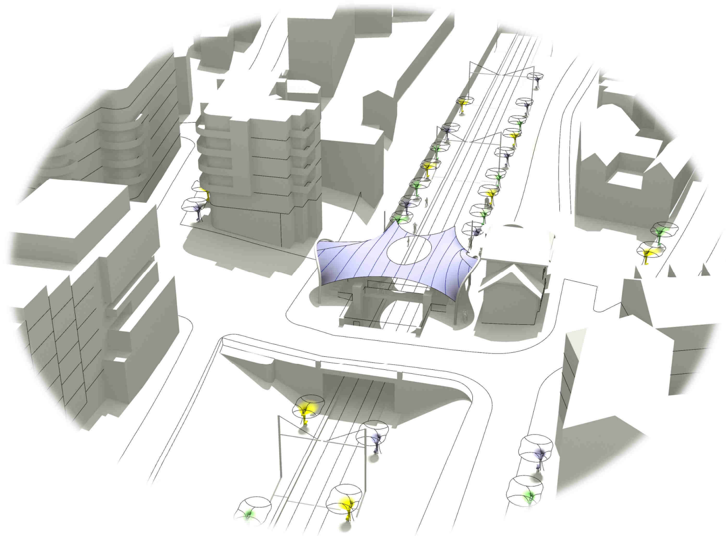
A new cover for the train station Meudon Val-Fleury



Master-Thesis

A thesis submitted in partial fulfillment
of the requirements for the degree of

Master Membrane Structures

submitted to

Anhalt University of Applied Sciences

Faculty of Architecture,
Facility Management and Geo Information

by

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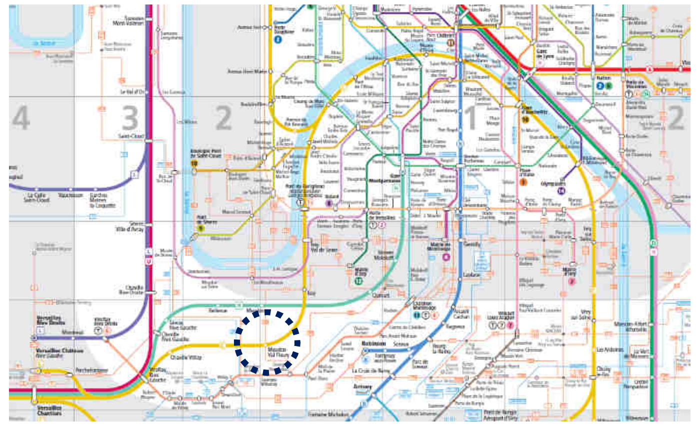
Agradeço a Alice pelo seu apoio.

Contents

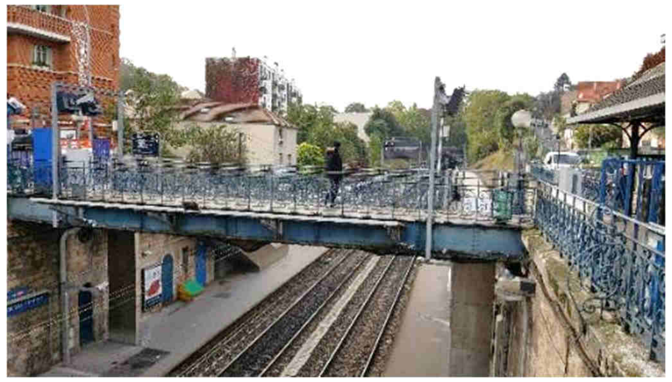
1 - Introduction

The aim of this project is to design and study the feasibility of a new textile structure dedicated to the protection of passengers at the Meudon Val-Fleury train station, five kilometers southwest from the Paris ring road. Line C of the regional express network that passes through this station has 84 stopping points. It is borrowed by 140 millions travelers a year. 530 trains run on the line every day. The operator estimates that around 5000 people get on the train in Meudon on business days, half during rush hours at the beginning oft he day and at the end.

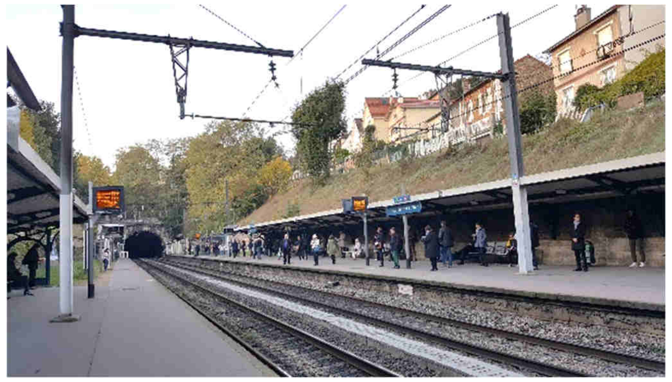


The station was built around 1900. It is now at the heart of a dense residential urban fabric built mainly in the twentieth century, with some local shops concentrated around the site. A two-lane bridge spans the railway line at the northeastern end of the platform. At the other extremity, the line goes through a three kilometers long tunnel to Versailles. There are two parking lots at each sides of the station, as well as several bus stops and an electric car rental site.

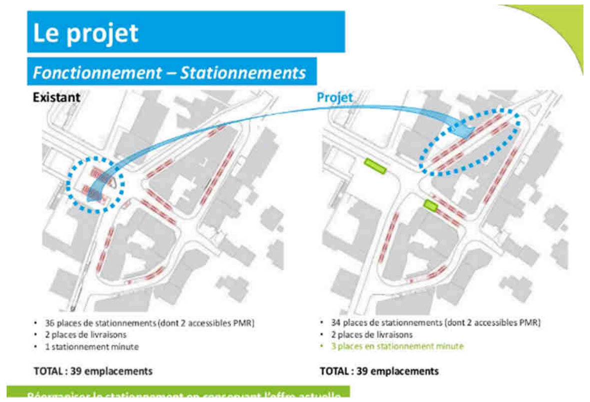
The railway is around 6 m below the level of the roadway. Platforms are both 200 meters long and accessible by an escalator from a pedestrian bridge. The soil along them is green and forty five degrees inclined. At the top of the slope, some flat surfaces are used as vegetable gardens. At the bottom, platforms are protected from ground movements by heavy masonry walls. Catenaries supports span the railway every 50 m. A minimum distance of three meters must be respected around the electric cables as well as a specific gauge above the rails, for safety reasons.

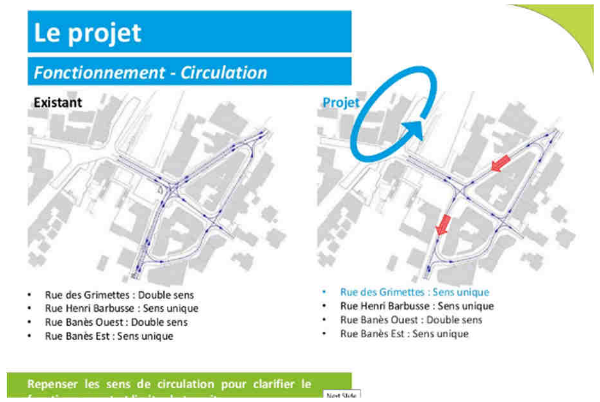


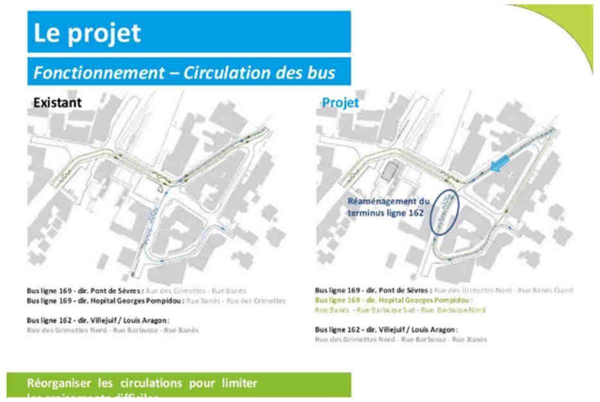
The current platform coverage extends eighty meters in the direction of Paris and forty in the opposite direction, where fewer passengers are used to waiting for the train. It is made of corrugated metal sheets that protect a half-width of the platform and are fixed on riveted trusses anchored in masonry walls. When trains are long, glazed shelters usefully supplement the coverage at the end of platforms. Furniture mainly consists of seats and nameplates. A linear lighting has been fixed under the coverage. Rain water is channeled through a large gutter.

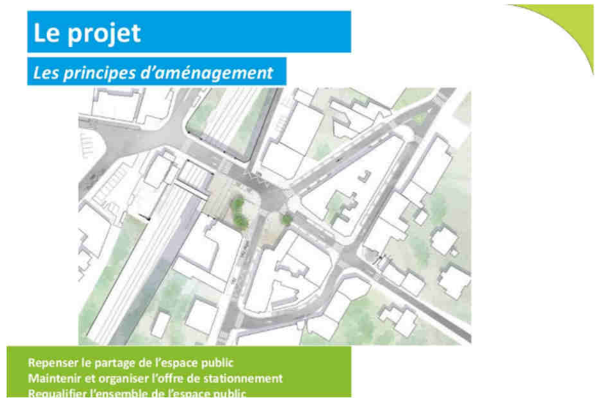


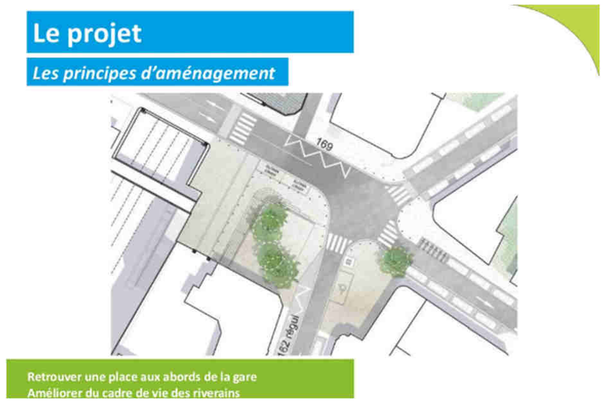
A recent urban project, presented in June 2018 to the citizens, propose to rearrange the traffic of cars and buses in order to transform the square Henri Brousse into a pedestrian and green area, in front of the eastern access to the station.











(www.meudon.fr)

Taking into account all these elements, the membrane project proposed in this thesis is to:

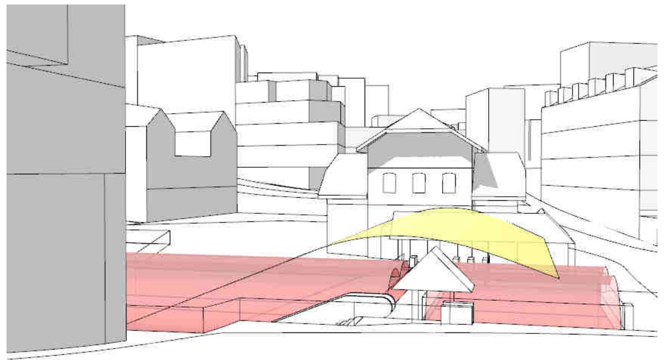
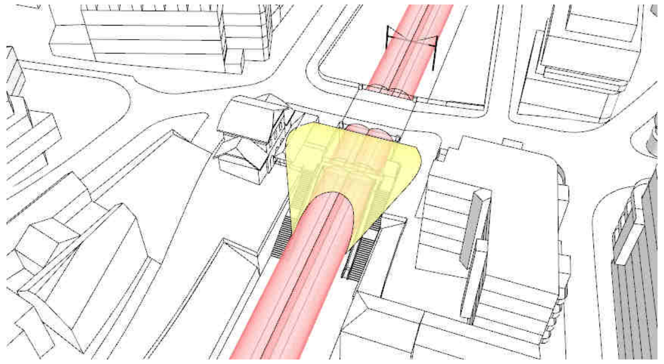
- erect a main structure above stairs, escalators and pedestrian bridge to:
  - protect passengers from rain, snow (even ice) and sun while accessing or leaving platforms;
  - further point out the station from the street;
- replace the coverages along the platform by several secondary transparent / translucent / colored membranes held by light structures.

This thesis contains a description of the design process, a structural dimensionning of main membrane, a way to pattern and implement it, some connection details and a cost estimation.

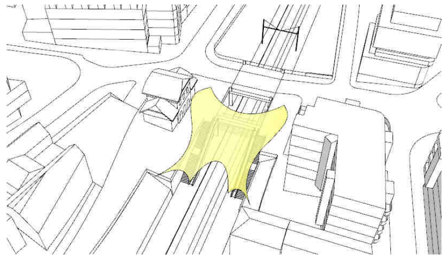
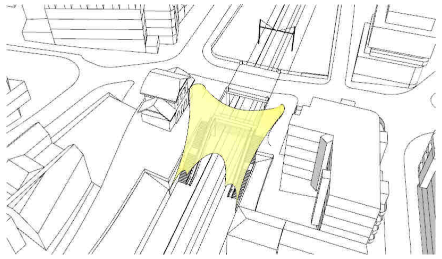
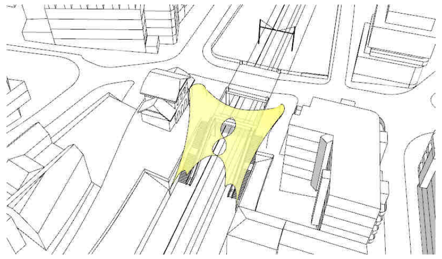
2 - Design process

2.1 - Main membrane

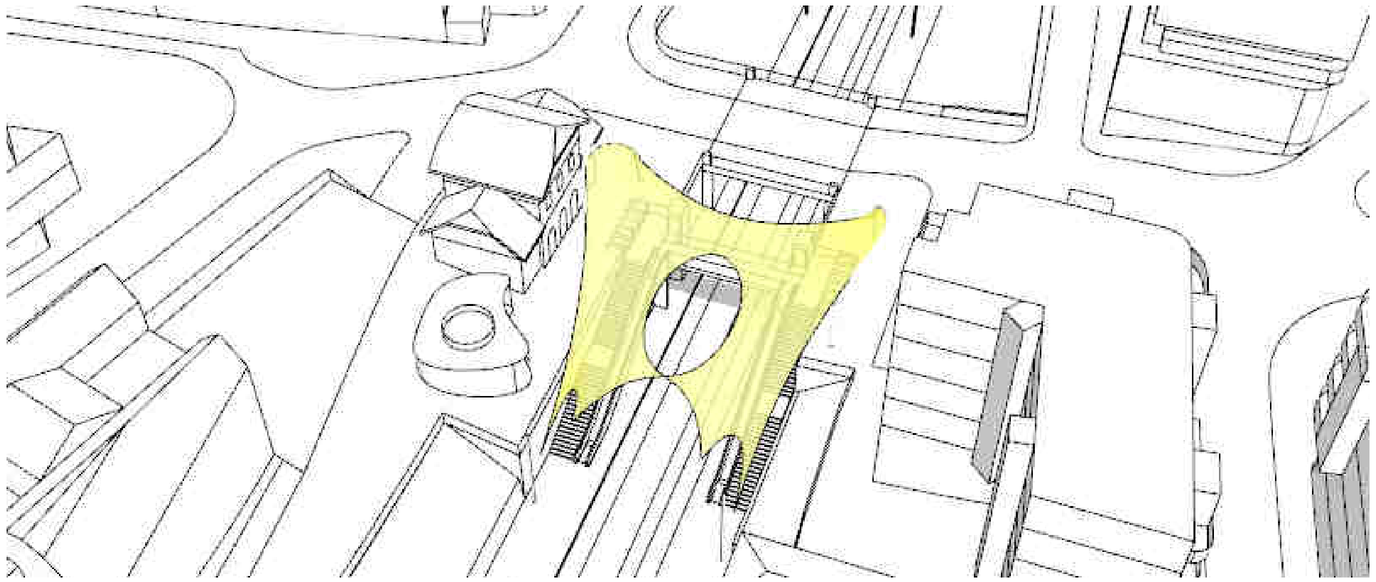
Initial step was to create a curved continuous section above areas to be covered. The protection distance around catenaries generates an elliptical cutout.

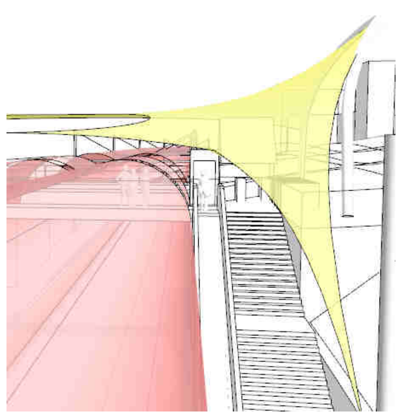
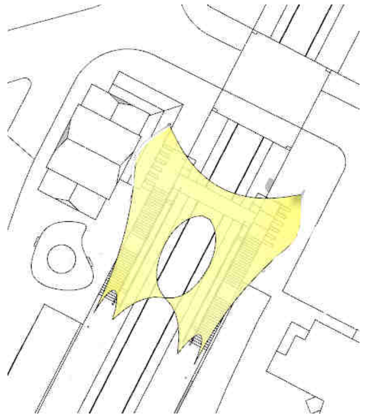
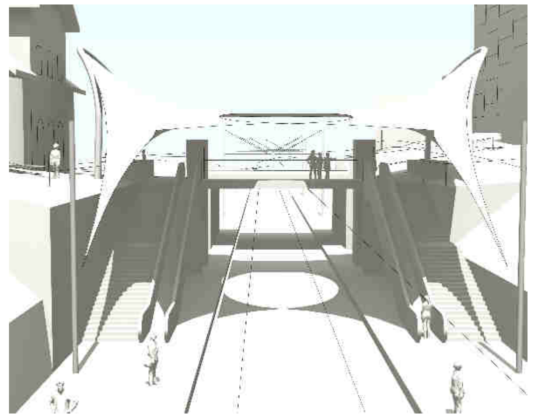
Once form-finded, this surface had to be connected to the ground not to collapse nor fly away. Complementary anchor points were necessary to improve the protection down the stairs. Huge arches were added to support the membrane above the entrances and proved for effectively signaling them thanks to wide sections. Then a double eye-looped shape was inserted in the middle of the membrane to reduce the amount of distributed loads, without reducing the protection.

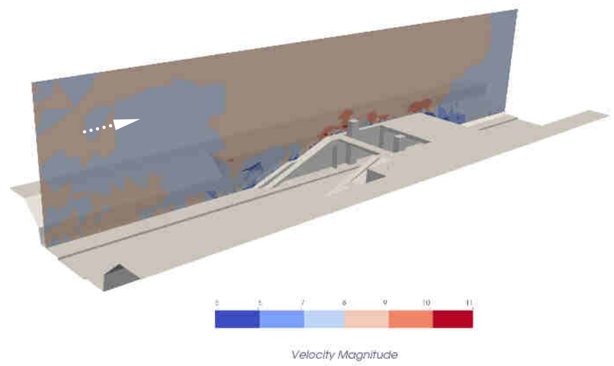
Finaly a single one was considered more efficient. Some equipements were modified or added, like a new curved newspaper stand or lifts on both platforms for people with reduced mobility, as in other stations of C line.

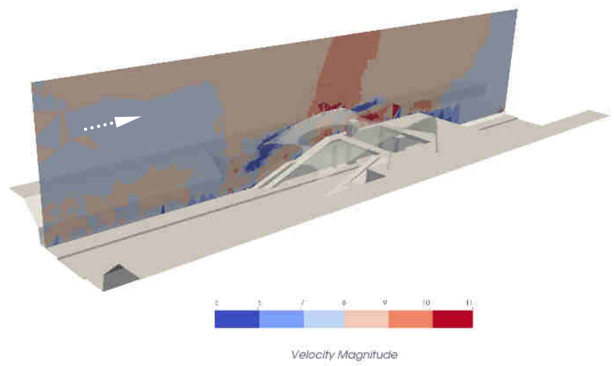


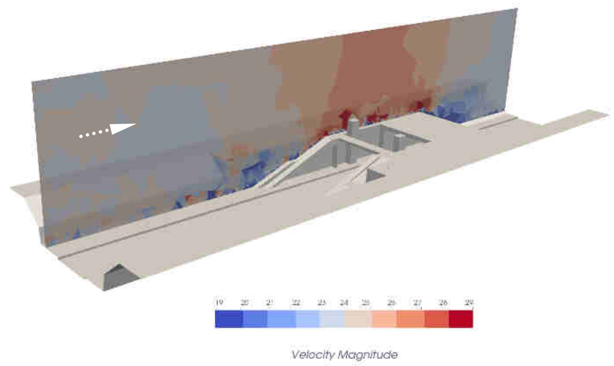
After calculations, it was manually checked that, even loaded with snow or wind, the membrane still does not fit in the safety distance around catenaries, thanks to a permanent gap of around one meter. A vertical view and a shaded perspective view (beginning of July, 14:00) show that the protection against rain, snow, ice and sun is correct except for few steps down the stairs.

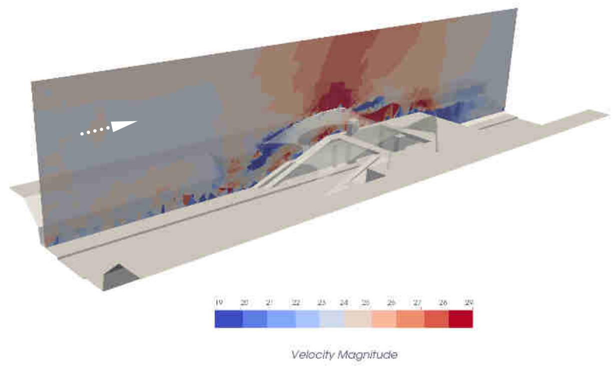




Buildings around the project have not been integrated in wind calculation models to avoid excessive complexity. Thanks to their density, we can reasonably consider that transversal winds will have no really impact on passenger comfort. But longitudinal flows along the rails create an acceleration above the membrane that can be important and it behaves like the extrado of a wing, as visible on next figures. For passengers on the stairs, longitudinal flows are not really modified neither at a usual maximum speed of 8 m/s (less than ten days per month during a quarter of a year and less than five days during the rest of the time, according to www.meteoblue.com) nor the extremum of 24 m/s (estimated by Eurocode).

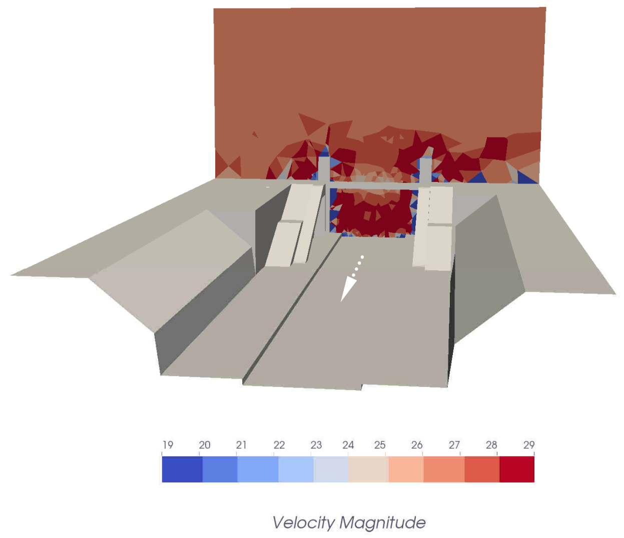


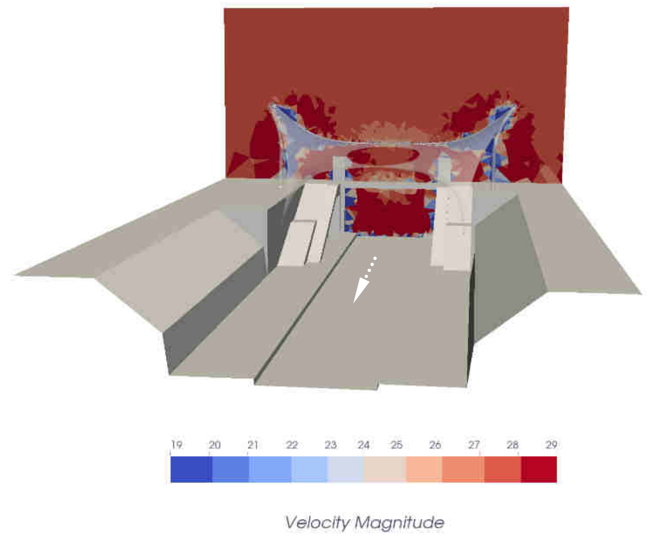




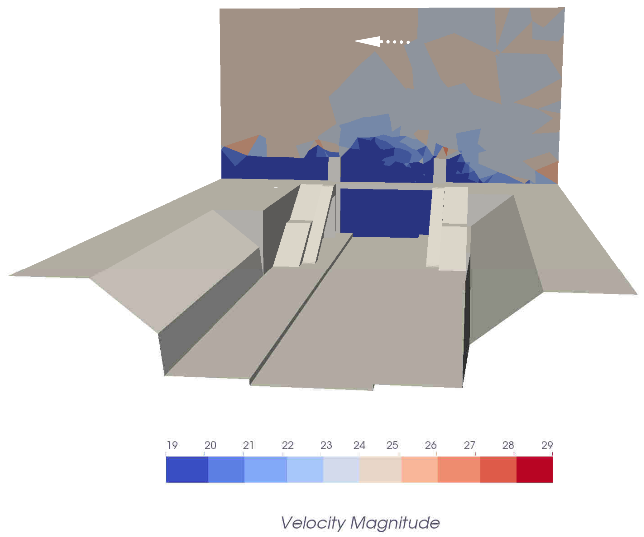


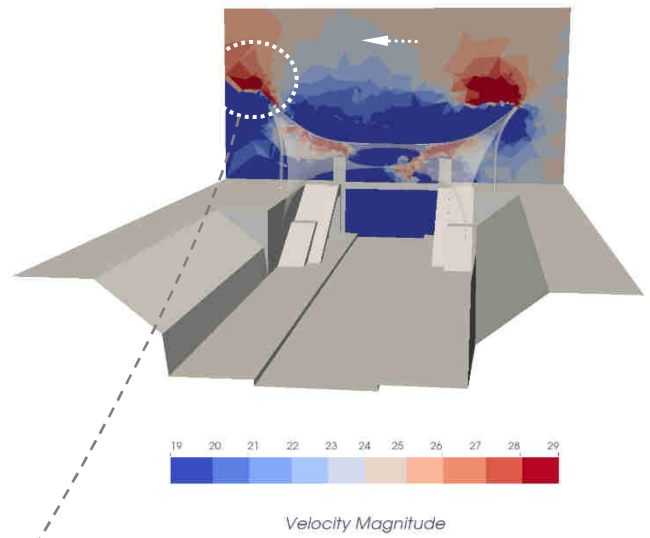
Longitudinal flows have no significant impact on buildings that are nearby, as visible below.

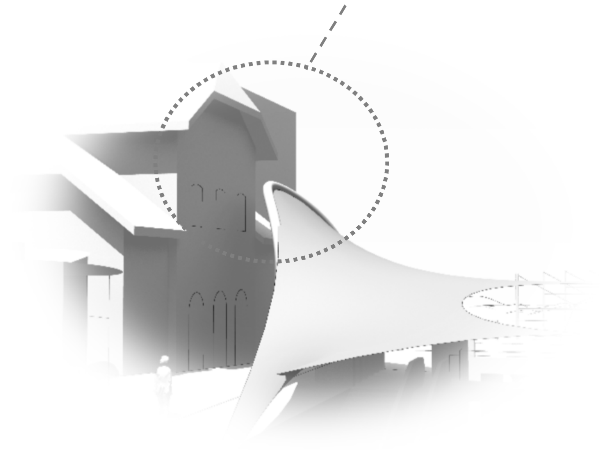




But transversal flow from east could be further investigated to determine whether coverage of current station needs to be strengthened or not.

