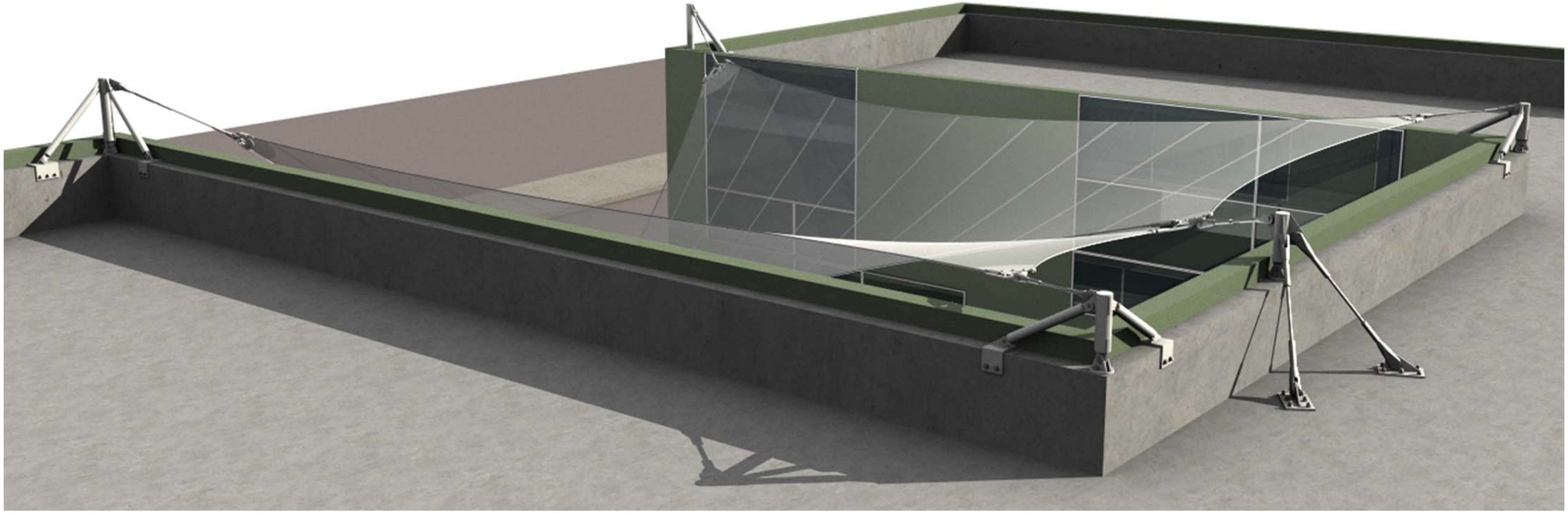
Master Thesis Project
Courtyard Cover for Anhalt University



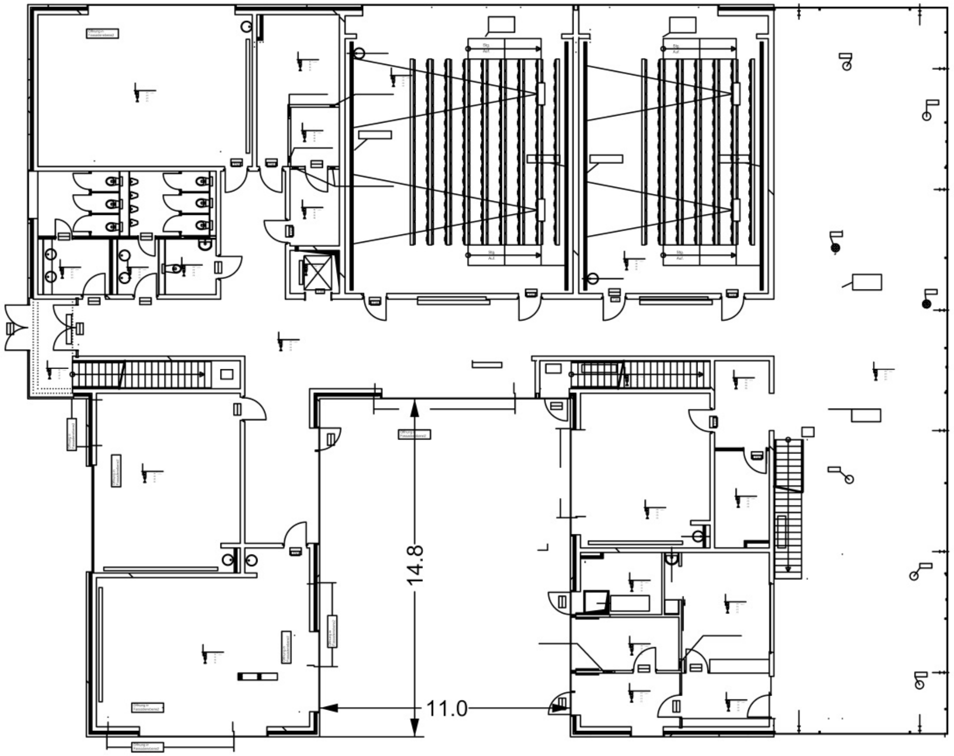
„Simplify, than add lightness"
Colin Chapman

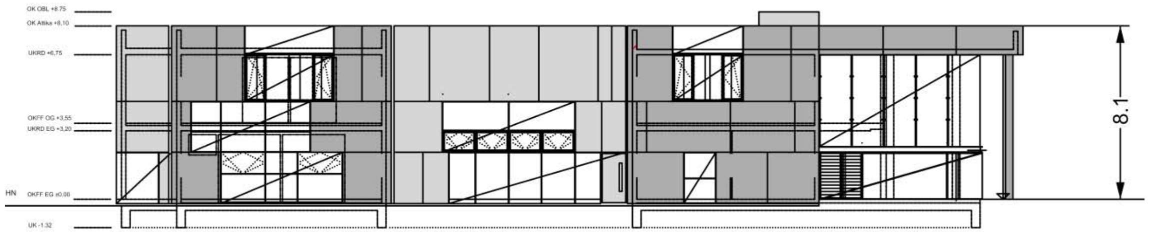
17.03.2016, DESSAU

ZOLTÁN ENDRE SIMON

CONTENT

1. AIMS, MOTIVATION, TASKS, THESIS CONCEPT

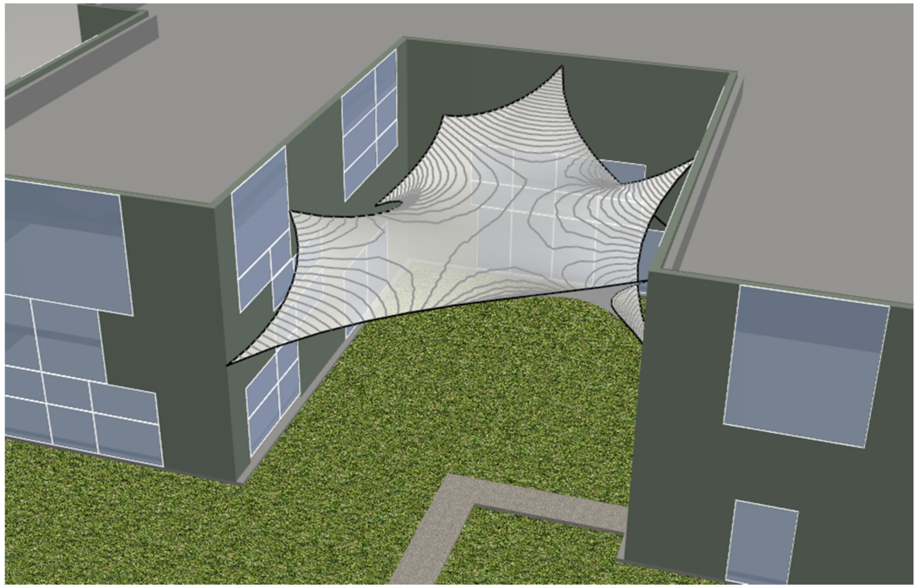


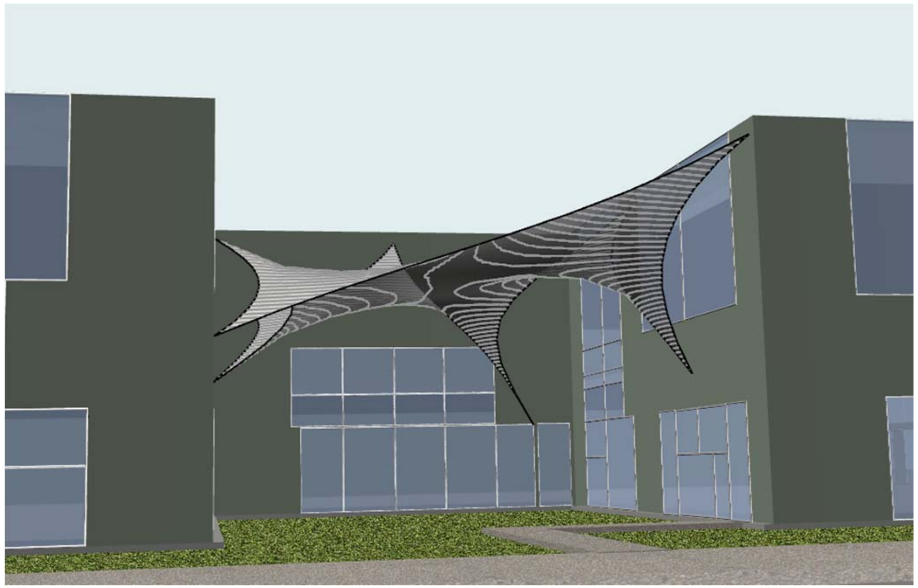


1. minimizing the limitation of the sun-exposur e
   (high translucent material)
2. convenient space for assemblies
   (minimizinf the fragmantation)
3. cost efficiency
   (simple membrane details, as less foundation and steel as possible)

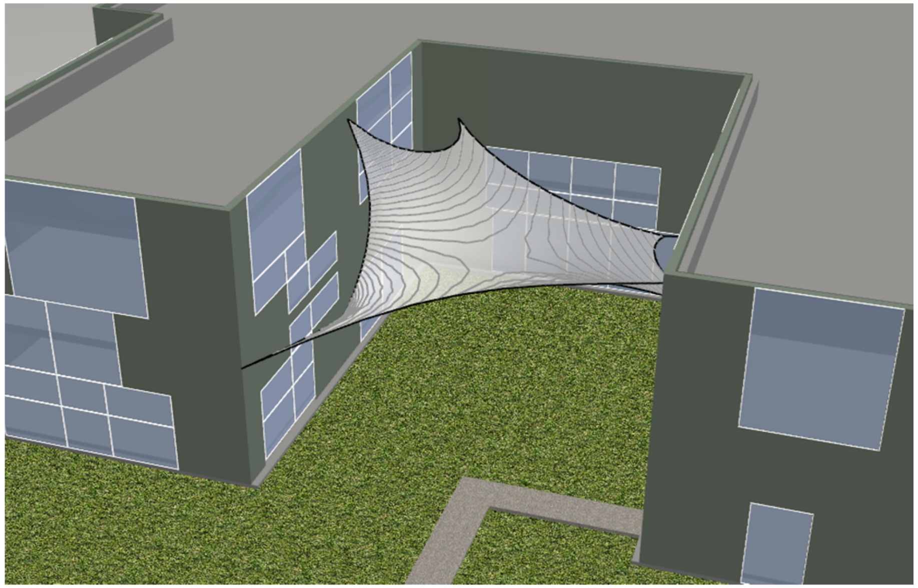
2. PROJECT FLOW & DESIGN STEPS / 1. Preliminary shape concepts

