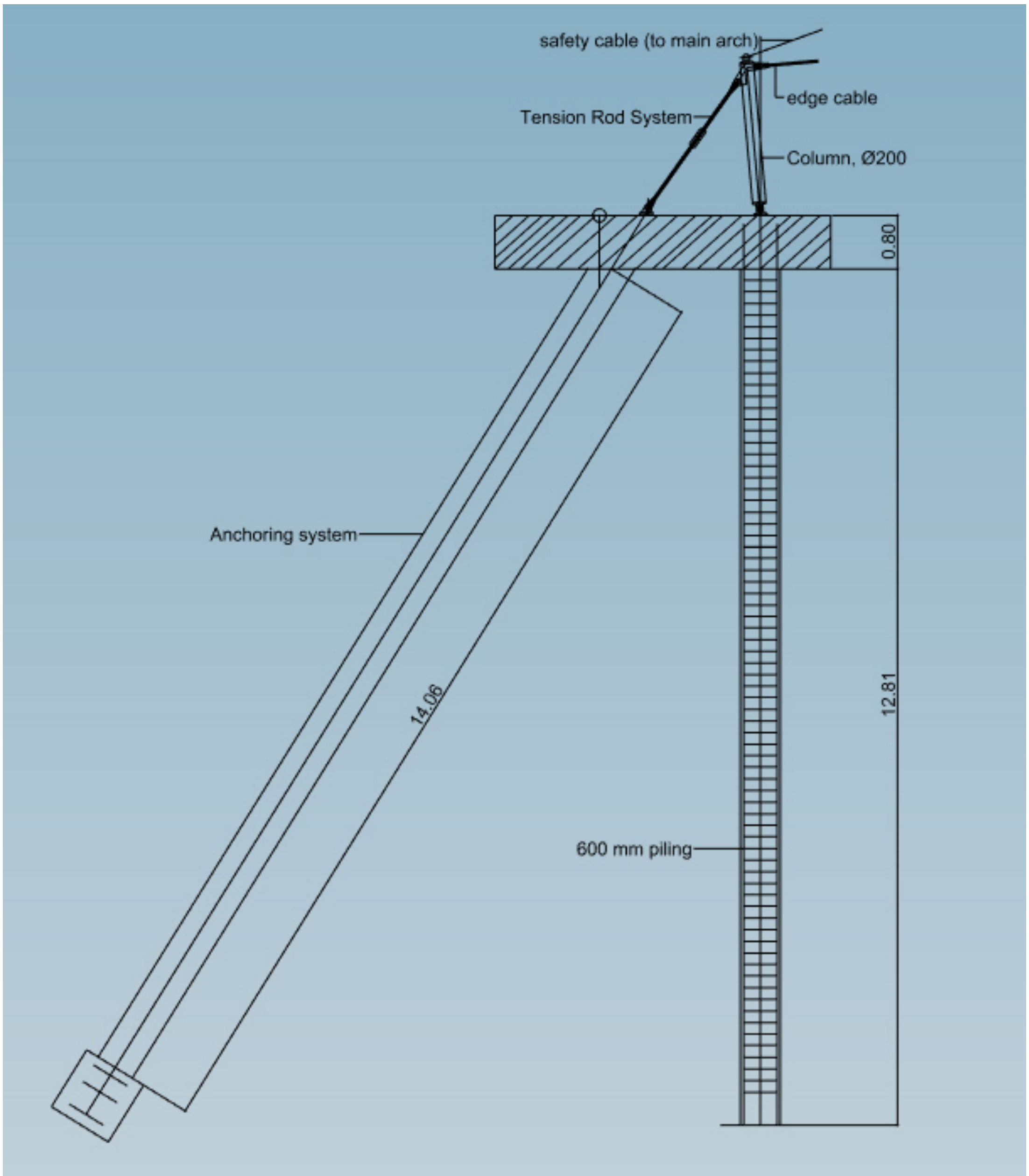


Figure 137: foundation anchor and piling at columns FC1, FC3, FC4, FC6

6.11 Project Schedule

Step 1: + 2 weeks
First meeting with the Customer.
Discussion to understand the need. See environment possibilities. Budget.

Pre-design. Form finding of different solutions. Rough budget estimation

Second Meeting with customer
Design and budget presentation. Design selection
Négociation of the engineering package

In case of approval

Step 2: + 2 weeks
Engineering development. Construction detail design. Final statical analysis.
Final cost estimation

Third meeting with customer
Presentation of the complete study. Final discussion on details
Discussion on possible Schedule for fabrication and installation.

Step 3: + 5 weeks
Material order. Material delivery time.
In same time: Foundation preparation.
Final on site measurement before fabrication

Step 4. Total : + 2 weeks
Membrane fabrication 2 weeks
Steel structure fabrication: 2 weeks
Quality control

Step 5. Installation: + 1 week
Mobile crane mobilisation
Scaffolding and installation devices delivery to site
Main central arch erection and temporary fixing by cable network
Mats installation
Formwork installation
Installation of protection sheet over steel elements in order to avoid possible damage during membrane installation.
Installation of the membrane on the central arch
Fitting equipments installation on the membrane (angle fittings and edge cables)
Pre-tensioning of the membrane with jack and belts.
Adjustments and final tensioning of the membrane.

TOTAL: 12 weeks

7. CONCLUSION

The design form finding process was an interesting part of the study.
The achieved shape of this central arch tent is aesthetically pleasant.
The fonction to bring shape on the pool area is realized.

The statical analysis was done taking in consideration local external weather loads; heavy monsoon rain and wind.

The wind load calculation, was done considering the 2 main criteria: velocity wind pressure and the Cp value coefficients. Velocity wind pressure is well known for this area: 83 daN/m² is prescribed by local official recommendation. Cp values are determinant; therefore, in absence of precise and practical information data or test data from wind tunnel measurements relating to this central arch tent case study, the statical analysis was done by following Eurocode procedure, which is certainly safe but anyhow a bit frustrating.

The central arch calculation, probably due to the asymmetric shape curvature, was problematic. I tried several options, with or without an inner prestressed cable system, hinged or fix footing and for both the 2 programs used for calculation; Easy and Rstab. Their results are large diameter pipes (from 393 to 700 mm). I compromised by using the largest possible diameter which could be bent locally in Vietnam, diameter 457 mm, and different steel tube wall thickness along the arch to agree with program calculation. Equilibrium was found, but in doubt, I will consider asking verification by a qualified structural engineer. An alternative to be studied would be a 3D truss beam.

The tension load in guying cables or tension rod system is important, in the range of 400 kN. To support such load a special soil anchoring system will be necessary. This particular point will add cost to the project.

An other critical factor is the wind pressure load on the membrane. With the wind uplift action on the membrane surface, most of the load is supported by edge cables. Considering the local velocity wind pressure of 83 daN/m² and Eurocode Cp values for a 20° slope duo pitch roof, the results pinpoint the need of large section cables, ∅ 20 to 28 mm. The total weight for edge cable and fitting is around 900 kg.

The overall necessary material to built this project stay in a reasonable range for this high quality 668 m² tent.

Acknowledgements

Some people went to extra lengths to help me during the redaction of the present thesis. Some are old friends; many thanks to them for their support. Some are people I had not known before, who generously dedicated their time to assist me.
My special gratitude goes to them, for without their generous help, this thesis might never have been finished.

I am grateful to all of them, particularly

my superviser Jürgen Hennicke for his constant support and insights into the world of tensile membrane.

Françoise Fournier and Serge Ferrari, whose advice and friendly support accompanied me during these years of study

Peter Singer and Dieter Ströbel - Technet company, for their constant teaching while I learned the Easy computer program.