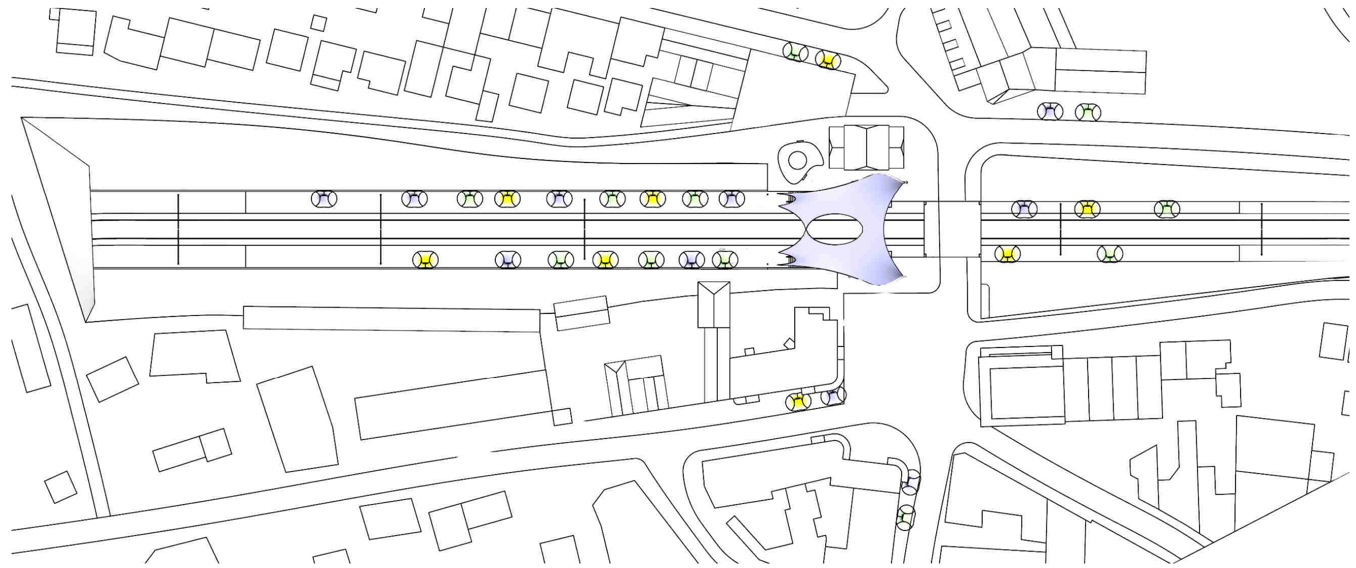


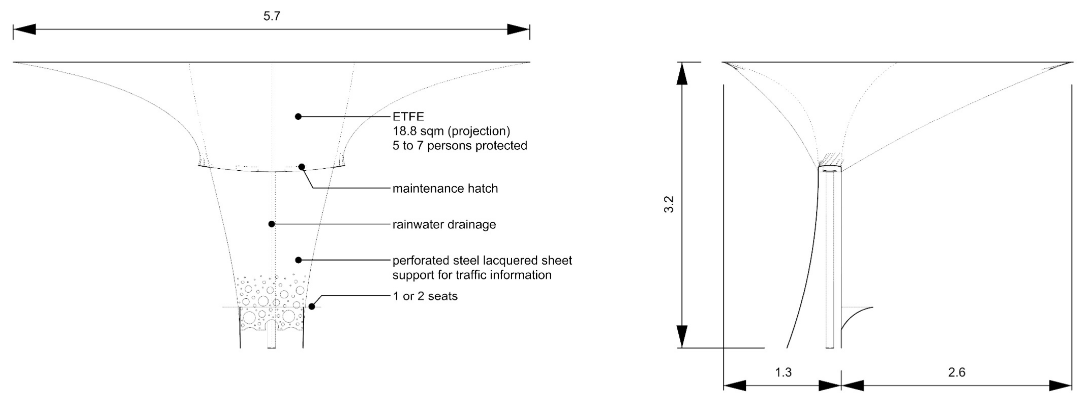


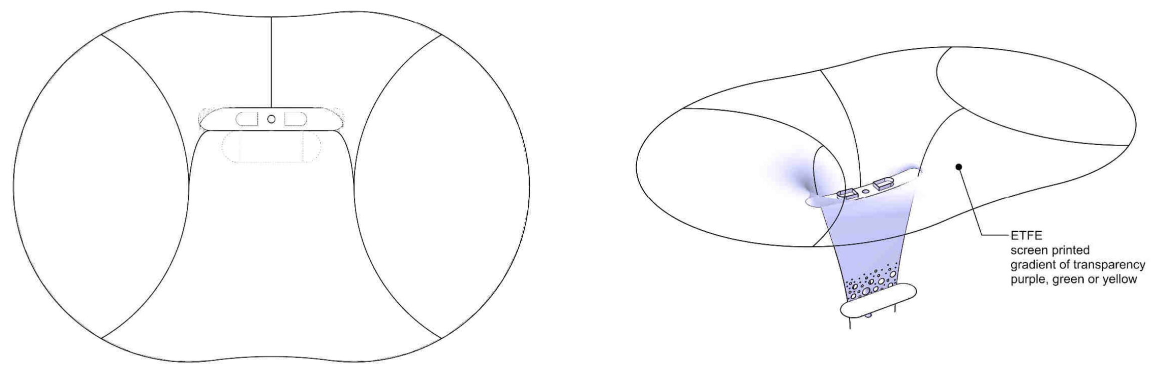


2.2 - Secondary membranes

Transparent / translucent / colored membranes replacing current continuous protections, irregularly added along the platforms, have been designed to protect the passengers too. The configuration can cover up to eighty persons in direction of Paris and sixty in direction of Versailles, without counting the passengers protected by the main membrane and the station. Rainwater is collected through buried pipes. Some secondary membranes are used as bus stop along the streets, two by two.

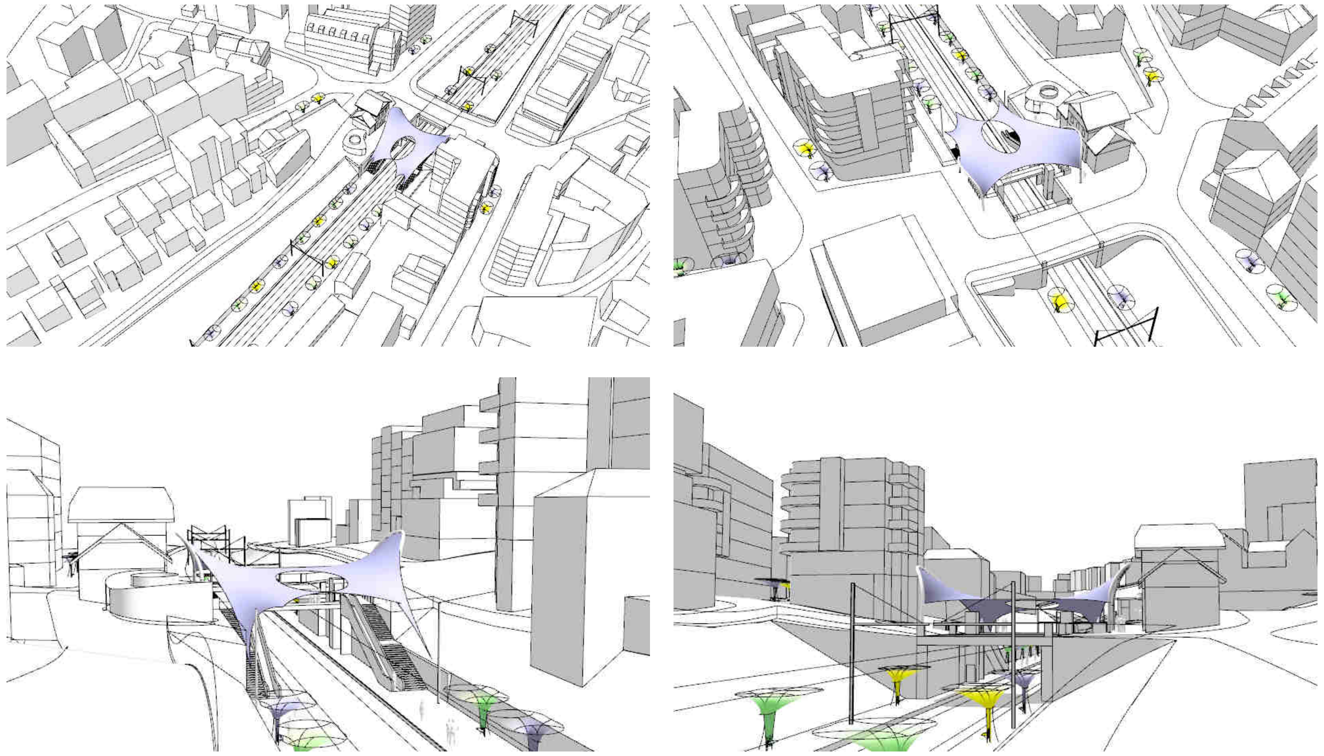




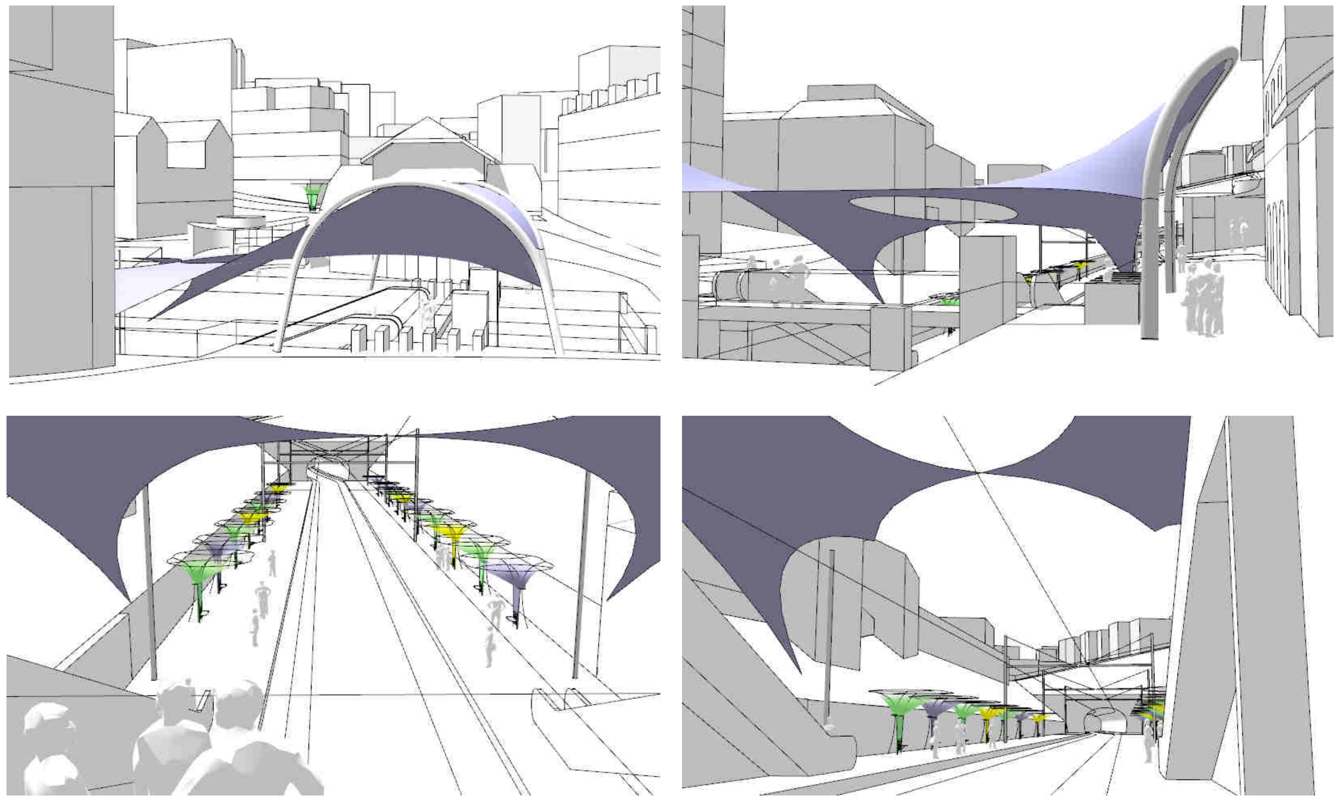


3 - Perspective views

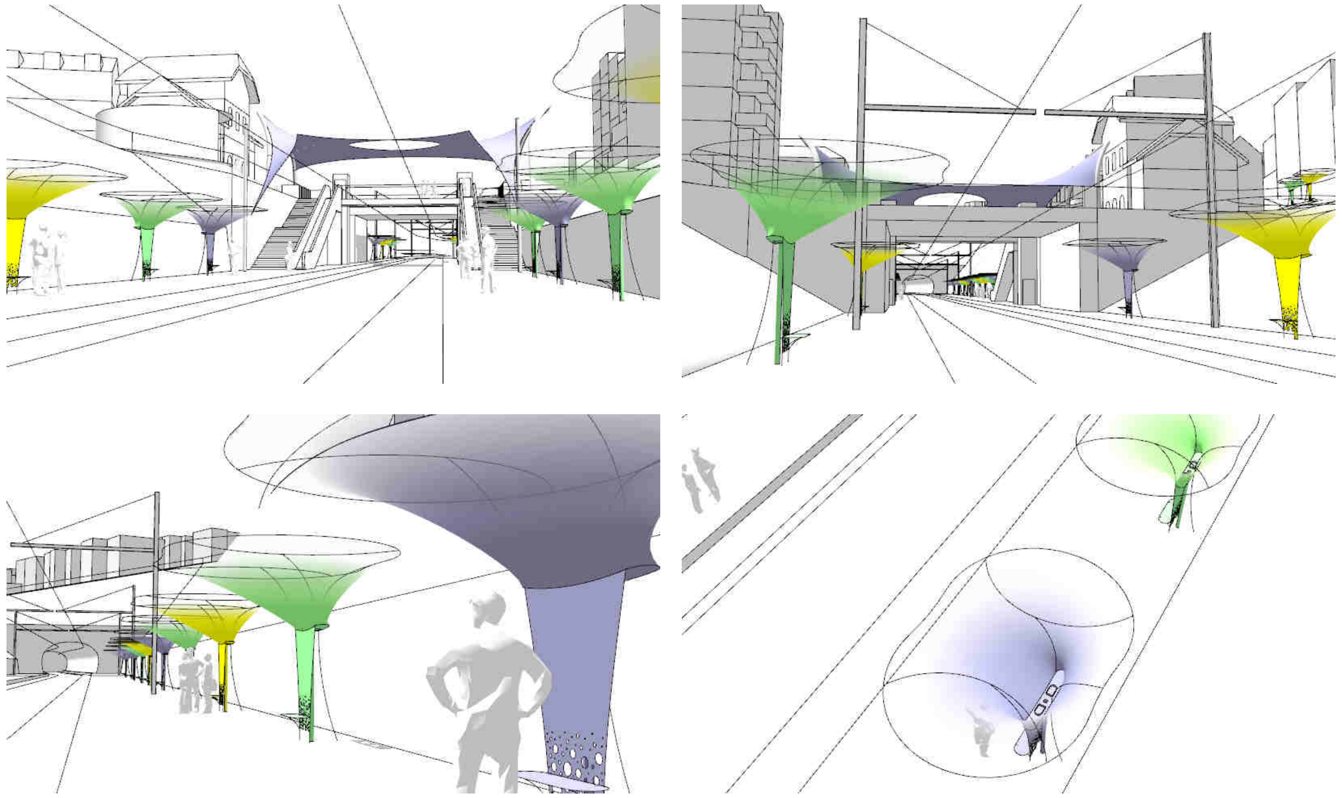
3.1 - Far



3.2 - Near



3.3 - Platforms



4 - Dimensioning

4.1 - General informations

Basic data	
Location	Meudon (92), France
Englobing area	30.4 m x 25.4 m
Material of primary structure	S355 steel
Utilization of the membrane construction	Protection of passengers against climatic aggressions
Absolute altitude above sea level	67.5 m (platforms level)
Maximum height of vertex above the ground	13.7 m (above platforms level)
Pitch of the roof	0 to 75°

Membrane		
Material	PVC coated polyester fabric Ferrari Precontraint 1502 or equivalent	
Tensile strength $F_{u,k}$	Warp direction : Weft direction :	200 kN/m 160 kN/m
E-Modulus	Warp direction : Weft direction :	787 kN/m 725 kN/m

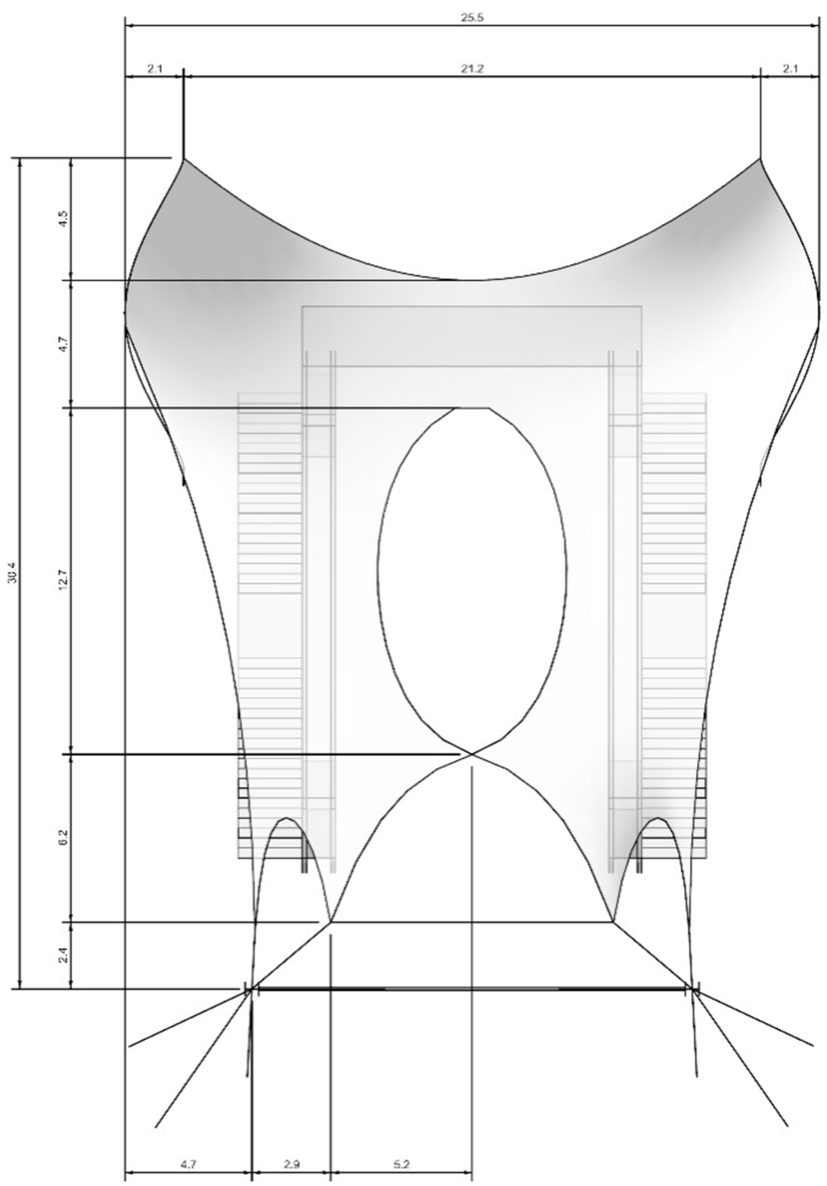
Cables	
Cable-type and material	Spiral strand cables - Stainless steel
Cable-amounts	111 m
Cable-fittings	Fork connectors with adapters and threated fittings

Softwares	
Membrane	IxCube 4-10, Rhino
CFD	Code Saturne
Steel	Robot Structural Analysis, Inventor

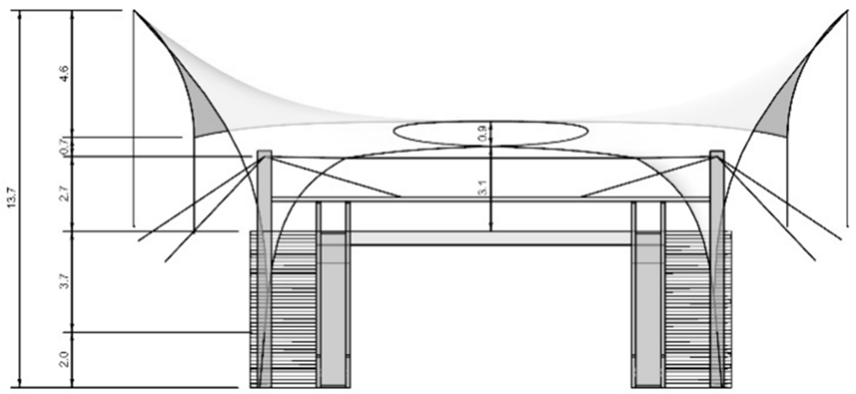
Units	
Forces	[kN]
Distributed forces	[kN/m]
Dimensions	[m] or [mm]

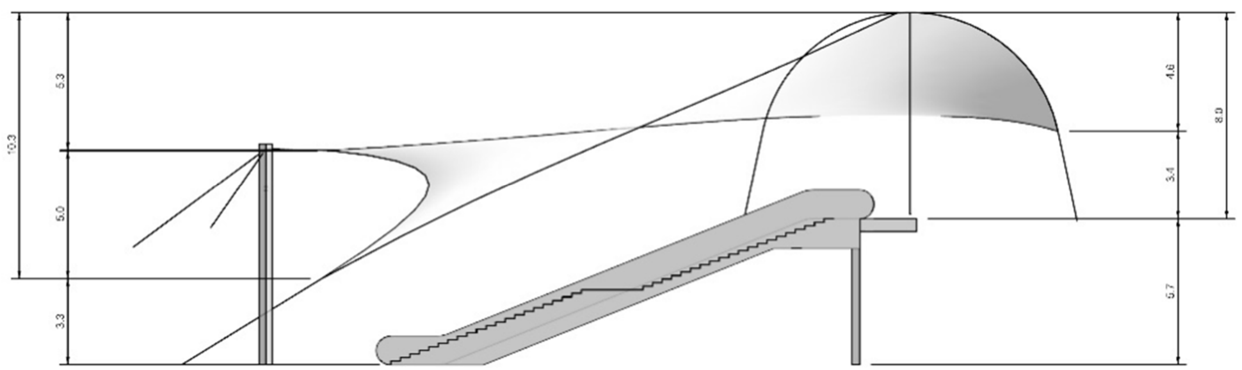
4.2 - Geometry

Ground plan view



Side elevations





4.3 - Load assumptions

Self weight

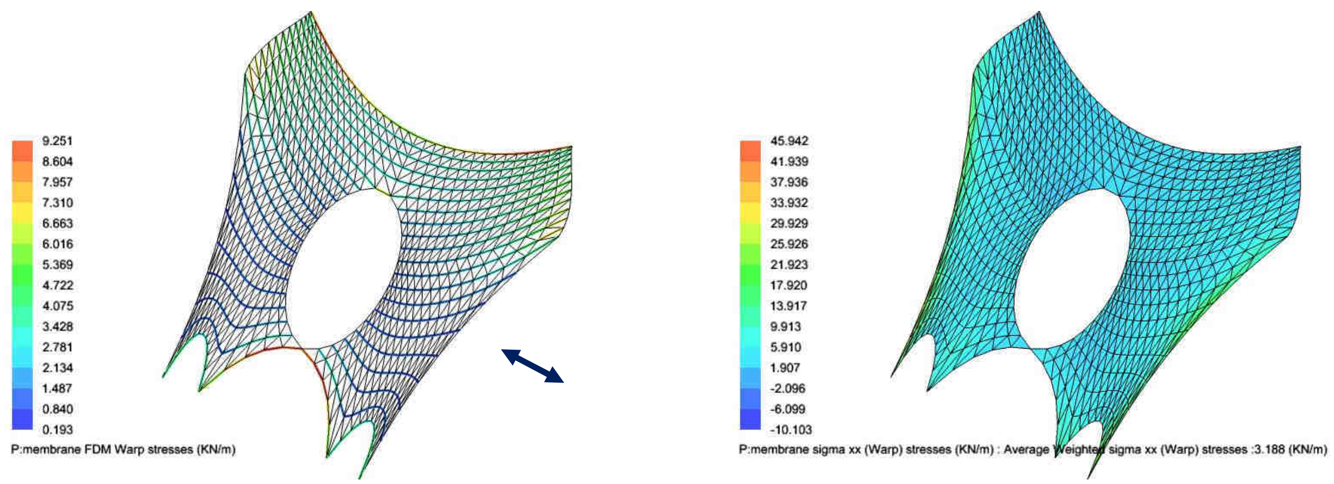
Applied code:

Eurocode 1 - EN 1991-1-1 : 2003

Actions on structures - Part 1-1: General actions

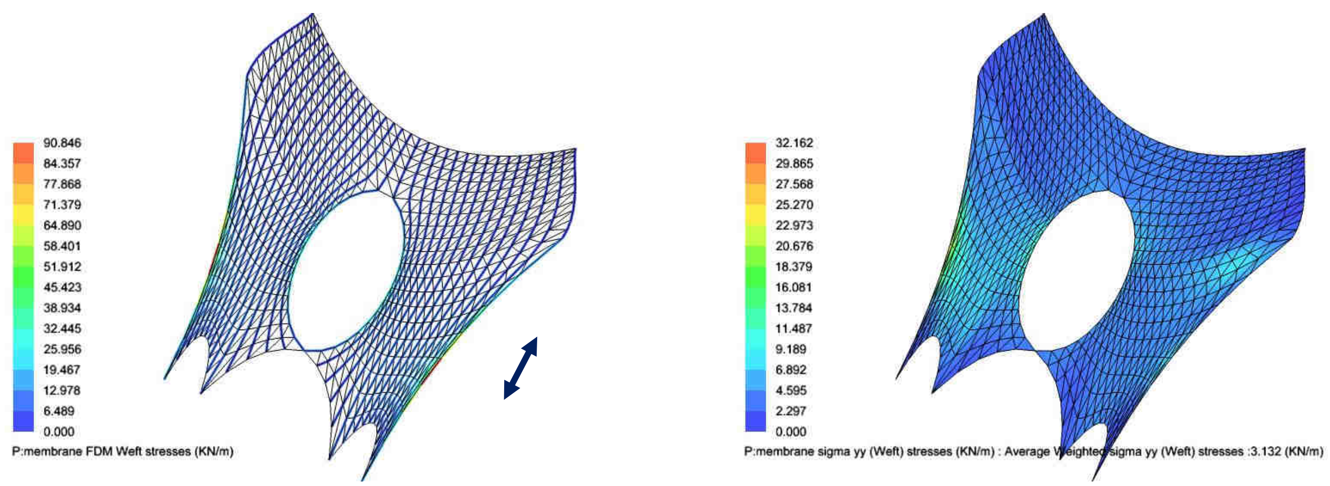
Membrane:	1500	g/m2
Steel :	7800	kg/m3

Pre-stress



C value: 3 kN/m - Average warp stress: 3.2 kN/m

Pre-stress distribution in membrane, warp direction

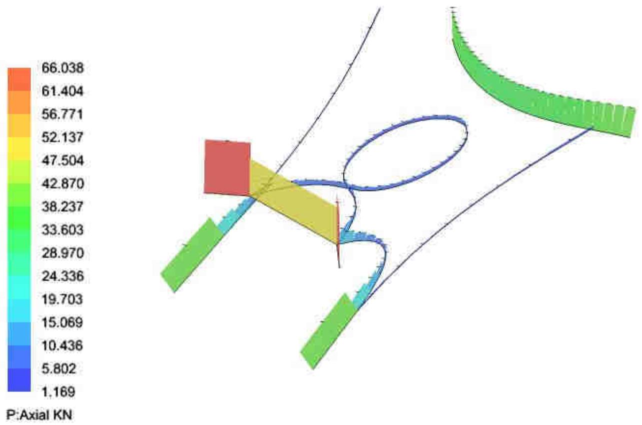


C value: 3 kN/m - Average weft stress: 3.1 kN/m

Pre-stress distribution in membrane, weft direction

Node A	Node B	C Value KN/m	Pre-stress KN
27	28	4,51E+00	4,67E+01
30	27	1,75E+01	6,60E+01
28	31	1,75E+01	6,60E+01
32	26	5,28E-01	1,88E+00
33	32	4,69E-01	1,37E+00
34	33	4,53E-01	1,21E+00
35	34	4,51E-01	1,17E+00
36	35	4,50E-01	1,20E+00
37	36	4,55E-01	1,32E+00
38	37	4,74E-01	1,59E+00
12	38	5,23E-01	2,28E+00
39	0	4,48E+01	3,69E+01
40	39	4,48E+01	3,64E+01
41	40	4,47E+01	3,59E+01
42	41	4,47E+01	3,54E+01
43	42	4,47E+01	3,49E+01
44	43	4,47E+01	3,45E+01
45	44	4,47E+01	3,40E+01
46	45	4,47E+01	3,36E+01
47	46	4,47E+01	3,32E+01
48	47	4,47E+01	3,29E+01
49	48	4,47E+01	3,26E+01
50	49	4,47E+01	3,25E+01
51	50	4,47E+01	3,23E+01
52	51	4,47E+01	3,22E+01
53	52	4,48E+01	3,22E+01
54	53	4,48E+01	3,22E+01
55	54	4,48E+01	3,22E+01
56	55	4,47E+01	3,22E+01
57	56	4,47E+01	3,23E+01
58	57	4,47E+01	3,25E+01
59	58	4,47E+01	3,26E+01
60	59	4,47E+01	3,29E+01
61	60	4,47E+01	3,32E+01
62	61	4,47E+01	3,36E+01
63	62	4,47E+01	3,40E+01
64	63	4,47E+01	3,45E+01
65	64	4,47E+01	3,49E+01
66	65	4,47E+01	3,54E+01
67	66	4,47E+01	3,59E+01
68	67	4,48E+01	3,64E+01
25	68	4,48E+01	3,69E+01
69	29	5,28E-01	1,88E+00
70	69	4,69E-01	1,37E+00
71	70	4,53E-01	1,21E+00
72	71	4,51E-01	1,17E+00
73	72	4,50E-01	1,20E+00
74	73	4,55E-01	1,32E+00
75	74	4,74E-01	1,59E+00
13	75	5,23E-01	2,28E+00
76	26	9,37E+00	1,87E+01
77	76	9,17E+00	1,32E+01
78	77	9,00E+00	9,39E+00
79	78	8,90E+00	6,63E+00
80	79	8,84E+00	4,89E+00
81	80	8,81E+00	4,43E+00
82	81	8,76E+00	5,33E+00