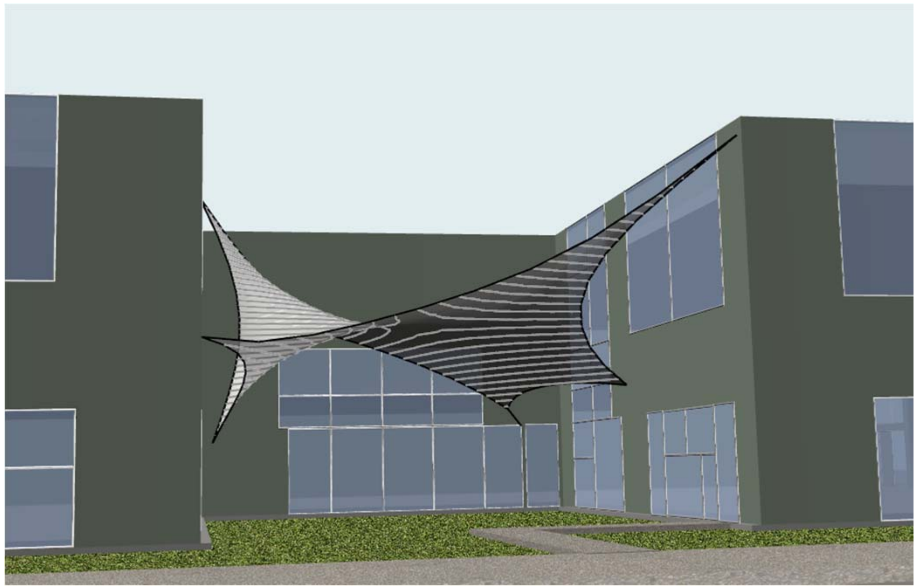
<u>V1-01</u>





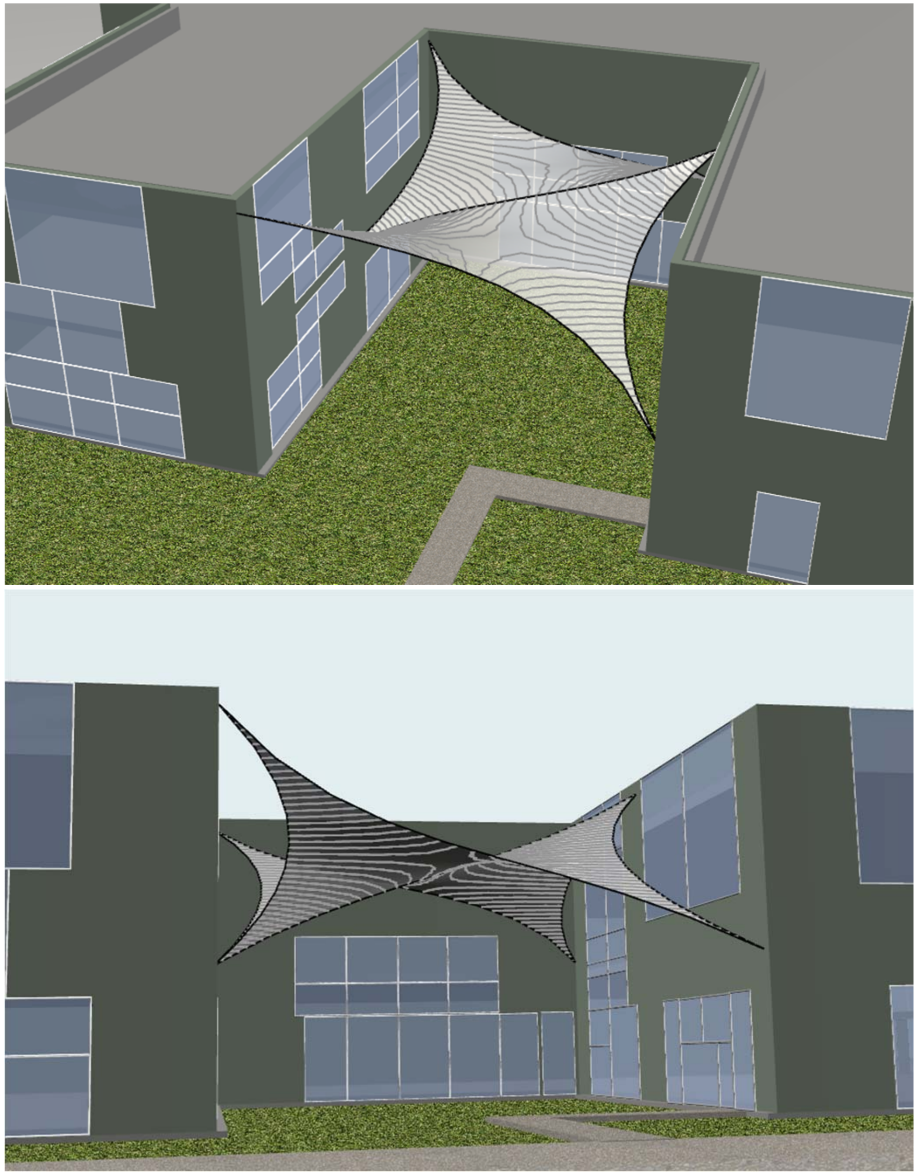
<u>V1-02</u>



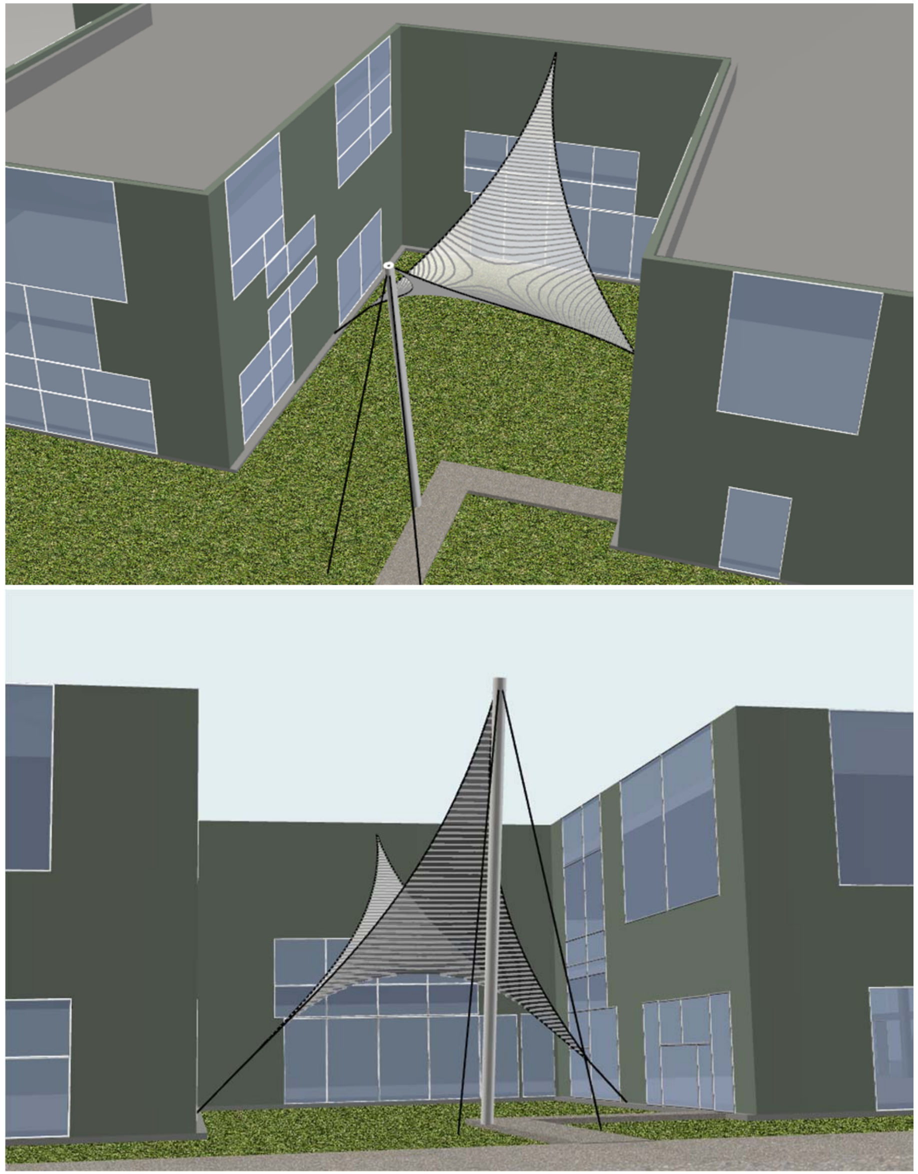


2. PROJECT FLOW & DESIGN STEPS / 1. Preliminary shape concepts

V1-03

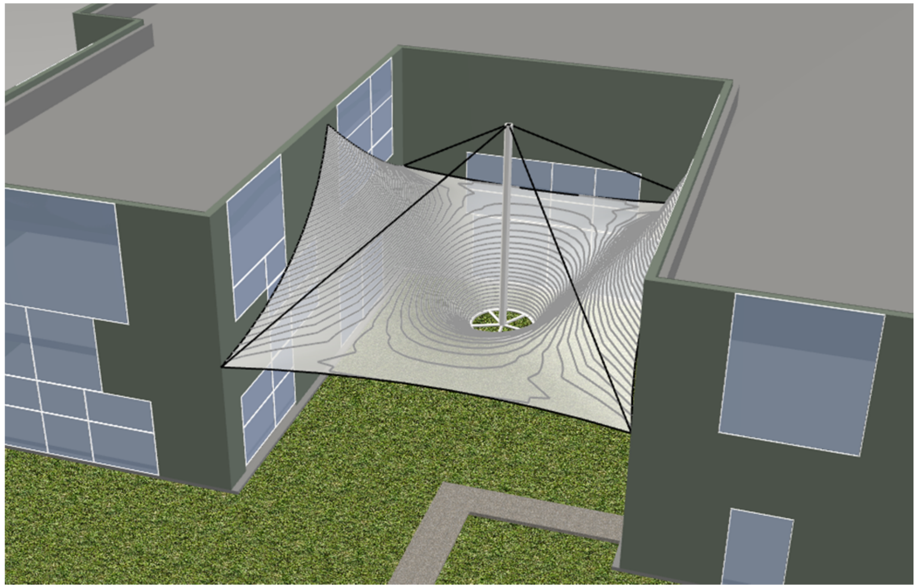


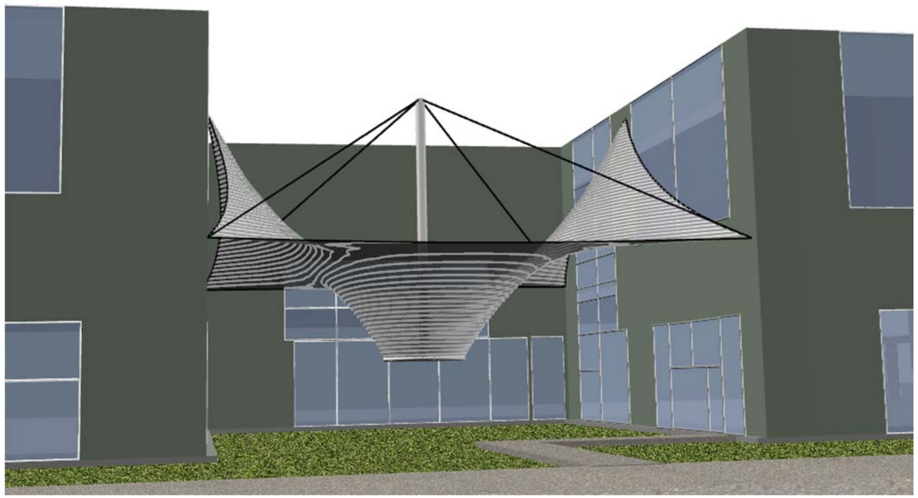
V1-04



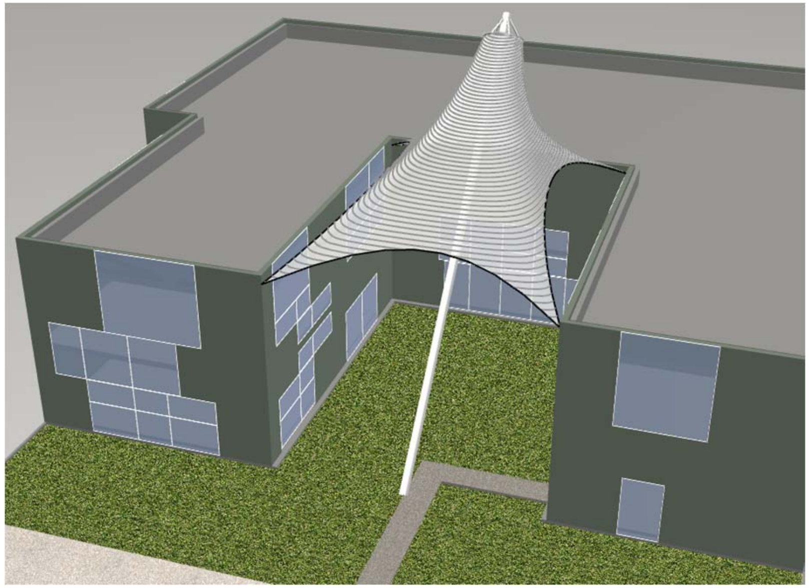
2. PROJECT FLOW & DESIGN STEPS / 1. Preliminary shape concepts

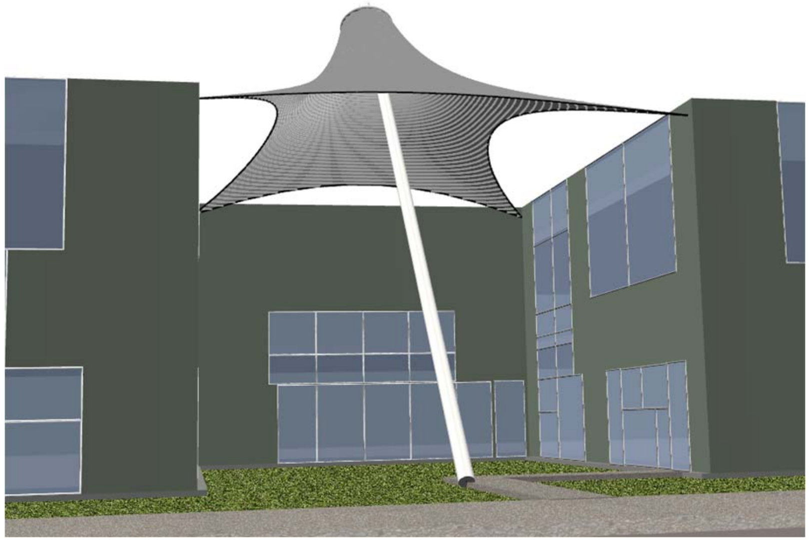
V1-06





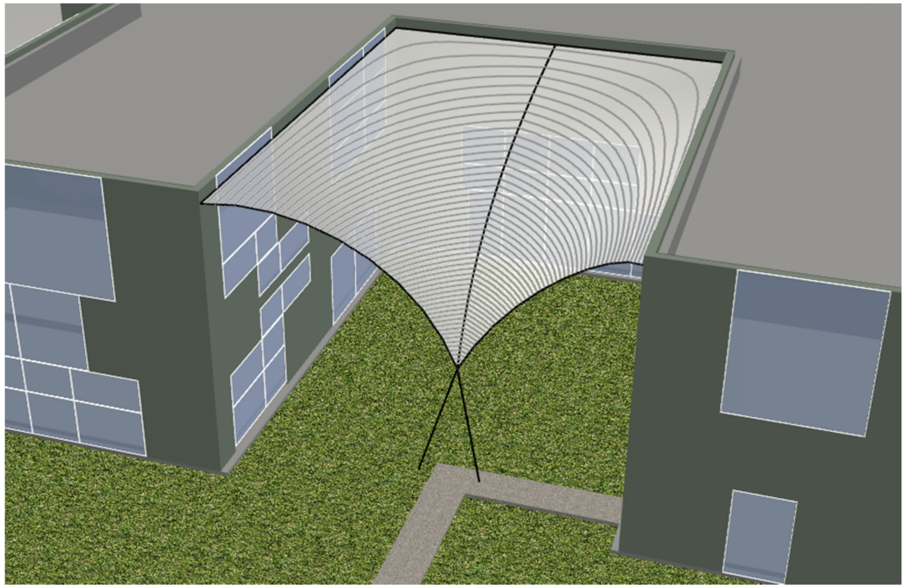
V1-07

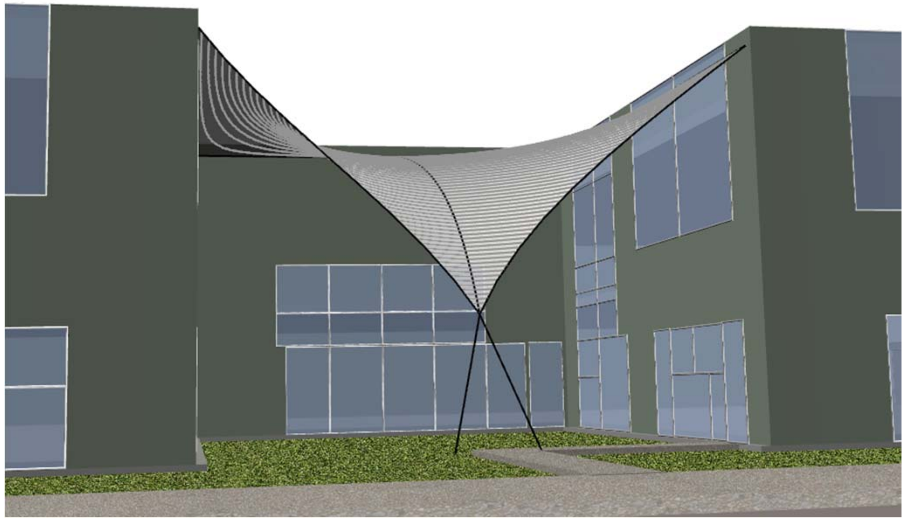




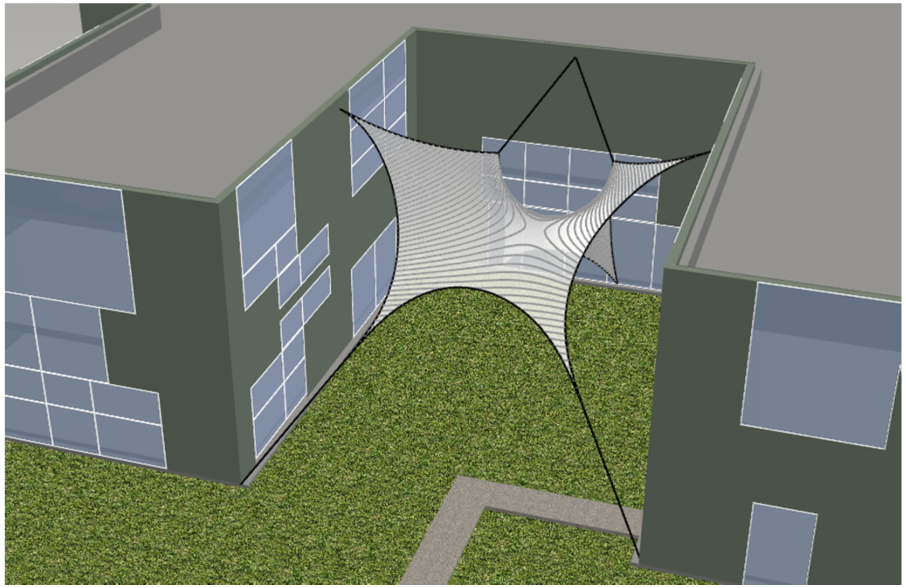
2. PROJECT FLOW & DESIGN STEPS / 1. Preliminary shape concepts