My thanks also go to my old friends for their unbreakable support during these last years

Julien Bergoz for his encouragements

Pierre Doriez always available when some technical advice was necessary

Jacques Prat - Prat-sa co, who generously accepted open discussion on aerodynamic values and arch design.

The Lightweight group for their moral encouragements

Robert Rothmayer for his advices and always positive mood.

I apologize to all those I did not mention.

Appendix

List of Appendixes:

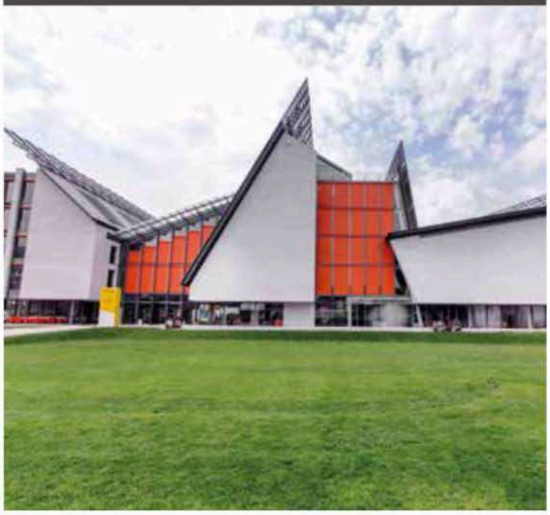
A selection of Polyester-PVC membrane which can be an interesting solution for solar protection.

Reports on membrane sustainability

Micro-perforated membrane dedicated to façade solar protection, can be also use for large umbrella, pergola, shade sail.

Serge Ferrari | Soltis Perform 92

Main applications
External blinds
Conservatory and skylight blinds



Visual & thermal performance

A real heat shield that blocks up to 97% of the heat when placed outside.

Major advantages

- The best thermal performance in the range
- Optimum visual comfort
- Excellent tear resistance and dimensional stability
- Weather and UV resistance
- Lightweight, durable and 100% recyclable
- High dimensional stability due to Precontraint® technology

Other applications

- Pergolas
- Projection blinds
- Shadesails

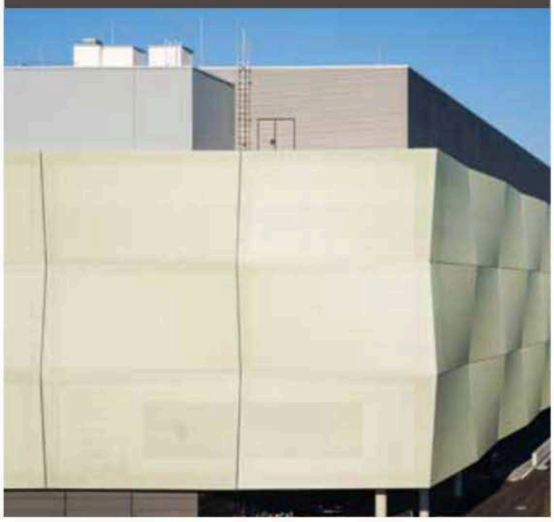
Technical specifications

Weight	420 g/m² - EN ISO 2286-2
Thickness	0.45 mm
Standard format length	50 lm in 177 cm width/40 lm in 267 cm width
Tensile strength (warp/weft)	310/210 daN/5 cm - EN ISO 1421
Tear strength (warp/weft)	45/20 daN - DIN 53.363
Flame retardancy	**B-s2,d0**/EN 13501-1 **M1**/NFP 92-507 — **B1**/DIN 4102-1— BS 7837 — BS 5867 — **Schwerbrennbar Q1-Tr1**/ ONORM A 3800-1 — **Classe 1**/UNI 9177-87 — **M1**/UNE 23.727-90 — **VKF 5.3**/SN 198898 **1530.3**/AS/NZS — **G1**/GOST 30244-94 — **Method 1**/NFPA 701 — CSFM T19 **Class A**/ASTM E84 — **Group 1**/AS/NZS 3837 — **Class 1**/EN 13773 — CAN/ULC-S109
Warranty	5 years
MOQ	177 cm: 2500 lm/267 cm: 3500 lm
Maximum delivery time	4 working weeks
Provided services	Cut length from 3 lm Special colour Short production runs Promised delivery dates are guaranteed up to 500 lm per colour

Frontside View 381 is a Mesh dedicated to façade application. Due to his good transparency and outdoor resistance it can also be used for various shading outdoor area

Serge Ferrari | **Frontside**
View 381

Main applications
New and renovated facades
Buildings with thermal efficiency



View-through facade mesh

Creative facade allowing solar protection, privacy and view-through

Major advantages

— High and durable resistance
— Thermal protection
— Visual comfort

Technical specifications

Front face	Metallic or pearl finish
Back face	Matt
Weight	550 g/m² - EN ISO 2286-2
Standard format length	50 lm
Thickness	0.95 mm - EN ISO 5084
Tensile strength (warp/weft)	330/330 daN/5cm - EN ISO 1421
Tear strength (warp/weft)	80/90 daN - DIN 53.363
Extreme usage temperatures	- 30°C/+ 70°C
Openess factor	28 %
Flame retardancy	**B-s2,d0**/EN 13501-1 **M1**/NFP 92-507 — **Method 1 & 2**/NFPA 701 — **Class A**/ASTM E84 CSFM T19 — **1530.3**/AS/NZS — **Group 1**/AS/NZS 3837 **G1**/GOST 30244-94 — **B1**/DIN 4102-1 — BS 7837 — **VKF 5.3**/SN 198898
Warranty	10 years
MOQ	3500 lm
Maximum delivery time	4 - 6 working weeks depending on the project size

High quality and very resistant mesh for shade and wind application

Serge Ferrari | Protect
Meshes 392 S2

Main applications
Wind screen
Glassroof protection
Thermal protection - Partitions, doors

Ideal for building applications with its weight/strength combination

A very opened mesh with a nice light transmittance for a durable protection, also flame retardant

Major advantages

- Long lifespan and easy cleanability
- Fire certification M2/B1
- High weight and mechanical strength

Other applications

- Partitions
- Doors
- Trampoline parks

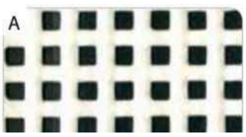
Technical specifications

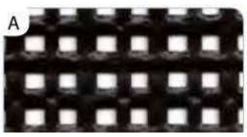
Weight	820 g/m² - EN ISO 2286-2
Standard format length	50 lm
Tensile strength (warp/weft)	300/300 daN/5 cm - EN ISO 1421
Tear strength (warp/weft)	60/60 daN/5 cm - DIN 53.363
Breathability	81 %
Porosity	27 %
Flame retardancy	**M2**/NFP 92-507 — **Method 2**/NFPA 701 — CSFM T19 **B1**/DIN 4102-1 — **G1**/GOST 30244-94 — **M2**/UNE 23.727-90 **VKF 5.3**/SN 198898 — **Schwerbrennbar Q1-Tr**1/ONORM A3800
MOQ	1500 lm for Custom made products
Maximum delivery time	6 working weeks

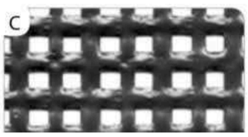
The technical data above are averaged values with a +/- 5% tolerance.