Node A	Node B	C Value KN/m	Pre-stress KN
83	82	8,72E+00	7,17E+00
84	83	8,71E+00	9,84E+00
27	84	8,79E+00	1,38E+01
85	27	4,28E+00	1,02E+01
86	85	4,27E+00	7,64E+00
87	86	4,28E+00	6,27E+00
88	87	4,28E+00	5,72E+00
89	88	4,30E+00	6,02E+00
90	89	4,30E+00	6,02E+00
91	90	4,28E+00	5,72E+00
92	91	4,28E+00	6,27E+00
93	92	4,27E+00	7,64E+00
28	93	4,28E+00	1,02E+01
94	28	8,79E+00	1,38E+01
95	94	8,71E+00	9,83E+00
96	95	8,72E+00	7,17E+00
97	96	8,76E+00	5,33E+00
98	97	8,81E+00	4,43E+00
99	98	8,84E+00	4,89E+00
100	99	8,90E+00	6,63E+00
101	100	9,00E+00	9,39E+00
102	101	9,17E+00	1,32E+01
29	102	9,37E+00	1,87E+01
89	103	4,29E+00	5,13E+00
103	104	4,25E+00	4,45E+00
104	105	4,22E+00	4,25E+00
105	106	4,21E+00	4,22E+00
106	107	4,19E+00	4,22E+00
107	108	4,18E+00	4,21E+00
108	109	4,17E+00	4,17E+00
109	110	4,17E+00	4,10E+00
110	111	4,17E+00	4,03E+00
111	112	4,17E+00	3,95E+00
112	113	4,17E+00	3,88E+00
113	114	4,18E+00	3,86E+00
114	115	4,18E+00	3,90E+00
115	116	4,20E+00	4,09E+00
116	117	4,22E+00	4,58E+00
117	118	4,29E+00	5,31E+00
118	119	4,22E+00	4,58E+00
119	120	4,20E+00	4,09E+00
120	121	4,18E+00	3,90E+00
121	122	4,18E+00	3,86E+00
122	123	4,17E+00	3,88E+00
123	124	4,17E+00	3,95E+00
124	125	4,17E+00	4,03E+00
125	126	4,17E+00	4,10E+00
126	127	4,17E+00	4,17E+00
127	128	4,18E+00	4,21E+00
128	129	4,19E+00	4,22E+00
129	130	4,21E+00	4,22E+00
130	131	4,22E+00	4,25E+00
131	132	4,25E+00	4,45E+00
132	89	4,29E+00	5,13E+00
133	26	1,46E+01	3,69E+01
134	29	1,46E+01	3,69E+01



Pre-stress distribution in cables

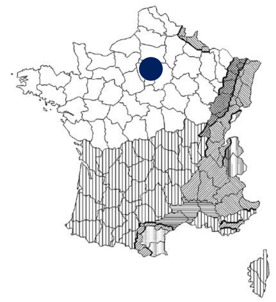
Snow

Applied code:

Eurocode 1 - EN 1991-1-3 : 2004

Actions on structures - Part 1-3: General actions

Location: 92 Hauts de Seine, altitude (67.5+13.7=) 81.2 m - Snowzone A1

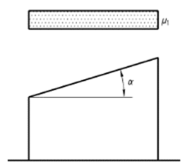


Régions :	A1	A2	B1	B2	C1	C2	D	E
Valeur caractéristique (S_k) de la charge de neige sur le sol à une altitude inférieure à 200 m :	0,45	0,45	0,55	0,55	0,65	0,65	0,90	1,40
Valeur de calcul (S_{Ad}) de la charge exceptionnelle de neige sur le sol :	—	1,00	1,00	1,35	—	1,35	1,80	—
Loi de variation de la charge caractéristique pour une altitude supérieure à 200 :	Δs_1							Δs_2

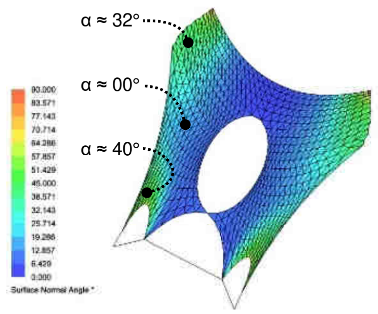
(charges en KN/m²)

Altitude A	Δs_1	Δs_2
de 200 à 500 m	A/1000 – 0,20	1,5 A/1000 – 0,30
de 500 à 1000 m	1,5 A/1000 – 0,45	3,5 A/1000 – 1,30
de 1000 à 2000 m	3,5 A/1000 – 2,45	7 A/1000 – 4,80

Snow map and characteristic load



	$0° \le \alpha \le 30°$	$30° < \alpha < 60°$	$\alpha \ge 60°$
μ_1	0,8	0,8(60 – α)/30	0,0

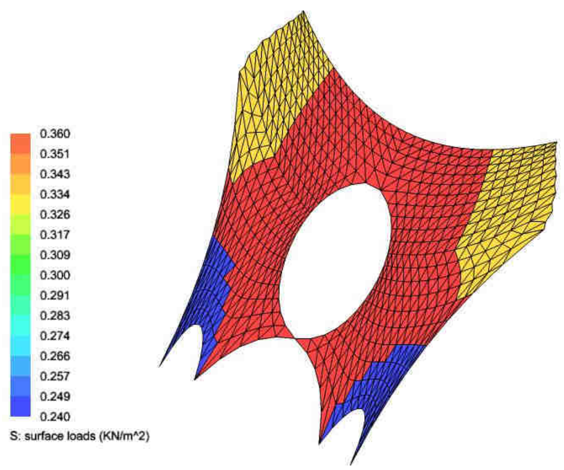


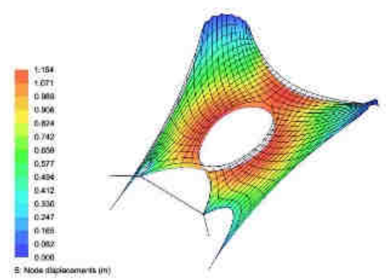
Principle of calculation and slopes selected

Snowzone	A1		
S_k	0,45		
α	*middle* 0°	*top* 32°	*bottom* 40°
μ_1	0,8	0,7	0,5
S_1	0,36	0,33	0,24

top: dx = 143.372 dy = -66.673 dz = -100.000 => 32°

bottom: dx = 83.129 dy = 86.240 dz = 100.000 => 40°





Load applied and corresponding deflection

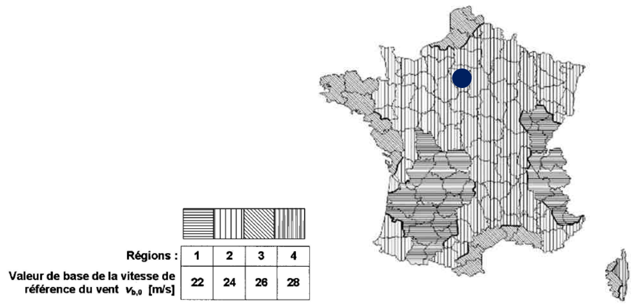
Wind: peak pressure

q_p is calculated in order to check C_p values after CFD analysis

Reference code:

Eurocode 1 - EN 1991-1-4 : 2005

Actions on structures - Part 1-4: General actions



	Category I Rough open sea, […], even, flat country
	Category II Farmland with boundary hedges, […], occasional small farm structures
	Category III Suburban or industrial areas and permanent forests
	Category IV Urban areas, in which at least 15% of the surface is covered with buildings and their average height exceeds 15m

Location	Meudon, France - Windzone 2	
Roughness	Category	IV
Mean velocity at 10 m above ground	$v_{b,0}$	= 24 m/s
Directional factor	c_{dir}	= 1.0
Seasonal factor	c_{season}	= 1.0
Basic wind velocity	v_b	= 24x1x1 = 24 m/s
Rugosity factor	c_r	= 0.19x(1/0.05)^0.07xln(15/1) = 0.63
Orographic factor	c_o	= 1.0
Mean velocity	v_m	= 24x0.63x1 = 15 m/s
Turbulence intensity	I_v	= (1x0.92)/1/ln(15/1) = 0.34
Peak pressure $q_p(z)$	q_p	= (1+7x0.34)x0.5x1.225x15^2 = 0.480 kN/m²

C_p values recommanded for the most similar structure (hyppar) in the European design guide:

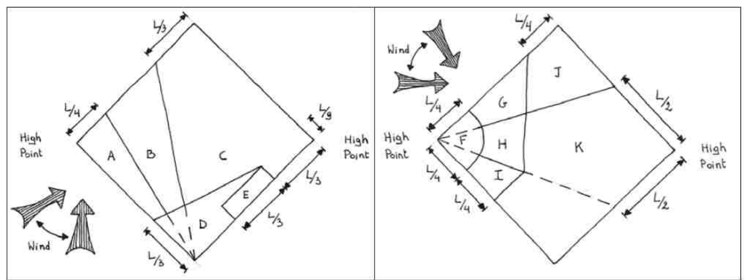


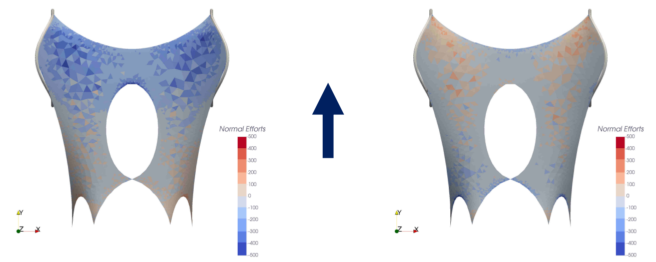
Fig. A1.6 Hypar C_p Zone Definition

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

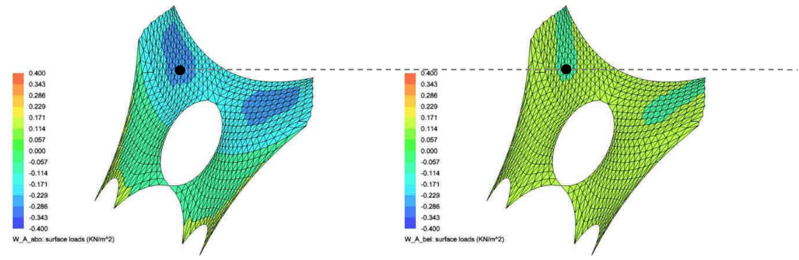
Significant C_p values are negatives → uprising
Minimum C_p values: -1.8 (F zone)
Frequent C_p value: -0.65 to -0.9 (BCD and HJK zones)

Wind: CFD analysis

Flow: 24 m/s ("mean velocity at 10 m above ground"), turbulent

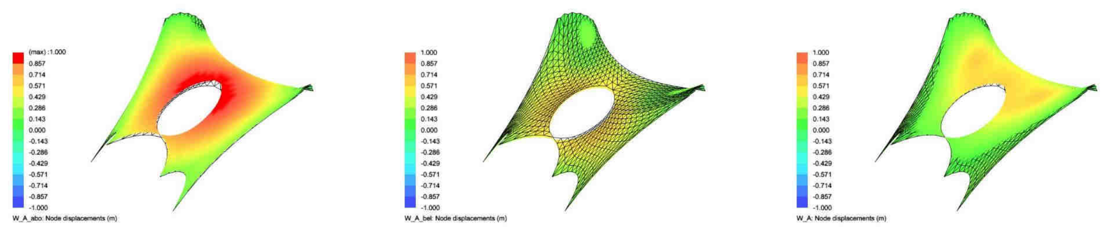


Wind from south: top then bottom views of CFD results, entering normal pressure, Pa

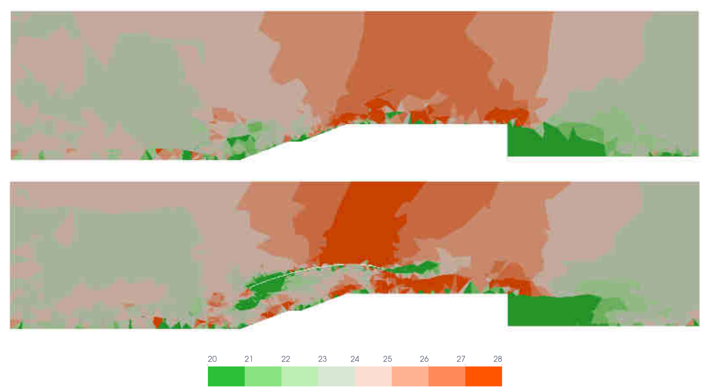


W = -300-100 = -400 kPa
C_p = -400/480 ≈ **-0.8**

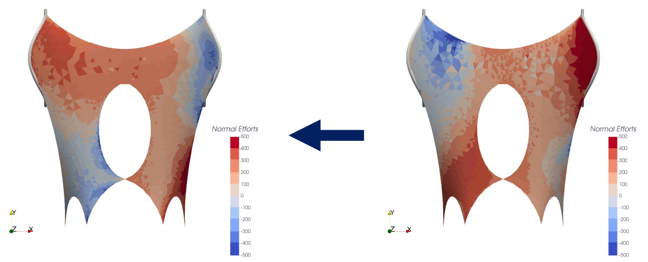
W_A loads implemented in membrane software: above then below



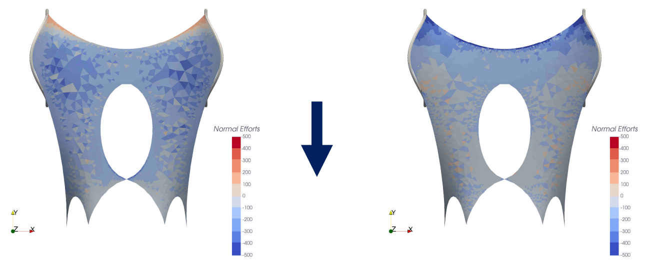
W_A deflections: above, below then cumulated



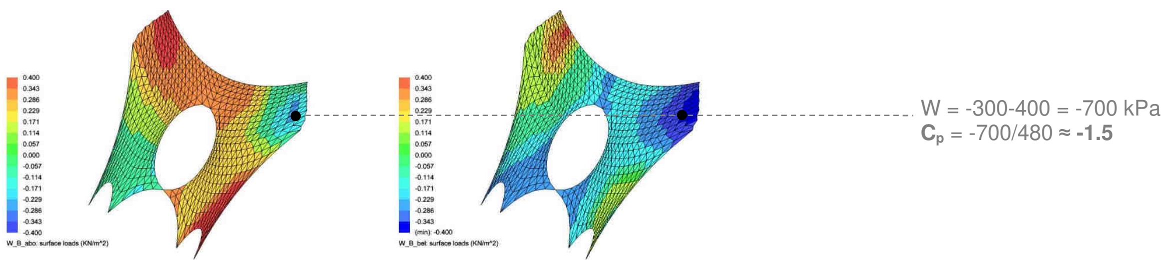
Wind from south: velocity over stairs without then with membrane, m/s



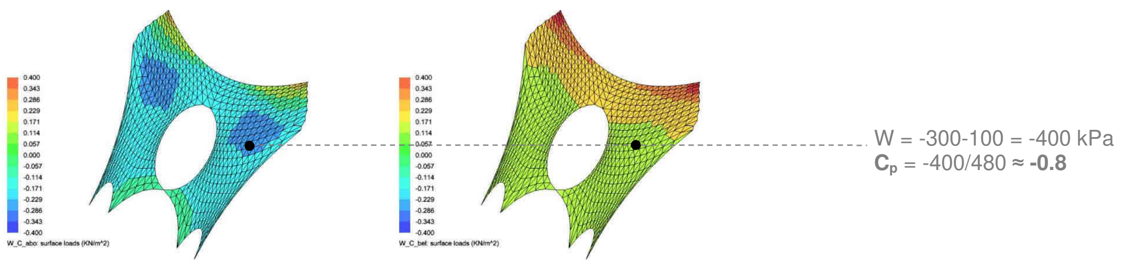
Wind from east: top then bottom views of CFD results, entering normal pressure, Pa



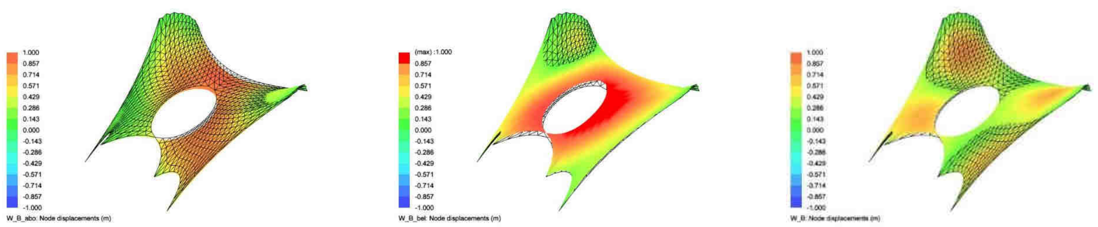
Wind from north: top then bottom views of CFD results, entering normal pressure, Pa



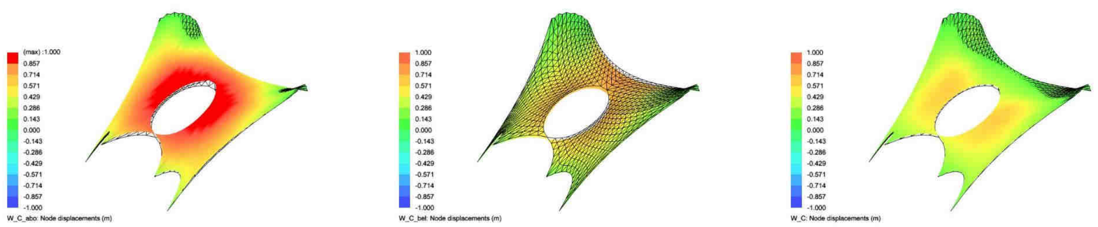
W_B loads implemented in membrane software: above then below



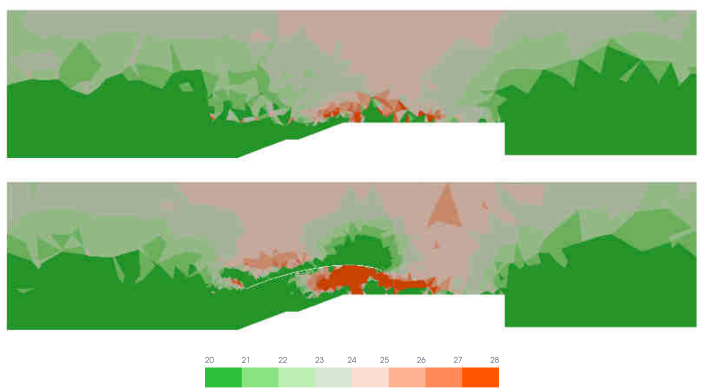
W_C loads implemented in membrane software: above then below



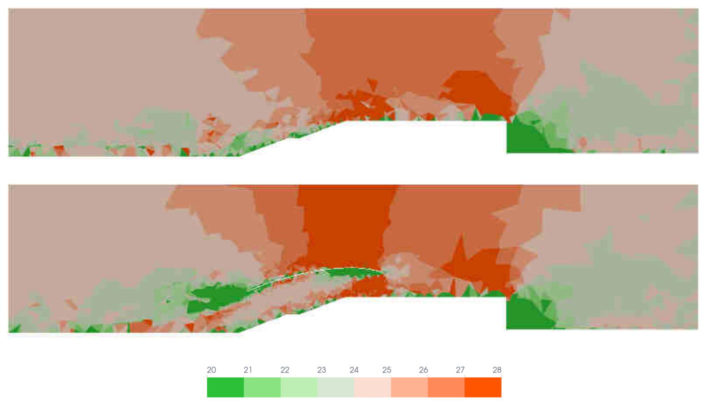
W_B deflections: above, below then cumulated



W_C deflections: above, below then cumulated

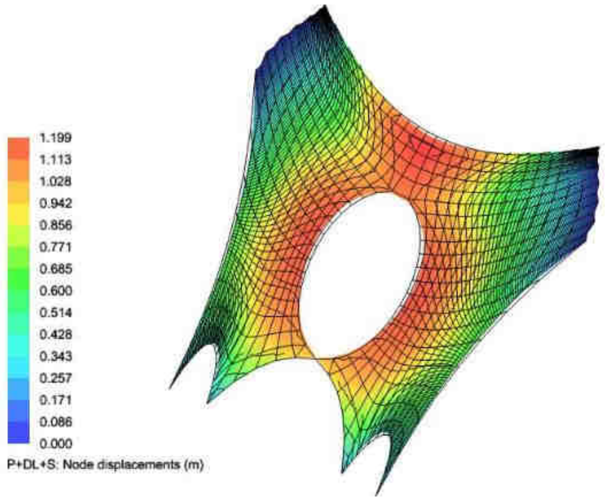


Wind from east: velocity over stairs without then with membrane, m/s



Wind from north: velocity over stairs without then with membrane, m/s

Water



Pounding curves - Vertical step 10 cm

⇨ No significant predictable pocket under P+DL+S combination: no water load

4.4 - Exposure and resistance sides

Combinations

	nr	combination	DL	P	S	W_A_abo	W_A_bel	W_B_bel	W_B_abo	W_C_bel	W_C_abo
type	1	TYP_1.0 DL_1.0 P	1	1							
	2	TYP_1.0 P_1.0 S		1	1						
	3	TYP_1.0 P_1.0 W_A		1		1	1				
	4	TYP_1.0 P_1.0 W_B		1				1	1		
	5	TYP_1.0 P_1.0 W_C		1						1	1
ponding	6	PON_1,0 DL_1,0 P_1,0 S	1	1	1						
SLS	7	SLS_1.0 DL_1.0 P	1	1							
	8	SLS_1.0 DL_1.0 P_1.0 S	1	1	1						
	9	SLS_1.0 DL_1.0 P_1.0 W_A	1	1		1	1				
	10	SLS_1.0 DL_1.0 P_1.0 W_B	1	1				1	1		
	11	SLS_1.0 DL_1.0 P_1.0 W_C	1	1						1	1
ULS	12	ULS_1.0 DL_1.3 P	1	1,3							
	13	ULS_1.0 DL_1.1 P_1.5 S	1	1,1	1.5						
	14	ULS_1.0 DL_1.1 P_1.6 W_A	1	1,1		1,6	1,6				
	15	ULS_1.0 DL_1.1 P_1.6 W_B	1	1,1				1,6	1,6		
	16	ULS_1.0 DL_1.1 P_1.6 W_C	1	1,1						1,6	1,6

Safety factors: type estimation

6.0	P+DL combination:	pre-stress and self weight
5.0	P+S combination:	pre-stress and snow
3.2	P+W combination:	pre-stress and wind

	T1 warp SI	T2 warp SI	T3 warp SI	T4 warp SI	T5 warp SI	Product warp SI
EN ISO 1421	50 kN/m	70 kN/m	100 kN/m	135 kN/m	170 kN/m	200 kN/m
P+DL	8 kN/m	12 kN/m	17 kN/m	23 kN/m	28 kN/m	33 kN/m
P+S	10 kN/m	14 kN/m	20 kN/m	27 kN/m	34 kN/m	40 kN/m
P+W	16 kN/m	22 kN/m	31 kN/m	42 kN/m	53 kN/m	63 kN/m

	T1 weft SII	T2 weft SII	T3 weft SII	T4 weft SII	T5 weft SII	Product weft SII
EN ISO 1421	50 kN/m	70 kN/m	90 kN/m	120 kN/m	145 kN/m	160 kN/m
P+DL	8 kN/m	12 kN/m	15 kN/m	20 kN/m	24 kN/m	27 kN/m
P+S	10 kN/m	14 kN/m	18 kN/m	24 kN/m	29 kN/m	32 kN/m
P+W	16 kN/m	22 kN/m	28 kN/m	38 kN/m	45 kN/m	50 kN/m