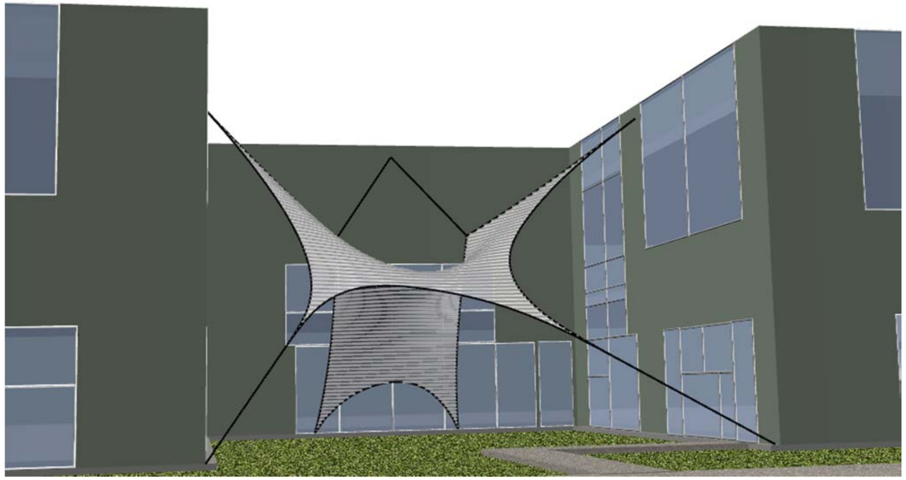
V1-08





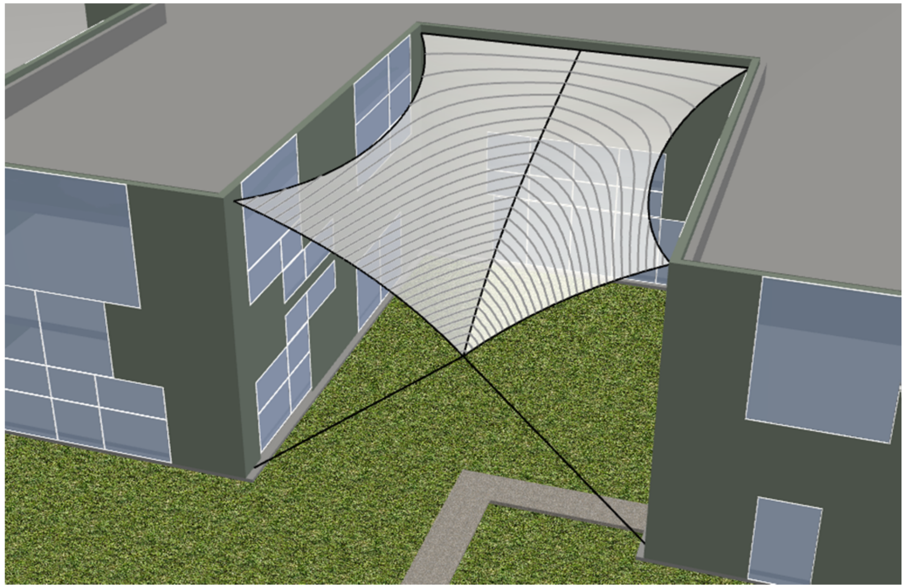
V1-09

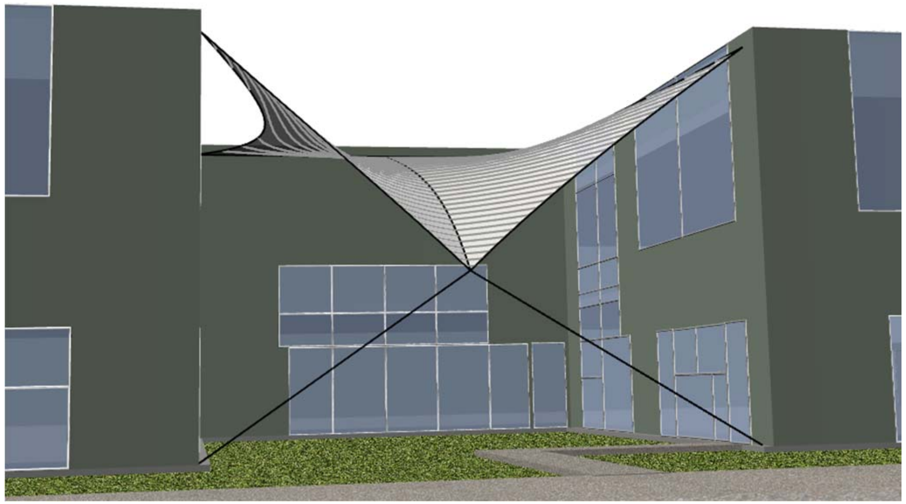




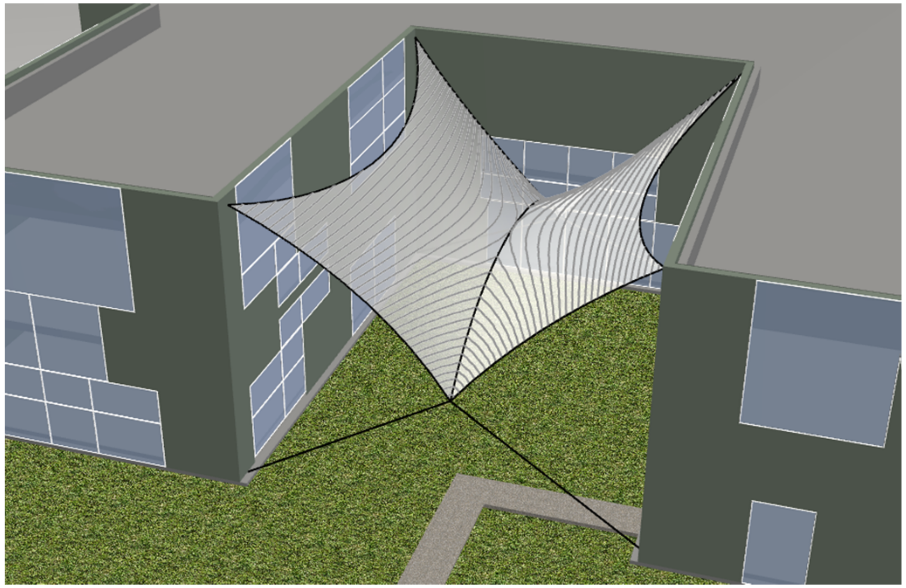
2. PROJECT FLOW & DESIGN STEPS / 1. Preliminary shape concepts