Precontraint® Technology

3 colours & references







Plain membrane for medium small shading structures

Serge Ferrari | **Soltis** Proof 502

Main applications
Shade sails
Fixed awnings

Heavy duty waterproof membrane

Colourful and heavy duty membrane designed to last over the years and to adapt to any project

Major advantages

- Satin finish
- Reinforced dirt resistance and easy cleanability
- Heat and weather protection
- High UV resistance
- High dimensional stability due to Precontraint® technology

Other applications

- Pergolas
- Projection blinds
- Exterior velums

Technical specifications

Weight	570 g/m² - EN ISO 2286-2
Thickness	0.45 mm
Standard format length	40 lm
Tensile strength (warp/weft)	200/200 daN/5 cm - EN ISO 1421
Tear strength (warp/weft)	20/20 daN - DIN 53.363
Flame retardancy	**B-s2, d0**/EN 13501-1 **M2**/NFP 92-507 — **B1**/DIN 4102-1 — BS 7837 — **1530.2 et 3**/AS/NZS **M2**/UNE 23.727-90 —**VKF 5.3**/SN 198988 — **Schwerbrennbar Q1-Tr1**/ONORM A 3800 **Group 1**/AS NZS 3837 — **CLASS 2**/UNI 9177-87 — **METHOD 1 & 2**/NFPA 701 CSFM T19 — **CLASS A**/ASTM E84 — **G1**/GOST 30244-94 — CAN/ULC-S109 — CPAI 84
Warranty	10 years
MOQ	2500 lm
Maximum delivery time	4 working weeks
Provided services	Cut length from 3 lm Special colour Short production runs

Plain membrane for medium size shading structures

Serge Ferrari | Flexlight
Perform

Main applications
Car parks
Shading structures

Consistency & Reliability

Provide reliable performances & dimensional stability for shading structures

Major advantages

— High dimensional stability due to Precontraint® technology
— Low maintenance
— Lighweight & recyclable via Texyloop process

Technical specifications

	Flexlight	
	Perform 912 S2	**Perform 1212 S2**
Base fabric	Anticapilarity low wick yarn treatment	
Weight	900 g/m² - EN ISO 2286-2	950 g/m² - EN ISO 2286-2
Standard format length	220 lm	220 lm
Tensile strength (warp/weft)	420/400 daN/5 cm	560/560 daN/5 cm
Flame retardancy	**B1, others on demand**	
Warranty*	10 years	
MOQ**	3500 lm	
Maximum delivery time	In stock	
Provided services	Custom made colour (on demand) Promissed delivery garanted up to 2000 lm	

* Please refer to the text of our warranty. The warranty is valid only after confirmation on case-by-case basis of warranty application. The warranty will not apply to mobile structures. The buyer of our products is fully responsible for their application or their transformation concerning any possible third party. The buyer of our products is responsible for their implementation and installation according to the standards, use and customs and safety rules of the countries where they are used.
** This MOQ is for category C products (Custom made)

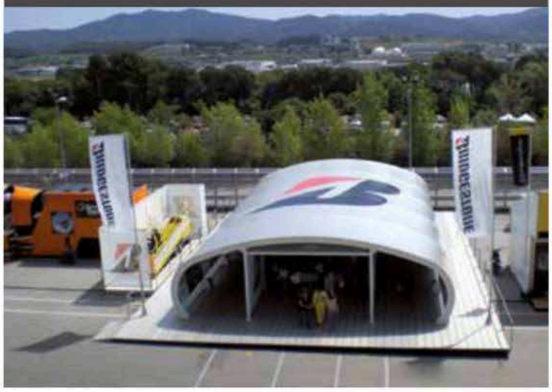
Precontraint® Technology

Opaque plain fabric

Serge Ferrari | **Flexlight**
Perform 702 S2 Opaque - 702 Opaque Alu

Main applications

For demanding environments
with dirt/high temperatures/UV
High end events



Exceptional dirt resistance and opacity

Optimum weight /strength/opacity ratio with an extended durability and cleanability

Major advantages

- High dimensional stability due to Precontraint® technology
- The best ratio of opacity/weight
- Consistent and reliable performance
- For Flexlight Perform 702 Opaque Alu: unique and uniform aluminum surface

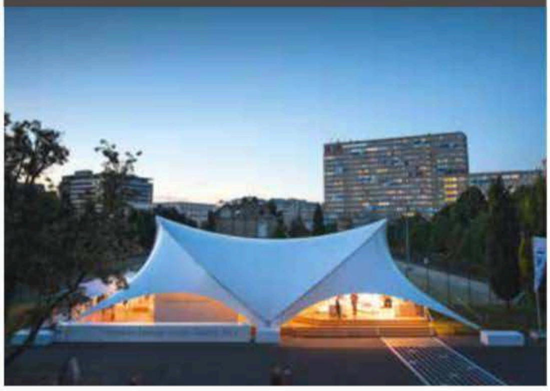
Technical specifications

	Flexlight	
	Perform	**Perform**
	702 S2 Opaque	**702 Opaque Alu**
Weight	830 g/m² - EN ISO 2286-2	830 g/m² - EN ISO 2286-2
Standard format length	50 lm - 300 lm	30 lm - 300 lm
Tensile strength (warp/weft)	280/280 daN/5 cm - EN ISO 1421	280/280 daN/5 cm - EN ISO 1421
Tear strength (warp/weft)	30/28 daN - DIN 53.363	30/28 daN - DIN 53.363
Elongation under load (warp/weft)	<1%/<1%	<1%/<1%
Finish	Formula S2 fluorinated varnish weldable	2-face acrylic varnish
Flame retardancy	**B-s2, d0**/EN 13501-1 — **M2**/NFP 92-507 **Method 2**/NFPA 701— CSFM T19 **B1**/DIN 4102-1— BS 7837 **1530.2 et 3**/AS/NZS **Schwerbrennbar Q1-Tr1**/ONORM A 3800-1 **M2**/UNE 23.727-90 — VKF 5.3/SN 198898 **Classe 2**/UNI 9177 — G1/GOST 30244.94 **Class E**/EN 11925-2 (SITAC)	**B-s2, d0**/EN 13501-1— **M2**/NFP 92-507 **Method 2**/NFPA 701 — CSFM T19 **B1**/DIN 4102-1— BS 7837 **1530.2 et 3**/AS/NZS — **Schwerbrennbar Q1-Tr1**/ONORM A 3800-1 **M2**/UNE 23.727-90 **VKF 5.3**/SN 198898 — **Classe 2**/UNI 9177 **G1**/GOST 30244.94 **Class E**/EN 11925-2 (SITAC)
Warranty	7 years	5 years
Maximum delivery time	3 working weeks	4 working weeks
	Jumbo rolls	

Opaque plain fabric

Serge Ferrari Flexlight
Classic 602 N Opaque - 782 S2 Opaque

Main applications
All kind of structures needing opacity and thermal insulation in hot weather



Perfect ratio of opacity and weight

Best in class opacity level with a unique consistent dimensional stability through Precontraint®

Major advantages

— High dimensional stability due to Precontraint® technology
— The best ratio of opacity/weight
— Consistent and reliable opacity performance