Safety factors: stress calculation

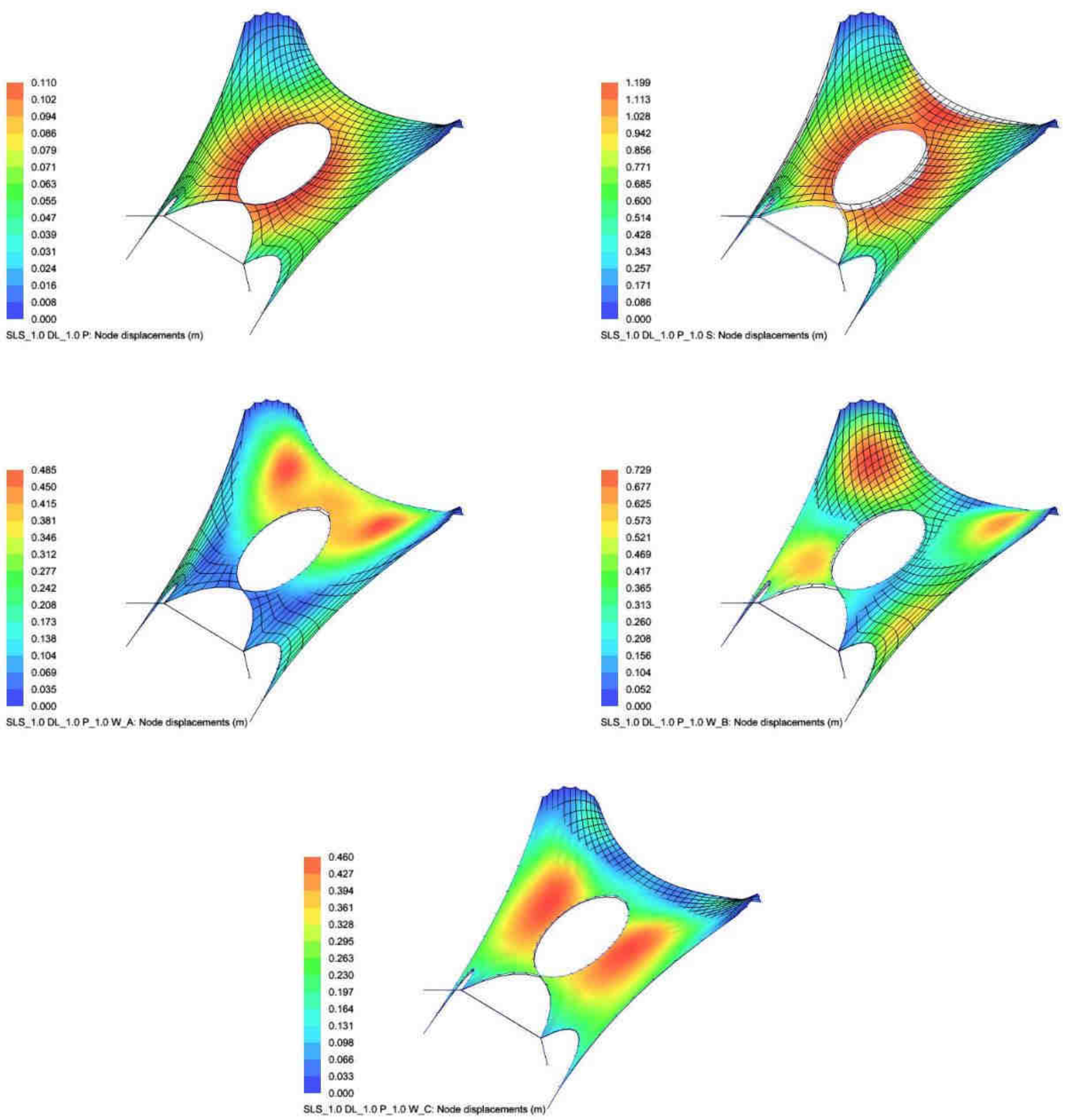
A_0	biaxial exposure on site / uniaxial tested material properties
A_1	long term / permanent exposure
A_2	environmental conditions
A_3	high temperature conditions
A_4	inaccuracy in the fabrication process

	nr	combination	γ_f	γ_m	A0	A1	A2	A3	$\gamma \times A_{res}$	$f_{u,d}$ warp	$f_{u,d}$ weft
ULS	12	ULS_1.0 DL_1.3 P	1,5	1,4	1,1	1,7	1,2	1,1	5,2	39 kN/m	31 kN/m
	13	ULS_1.0 DL_1.1 P_1.5 S	1,5	1,4	1,1	1,7	1,2		4,7	42 kN/m	34 kN/m
	14	ULS_1.0 DL_1.1 P_1.6 W_A	1,6	1,4	1,1		1,2		3,0	68 kN/m	54 kN/m
	15	ULS_1.0 DL_1.1 P_1.6 W_B	1,6	1,4	1,1		1,2		3,0	68 kN/m	54 kN/m
	16	ULS_1.0 DL_1.1 P_1.6 W_C	1,6	1,4	1,1		1,2		3,0	68 kN/m	54 kN/m

4.5 - Results

Membrane deflection

Deflections are not limited, just checked and compared to minimal global dimension (L = 25.4 m)



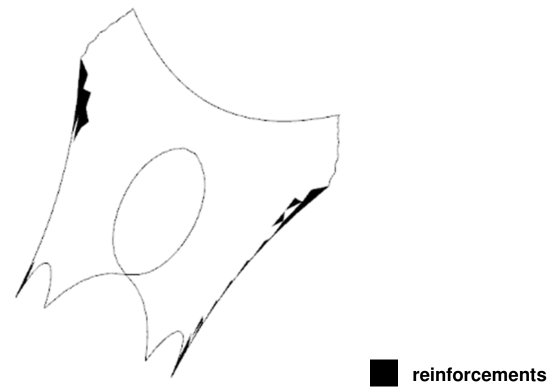
	nr	combination	max. defl.	ratio
SLS	7	SLS_1.0 DL_1.0 P	0,11 m	L / 229
	8	SLS_1.0 DL_1.0 P_1.0 S	1,20 m	L / 21
	9	SLS_1.0 DL_1.0 P_1.0 W_A	0,49 m	L / 52
	10	SLS_1.0 DL_1.0 P_1.0 W_B	0,73 m	L / 35
	11	SLS_1.0 DL_1.0 P_1.0 W_C	0,46 m	L / 55

SLS deflections

Membrane: type estimation

Selection : type 5 with reinforcements

Reinforcements: 211% maximum of product properties, P+DL configuration

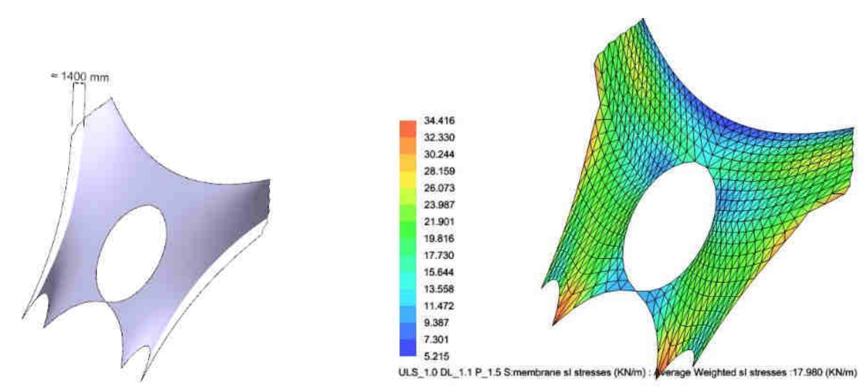


Location of considered reinforcements

Membrane: stress calculation

$$f_d = S_{ULS\ \max} \quad \text{and} \quad f_{u,d} = \frac{f_{u,k}}{\gamma . A_{res}} \quad \Rightarrow \quad f_d \leq f_{u,d}$$

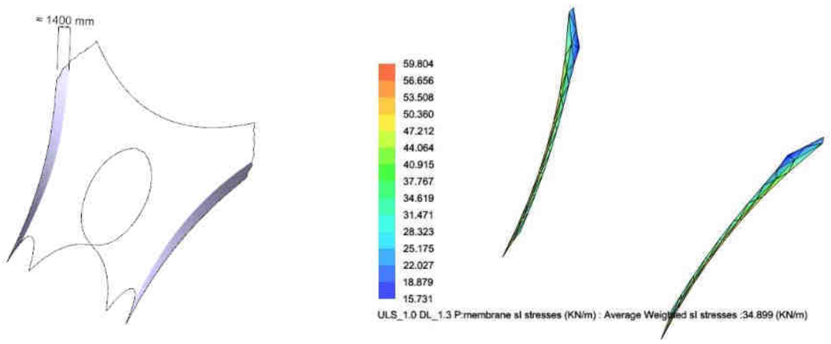
Main single layer: 81% maximum of product properties, P+DL+S configuration



n°	Combinations	fu,d warp	SI max	fu,d weft	SII max	use rate
12	ULS_1.0 DL_1.3 P	39 kN/m	22,4 kN/m	31 kN/m	3,5 kN/m	58%
13	ULS_1.0 DL_1.1 P_1.5 S	42 kN/m	34,4 kN/m	34 kN/m	7,2 kN/m	81%
14	ULS_1.0 DL_1.1 P_1.6 W_A	68 kN/m	24,7 kN/m	54 kN/m	3,0 kN/m	37%
15	ULS_1.0 DL_1.1 P_1.6 W_B	68 kN/m	34,5 kN/m	54 kN/m	5,5 kN/m	51%
16	ULS_1.0 DL_1.1 P_1.6 W_C	68 kN/m	23,8 kN/m	54 kN/m	3,9 kN/m	35%

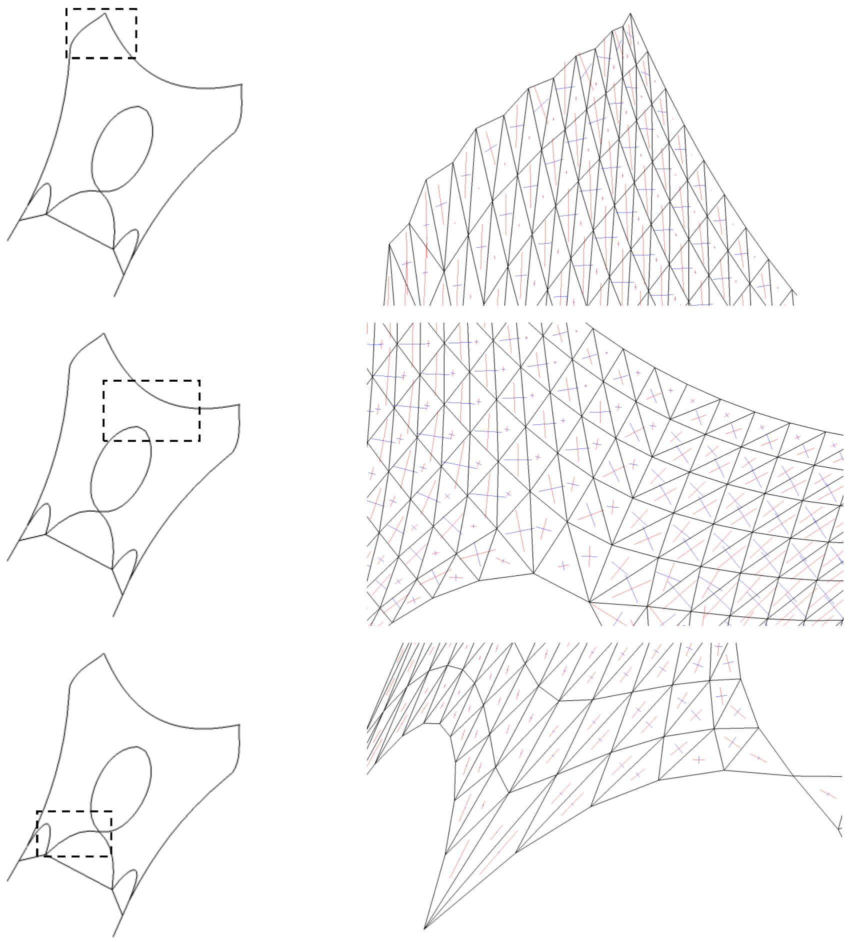
ULS stresses: main single layer area

Reinforced area: 155% maximum of product properties, P+DL configuration



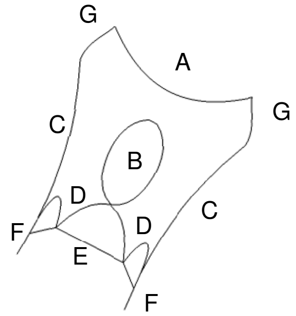
n°	Combinations	fu,d warp	SI max	fu,d weft	SII max	use rate
12	ULS_1.0 DL_1.3 P	39 kN/m	59,8 kN/m	31 kN/m	0,9 kN/m	155%
13	ULS_1.0 DL_1.1 P_1.5 S	42 kN/m	58,1 kN/m	34 kN/m	1,2 kN/m	137%
14	ULS_1.0 DL_1.1 P_1.6 W_A	68 kN/m	54,1 kN/m	54 kN/m	0,9 kN/m	80%
15	ULS_1.0 DL_1.1 P_1.6 W_B	68 kN/m	60,9 kN/m	54 kN/m	1,3 kN/m	90%
16	ULS_1.0 DL_1.1 P_1.6 W_C	68 kN/m	54,4 kN/m	54 kN/m	0,8 kN/m	80%

ULS stresses: reinforcements areas



ULS stresses: SI and SII directions, P+DL+S configuration

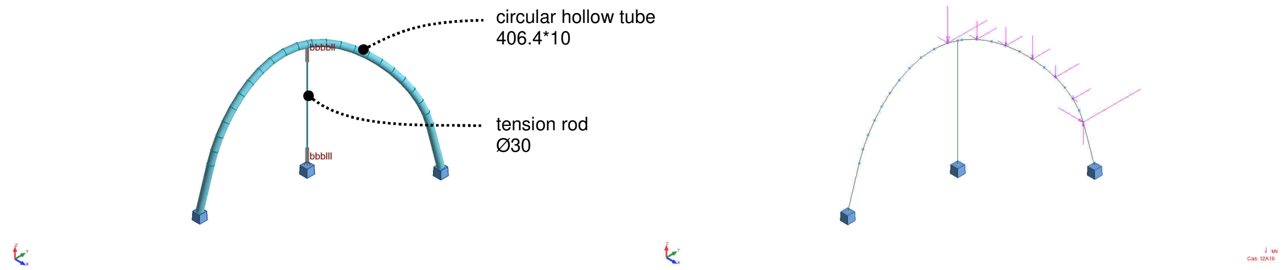
Cables stresses



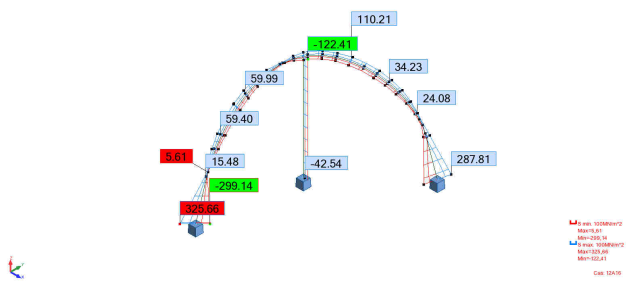
n°	Combinations	A	B	C	D	E	F	G
12	ULS_1.0 DL_1.3 P	45 kN	8 kN	3 kN	24 kN	86 kN	47 kN	11 kN
13	ULS_1.0 DL_1.1 P_1.5 S	17 kN	48 kN	36 kN	51 kN	180 kN	54 kN	43 kN
14	ULS_1.0 DL_1.1 P_1.6 W_A	85 kN	4 kN	8 kN	28 kN	92 kN	55 kN	10 kN
15	ULS_1.0 DL_1.1 P_1.6 W_B	58 kN	21 kN	28 kN	34 kN	127 kN	83 kN	25 kN
16	ULS_1.0 DL_1.1 P_1.6 W_C	55 kN	6 kN	9 kN	26 kN	79 kN	54 kN	14 kN

	A	B	C	D	E	F	G
Fe,d	85 kN	48 kN	36 kN	51 kN	180 kN	83 kN	43 kN
K	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Ke	1	1	1	1	1	1	1
d min	14,3 mm	11,0 mm	9,7 mm	11,2 mm	20,3 mm	14,1 mm	10,4 mm
type	Pfeifer PE15	Pfeifer PE10	Pfeifer PE10	Pfeifer PE10	Pfeifer PE30	Pfeifer PE15	Pfeifer PE10
Fr,d	86 kN	61 kN	61 kN	61 kN	180 kN	86 kN	61 kN
d	14,1 mm	11,9 mm	11,9 mm	11,9 mm	20,5 mm	14,1 mm	11,9 mm

West gantry

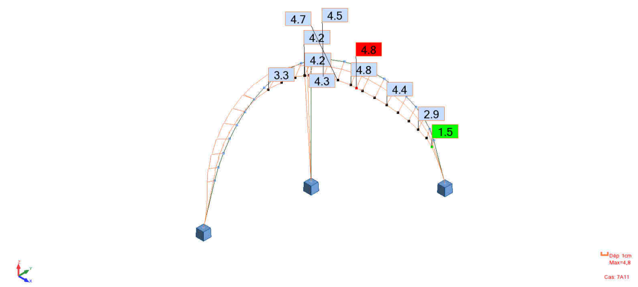


Structure and loads transferred in steel software



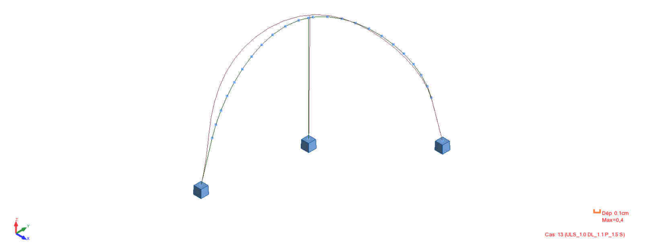
	S max [MPa]	S min [MPa]
Type (couleur) de ligne		
Echelle : (cm) =	300.00	300.00
MAX	325,66	5,61
Barre	101	102
Point	x = 0.0000	x = 0.3529
Cas de charge	13	16
MIN	-122,41	-299,14
Barre	2	101
Point	x = 1.0000	x = 0.0000
Cas de charge	13	13

Stresses calculated



	Déformée exacte [cm]
Type (couleur) de ligne	
Echelle : (cm) =	3.0
MAX	4,8
Barre	117
Point	x = 0.5000
Cas de charge	8
MIN	0,0
Barre	117
Point	x = 0.0000
Cas de charge	8

Deflections

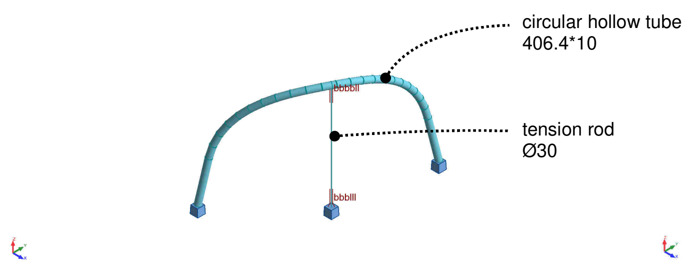


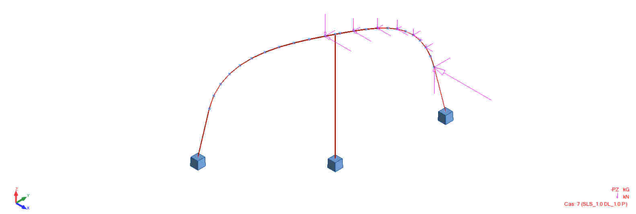
	Coef.crit.	Précision
MAX	3,87307e+01	1,09395e-09
Cas	13	13
Mode	5	5
MIN	3,87307e+01	1,09395e-09
Cas	13	13
Mode	5	5

Buckling ratio

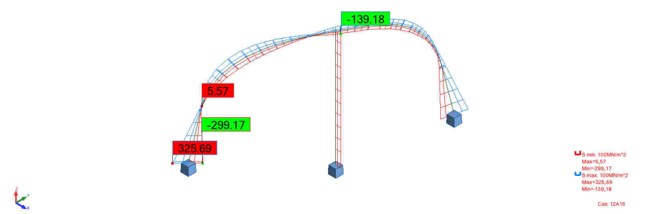
- ⇨ Stress ratio: 92% (=326/355)
- ⇨ Displacement ratio: 1/262 (=4,8/1260)
- ⇨ Buckling ratio: 38

East gantry



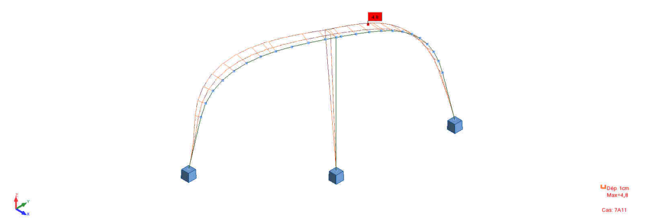


Structure and loads transferred in steel software



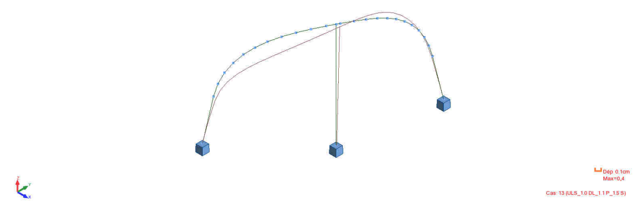
	S max [MPa]	S min [MPa]
Type (couleur) de ligne		
Echelle : (cm) =	300.00	300.00
MAX	325,69	5,57
Barre	201	202
Point	x = 0.0000	x = 0.3529
Cas de charge	13	16
MIN	-139,18	-299,17
Barre	3	201
Point	x = 1.0000	x = 0.0000
Cas de charge	15	13

Stresses



	Déformée exacte [cm]
Type (couleur) de ligne	
Echelle : (cm) =	5.0
MAX	4,8
Barre	217
Point	x = 0.5000
Cas de charge	8
MIN	0,0
Barre	217
Point	x = 0.0000
Cas de charge	8

Deflections

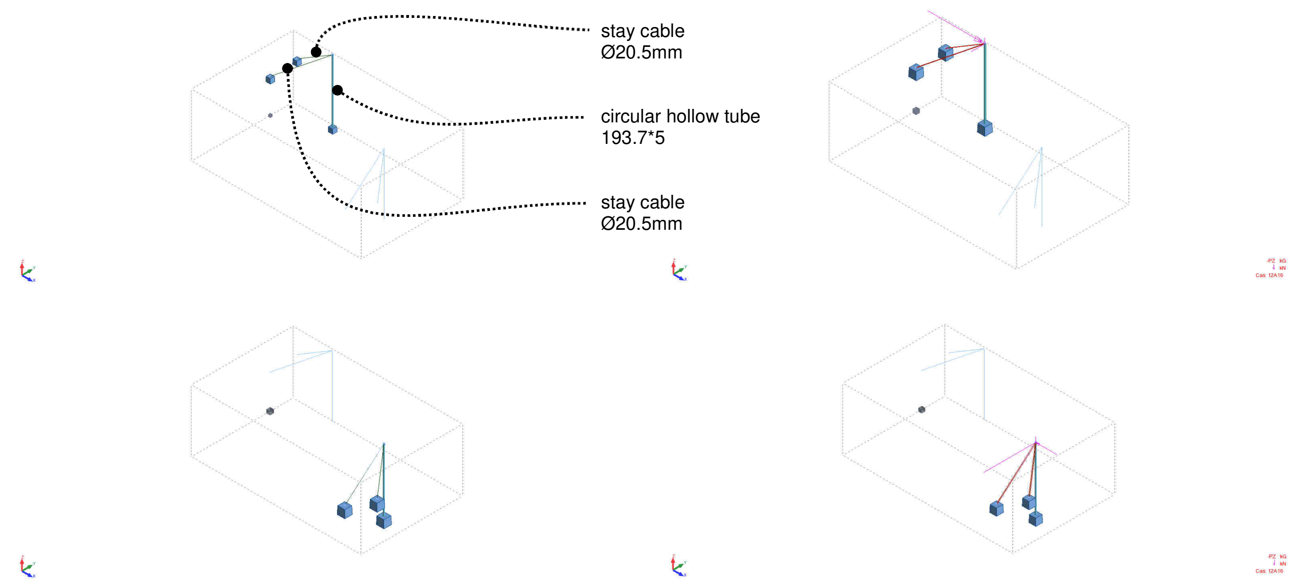


	Coef.crit.	Précision
MAX	3,87336e+01	2,61017e-09
Cas	13	13
Mode	5	5
MIN	3,87336e+01	2,61017e-09
Cas	13	13
Mode	5	5

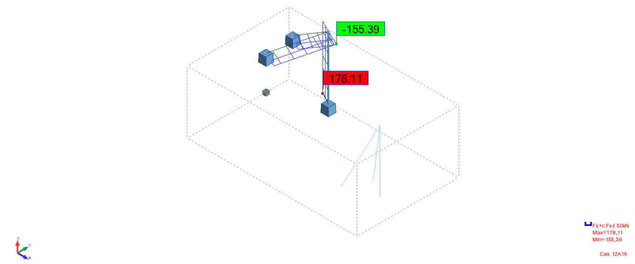
Buckling ratio

- ⇨ Stress ratio: 92% (=326/355)
- ⇨ Displacement ratio: 1/262 (=4,8/1260)
- ⇨ Buckling ratio: 38

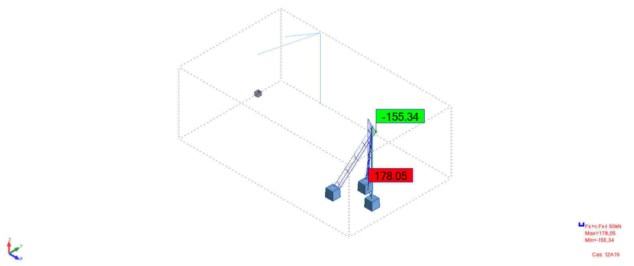
Columns and stay cables



Structure and loads transferred in steel software

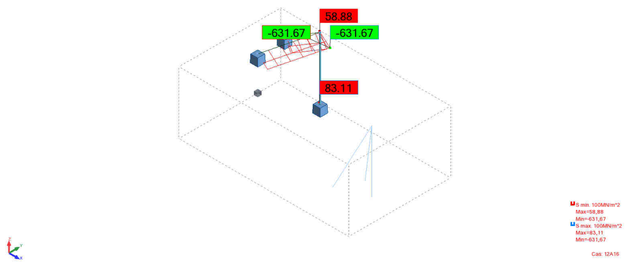


	FX [kN]
Type (couleur) de ligne	
Echelle : (cm) =	150.00
MAX	178,11
Barre	3
Point	x = 0.0000
Cas de charge	13
MIN	-155,39
Barre	6
Point	x = 0.0000
Cas de charge	13

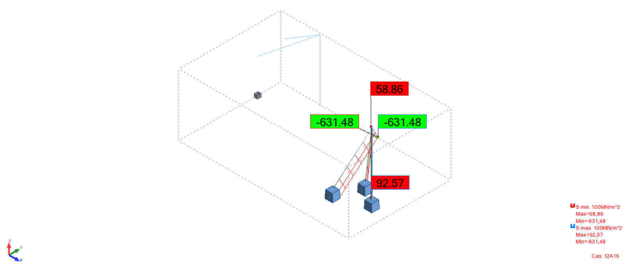


	FX [kN]
Type (couleur) de ligne	
Echelle : (cm) =	200.00
MAX	178,05
Barre	3
Point	x = 0.0000
Cas de charge	13
MIN	-155,34
Barre	6
Point	x = 0.0000
Cas de charge	13

Axial forces

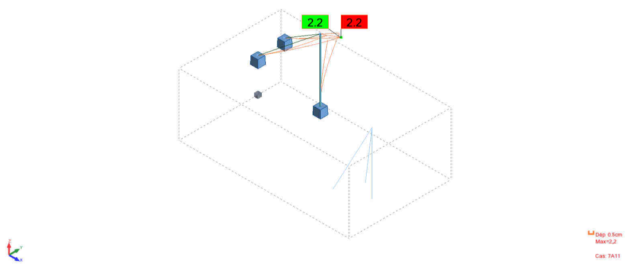


	S max [MPa]	S min [MPa]
Type (couleur) de ligne		
Echelle : (cm) =	500.00	500.00
MAX	83,11	58,88
Barre	3	3
Point	x = 0.0000	x = 1.0000
Cas de charge	13	13
MIN	-631,67	-631,67
Barre	6	6
Point	x = 0.0000	x = 0.0000
Cas de charge	13	13

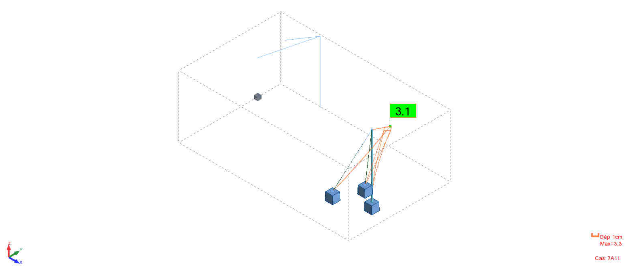


	S max [MPa]	S min [MPa]
Type (couleur) de ligne		
Echelle : (cm) =	500.00	500.00
MAX	92,57	58,86
Barre	3	3
Point	x = 0.0000	x = 1.0000
Cas de charge	13	13
MIN	-631,48	-631,48
Barre	6	6
Point	x = 0.0000	x = 0.0000
Cas de charge	13	13

Stresses

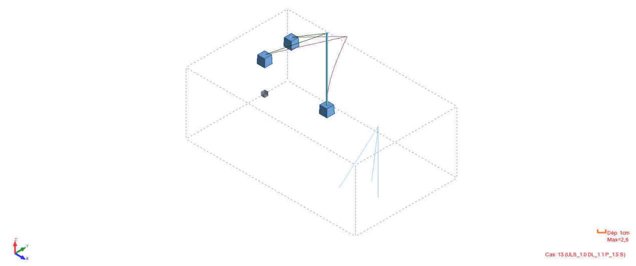


	Déformée exacte [cm]
Type (couleur) de ligne	
Echelle : (cm) =	2.0
MAX	2,2
Barre	6
Point	x = 0.0098
Cas de charge	8
MIN	0,0
Barre	6
Point	x = 0.0000
Cas de charge	8