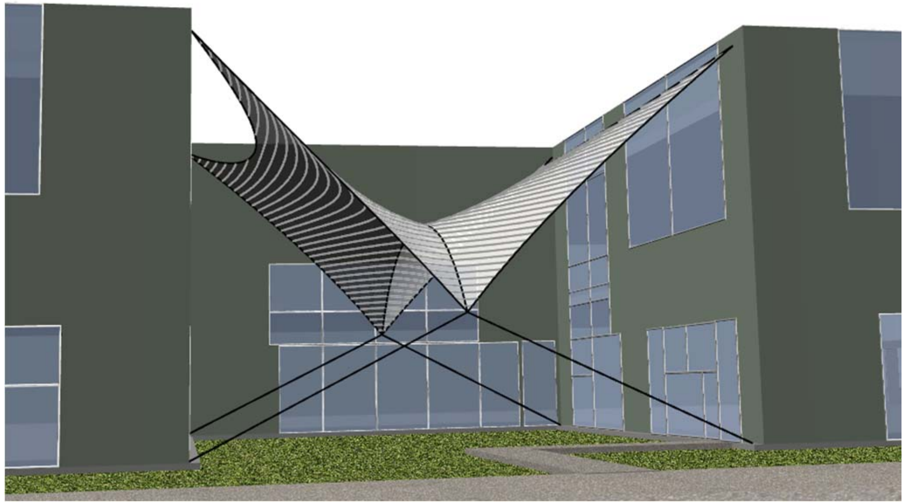
V2-04





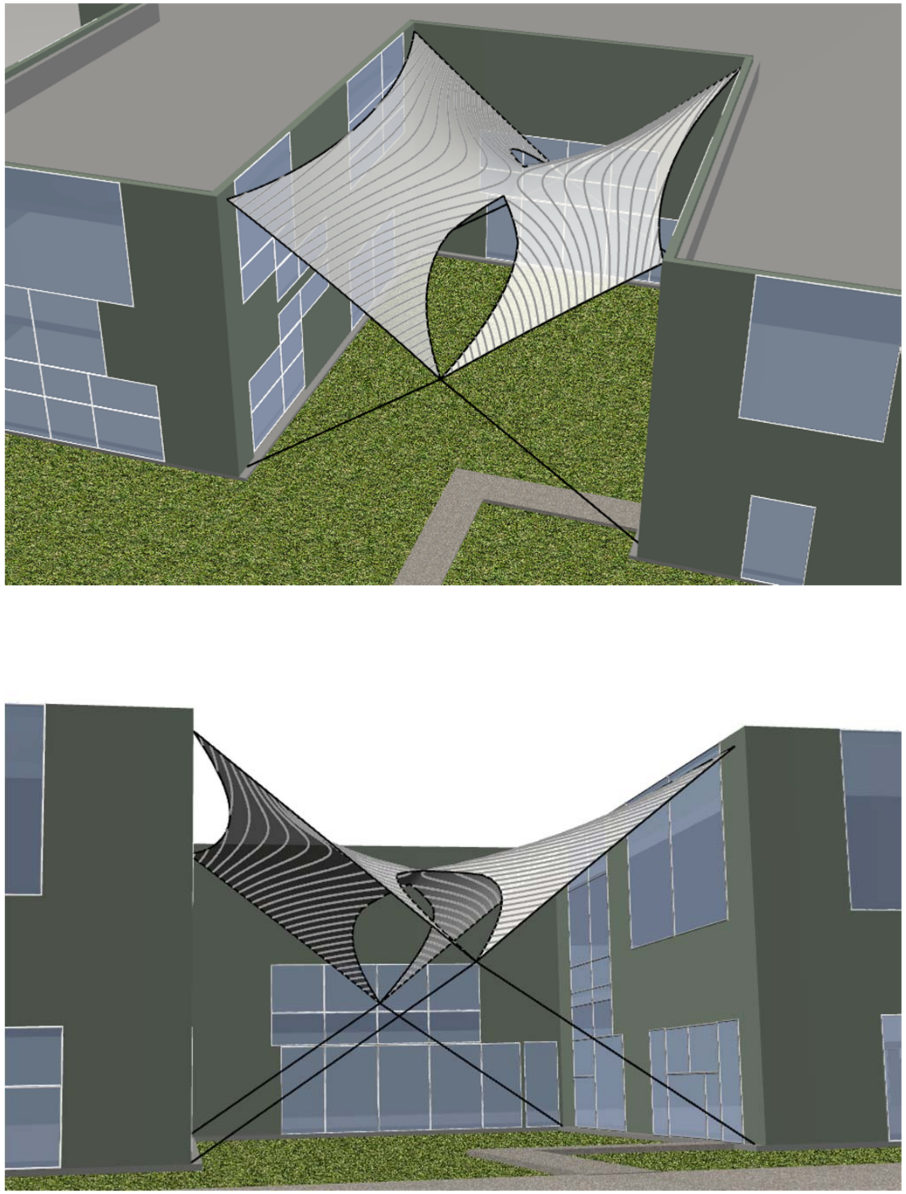
V2-05



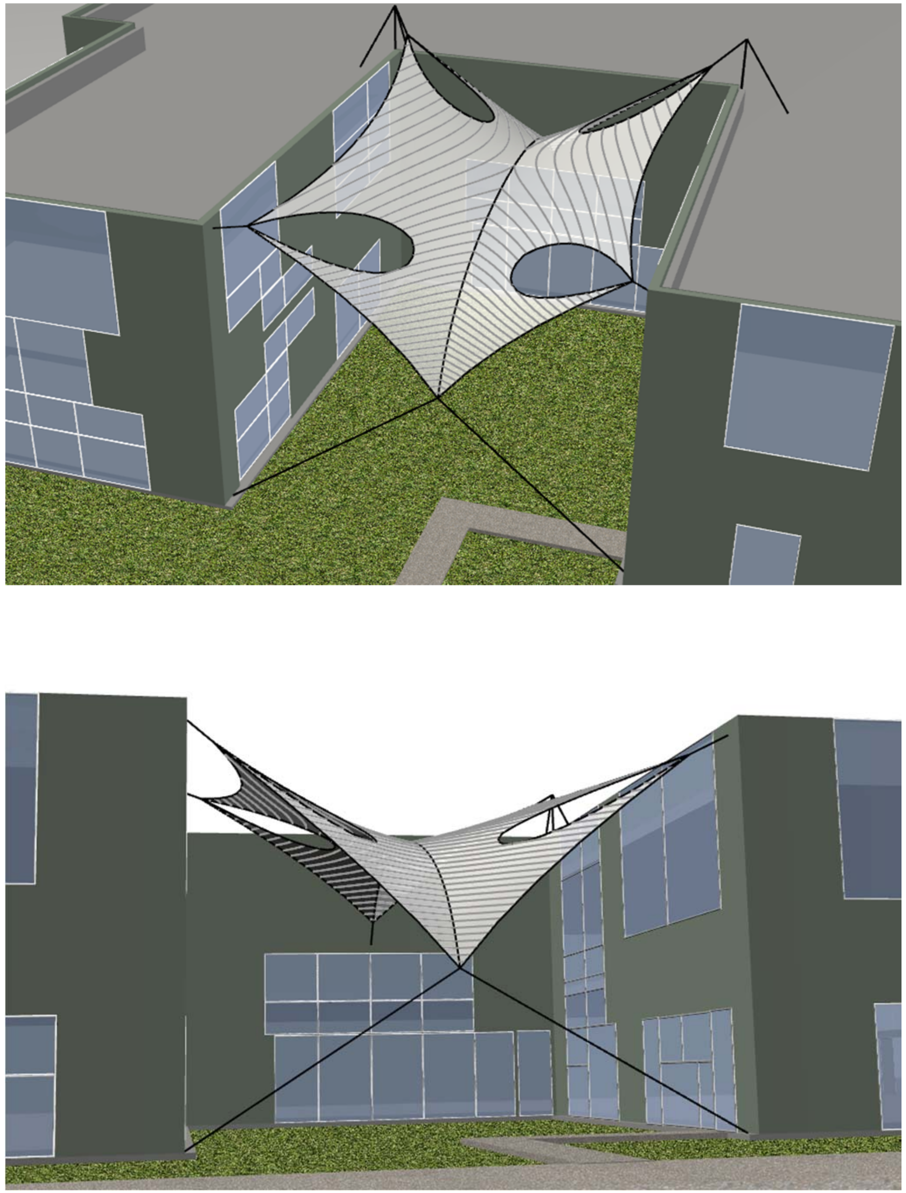


2. PROJECT FLOW & DESIGN STEPS / 1. Preliminary shape concepts

V2-06



V2-10



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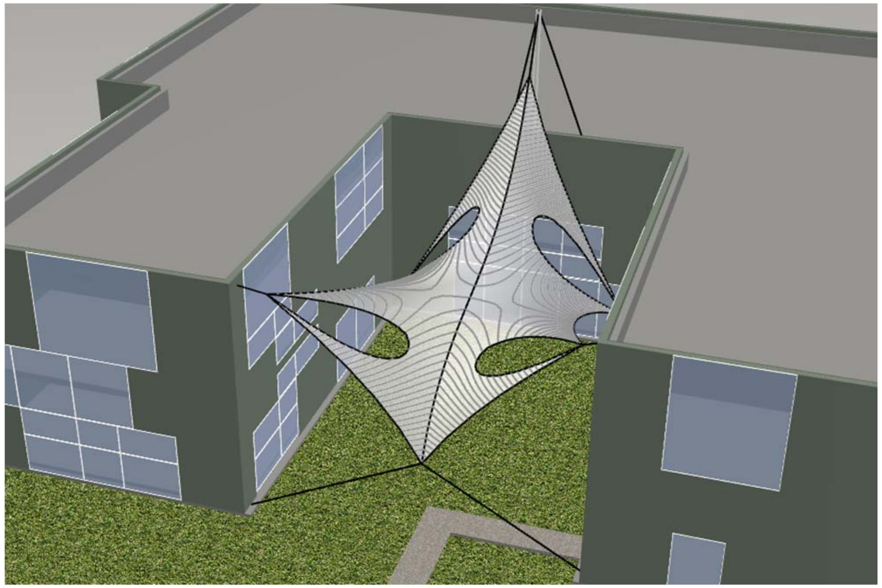
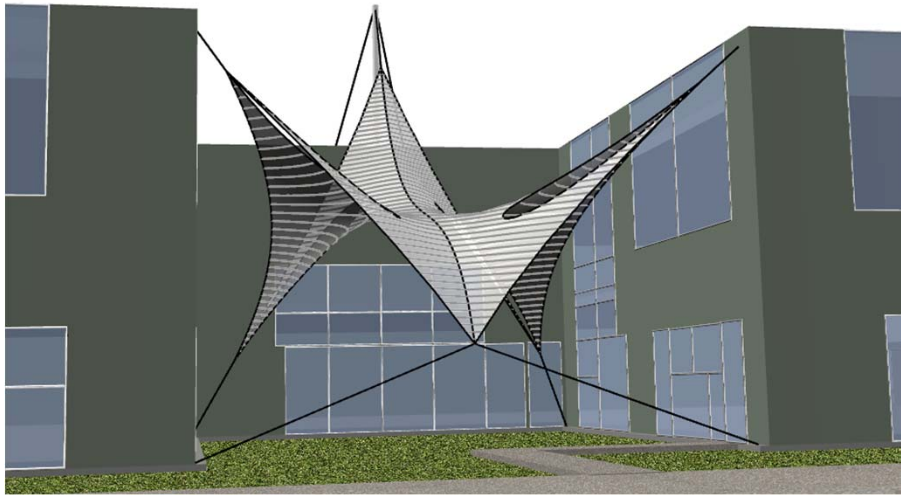