Technical specifications

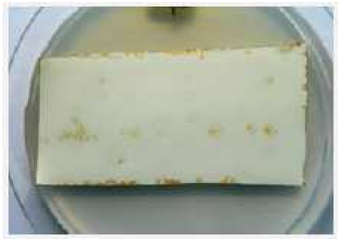
	Flexlight	
	Classic 602 N Opaque	**Classic 782 S2 Opaque**
Weight	750 g/m² - EN ISO 2286-2	830 g/m² - EN ISO 2286-2
Standard format length	50 lm - 300 lm	50 lm - 250 lm
Tensile strength (warp/weft)	230/220 daN/5 cm - EN ISO 1421	350/350 daN/5 cm - EN ISO 1421
Tear strength (warp/weft)	20/20 daN - DIN 53.363	45/40 daN - DIN 53.363
Elongation under load (warp/weft)	<1%/<1%	<1%/<1%
Finish	Varnish both sides	Formula S2 fluorinated varnish weldable
Flame retardancy	**M2**/NFP 92-507 — **B1**/DIN 4102-1 **M2**/UNE 23.727-90 — BS 7837 **1530.2** and 3 — ASTM E 662 **Method 1**/NFPA 701 **Method 2**/NFPA 701 — CSFM T19	**M2**/NFP 92-507 **B1**/DIN 4102-1 **G1**/GOST 30244-94 **1530.2 et 3**/AS/NZS
Warranty	-	7 years
Maximum delivery time	3 working weeks	3 working weeks
Provided services	Jumbo rolls Cut length Slitting Length/width adjustment Short production runs Promised delivery guaranteed up to 3 000 lm	Jumbo rolls Cut length Slitting Length/width adjustment Short production runs Promised delivery guaranteed up to 3 000 lm

Resistance to micro-organisms

AESTHETICAL LONGEVITY
RESISTANCE TO MICRO-ORGANISMS

TEST METHOD
Resistance to micro-organisms development is tested in compliance with **ISO 846** Method A. The material is exposed for 4 weeks at 29°C in a solution containing various micro-organisms. The material is rated on a scale from 0 (inert: no micro-organisms development) to 5 (100% of the material surface colonised by micro-organisms).


> Classe 0 (inert)


> Classe 2 (25% area colonised by micro-organisms)

RATING OF PRECONTRAINT PRODUCTS / BRAND NEW

Resistance to micro-organisms	ISO 846 Method A
• PRECONTRAINT T2 range	Classe 0 (inert)
• PRECONTRAINT TX30 range	Classe 0 (inert)

RATING AFTER NATURAL AGEING ON SITE


Ladies Pavilion - Abu Dhabi, UAE
PRECONTRAINT 1202 T - Average relative humidity: 65%
Installation : 1996 - Sampling : 2006


Train Station Sukan Negara - Kuala Lumpur, Malaysia
Précontraint 1202 T - Average relative humidity: 80%
Installation : 1997 - Sampling : 2010

Resistance to micro-organisms	ISO 846 Method A
• Initial	Classe 0 (inert)
• After 10 years (Abu Dhabi)	Classe 0 (inert)
• After 13 years (Malaisie)	Classe 0 (inert)

The results show the resistance of PRECONTRAINT materials to micro-organisms over long term exposure, even in tropical climates.

Serge Ferrari

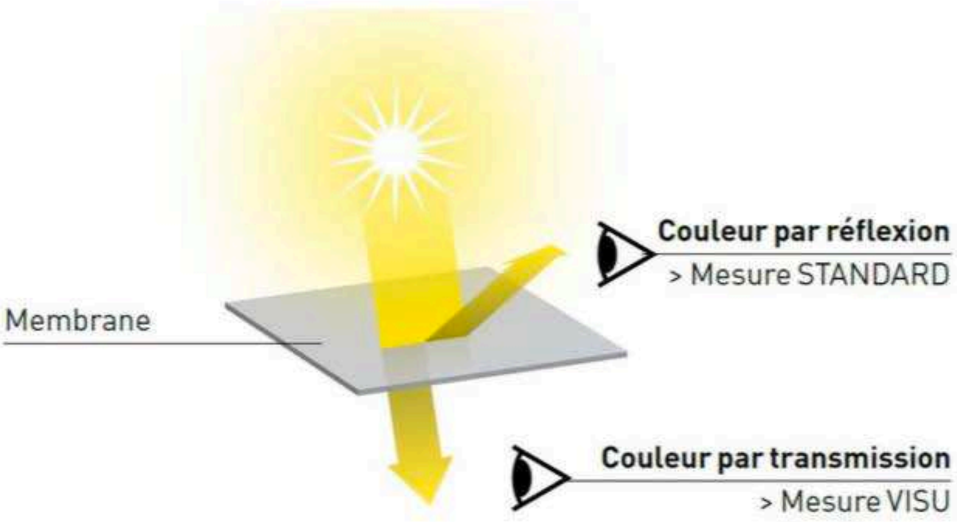
July 2014

Consistent appearance in transparency, page 1

Serge Ferrari

Consistent appearance in transparency
VISU SERVICES

Color per translucency (view from inside) of membrane covers is an important aesthetic criterion. Most of the fabricators measure only the color by reflection (view from outside). Serge Ferrari Group has developed innovative tools to measure and continuously monitor the color per translucency during production: **VISU SERVICES**



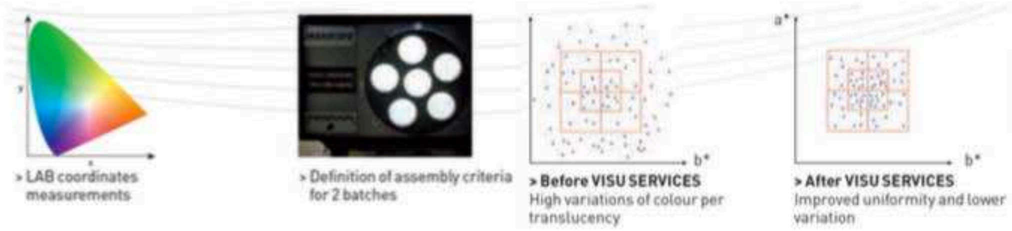
A beautiful project cannot bear significant variations of color per transparency.

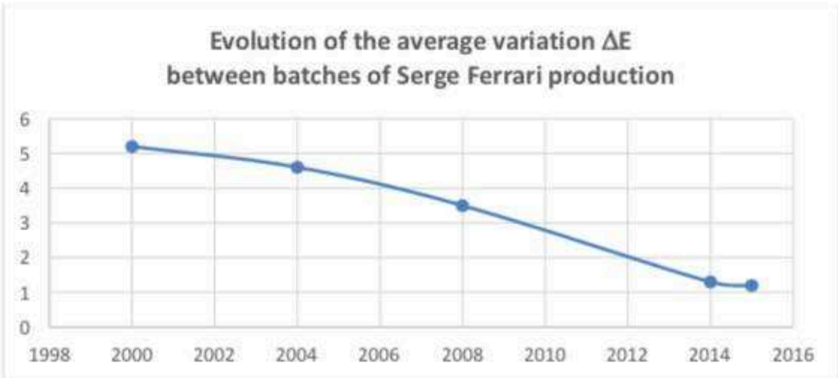
Non homogeneous color per transparency	Homogeneous color per transparency
ΔE > 5	**ΔE < 1,5**

Consistent appearance in transparency, page 2

Serge Ferrari

Thanks to VISU SERVICES tool Serge Ferrari was able to understand and gradually improve the consistency of the color per translucency within the same production and form one production to the other one. The difference of the color per translucency between batches has been strongly reduced since the founding of VISU SERVICES.





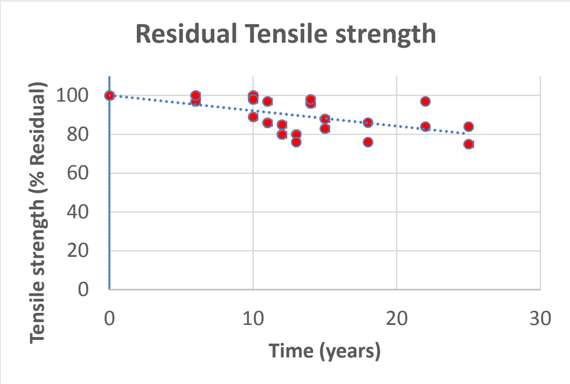
Currently, the variations are greatly reduced in ranges although there are still small variation that lead Serge Ferrari classify productions into batches.