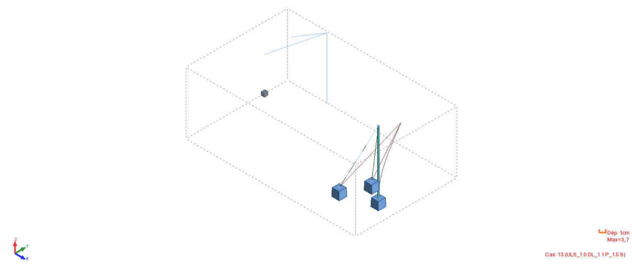


	Déformée exacte [cm]
Type (couleur) de ligne	
Echelle : (cm) =	3.0
MAX	3,3
Barre	4
Point	x = 0.0000
Cas de charge	8
MIN	0,0
Barre	4
Point	x = 0.0000
Cas de charge	8

Deflections



	Coef.crit.	Précision
MAX	7,09058e+02	9,41096e-06
Cas	14	13
Mode	4	3
MIN	6,63400e+00	3,53201e-17
Cas	13	16
Mode	1	1



	Coef.crit.	Précision
MAX	8,09685e+02	8,16261e-10
Cas	16	16
Mode	4	4
MIN	6,63815e+00	2,00920e-19
Cas	13	16
Mode	1	1

Buckling ratios

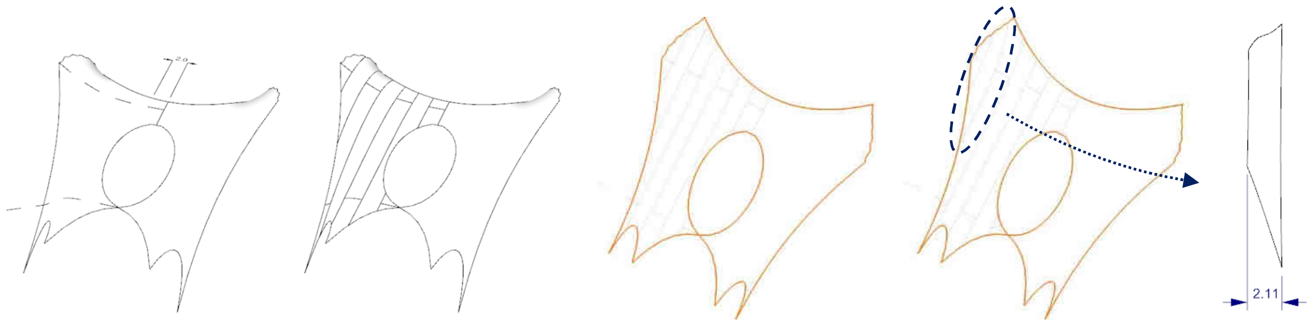
- ⇨ Axial forces (cables): 87% (=156/180)
- ⇨ Stress ratio: 27% (=93/355)
- ⇨ Displacement ratio: 1/253 (=3,3/836)
- ⇨ Buckling ratio: 6

5 - Patterning

5.1 - Method

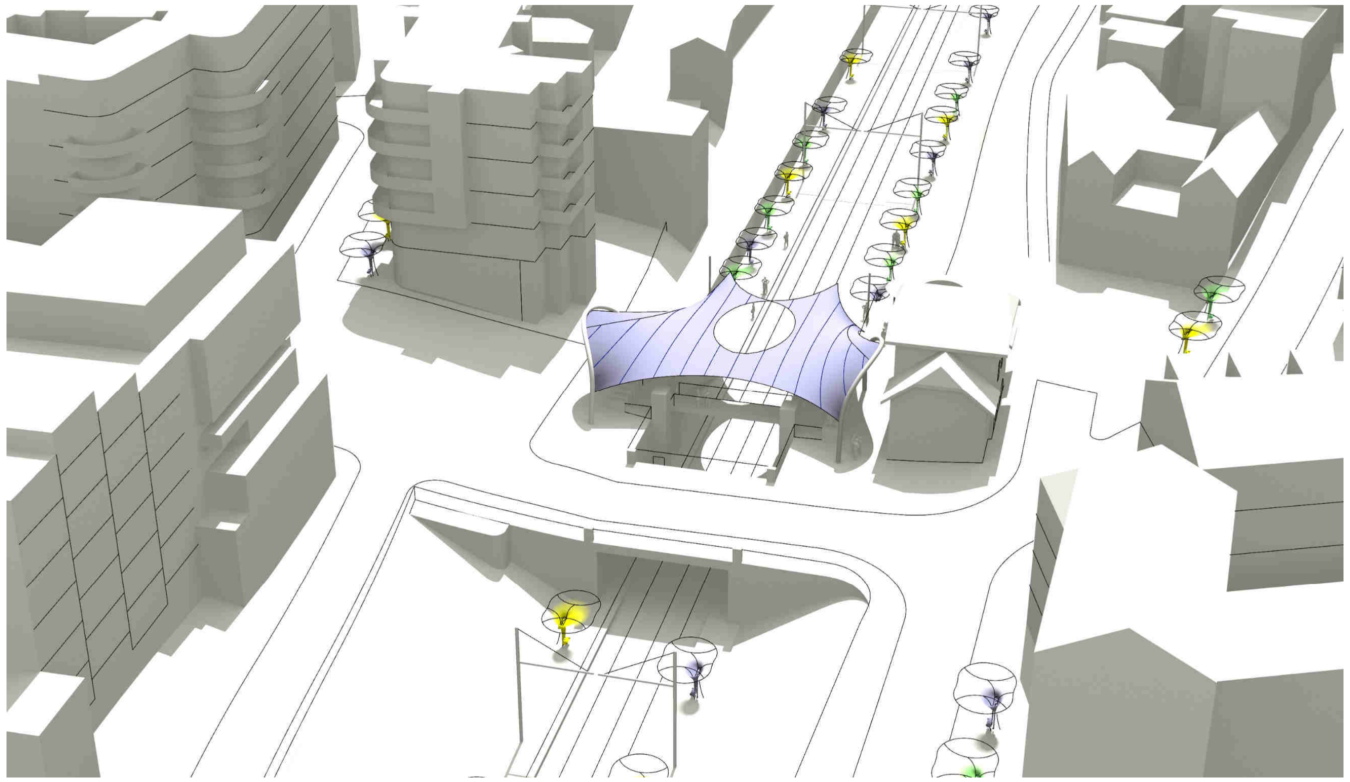
Principal SI and SII stresses are almost equal over the entire membrane, except in reinforced areas and southern angles. Choosen method is to cut the membrane parallel to the rails for graphical reason. It also allows to keep seams as parallel as possible to SI stresses around southern angles.

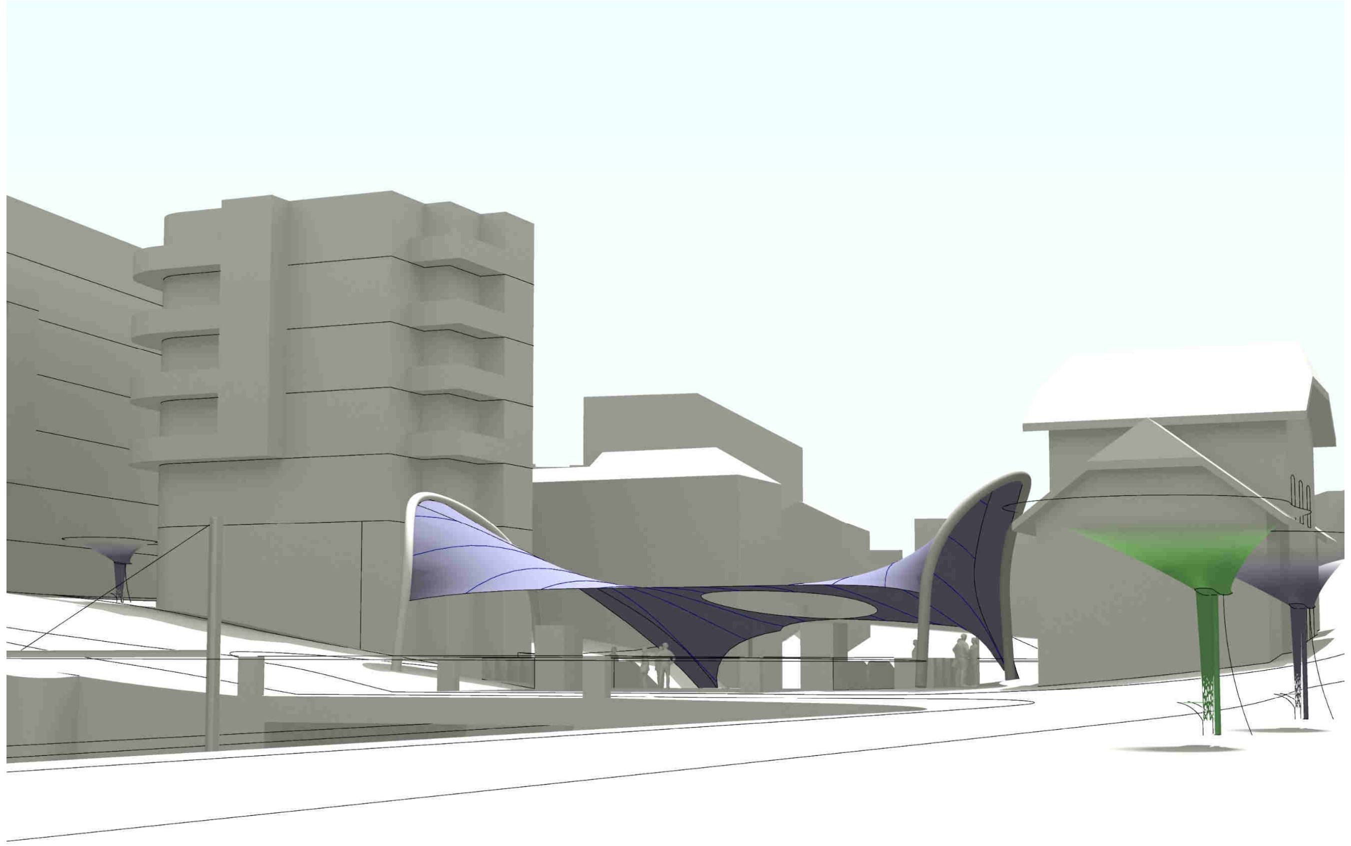
Two meters large strips were first drawn with Rhino software. Then geodesic lines were outlined (_shortpath command) and checked in IxCube. After calcuation, widths of strips do not exceed 2110 millimeters, less than limitation of main available manufactured products. Finally reinforcement areas were added.

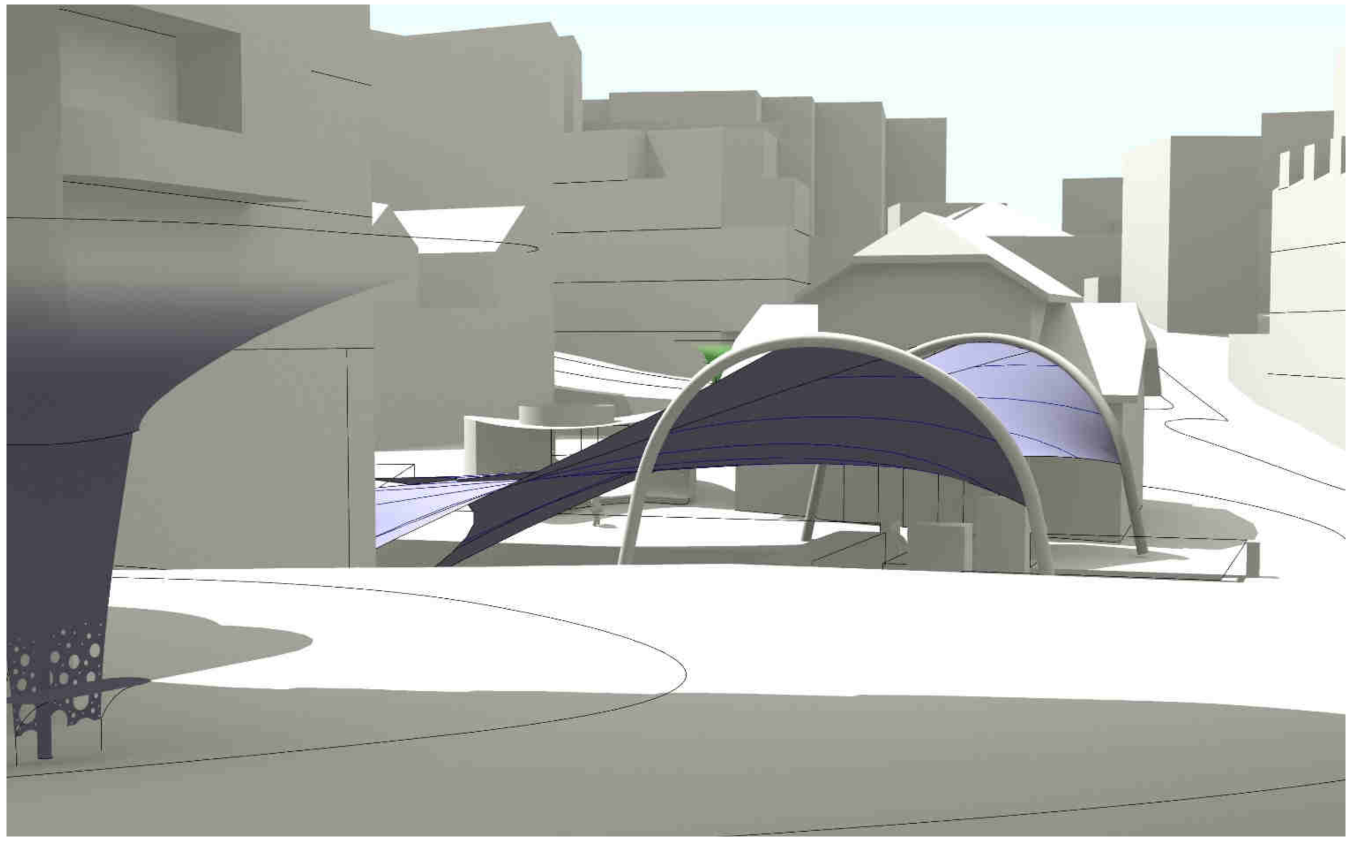


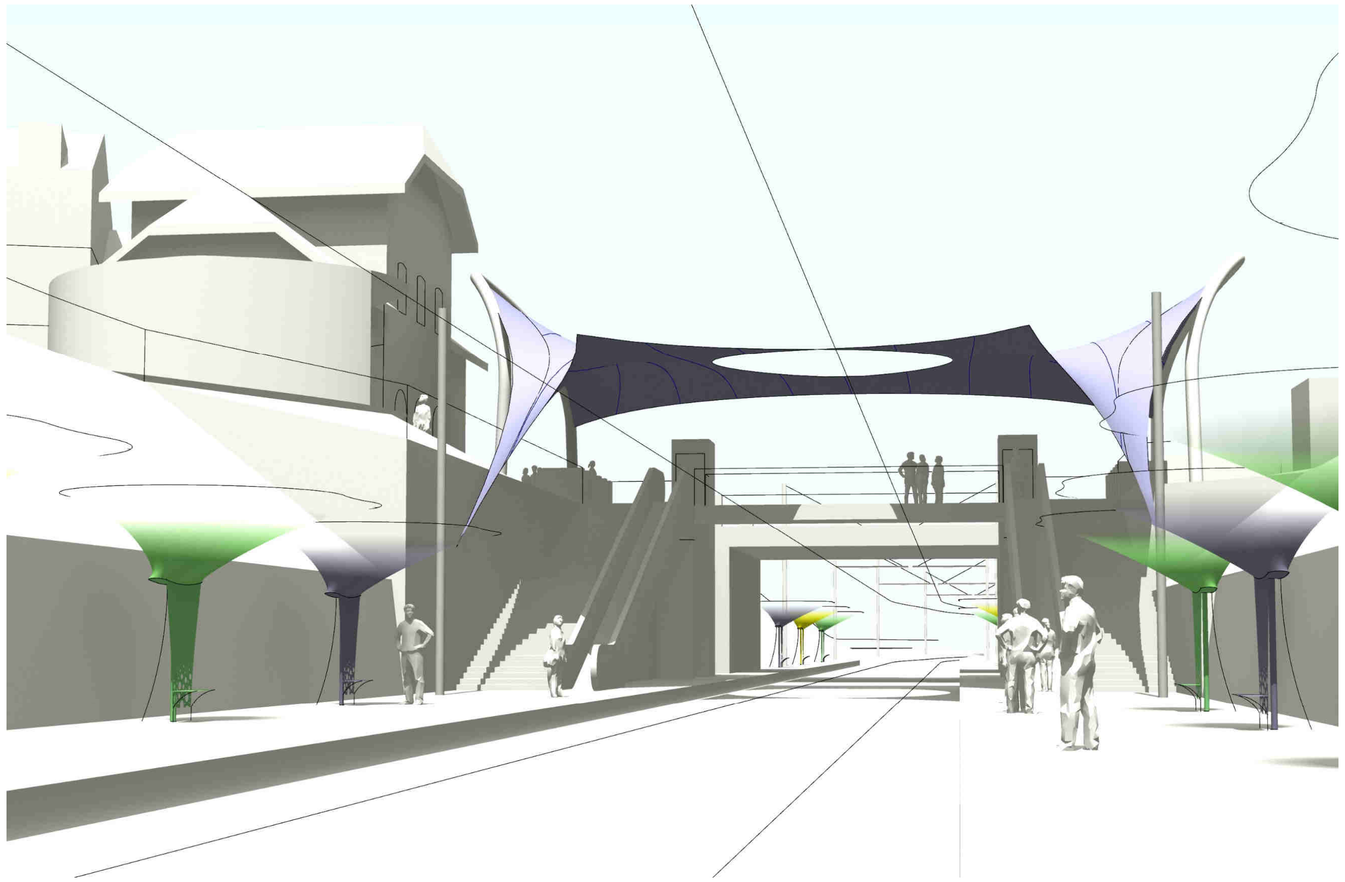
Welding and compensation are not taken into account due to educational version of software, but it has no important impact for a feasibility study.