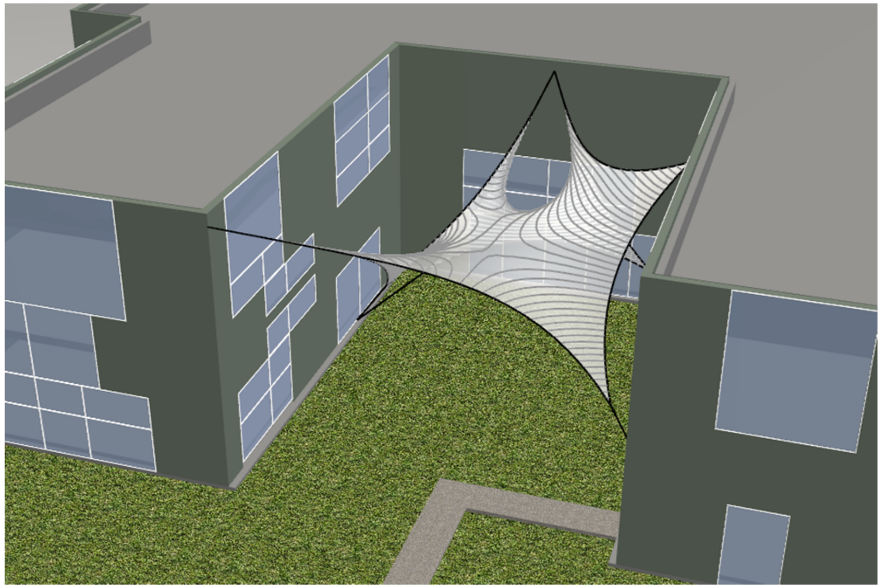
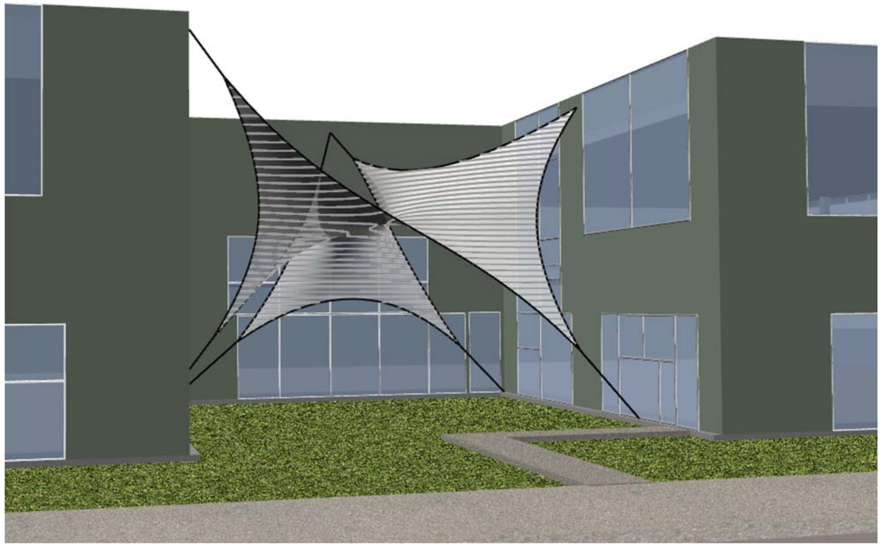
V2-12



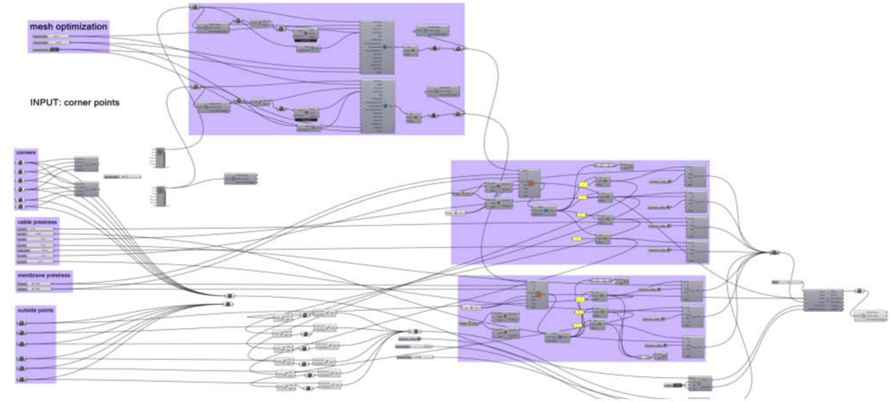


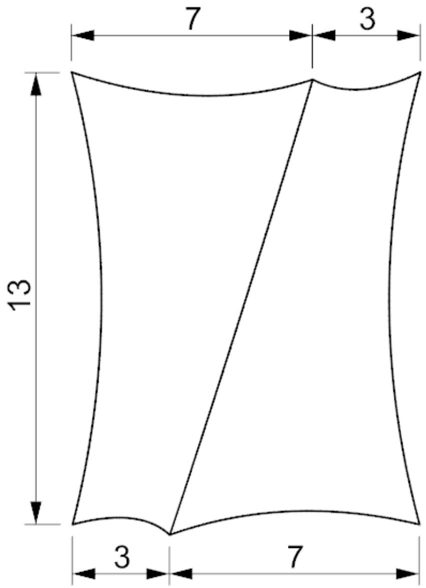
V3-04

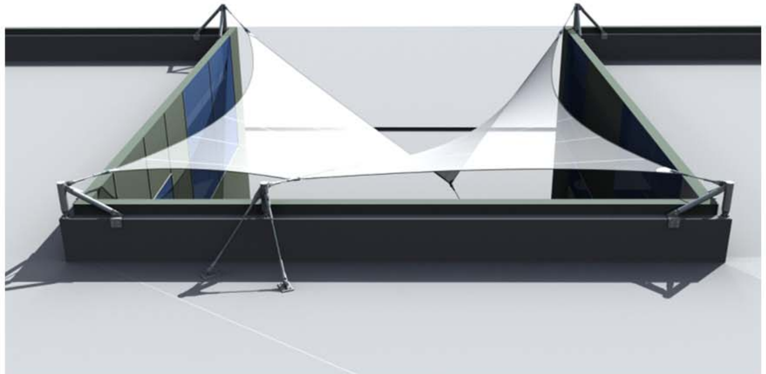


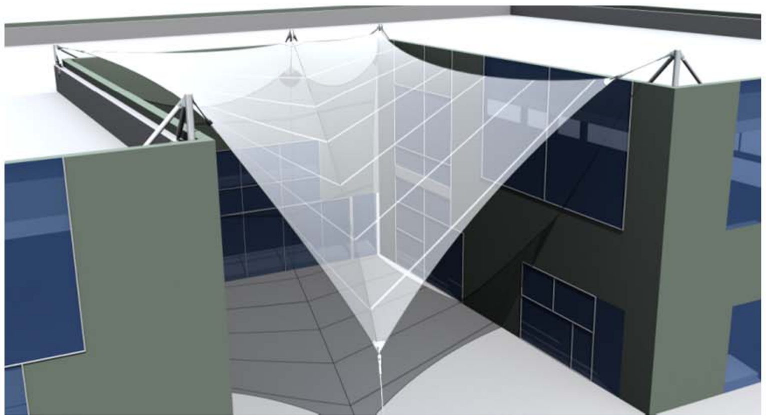


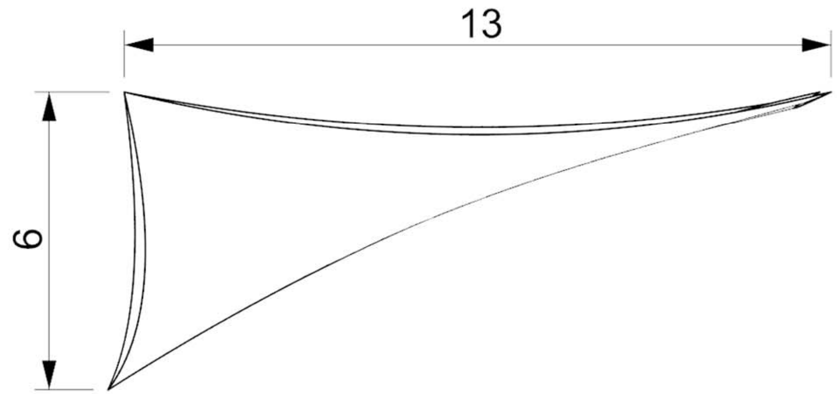
2. PROJECT FLOW & DESIGN STEPS / 2. Final shape