VISU SERVICES is a daily assistance to our customers to ensure a reduced gap and selecting the most homogenous production batches translucency for a given project.
The customer can be assured of being able to mix membrane rolls of the same batch on a continuous roofing project. The customer having several different batches in its stock may request to Serge Ferrari if they can be assembled or not. Serge Ferrari ADV will be able to say whether it is compatible or not.

SERVICE LIFE : PRECONTRAINT vs PTFE

LONGEVITY CASE STUDIES / FABRICS SAMPLED FROM SITE

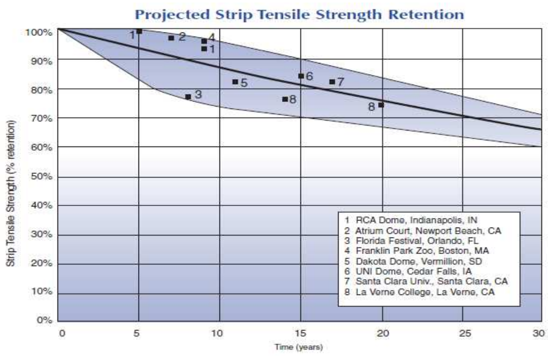
PRECONTRAINT - Residual Tensile Strength



See p.2/3/4 the project details and precise values

PTFE - Residual Tensile Strength

Birdair documentation extract : Sheerfill PTFE projects



CONCLUSION : Measures show that PRECONTRAINT membranes have at least similar remaining tensile strength to Glass / PTFE membranes.

Serge Ferrari

July 2014

PRECONTRAINT SERVICE LIFE

LONGEVITY CASE STUDIES / FABRIC SAMPLED FROM SITE

After **25 years**:
La Tour-du-Pin – France
Warehouse – Installation 1989

Precontraint 832
Residual Tensile strength
Warp **84%** - Weft **75%**

After **22 years**:
Bremen – Germany
Airbus hangar - Installation1982

Precontraint 1302
Residual Tensile strength
Warp **97%** - Weft **84%**

After **18 years**
Port-Gentil - Gabon
Exhibition hall – Installation 1982

Precontraint 1302
Residual Tensile strength
Warp **86%** - Weft **76%**

After **15 years**
Tsingdao – China
Stadium – Installation 1999

Precontraint 1302 T
Residual Tensile strength
Warp **88%** - Weft **83%**

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July 2014

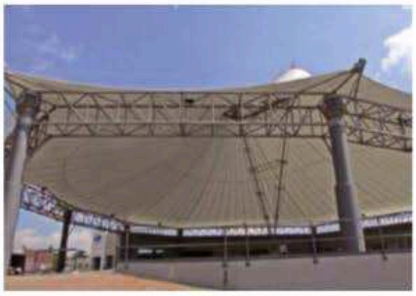
service life, page 3

After **14 years**
Kerikeri – New Zeland
School Covered – Installation 1994

Precontraint 702
Residual Tensile strength
Warp **96%** - Weft **98%**

After **13 years**
Bahrein
Shopping mall – Installation 2000

Precontraint 1202 T
Residual Tensile strength:
Warp **80%** - Weft **76%**



After 12 years
Johannesburg - South Africa
Car dealership - Installation2000

Precontraint 1002
Residual tensile strength
Warp **80%** - Weft **85%**

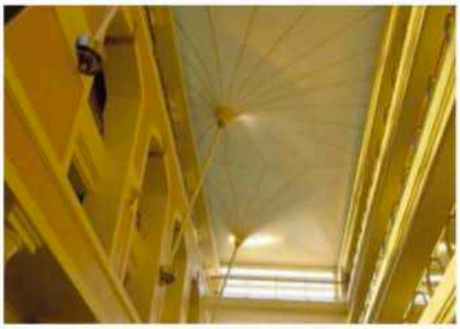
After **11 years**
Paris - France
Walkway Cover – Installation1989

Precontraint 1002
Residual Tensile Strength
Warp **97%** - Weft **86%**

Serge Ferrari

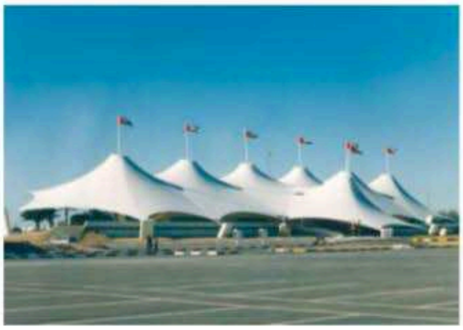
July 2014

Service life, page 4



After **10 years**:
Radisson Hotel - Installation 1996
Cape Town - South Africa

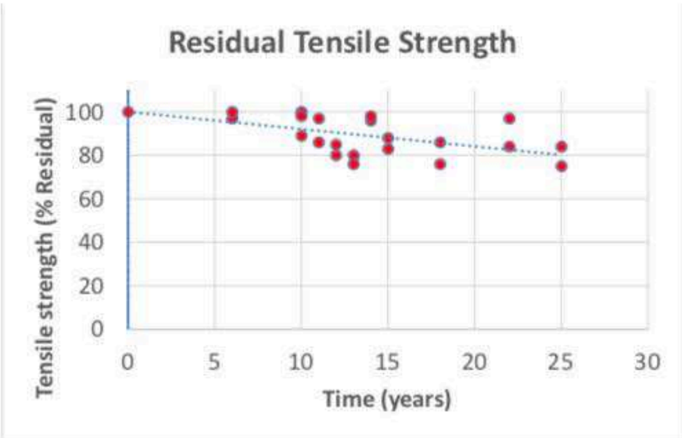
Precontraint 1002
Residual Tensile Strength
Warp **99%** - Weft **100%**



After **10 years**:
Abu Dhabi - U.A.E
Ladies Pavilion – Installation 1996

Precontraint 1202 Fluotop T
Residual tensile strength
Warp **89%** - Weft **98%**

PRECONTRAINT - Residual Tensile Strength



CONCLUSION : The measurements on PRECONTRAINT material sampled on site, prove the high level of remaining tensile strength of PRECONTRAINT membranes after long term outdoor exposure in different climatic conditions. Those field results confirm the conclusions of the 30 year artificial weathering study.

Serge Ferrari

July 2014

WEATHERING STUDY

Accelerated weathering protocol 30 years

To simulate in a reliable way, the ageing of polyester/PVC membranes, Serge Ferrari worked with the which european expert of the photochemical ageing of materials. A method of accelerated ageing in climatic chamber has been developped and finalized by making sure :

- That the level of UV and Heat do not exceed the critical level beyond of which the simulation does not reproduce anymore the reality of the natural ageing of Polyester/PVC coated materials.
- That the observed results correlate well with the experience feedback of the naturally aged materials.

Having testing several conditions of exposures, the experts chose the most appropriate protocol.