5.2 - Detailed renderings



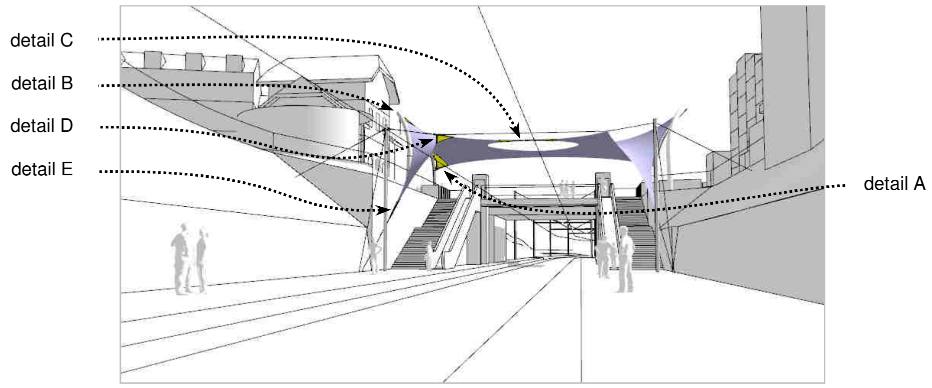


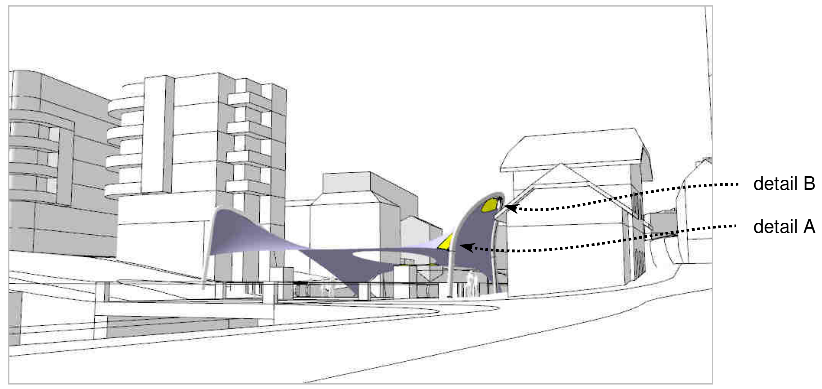


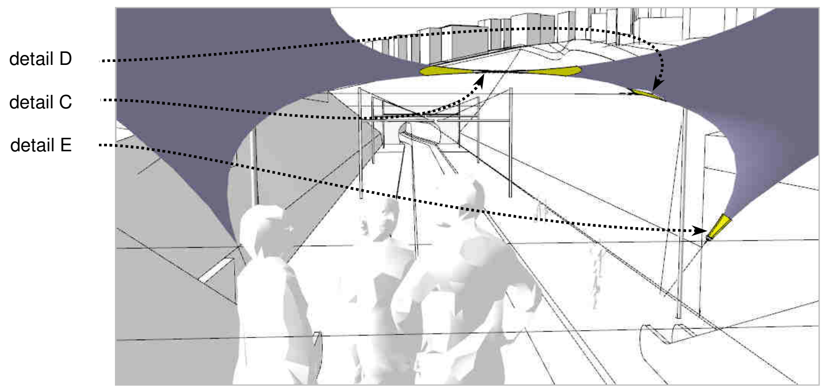


6 - Details

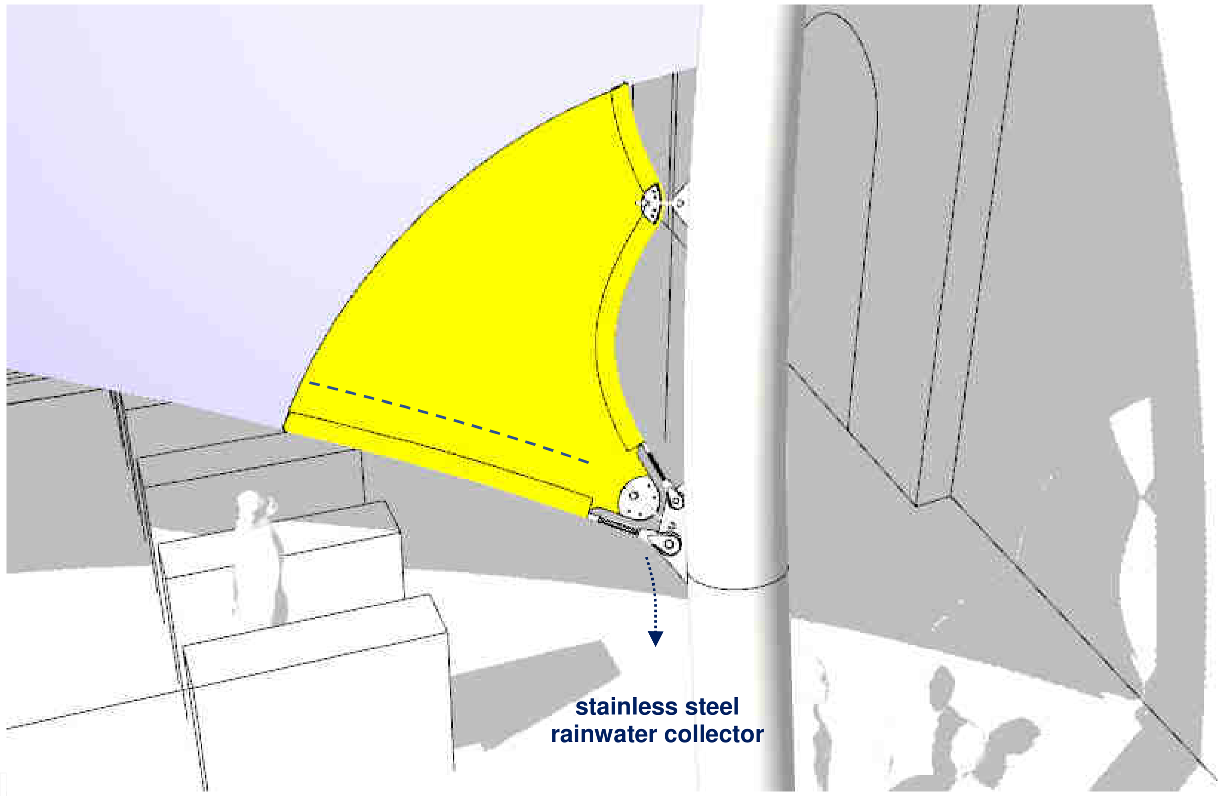
6.1 - Location

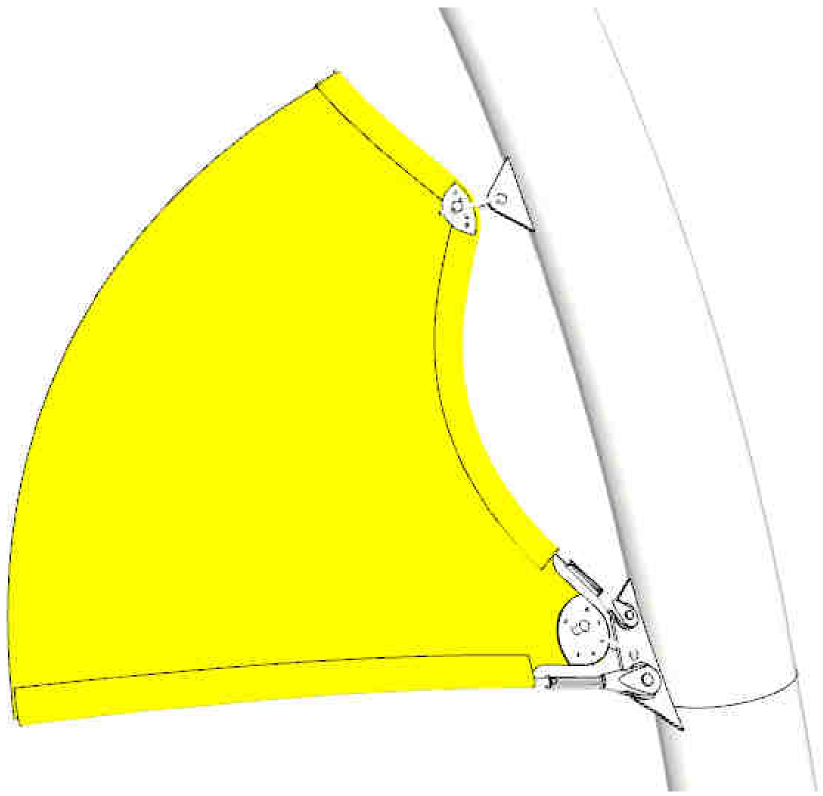


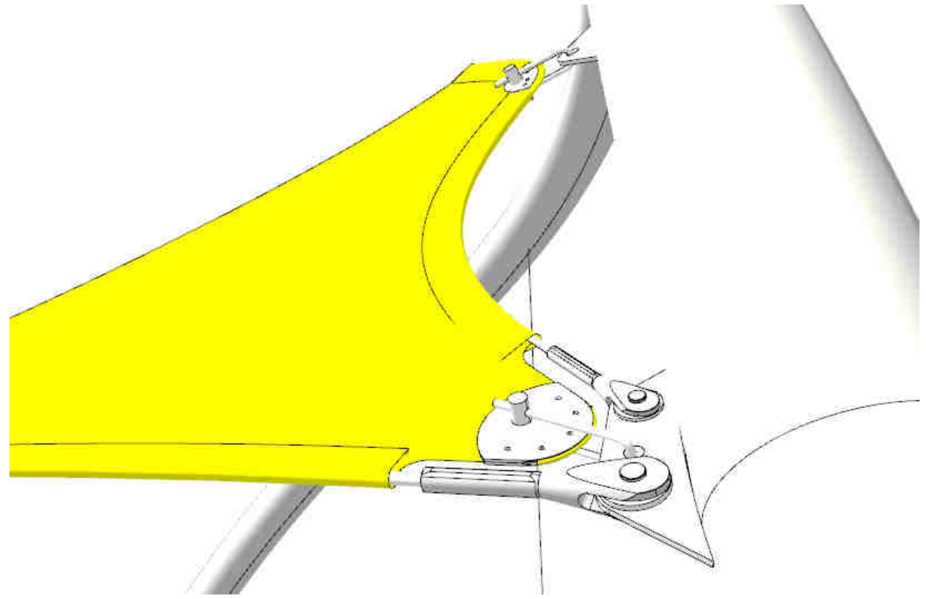


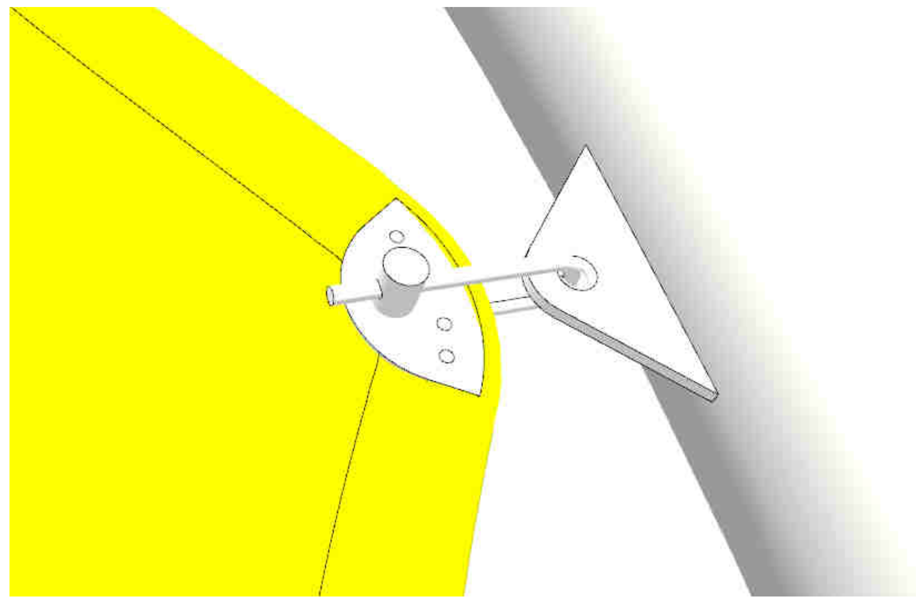


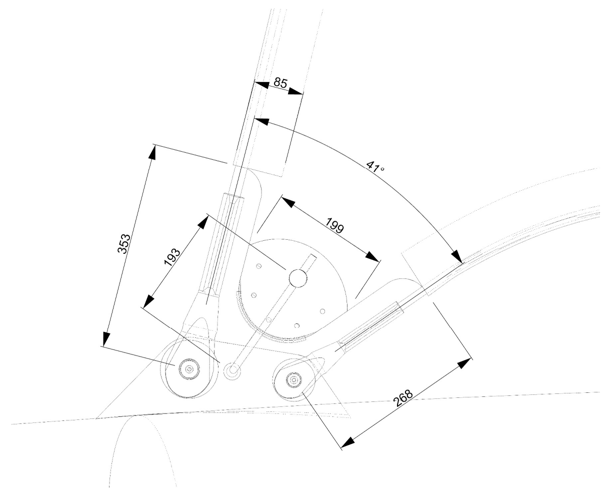
6.2 - Detail A

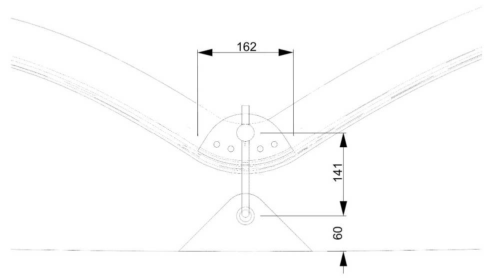

stainless steel
rainwater collector



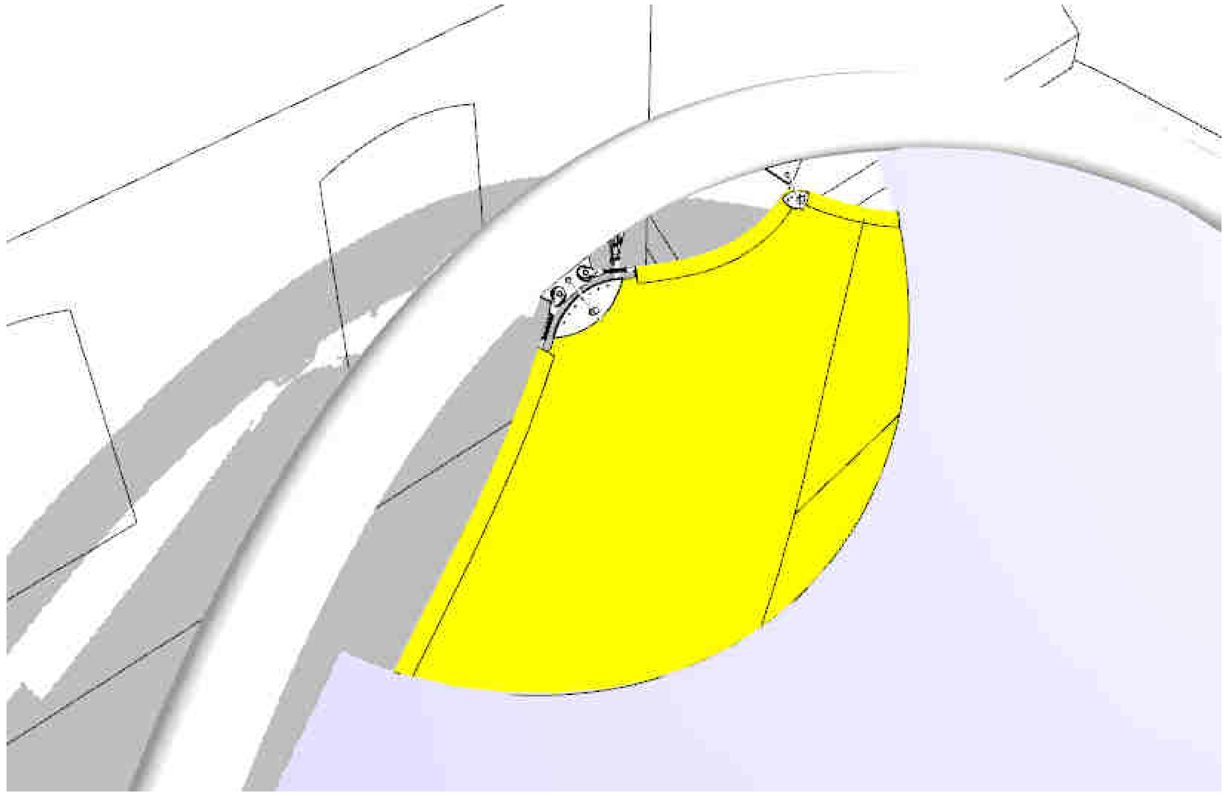


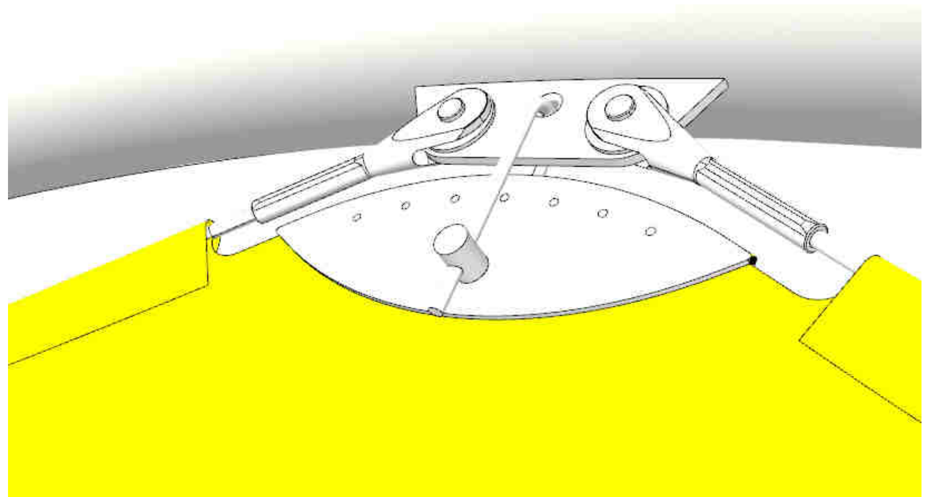


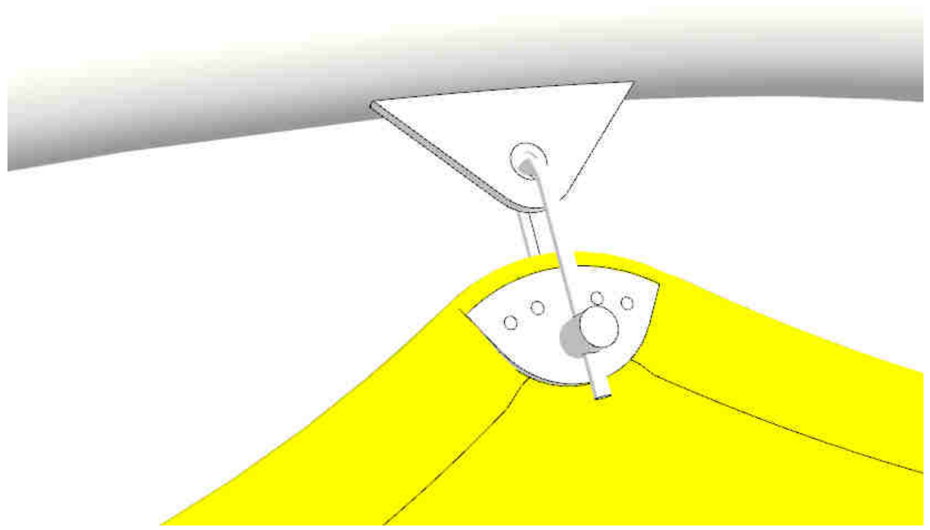

85
41°
199
353
193
268

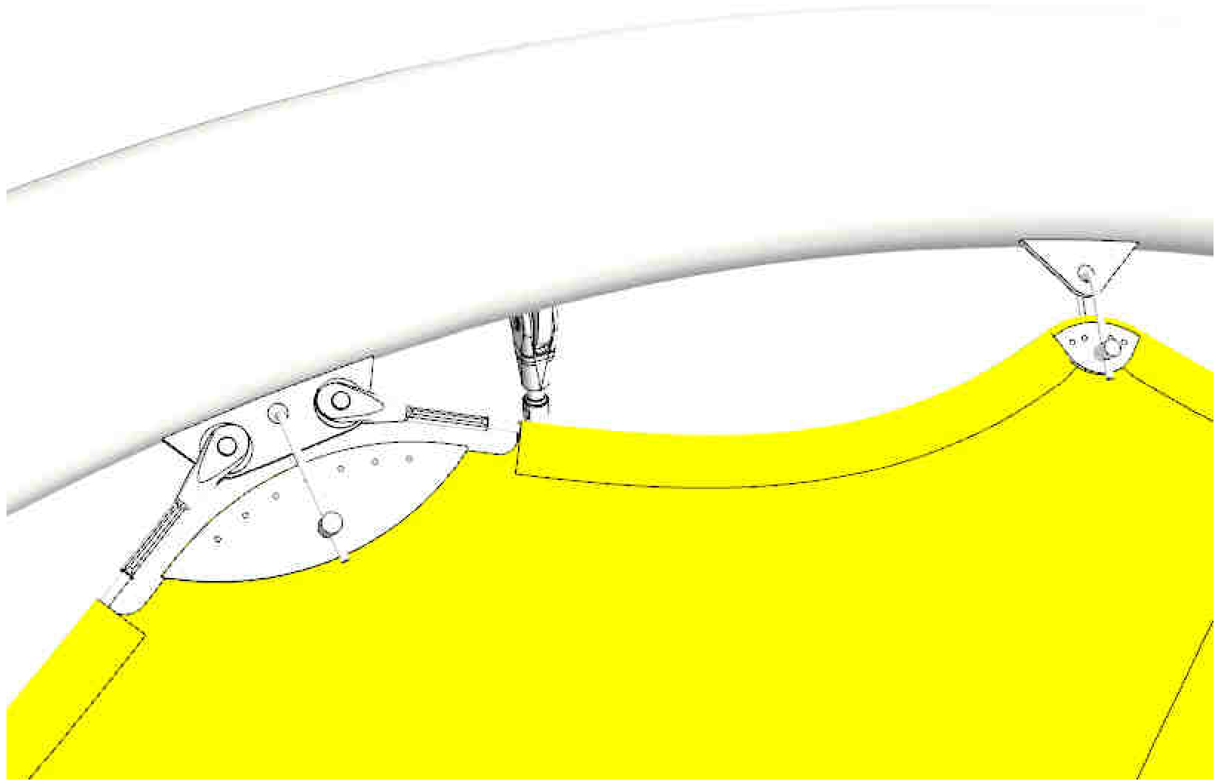

162
141
60

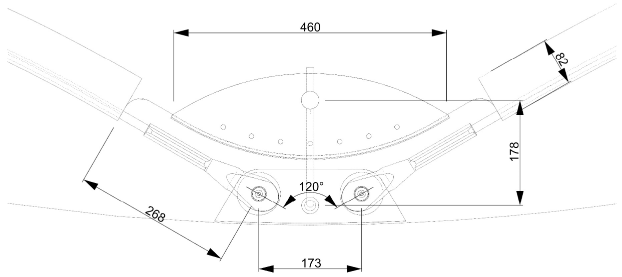
6.3 - Detail B

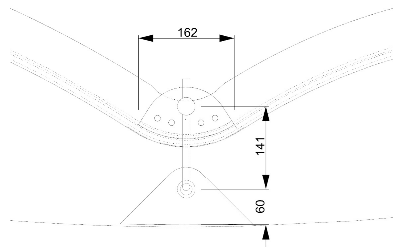




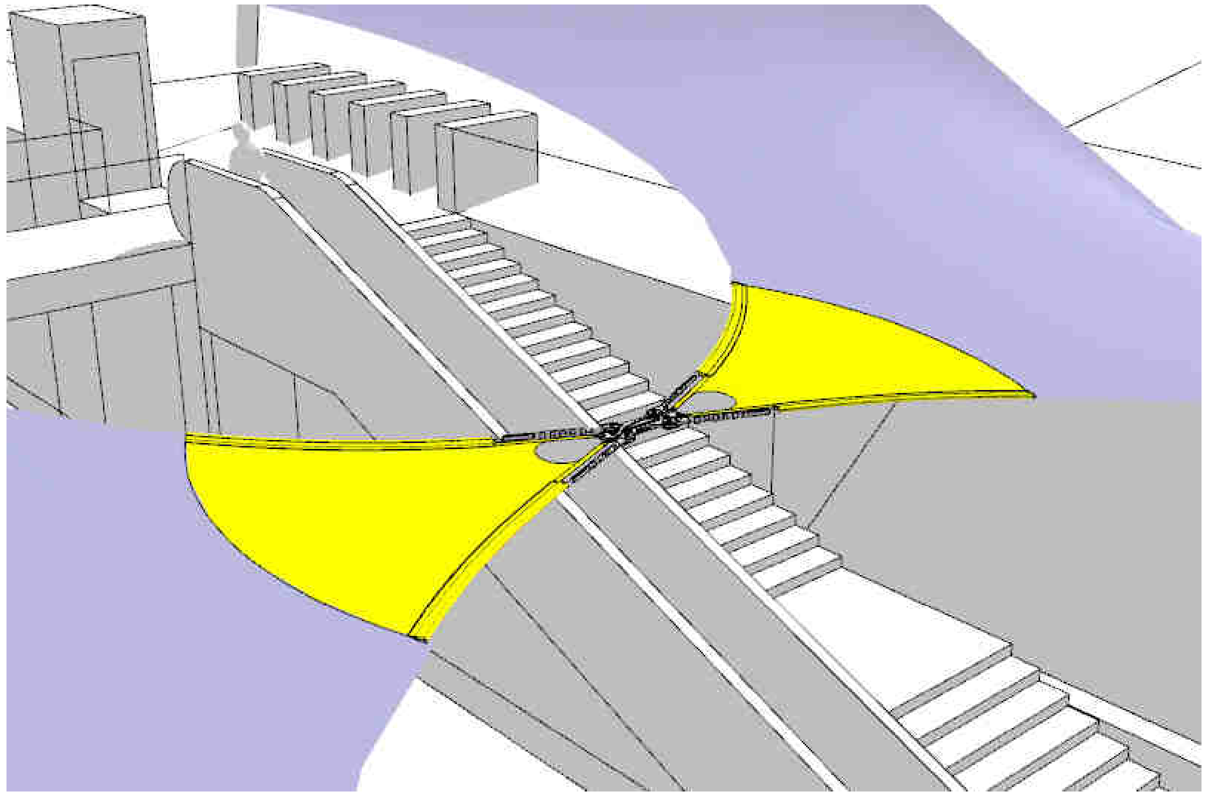


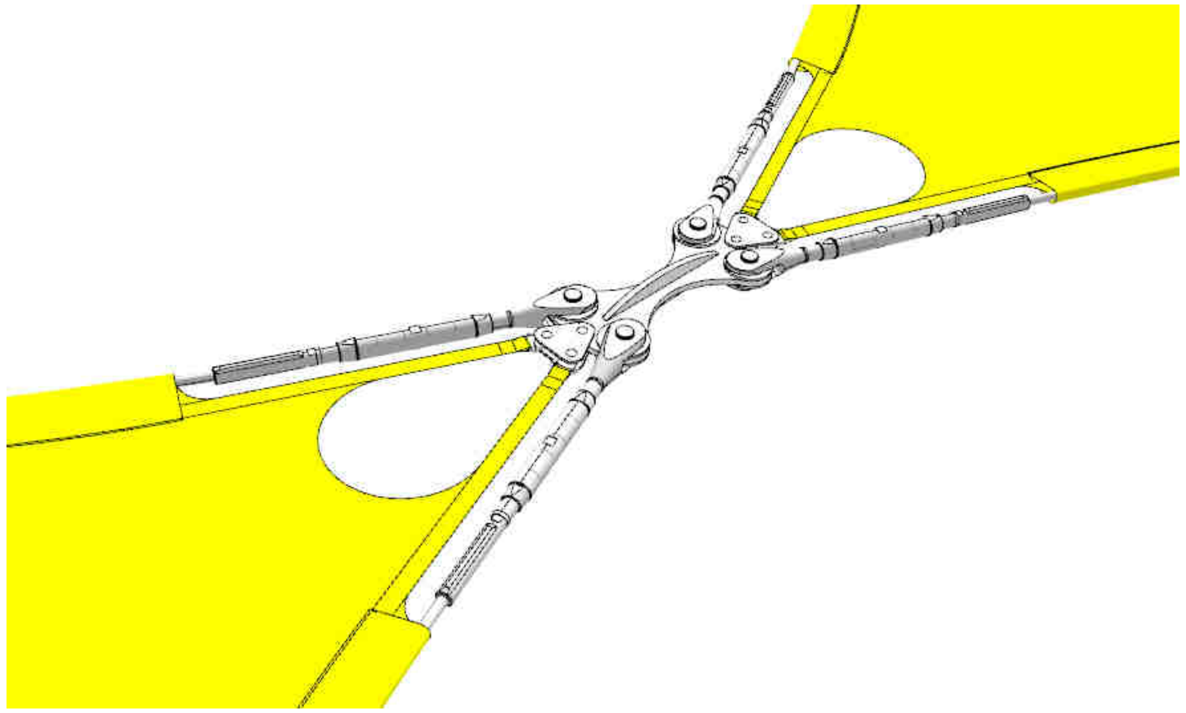


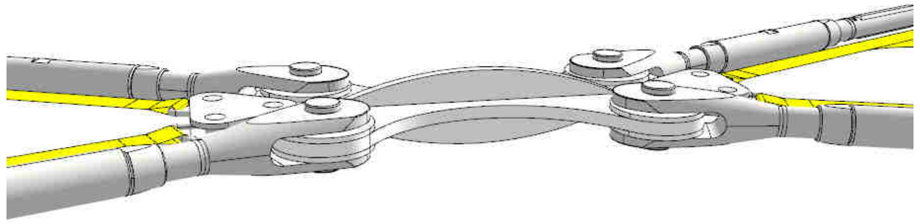


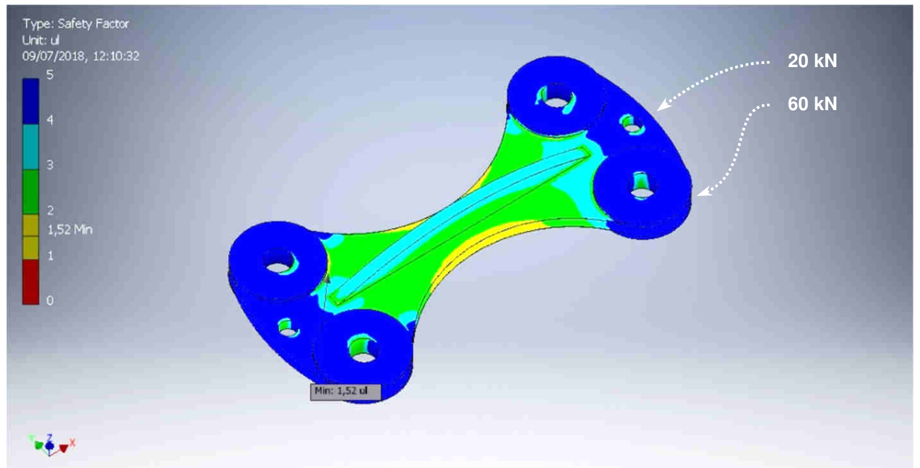


6.4 - Detail C





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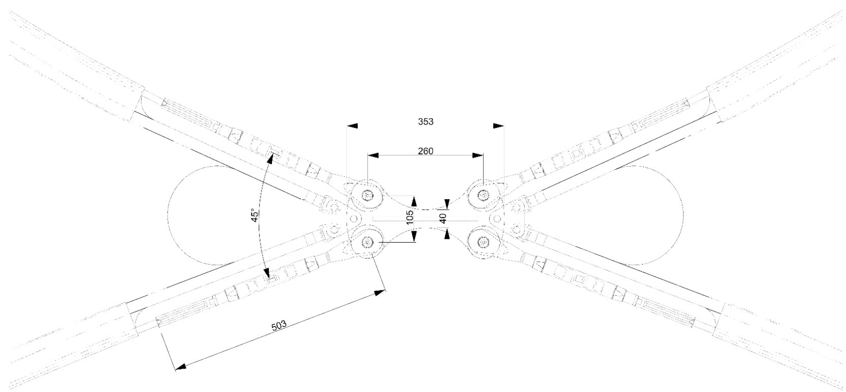
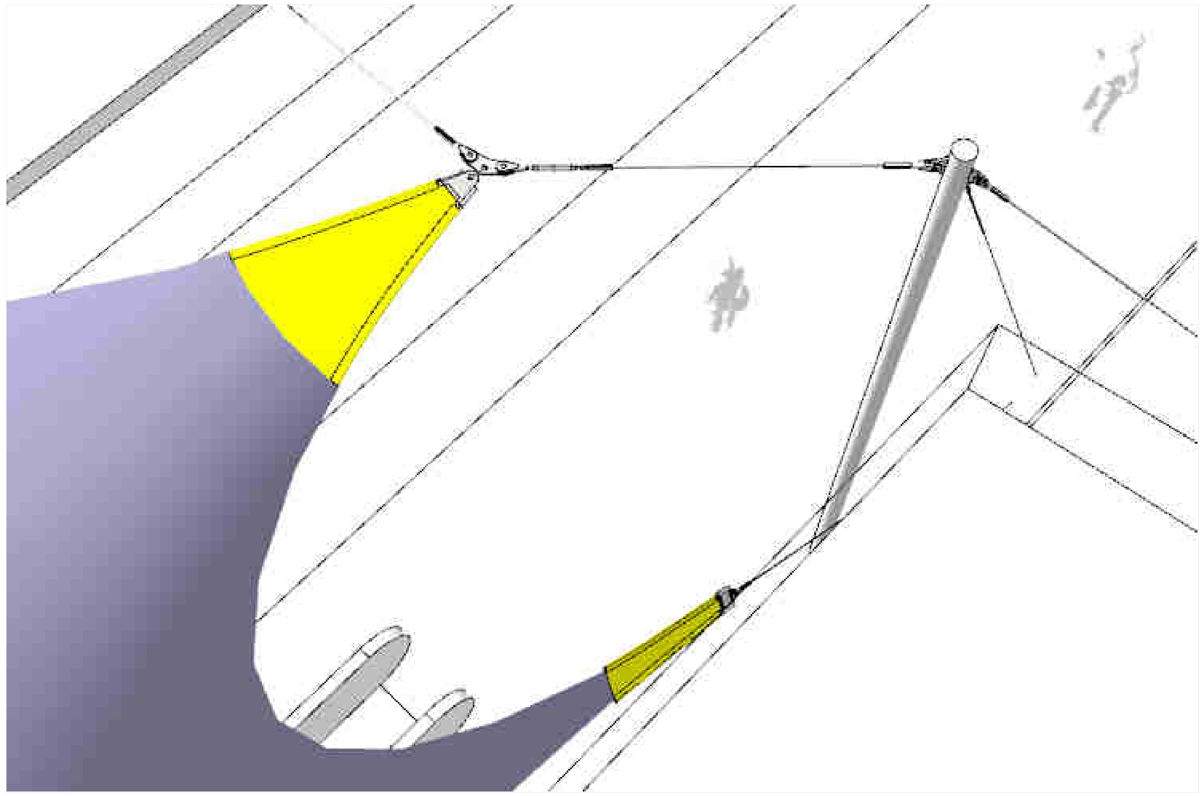
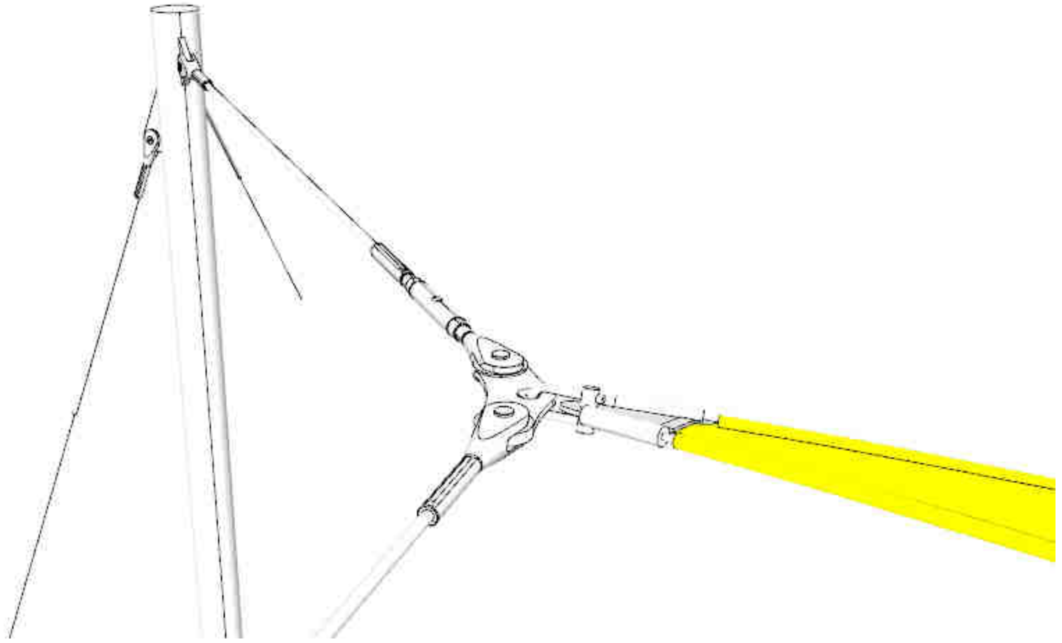
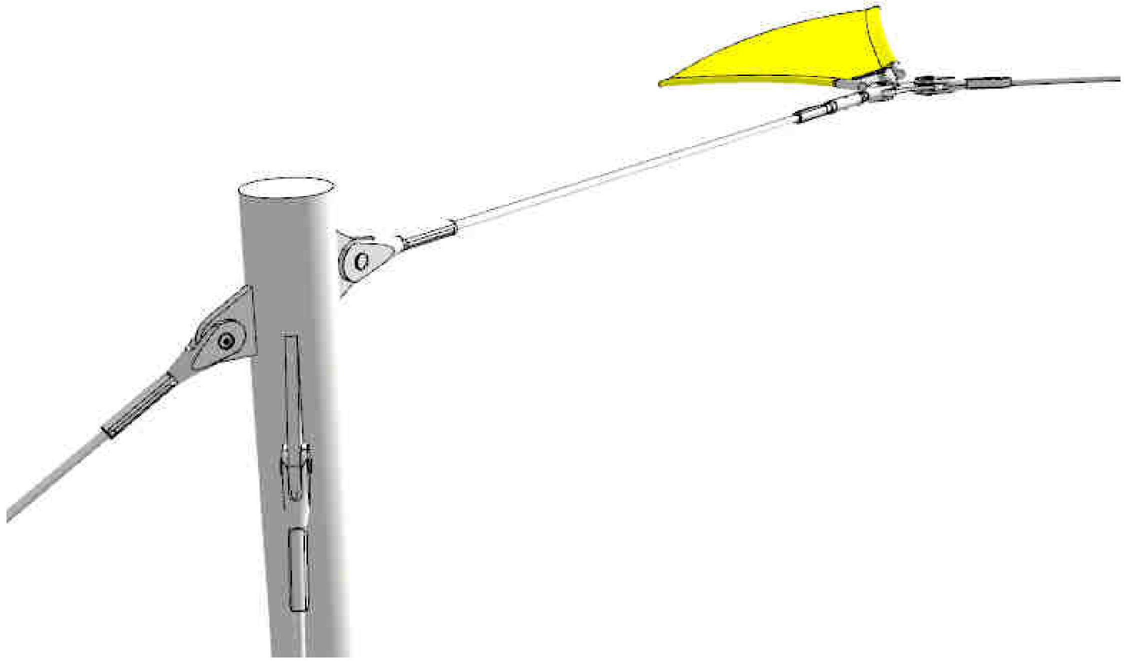
Unit: ul
09/07/2018, 12:10:32
5
4
3
2
1,52 Min
1
0
20 kN
60 kN
Min: 1,52 ul