FLEXLIGHT FX 701

FX 701

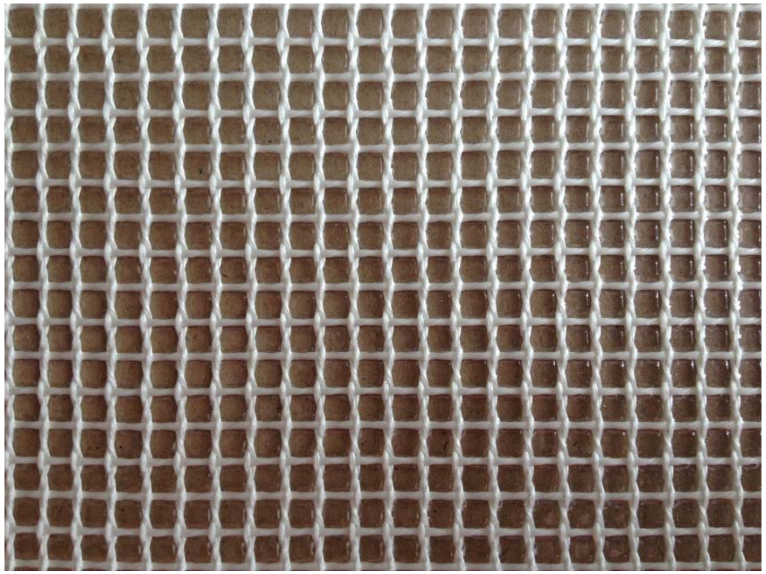
DATA SHEET

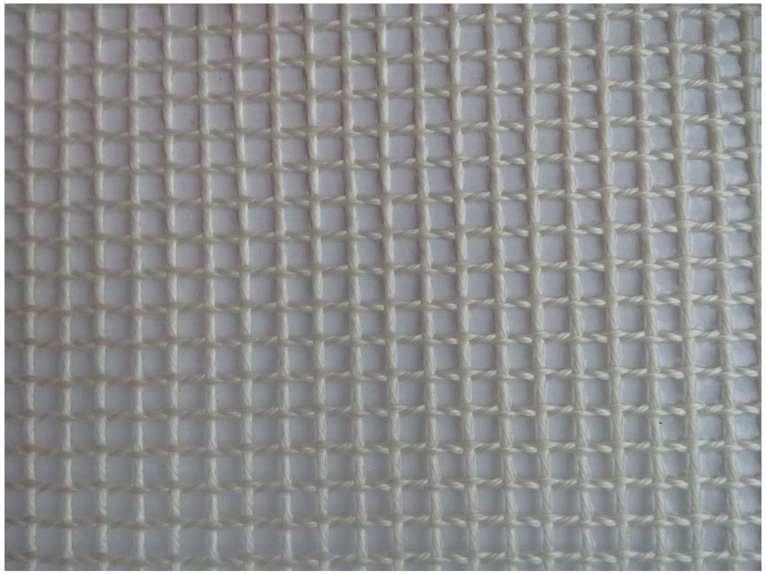
	Flexlight FX 701	Standards
Yarn	Glass	
Coating	Fluopolymer	
Total Weight	1050 g/sqm ± 5%	EN ISO 2286-2
Width	150 cm	
Tensile strength (warp/weft)	300/300 daN/5 cm	EN ISO 1421
Tear strength (warp/weft)	40/40 daN	DIN 53.363
Flame retardancy (Euroclass)	**B-s1,d0**	EN 13501-1
Adhesion	15/15 daN/5 cm	EN ISO 2411
Solar optical values	Ts 62% Rs 28% As 10% **TV 62%**	EN 410
UV transmission	57%	
Making up	HF Weldable	
Quality management system		ISO 9001

Material supplier: Serge Ferrari
Type: FLEXLIGHT FX701

<u>advantages:</u>
- high light-translucency (62%)
- weldabel with high frequency welding machine

<u>breaking load</u>
f_{tk} (warp/fill) = 3000/3000 N/5cm = 60/60 kN/m





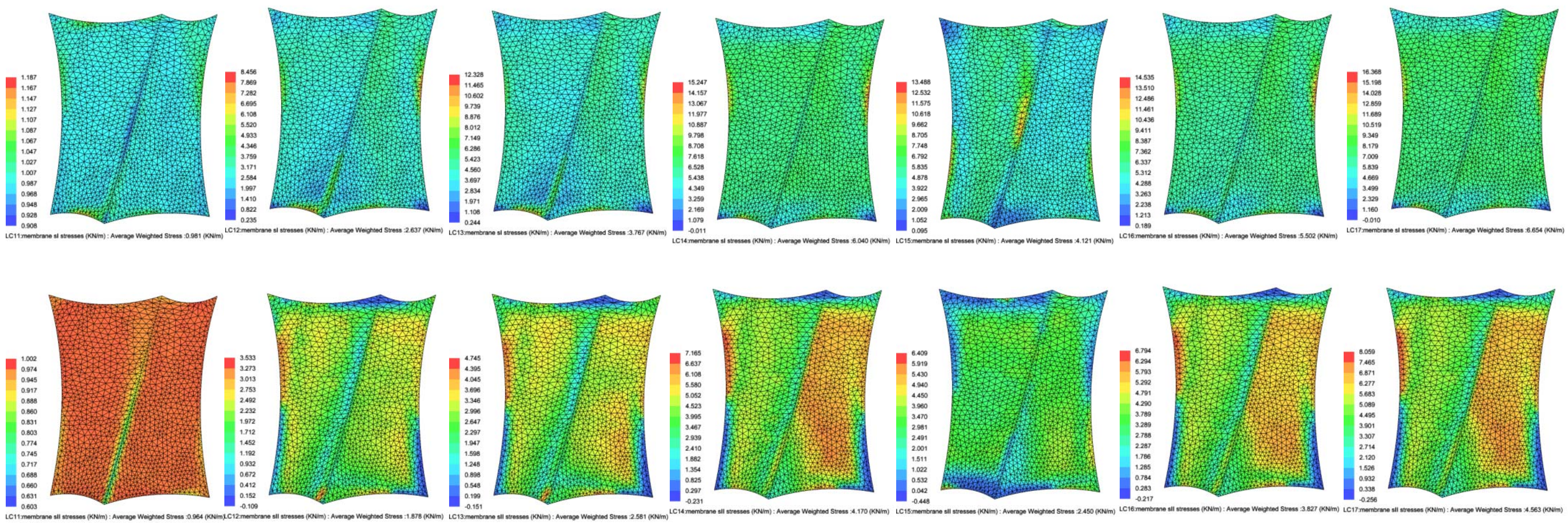
2. PROJECT FLOW & DESIGN STEPS / 4. Preliminary statical analysis (assumed E-value)

E-values (predected):

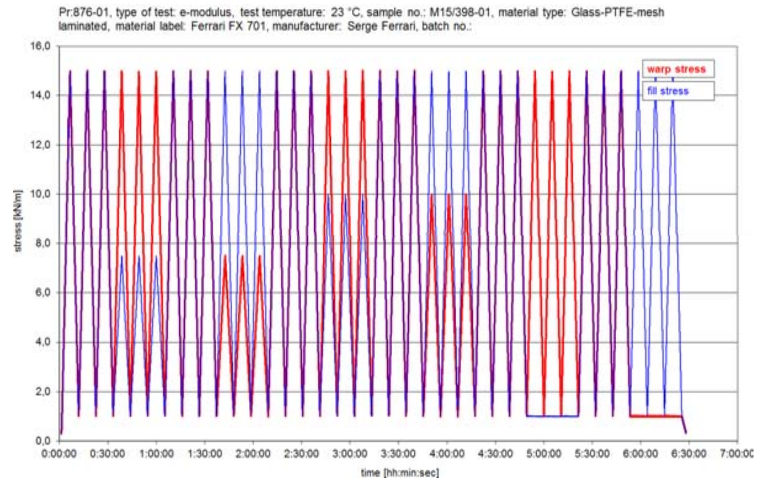
E_1= 2400 kN/m

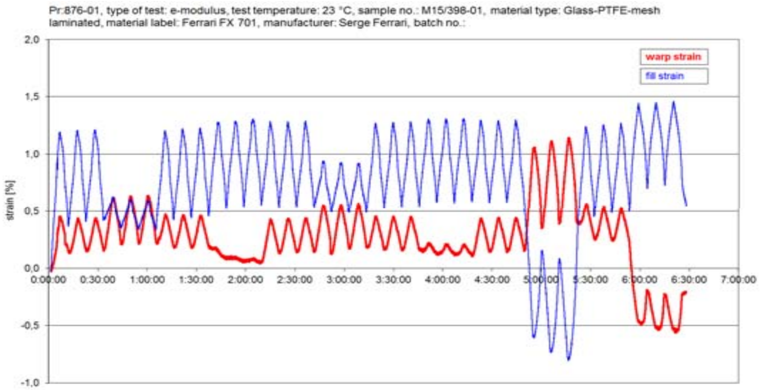
E_2= 1550 kN/m

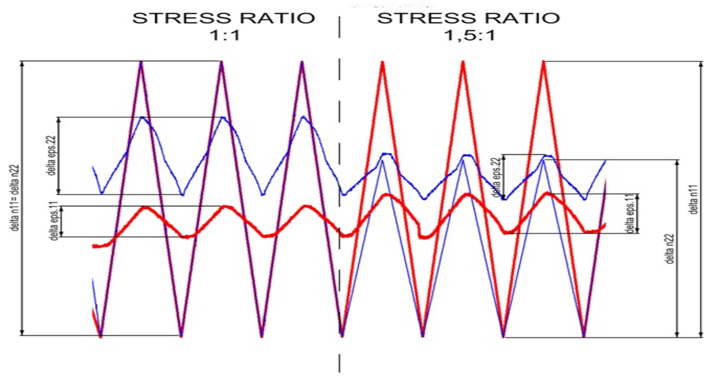
SLS	Self Weight	Prestress	Snow	Snow Acc.	Wind Pr.	Wind Sct.	Warp Stress (average)[kN/m]	Fill Stress (average) [kN/m]	warp:fill stress ratio
LC11	1	1	0	0	0	0	0,98	0,96	~1:1
LC12	1	1	1	0	0	0	2,6	1,9	~1,3:1
LC13	1	1	0	1	0	0	3,8	2,6	~1,5:1
LC14	1	1	0	0	1	0	6,0	4,2	~1,5:1
LC15	1	1	0	0	0	1	4,1	2,5	~1,5:1
LC16	1	1	1	0	0,6	0	5,5	3,8	~1,5:1
LC17	1	1	0,5	0	1	0	6,7	4,6	~1,5:1



We got the warp/fill stress ratio for the load history definition of the biaxial test for E-value







$$\begin{bmatrix} n_{11} \\ n_{22} \end{bmatrix} = \begin{bmatrix} E_{1111} & E_{1122} \\ E_{1122} & E_{2222} \end{bmatrix} \begin{bmatrix} \varepsilon_{22} \\ \varepsilon_{22} \end{bmatrix}$$

with the inversion:

$$\begin{bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \end{bmatrix} = \begin{bmatrix} C_{1111} & C_{1122} \\ C_{1122} & C_{2222} \end{bmatrix} \begin{bmatrix} n_{22} \\ n_{22} \end{bmatrix}$$

or, explicitly:

$\Delta n_{11} = E_{1111}\, \Delta\varepsilon_{11} + E_{1122}\, \Delta\varepsilon_{22} = E_{1111}\, (\Delta\varepsilon_{11} + \nu_{12}\, \Delta\varepsilon_{22})$