1. Artificial Weathering protocol

The artificial weathering is conducted according to the folowing standards :
- **NFT 51-195-5** (2008)« *méthode de vieillissement avec une lampe à vapeur de mercure moyenne pression filtrée* »
- **EN 16472** (2012) « Plastics - Method for accelerated photoageing using medium pressure mercury vapour lamps»

Conditions d'exposition

UV irradiance (290 – 410nm) = **90W/m²** Temperature = **60°C** +/-3°C	*+ soaking 1 hour in the water at 40°C every 250 hours, for the hydrolysis and the washing of products degraded / oxidized on surface*

Correlation between artificial and natural ageing

The acceleration of the ageing is obtained by an exposure to a strong UV irradiance (90W/m2) and a high temperature (60 °C) accelerating the thermal degradation. The factor of correlation of artificial and natural ageing was established on the basis of :

- the standard ISO 10640 wich allows to analyse the process of oxidation of the material
- The comparison of the samples naturally aged and articially aged

Artificial exposure time	Equivalent natural ageing time
250 hours	1 year Floride
7500 hours	30 years Floride

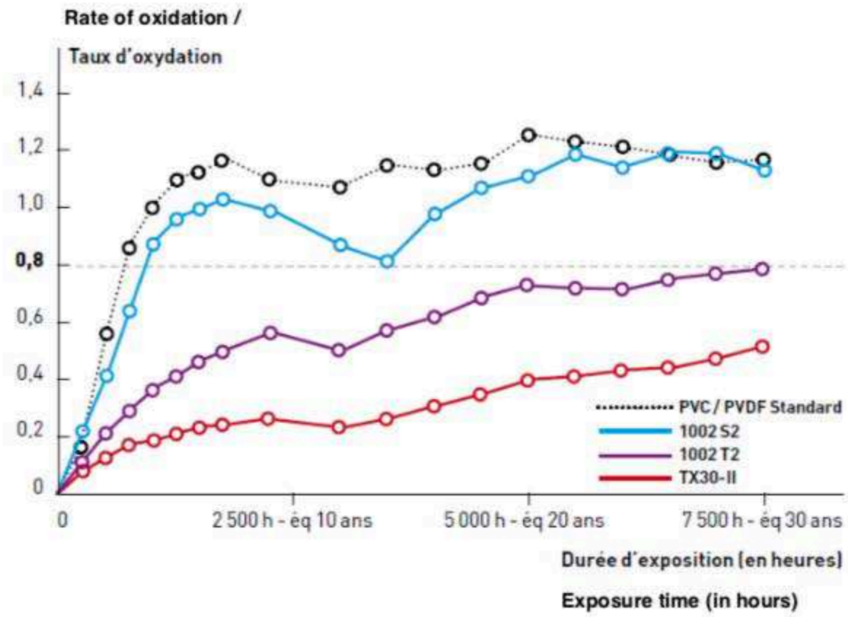
This correlation is based on the hypothesis that metrials have a global energy of activation of the order of 70 to 75 KJ.mol-1 (empirical law of the factor 2 for 10°C of increase of temperature). And the hypothesis wich the degradation satisfies the model of Arrhenius.

Serge Ferrari

July 2014

2. Measure of photo-oxidation of the surface

The chemical oxidation of the PVC plasticized polymeric material was analyzed by means of FTIR spectrometry, according to International standard ISO 10640.
Ultimate oxidation photoproducts issued from the scission of the polymeric chain were detected by a specific IR absorption band at 1780cm^{-1}. The increase of the IR absorbance at 1780cm^{-1} vs exposure time corresponds to the rate of photooxidation at the exposed surface. The oxidation remain limited to a superficial layer (<10 to 15µm depth) due to the screening effect of the pigments.
Chemical oxidation will lead to physical and mechanical degradation
The oxydation rate gives an indication of the speed of the degradation at the surface of the material.



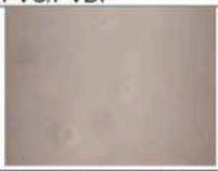
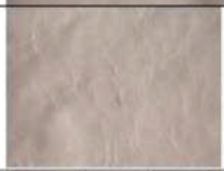
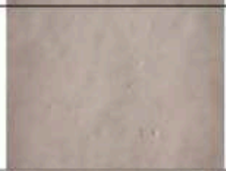
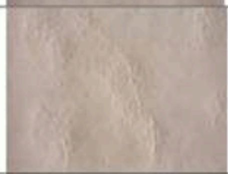
Threshold of oxidation **A1780cm-1**	Standard PVC/PVDF	PRECONTRAINT 1002 S2	PRECONTRAINT 1002 T2	PRECONTRAINT TX30-II
0.4 Threshold for Occurrence of Microcracks	450 h	450 h	1250 h	5000 h
0.8 Threshold for Loss of flexibility and significant microcracks (Rz >20 µm)	700 h	900 h	7500 h	>7500 h

The analyses of surface allowed to highlight thresholds of oxidation correponding to various levels of microcracks. The threshold of 0.4 corresponds to the appearance of microcracks and the threshold of 0.8 correponds to a stong level of microcracks. The material Précontraint TX30 is approximately 10 times more stable than standard PVC/PDVF and Précontraint S2 membranes. Précontraint TX30 is twice as stable at least as the material Précontraint S2.

Weathering study, page 3

3. Evolution of surface aspect

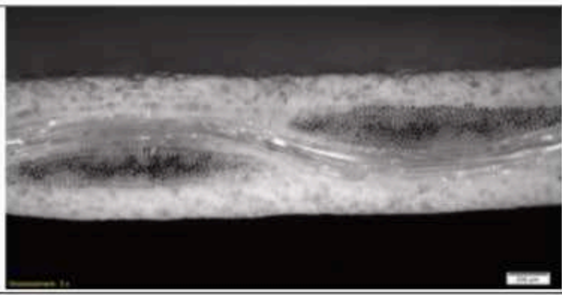
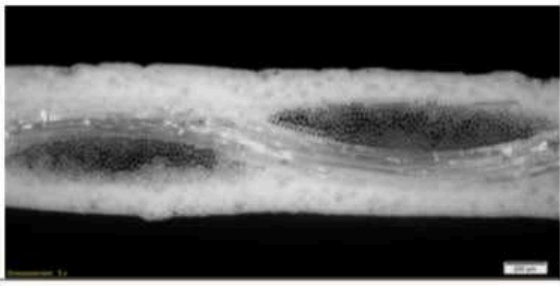
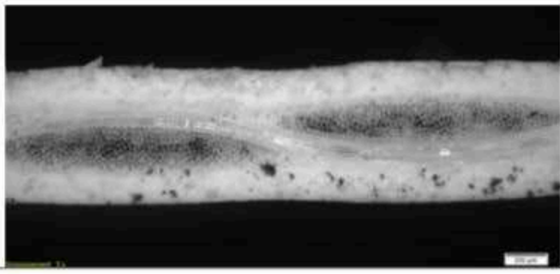
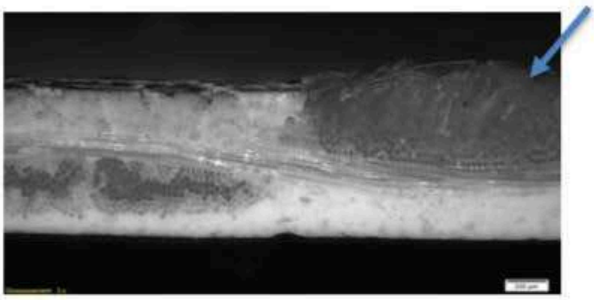
The materials were observed at different step of the ageing. The observations allow to visualize the appearence of microcracks and shows the progressive physical degradation of the products.

	Standard PVC/PVDF	Précontraint 1002 S2	Précontraint 1002 T2	Précontraint TX30-II
Initial				
2500 h				
4500 h				
6000 h				
7500h				

The progress of microcracks is very steady on the standard formulae PVC/PVDF and précontraint S2. The progress is slow on the Precontraint 1002 T2 and almost non-existent on the crosslinked Précontraint TX30-II. After 7500h, TX30-II has a surface aspect close to the initiale state.

4. Thickness of protective coating at the top of the yarns

The views in section after 7500h de veillissement are presented and commented here below.