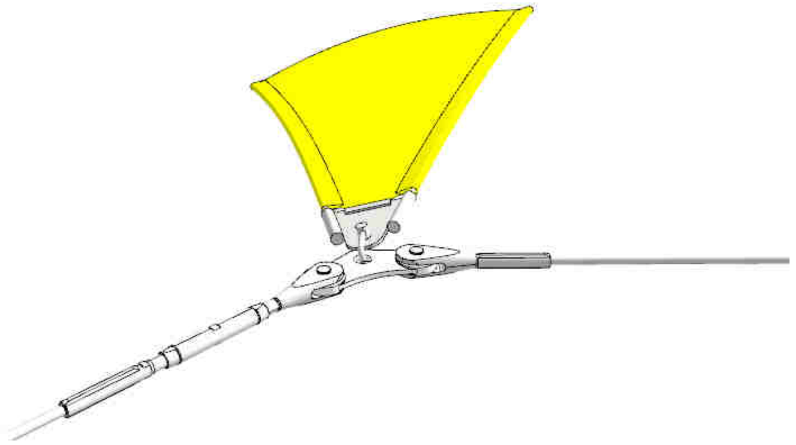

353
260

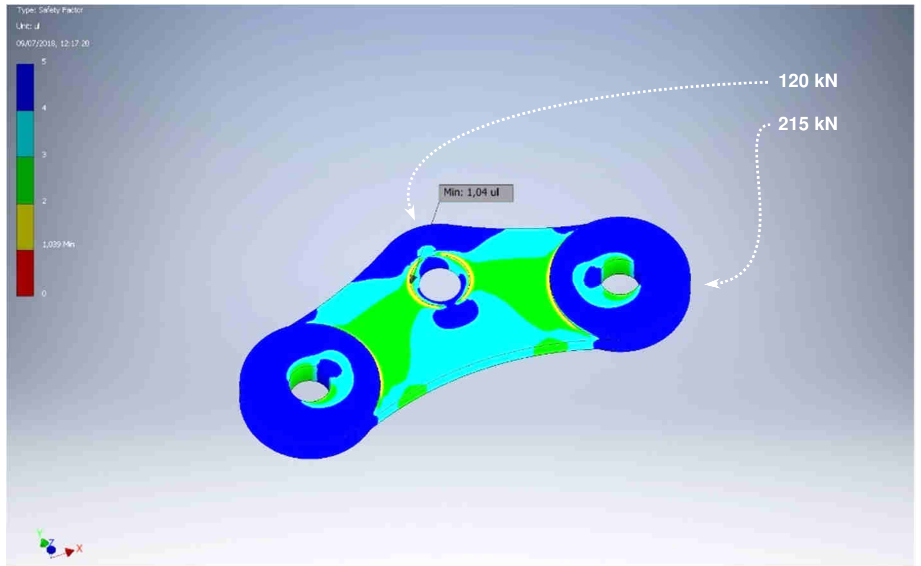
6.5 - Detail D







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Unit: ul
09/07/2018, 12:17:20
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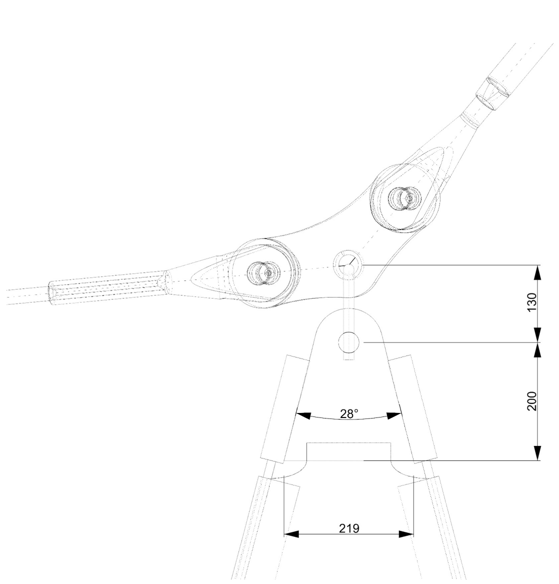
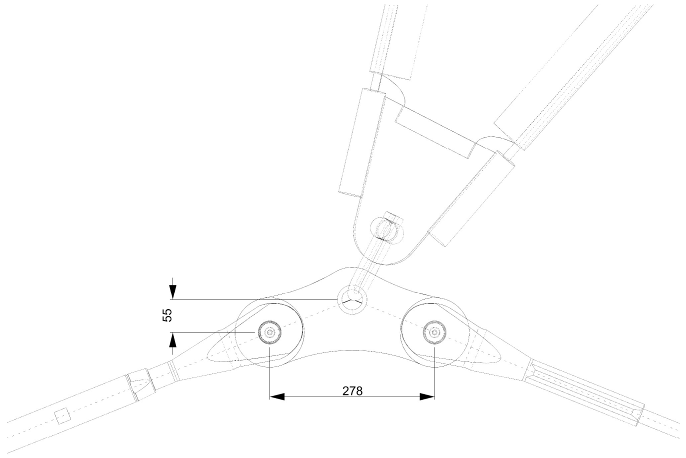
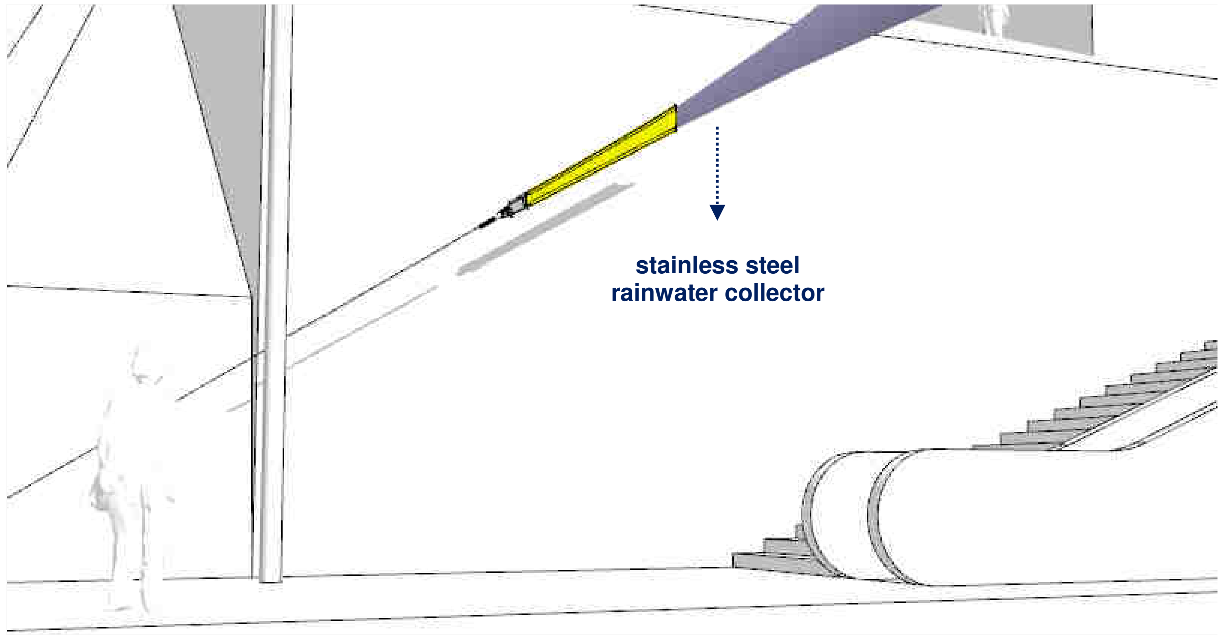
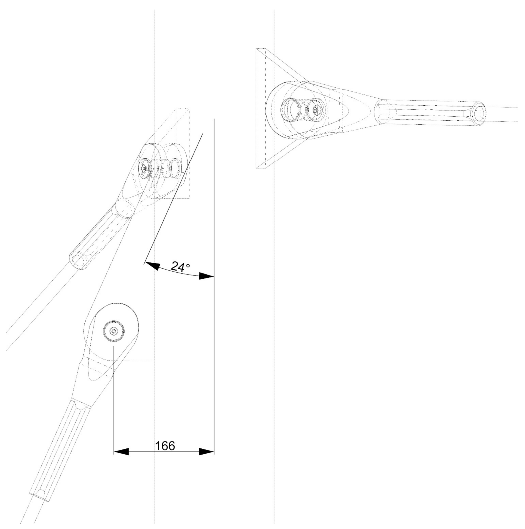
4
3
2
1,039 Min
0
120 kN
215 kN
Min: 1,04 ul

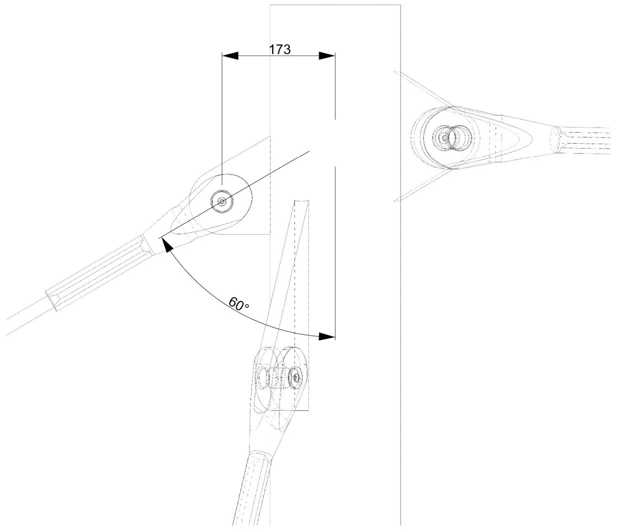

130
200
28°
219

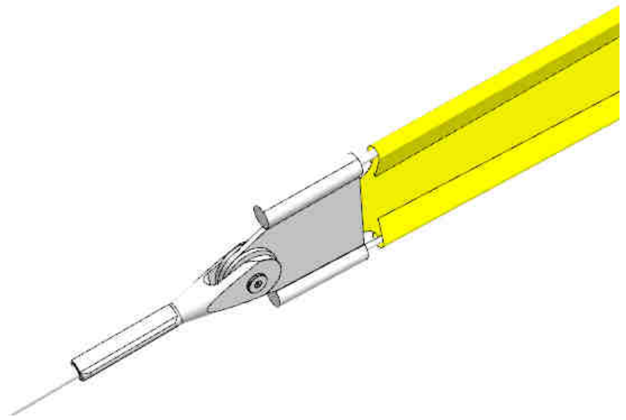

55
278

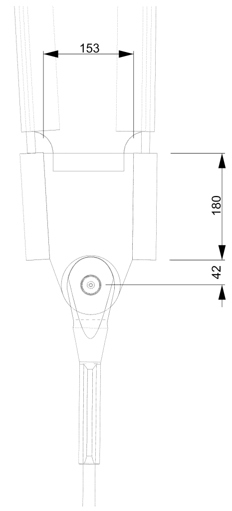
6.6 - Detail E


stainless steel
rainwater collector

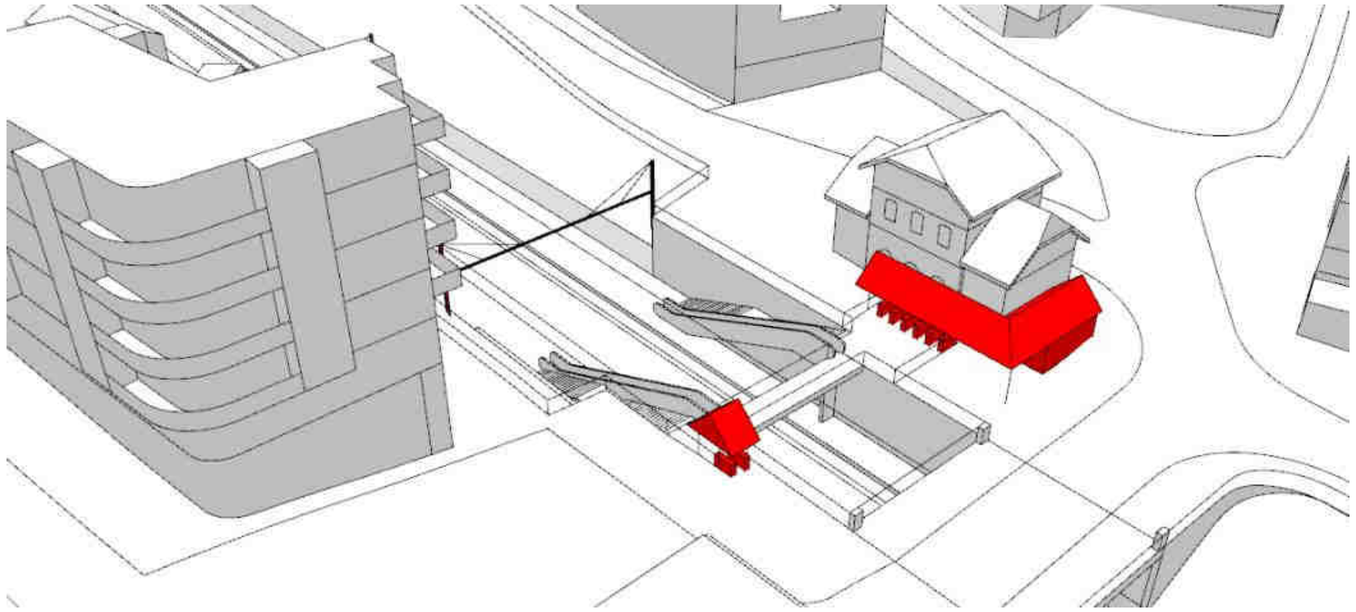

24°
166


173
60°

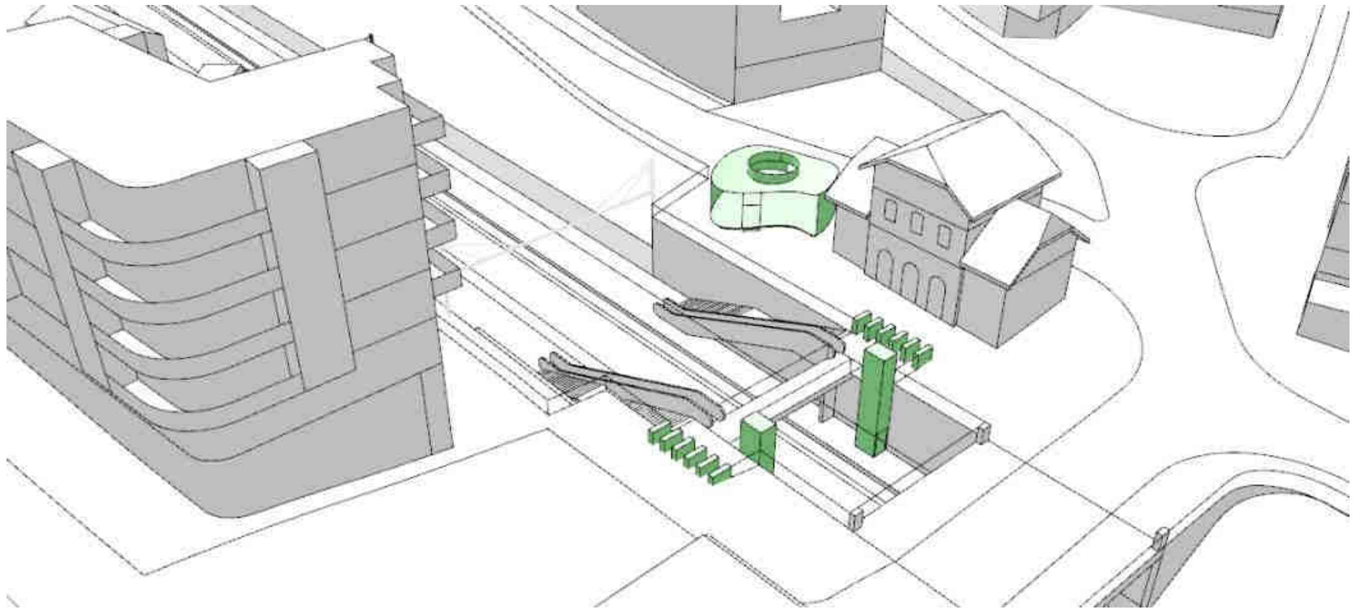



153
180
42

7 - Implementation

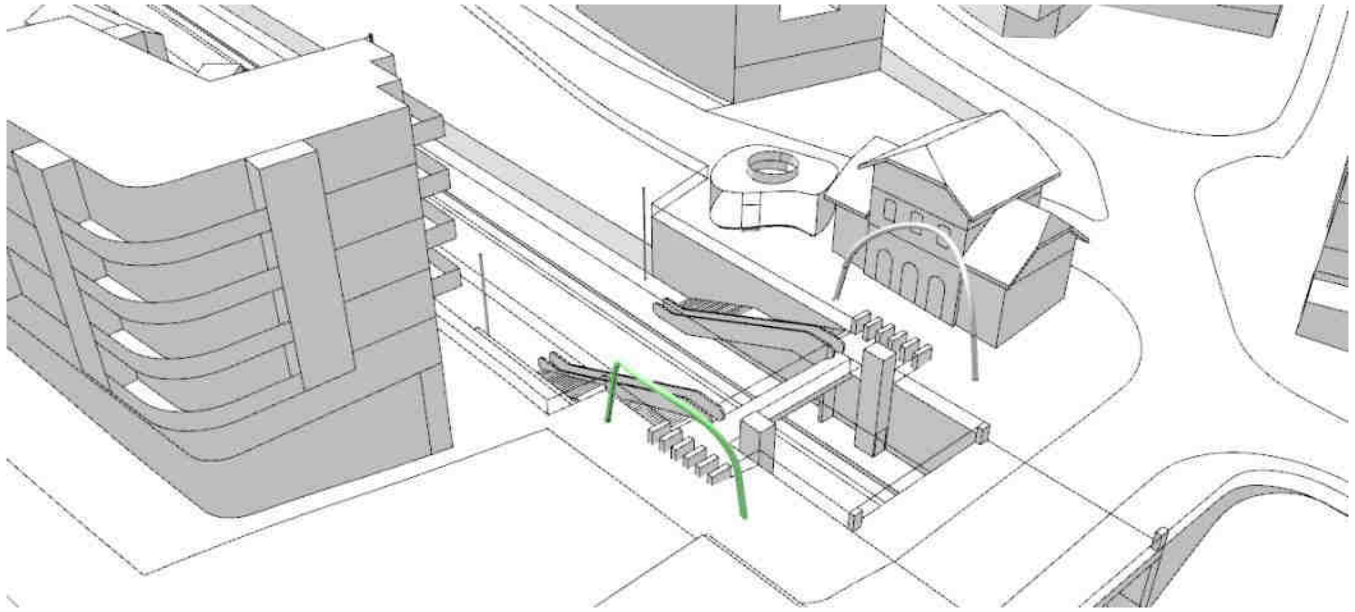


Step 1: removal of current roofs, composting machines and newsagent's shop.



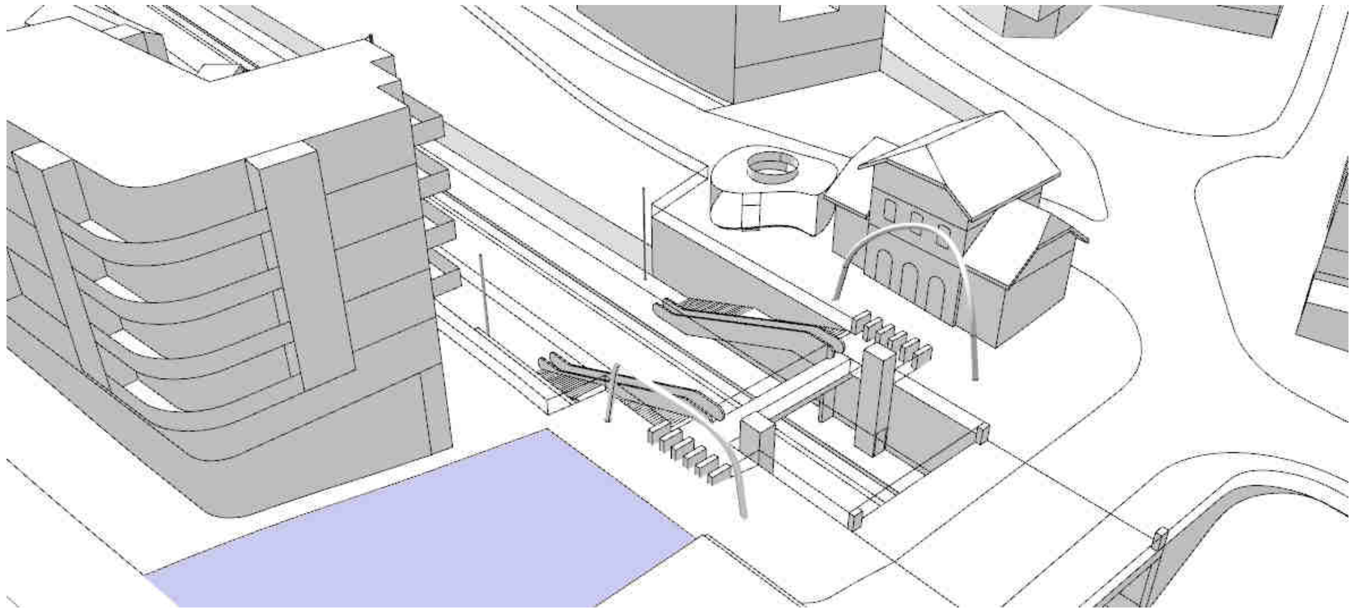
Step 2:

- removal of catenaries support near the bottom of the stairs (if impossible, columns and stay cables are compatible with the location of the current support) and reinforcement of supports under the road bridge;
- implementation of a new wooden curvy newsagent's shop, composting machines and lifts for people with reduced mobility.



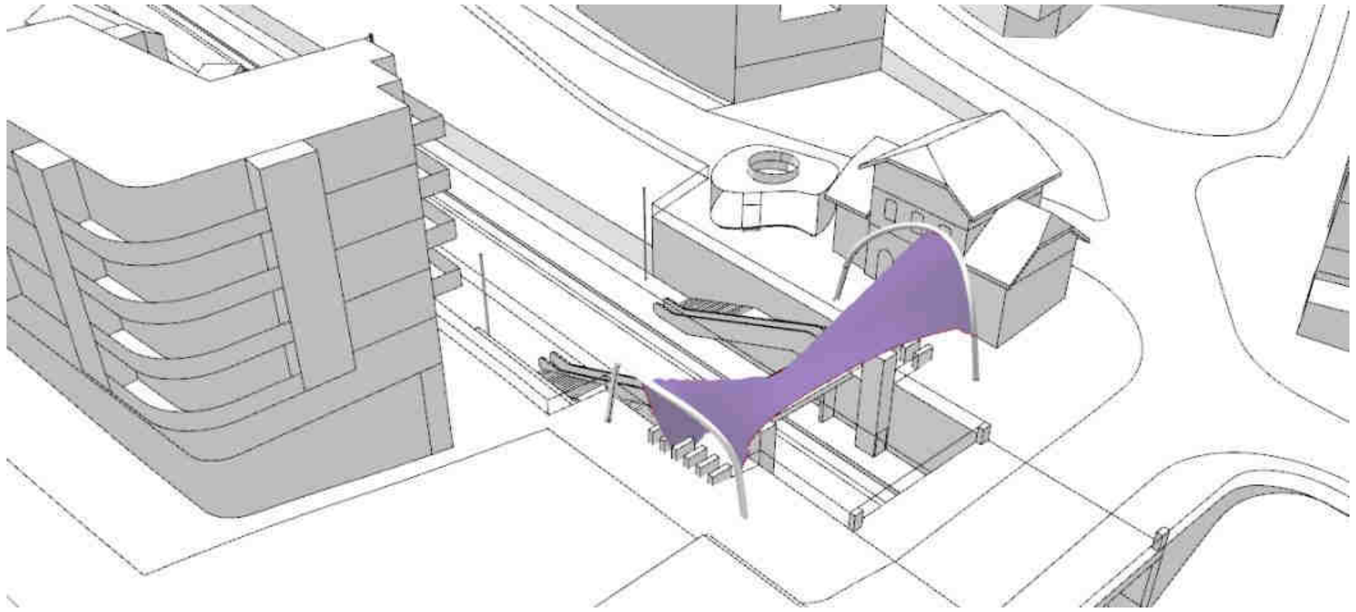
Step 3: implementation of:

- gantries at the road level;
- columns and anchoring points for stay cables at the platforms one.



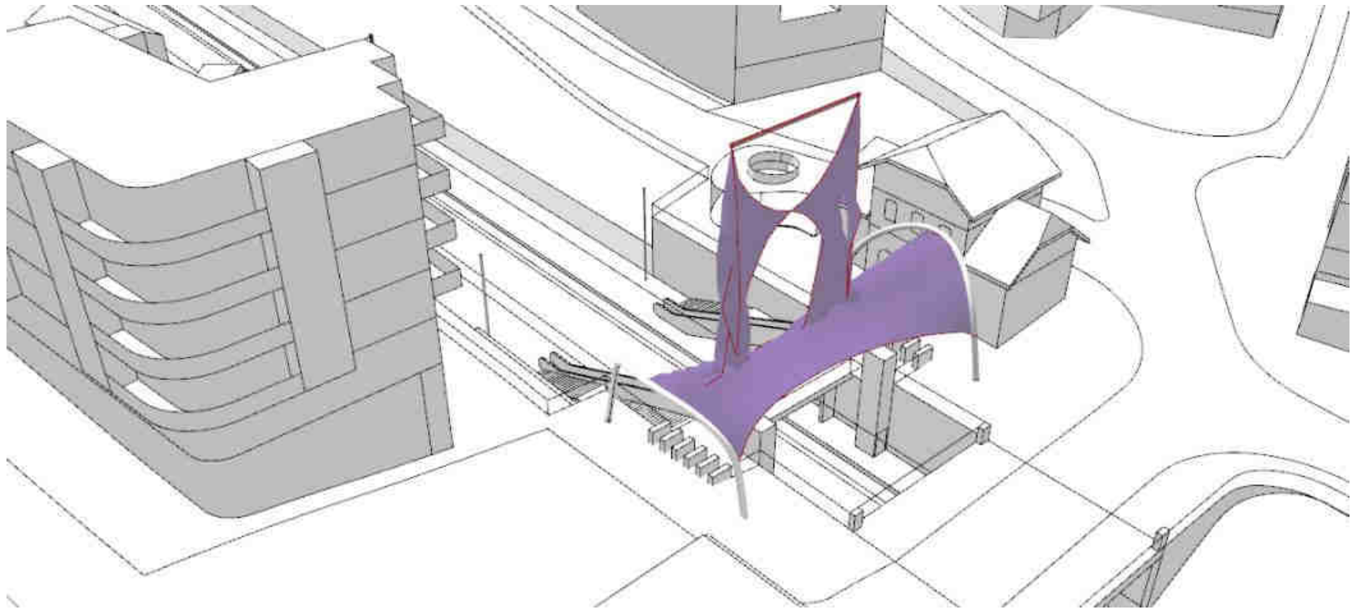
Step 4:

- installation a mobile crane and delivery of the packed membrane on the square Henri Brousse;
- preparation and insertion of the cables that have to be fixed on gantries.