$\Delta n_{22} = E_{1122} \Delta\, \varepsilon_{11} + E_{2222}\, \Delta\varepsilon_{22} = E_{2222}\, (\nu_{21}\, \Delta\varepsilon_{11} + \Delta\varepsilon_{22})$

with the inversion:

$\Delta\varepsilon_{11} = C_{1111}\, \Delta n_{11} + C_{1122}\, \Delta n_{22}$

$\Delta\varepsilon_{22} = C_{1122}\, \Delta n_{11} + C_{2222}\, \Delta n_{22}$

$$\det C = C_{1111} C_{2222} - C_{1122} C_{1122}$$

$$\mathrm{Adj}\,(C) = \begin{bmatrix} C_{2222} & -C_{1122} \\ -C_{1122} & C_{1111} \end{bmatrix}$$

$$E = C^{-1} = \frac{1}{\det C}\, \mathrm{Adj}\,(C) = \begin{bmatrix} E_{1111} & E_{1122} \\ E_{1122} & E_{2222} \end{bmatrix}$$

<u>Classical E-value calculation:</u>

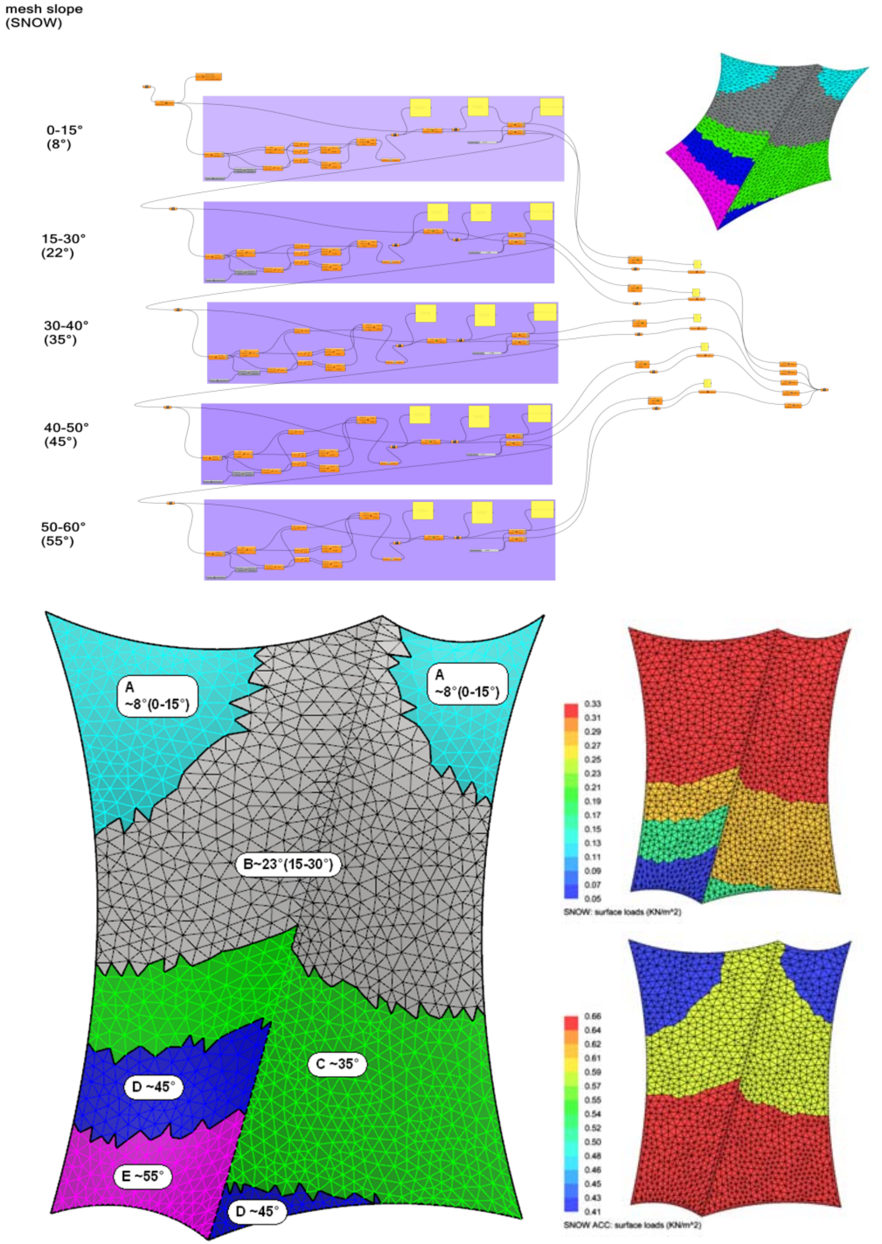
$$E_1 = E_{1111}\left(1 - \frac{E_{1122}^{\ 2}}{E_{1111}\, E_{2222}}\right)$$

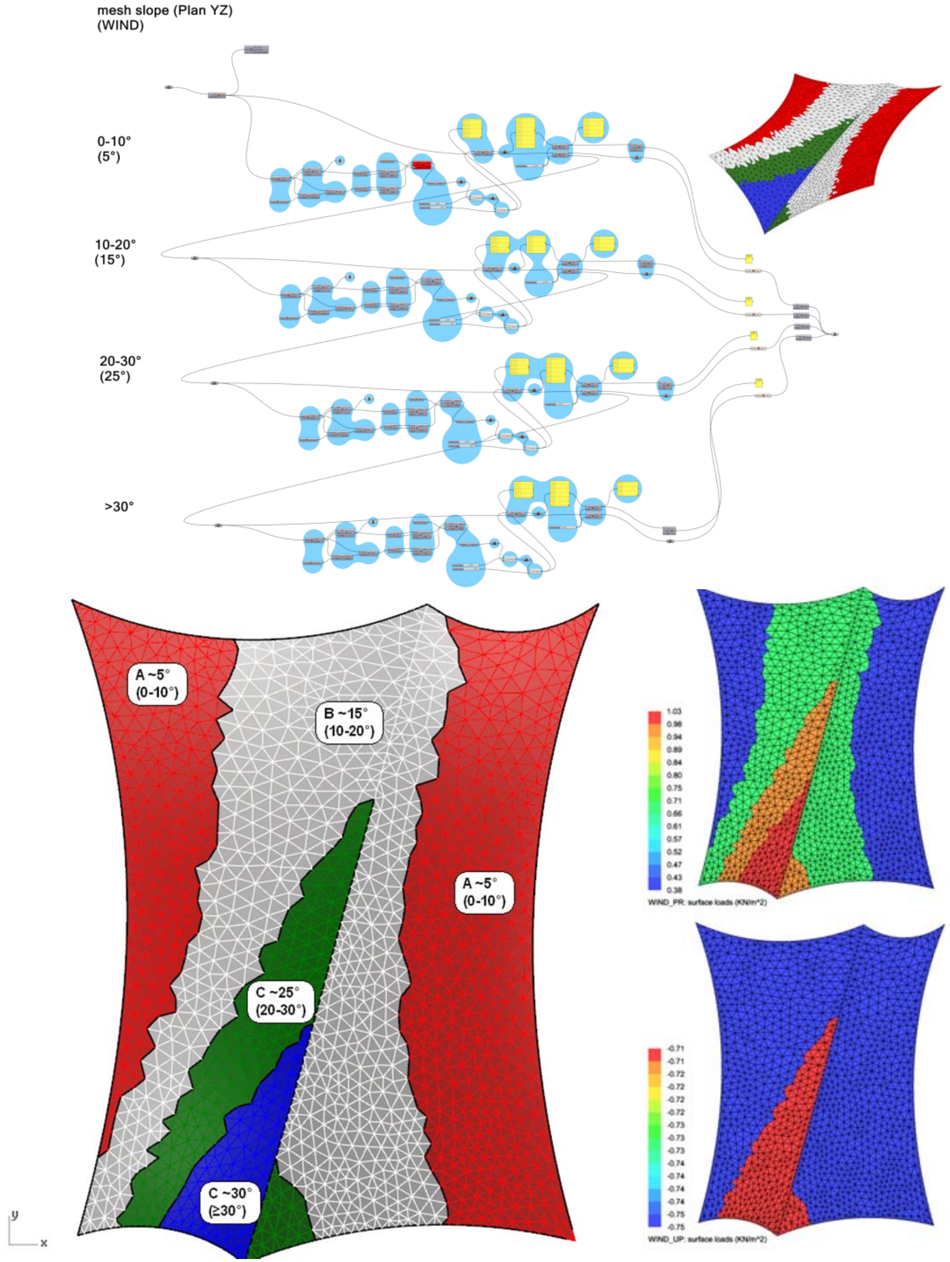
$$E_2 = E_{2222}\left(1 - \frac{E_{1122}^{\ 2}}{E_{1111}\, E_{2222}}\right)$$

$$\boxed{\begin{aligned} E_1 &= E_{1111}\left(1 - \frac{E_{1122}^{\ 2}}{E_{1111}\, E_{2222}}\right) = 2213 \text{ kN/m} \\ E_2 &= E_{2222}\left(1 - \frac{E_{1122}^{\ 2}}{E_{1111}\, E_{2222}}\right) = 1354 \text{ kN/m} \end{aligned}}$$

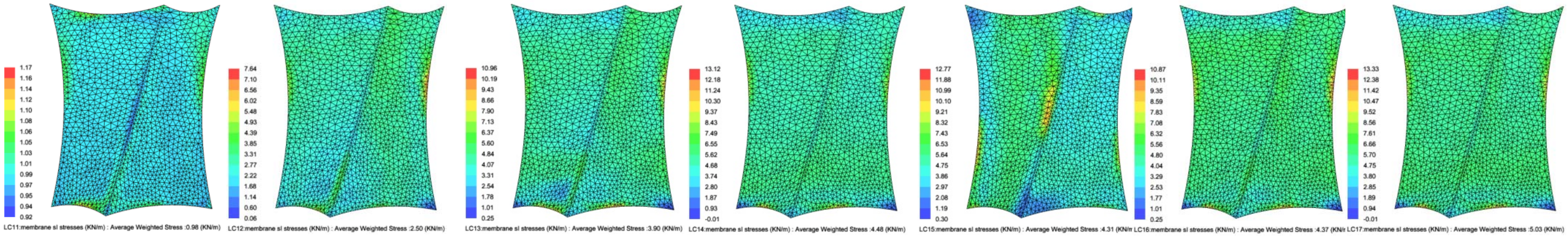
With biaxial material test we can calculate exactly the E values, so we know the material stiffness, which is necessary for starting an exact statical calculation.