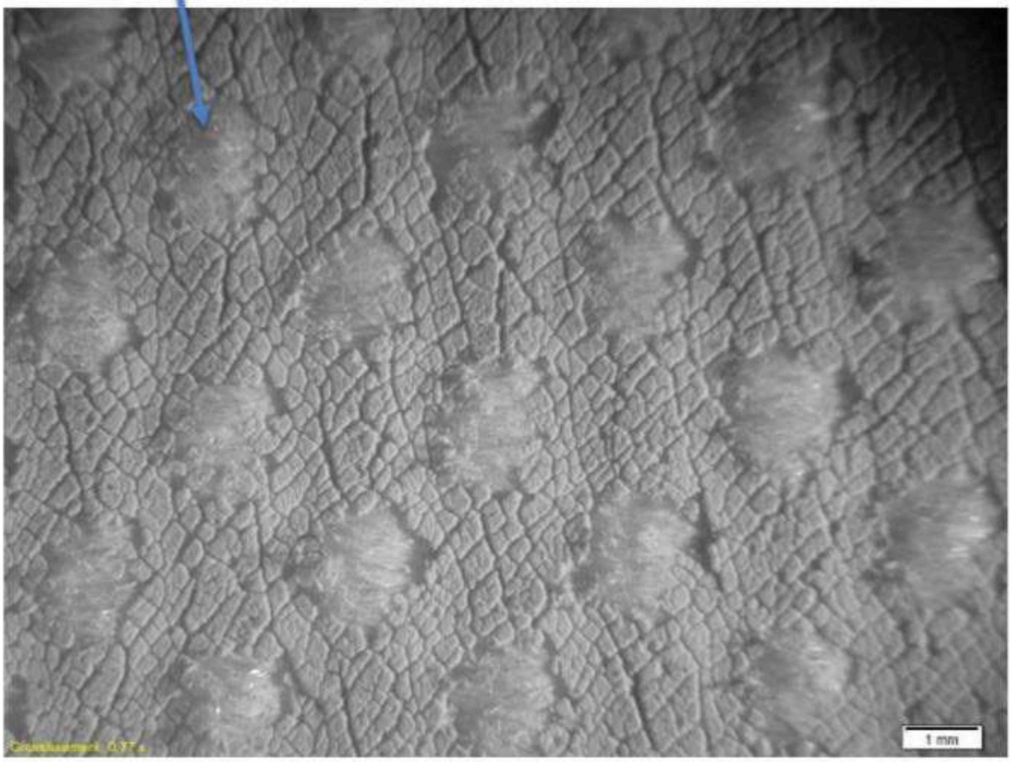
PRECONTRAINT 1002 S2 **After 7500 h** **Thick coating and good protection of the yarn is Maintained**	
PRECONTRAINT 1002 T2 **After 7500 h** **Thick coating and good protection of the yarn is Maintained**	
PRECONTRAINT TX30-II **After 7500 h** **Thick coating and good protection of the yarn is Maintained**	
STANDARD PVC/PVDF **After 7500 h** **No coating at top of yarn directly exposed to UV**	

Weathering study, page 5

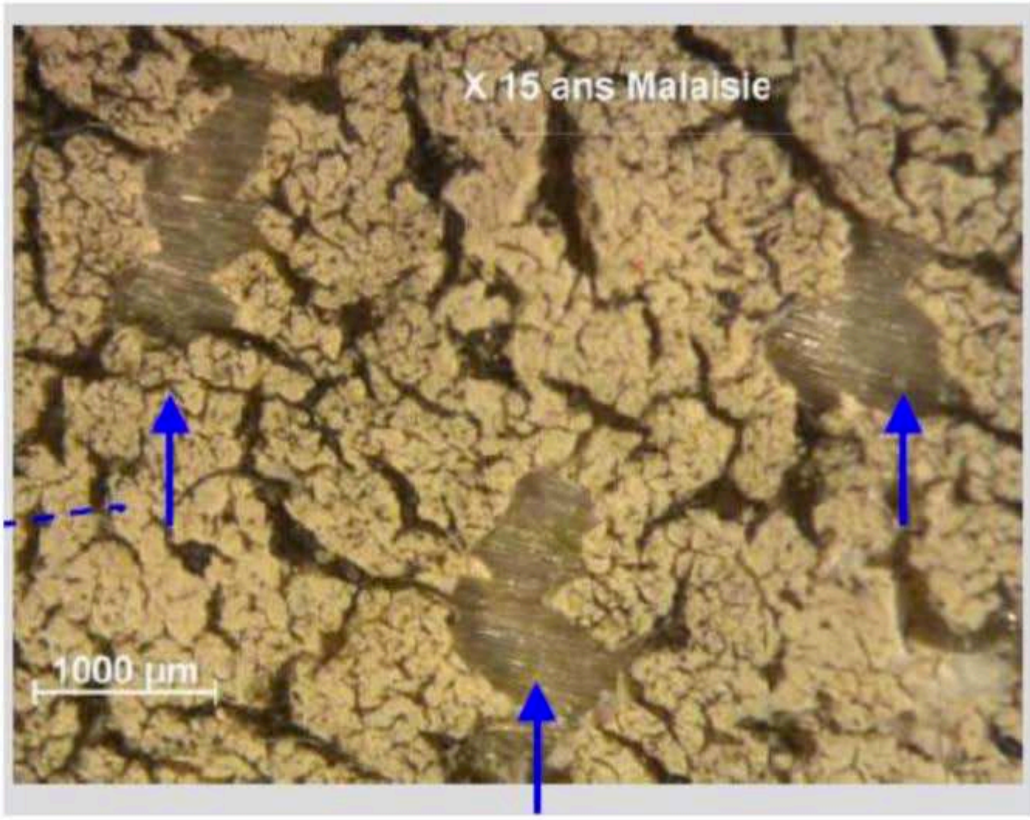
The tickness at the top of the yarn have been measured at the top of weft yarns on the front side. After 7500h, the 3 PRECONTRAINT membranes maintain at least 180 µm of protective coating which is higher than the initial thickness of the protective coating of the standard PVC/PVDF. This latter loose progressively the whole protective coating. The yarns are exposed directly to UV and present a high risk of UV degradation that may affect the mecanical properties.

	STANDARD PET/PVC/PVDF		PRECONTRAINT 1002 S2		PRECONTRAINT 1002 T2		PRECONTRAINT TX30-II	
	µm	relative	µm	relative	µm	relative	µm	Relative
0	130	100%	260	100%	220	100%	230	100%
3500 h	100	77%	200	77%	190	86%	220	95%
5000 h	30	23%	190	73%	190	86%	220	95%
7500 h	NAKED YARNS	0	180	69%	190	86%	200	86%

Average values - 3 samples



Standard PVC/PVDF **after 7500 h ageing** – Polyester yarns no more protected



Standard PVC/PVDF **after 15 years in MALAYSIA** - Polyester yarns no more protected