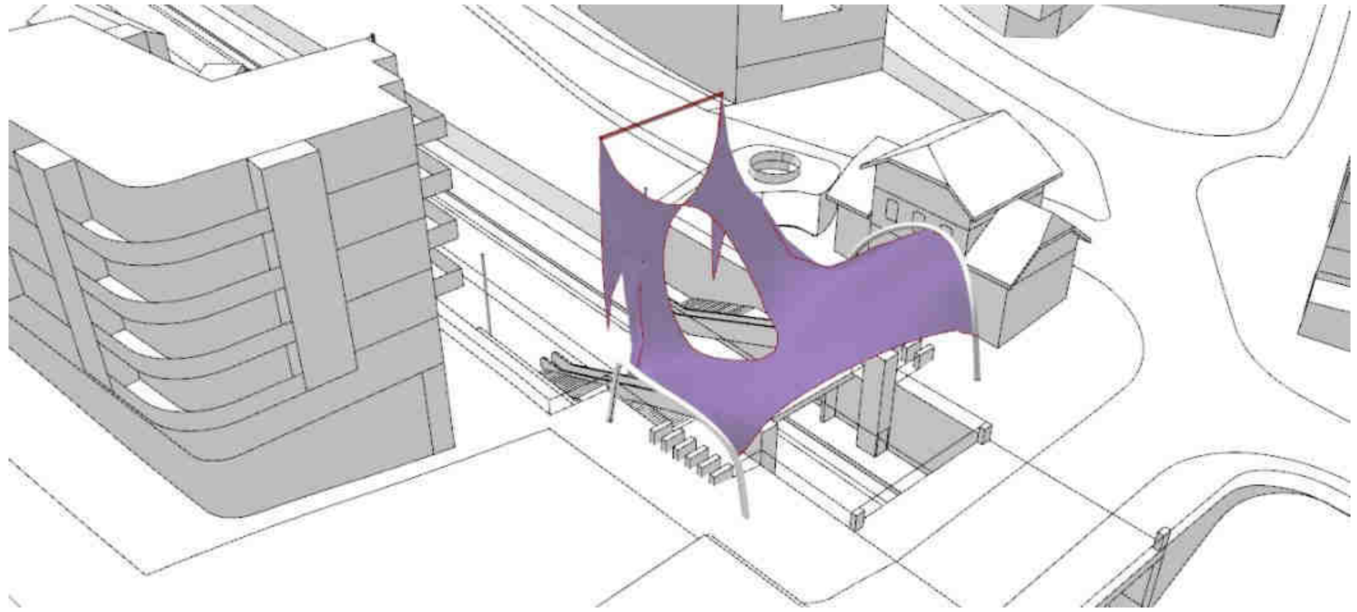


Step 5: implementation oft he prepared membrane thanks to the crane, during a night for safety reason:

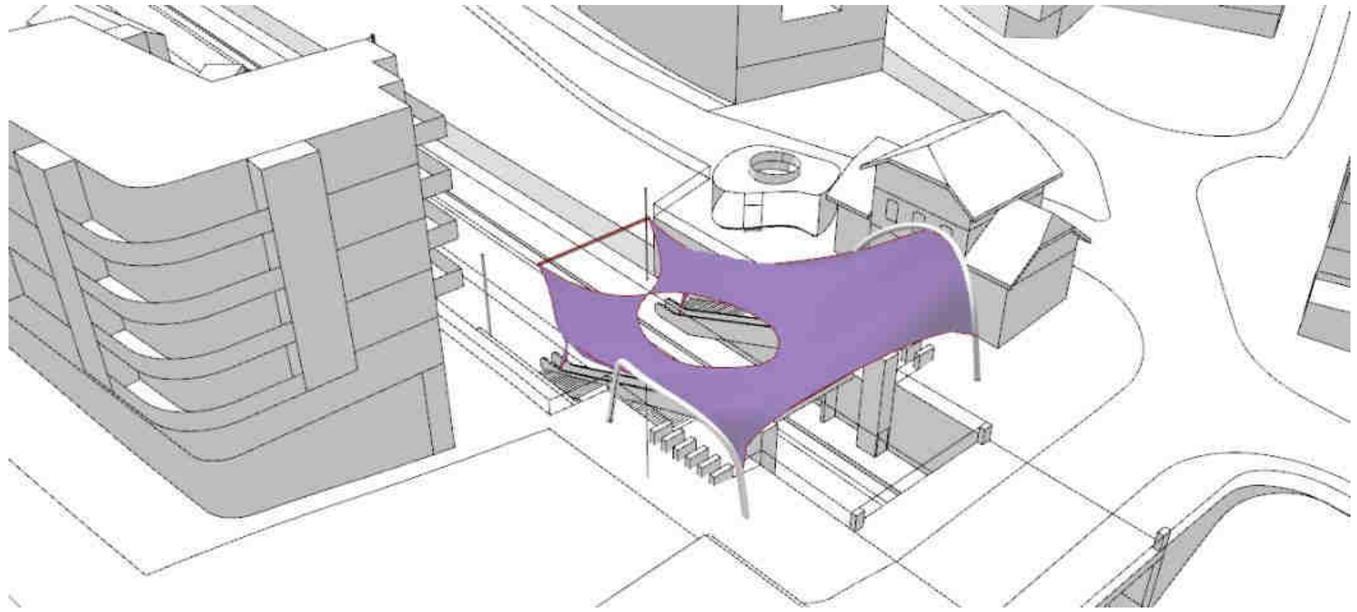
- cables are fixed on east gantry then on west one, while the rest of the membrane remains on the pedestrian bridge;
- preparation and insertion of the other cables.



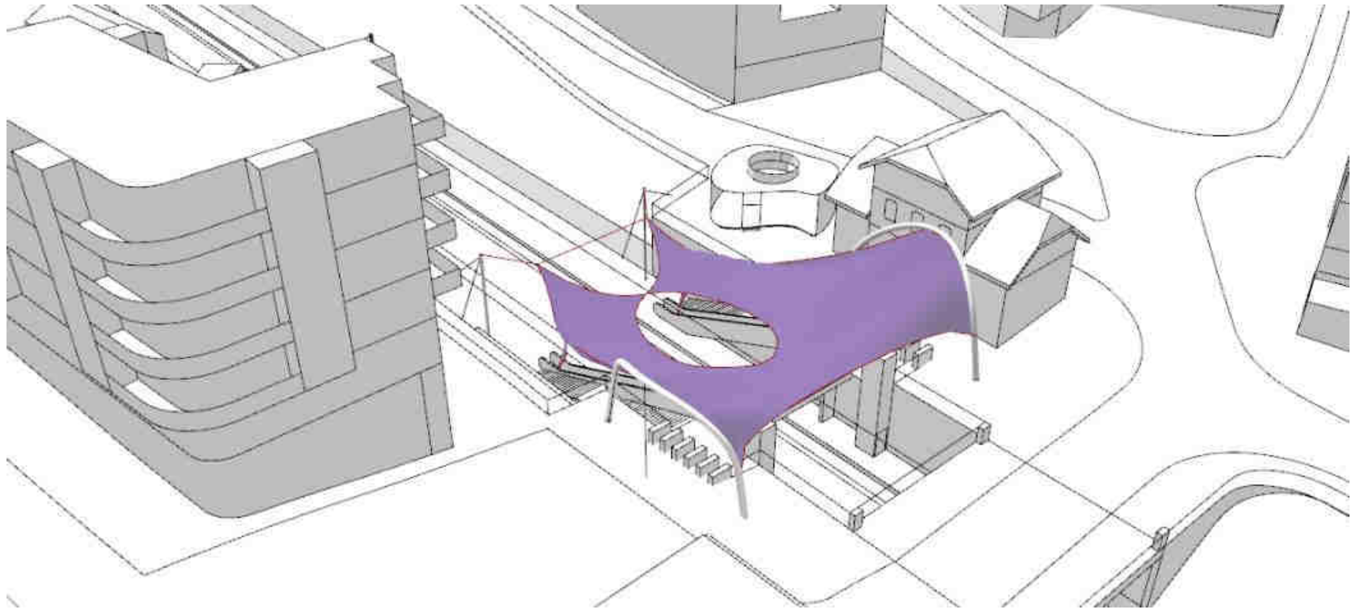
Step 6: lifting of the unfixed membrane with a bar and a sling.



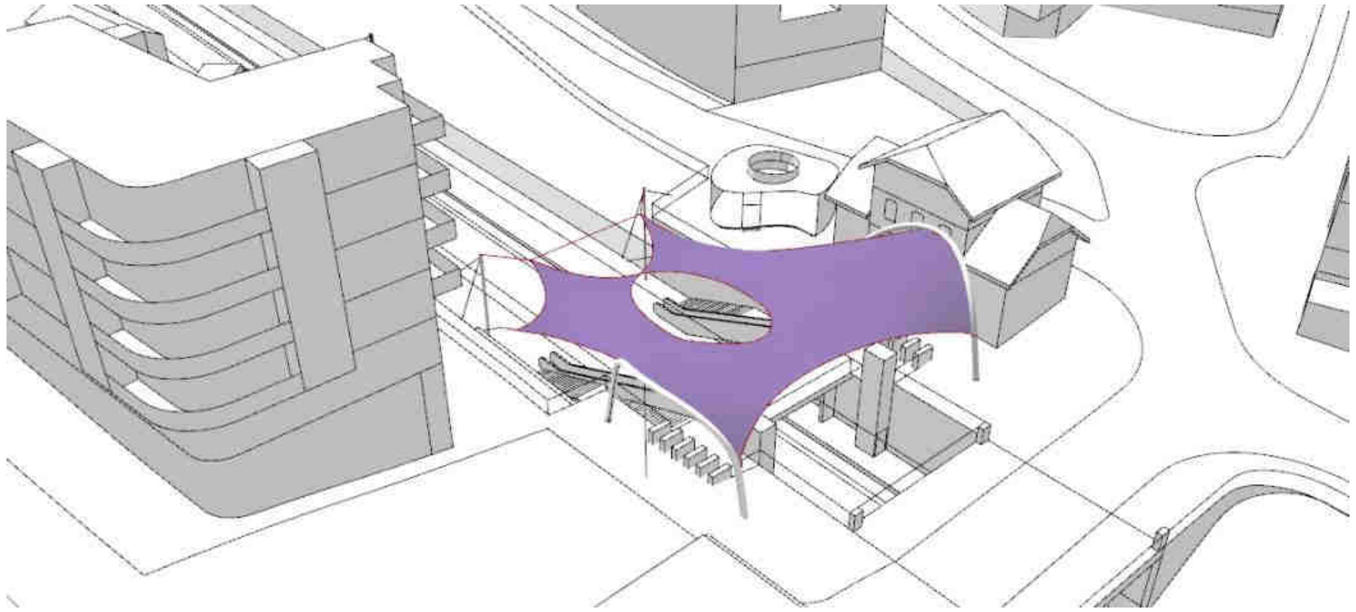
Step 7: gradual placement…



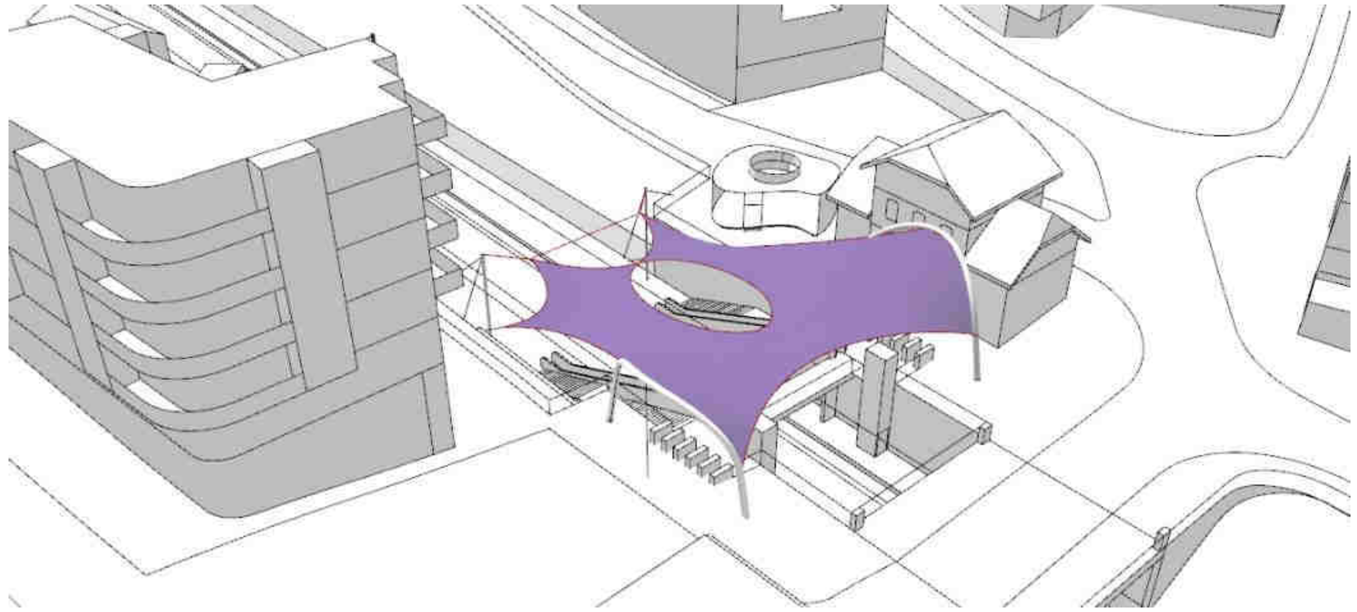
Step 8: … to the final approximate location.



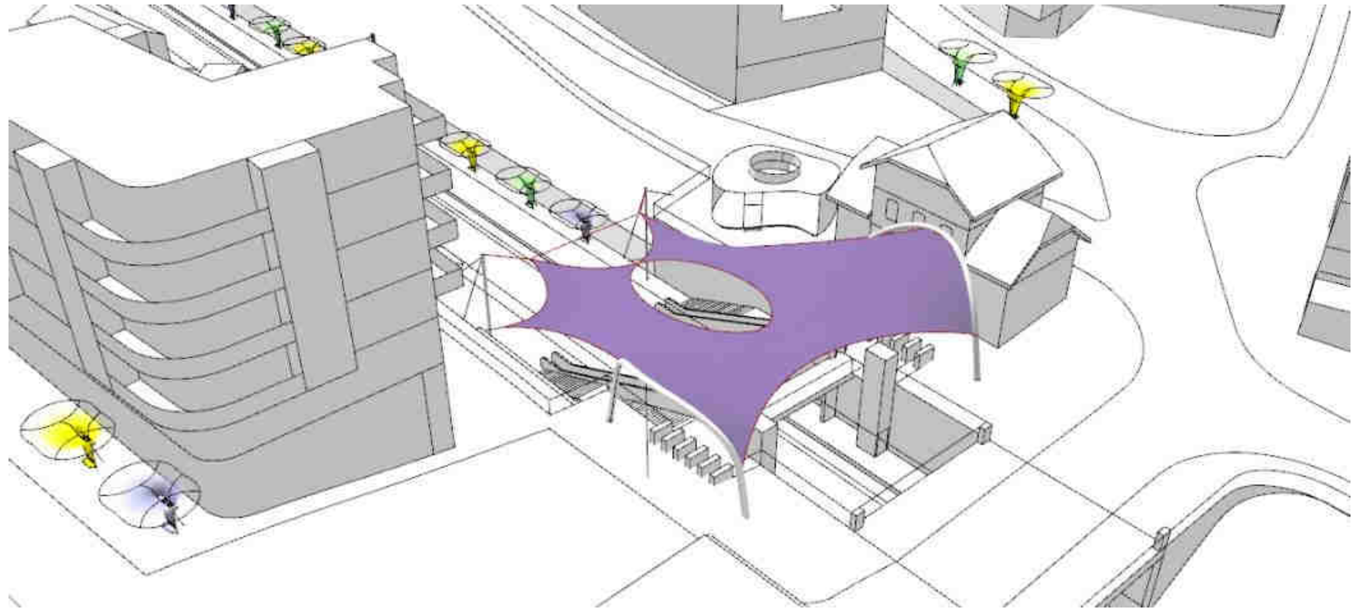
Step 9: installation of the stay cables on the columns thanks to a light aerial platform.



Step 10: installation of the two last cables up to the anchoring points in the ground.



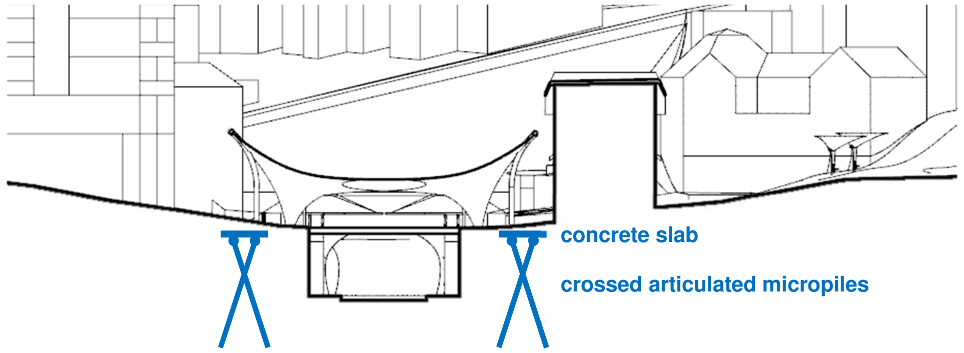
Step 11: cables and fasteners adjustments, progressive tensioning of the membrane.



Step 12: delivery on the square and installation of the secondary membranes on platforms and streets.

8 - Cost estimation

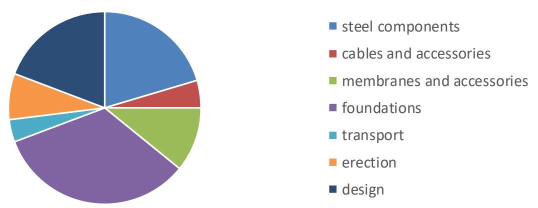
The following estimation includes only the provision and the installation of the main membrane. Foundations have to be further investigated to check if typologie proposed below is suitable.



A complementary study will be necessary to estimate the cost of secondary membranes, replacement of newsagent's shop, modifications on catenaries, new lifts and composting machines.

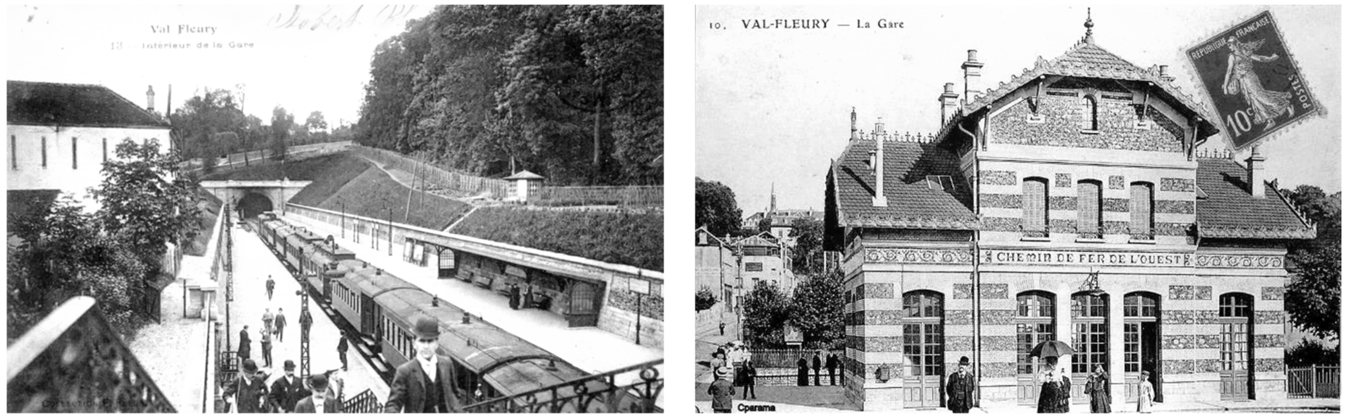
Estimated costs for a new covering membrane: Meudon Val-Fleury train station (France)									damage		probability	amount of risk
								[€]	[%]	[€]	[%]	[€]
				quantities [unit]	weight [kg/unit]	[kg]	standard price (approx.)					
Materials and products	steel components	columns	Ø 194*5	17 m	23	393	6,0 €/kg	2 358	25%	590	30%	177
		gantries	Ø 406*16	46 m	39	1822	8,0 €/kg	14 578	25%	3 644	30%	1093
		tension rods	Ø 60	15 m	22	331	8,0 €/kg	2 646	25%	662	30%	198
		bottom plates		10 u	59	585	6,0 €/kg	3 510	25%	878	30%	263
		other parts: 20% of total weight				626	4,0 €/kg	2 505	0%	0	0%	0
	cables and accessories	edge cables	Ø 14	160 m			9,0 €/m	1 440	25%	360	30%	108
		fittings for edge cables		22 u			80,0 €/u	1 760	25%	440	30%	132
		stay cables	Ø 24	60 m			12,0 €/m	720	25%	180	30%	54
		fittings for stay cables		12 u			100,0 €/u	1 200	25%	300	30%	90
		connection plates		3 u			200,0 €/u	600	25%	150	30%	45
	membranes and accessories	PVC/PES membrane		409 m²			25,0 €/m²	10 219	40%	4 087	50%	2044
		belts		12 u			30,0 €/u	360	40%	144	50%	72
		prefabricated pockets		160 m			10,0 €/m	1 600	40%	640	50%	320
								43 496 €				**4 597 €**
Foundations	foundations for gantries and tension rods: concrete slabs and crossed micropiles							25 000	40%	10000	30%	3000
	foundations for columns and stay cables							15 000	40%	6000	30%	1800
								40 000 €				**4 800 €**
Transport	delivery of steel components, cables and membranes							5 000	0%	0	0%	0
								5 000 €				**0 €**
Erection	columns, gantries and tension rods							4 600	25%	1150	50%	575
	main membrane and stay cables							4 600	25%	1150	50%	575
								9 200 €				**1 150 €**
Others	removal of the current newsagent's shop, provision and installation of a new one							rememb.				
	removal of catenaries support and reinforcements											
	provision and installation of new lifts											
	removal of current composting machines, provision and installation of new ones											
	provision and installation of secondary membranes											
Design	concept							-				
	structure							9 600	25%	2 400	30%	720
	details							14 400	25%	3 600	30%	1 080
								24 000 €				**1 800 €**
							Total (without VAT) :	**121 696 €**			**Risk :**	**12 347 €**
							Total with risk (without VAT) :	**134 043 €**				

Statistical values, without risk:		Aim	Comments
steel components	22%	25%	-
cables and accessories	5%	25%	-
membranes and accessories	12%		-
foundations	37%	30%	specific foundations behind a retaining wall
transport	4%	-	-
erection	9%	25%	-
design	21%		-



9 - Conclusion

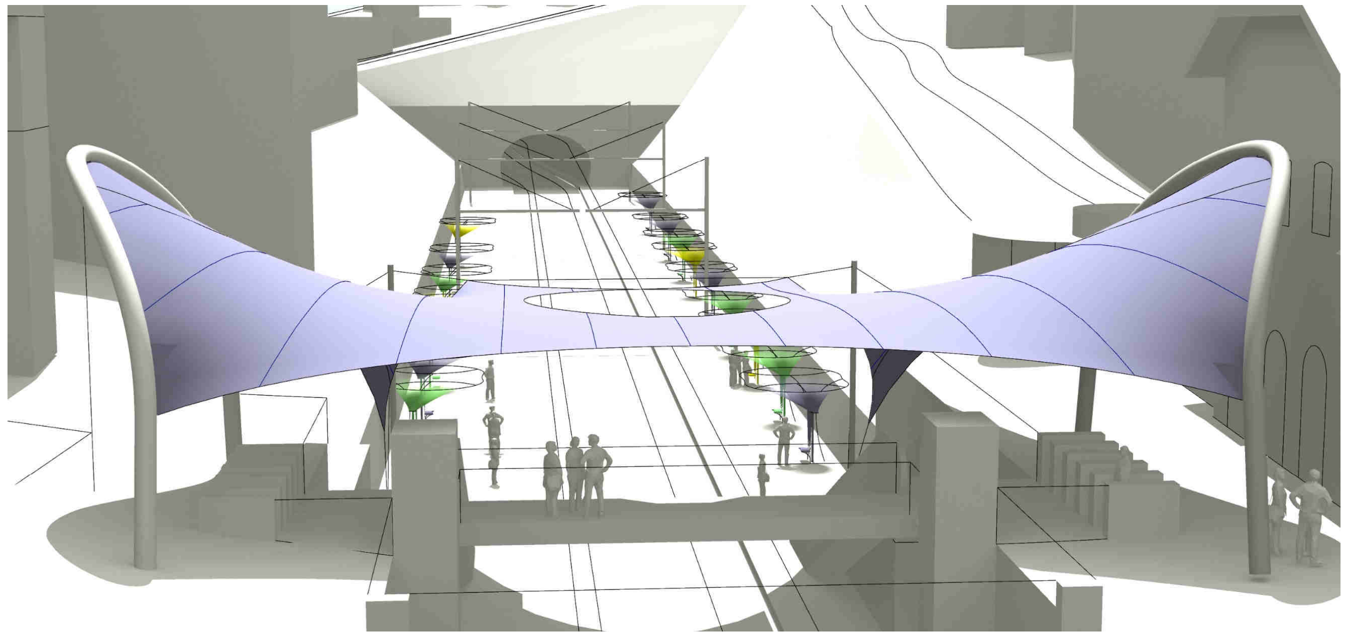
This thesis proposes a development project intended to protect the travelers reaching or leaving trains at the station Meudon Val-Fleury, on C line near Paris. The configuration of the station has changed little since its construction, shortly after the Exposition of 1900. At the time, the goal was to add a stop at the end of the new long tunnel connecting Paris to Versailles for safety reason, in a wooded area where constructions and travelers were few.



(www.cartophilie-viroflay.org)

Today, the density of surrounding buildings and the concentration of shops around the station have profoundly changed the landscape. Accessing train comfortably has become an important daily issue for many passengers who live nearby or seek to borrow.

The project presented here preserves the central role of the station, wich remains a necessary crossing point to recover tickets, while its street side façade keeps the same institutional image. The main membrane deployed over the access with the secondary membranes, laid on the platforms and sidewalks, can be seen by poets like a butterfly on a field of colorful flowers. But it is mainly an efficient protection against climatic aggressions that necessarily appears as a contemporary extension in the eyes of each traveler, resident or passersby.



The content of this thesis shows the effectiveness of the protection that would be provided, its technical feasibility as well as its urban impact through some illustrations. This work allowed me to spend pleasant moments imagining forms, seeking technical solutions or determining ways of implementation. Thanks again to the tutors for their advice and the Anhalt University for such an opportunity.

10 - Bibliography

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Review Detail: *Membrane construction*, September 2000
Review Detail: *Temporary structures*, December 1996

www.tensinet.com

Statement

I hereby declare that the work presented in this Master thesis, entitled “A new cover for the train station Meudon Val-Fleury”, is entirely my own and that I did not use any sources or auxiliary means other than those referenced.

Dessau-Roßlau, September 2018