5. Measure of the evolution of tensile strength

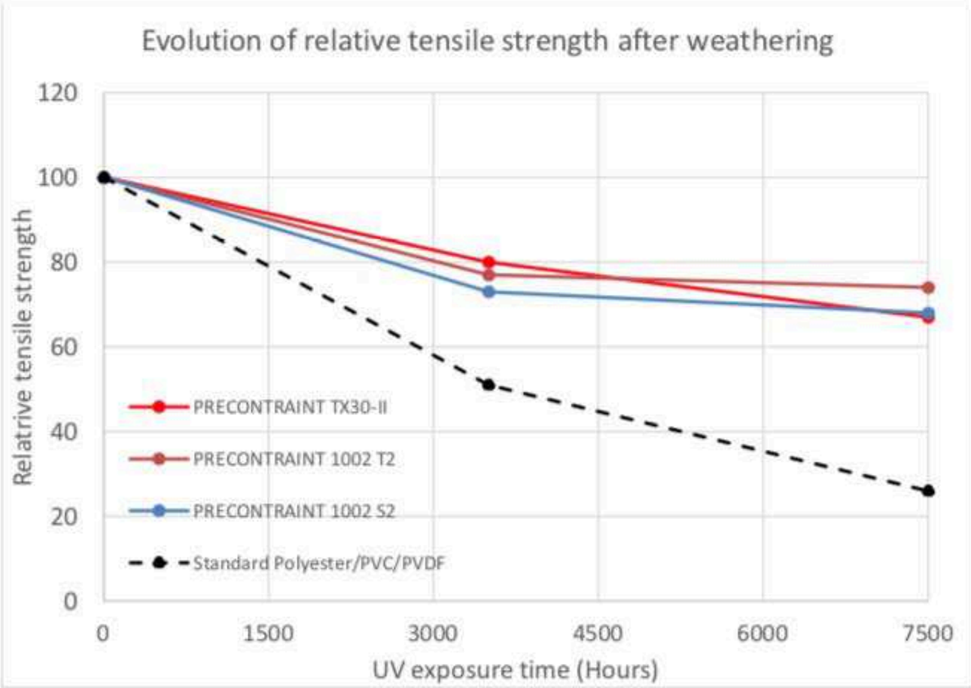
Tensile strength was measured according to EN ISO 1421. The test were conducted in weft direction.

		1002 S2	1002 T2	TX30-II	STANDARD PVDF Typ III
Before	**Initial**	494	464	436	560
After exposure	3500	362	358	348	288
	7500	338	344	292	144

Values in daN/5cm. Average of 2 tests.

		1002 S2	1002 T2	TX30-II	STANDARD PVDF
Before	**Initial**	100	100	100	100
After exposure	3500	73	77	80	51
	7500	68	74	67	26

Relative value in % of the inital value



Precontraint material maintains a level of tensile strength higher at least higher than 66% after 7500h of artificial ageing. In same condition the Standard PVC/PVDF maintain only 26% of its initial tensile strength. Those results can be explained and correlated with the microscopic observation that show :

- Low level of erosion and high thickness of coating after 7500h for the Precontraint membranes
- High level of erosion and lack of yarns protection due too lower initial coating thickness and higher erosion at the surface of the standard PVC/PVDF.
-

6. CONCLUSION

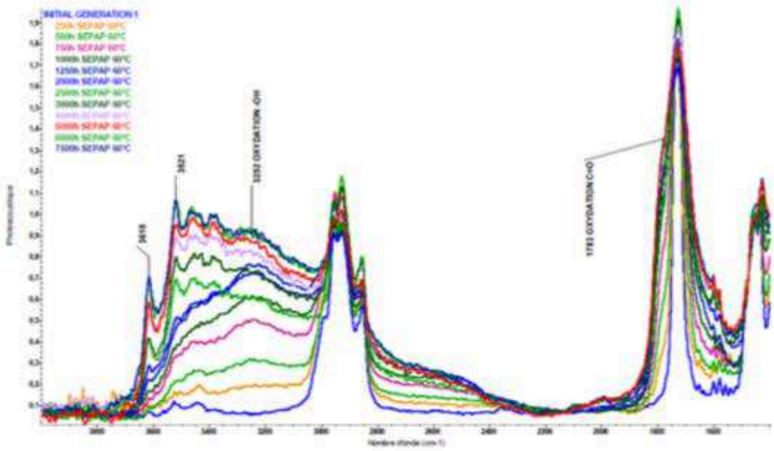
The results obtained after artificial ageing are coherent and well correlated with natural ageing.

After 7500h (eq 30 years in florida), the 3 PRECONTRAINT membranes maintains more than 66% of the initial tensile strength while the standard PVC/PVDF maintain only 26%.

After 7500h (eq 30 years in florida), the surface aspect of the PRECONTRAINT TX30 is still very smooth and almost without any microcrack. PRECONTRAIN 1002 T2 still maintain an acceptable level of cracks while PRECONTRAINT 1002 S2 and Standard PVDF exhibit a very high level of cracks that start early.

ANNEXE 1

CHEMICAL OXIDATION at the surface of Polyester/PVC membranes
Spectrométrie IRTF-PAS détection acoustique (surface ~10 à 15µm)



Augmentation de l'absorbance à 1780cm-1 vs durée à **vitesse d'oxydation**

ANNEXE 2

CORRELATION WITH EXPERIENCE FEEDBACK –

Standard PVC/PVDF after 15 years malaysia	
 	No more protection at top of weft yarns. High progress of microcracks Loss of flexibility

weathering study, page 9

ANNEXE 3

TENSILE STENGTH AFTER NATURAL AGEING / PROJECTS

PROJECT REFERENCES	DATE OF INSTALLATION	TIME IN USE	RESIDUAL TENSILE STRENGTH VALUES	
AIRBUS AIRCRAFT HANGARS Bremen/Germany Précontraint® 1302	1982	**22 Years**	Warp: 97% Weft: 84%	
EXHIBITION HALLS Port Gentil/Gabon Précontraint® 1302	1982	**18 Years**	Warp: 86% Weft: 76%	
AIRPORT TERMINAL Lyon/France Précontraint® 1202	1989	**16 Years**	Warp: 78% Weft: 98%	
HALLES D'AVIGNON FACADE Avignon/France Précontraint® 392	1994	**12 Years**	Warp: 90% Weft: 80%	
WALKWAY COVER Paris/France Précontraint® 1002	1989	**11 Years**	Warp: 97% Weft: 86%	
RADISSON HOTEL Cape Town/South Africa Précontraint® 1002 Fluotop	1996	**10 years**	Warp: 99% Weft: 100%	
UNITED AIR LINE HANGAR Miami/USA Précontraint® 1002 Fluotop	1999	**6 Years**	Warp: 97% Weft: 100%	

Computer programs:

Form finding and statical analysis of all the projects described in this document was calculated with EASY, and drawings and rendering with Rhino programs.

A/ EASY description: The 4 Modules

Easy is a software for the integrated planning and calculation of lightweight surface structures. The program system is composed of 5 modules:

Easy.Form: Formfinding is a process to evaluate the geometry of a stressed surface: it is only required for lightweight surface structures, because a separation of geometry and physical behavior isn't possible. The geometry of conventional structures can be defined by an architect at the drawing-board. In Easy.Form a stress harmonic surface will be configured under consideration of user-defined conditions.

Easy.Stat: The function of the static analysis is to materialize the surfaces created by the Formfinding process (i.e. To assign material properties to the membrane), to consider the external causes resulting of the statutory provisions (e.g. Self-weight, wind and snow loads) and to calculate the inner stresses and deformations: thus the stability of the overall structure can be verified.

Easy.Cut: The cutting pattern generation is a task which is well known in a similar way from map projection. The map projection doctrine treats the projection of the earth into plane maps. In the cutting pattern generation of fabrics the three-dimensional surfaces being in equilibrium are also projected into a plane; here too unavoidable aberrations should become as small as possible.

Easy.Beam: Only a combined calculation of beam structures together with prestressed textile surfaces (respectively cable nets or foils) guarantees an efficient and optimal utilization of all cross-sections. The division of static systems into subsystems for lightweight surface structures with non-linear behavior gets wrong results. The simultaneous calculation of the complete system in Easy.Beam makes allowance for this circumstance and optimizes resources.

B/ Rendering in this study was all done with program RHINO

C/ Steel structure calculation was all done with RSTAB from DLUBAL co

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- Serge Ferrari, Consistence appearance in transparency
- Serge Ferrari Life Test Report
- Serge Ferrari Weather Study

List of figures, charts, diagrams