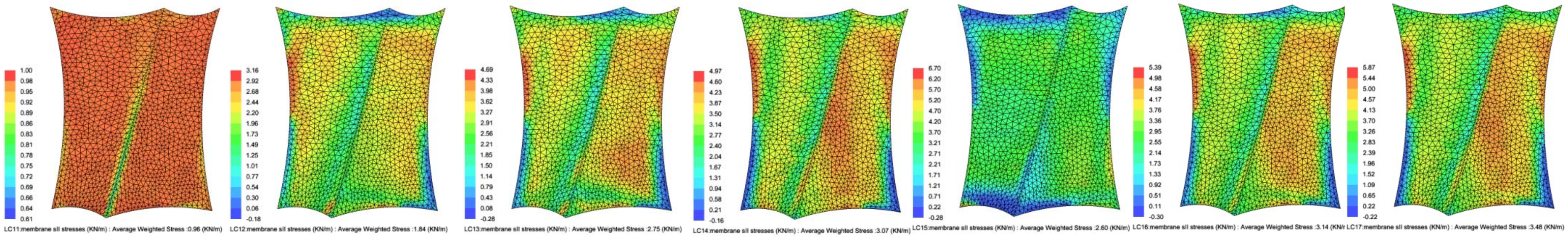
2. PROJECT FLOW & DESIGN STEPS / 6. Final statical analysis (exact loading & E-value)





2. PROJECT FLOW & DESIGN STEPS / 6. Final statical analysis (exact loading & E-value)



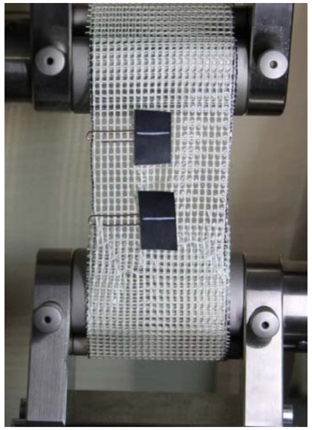
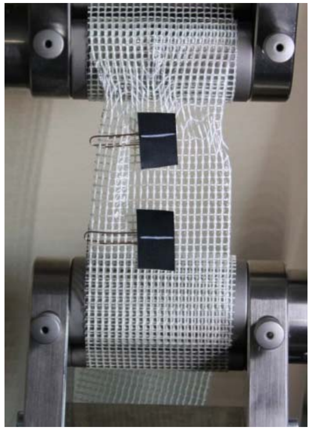
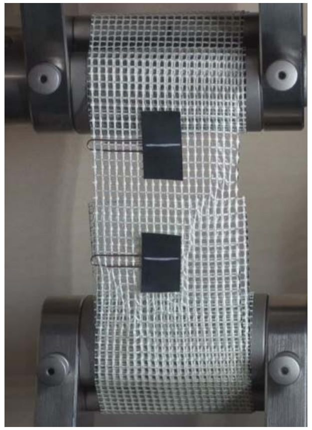


SLS	Warp Stress [kN/m]		Fill Stress [kN/m]	
	max	average	max	average
LC11	1,17	0,98	1	0,96
LC12	7,64	2,5	3,16	1,84
LC13	11	3,9	4,69	2,75
LC14	13,1	4,48	4,97	3,07
LC15	12,8	4,31	6,7	2,6
LC16	10,9	4,37	5,39	3,14
LC17	13,3	5,03	5,87	3,48

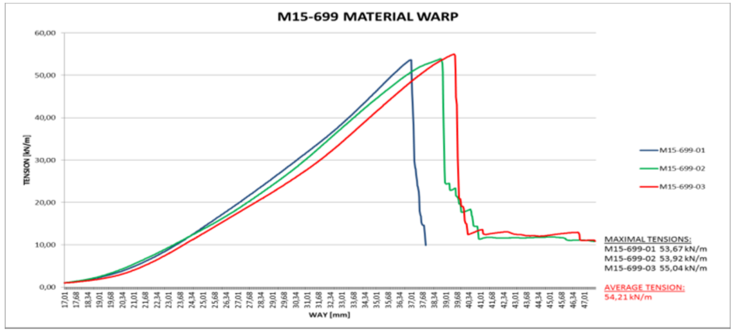
SLS		Warp Stress [kN/m]	Fill Stress [kN/m]
		max	max
PERMANENT	LC11	1,17	1
WIND STORM	LC14,15,17	13,33	6,7
SNOW MAX	LC12,13,16	10,96	5,39

The stress result are grouped in three groups: permanent combination; wind storm; maximum snow

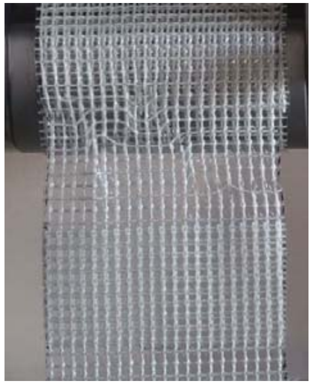
2. PROJECT FLOW & DESIGN STEPS / 7. MONOAXIAL tests & membrane verification

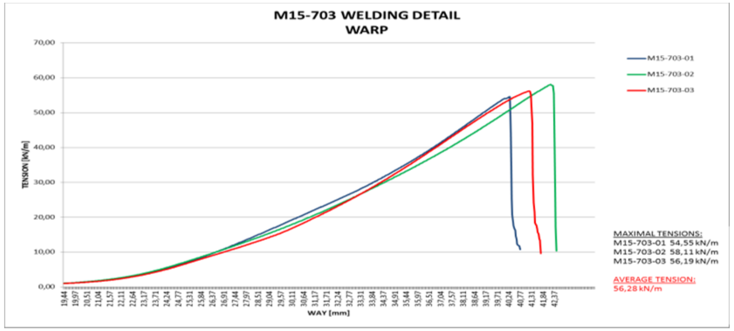
M15-699-MATERIAL-WARP







M15-703-WELDING SEAM-WARP

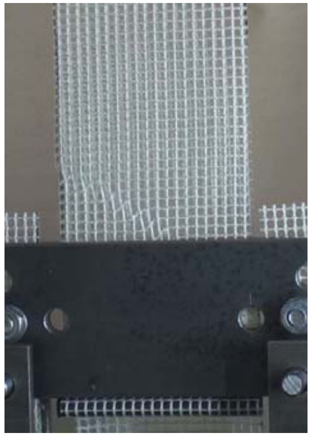
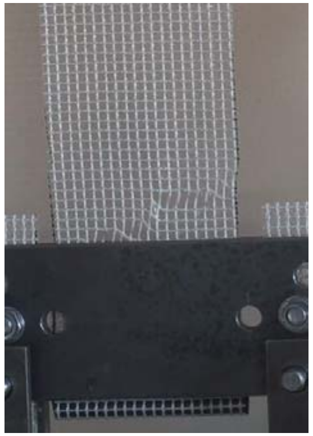


<u>Test groups:</u>

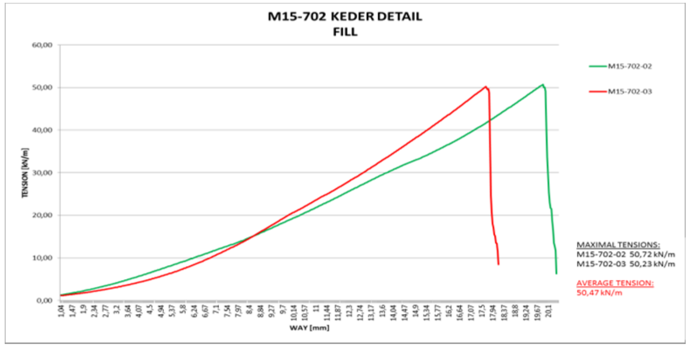
- **Material**
- Detail

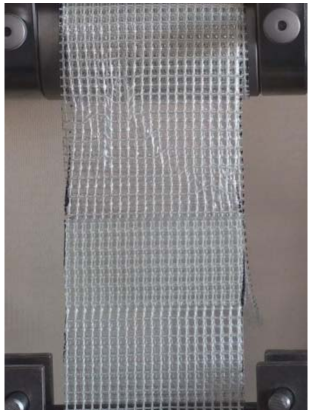
<u>Detail</u>

- **Welding seam detail**
- Keder Pocket detail
- Cable pocket detail

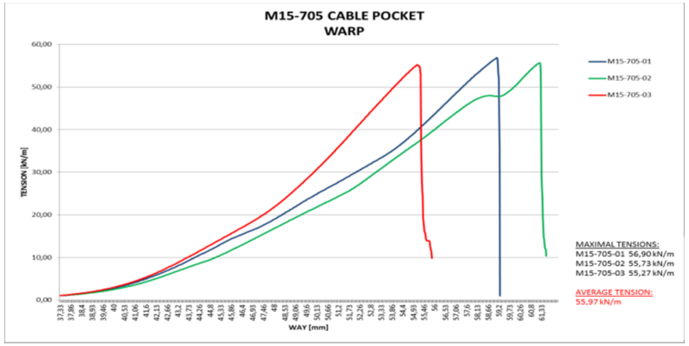



M15-702-KEDER POCKET-FILL




M15-705-CABLE POCKET-WARP

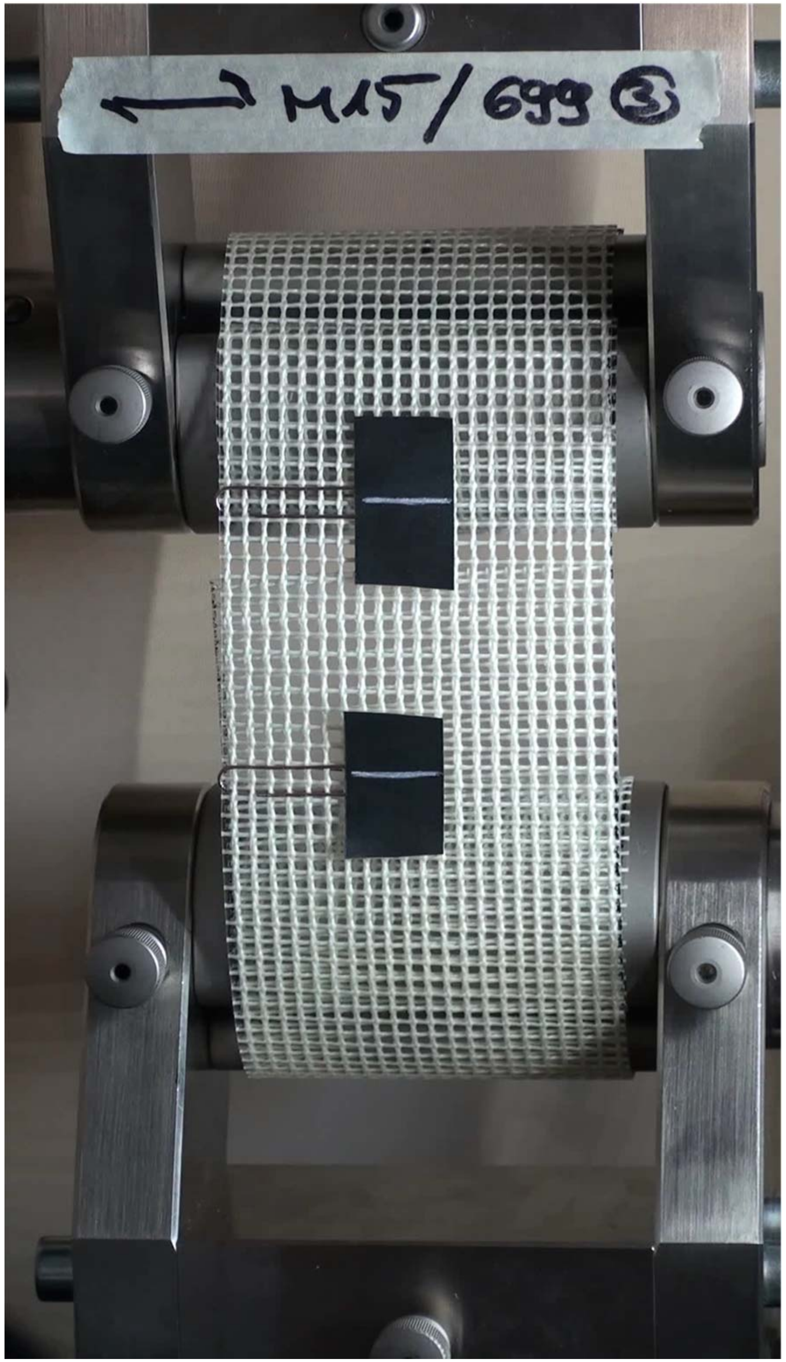


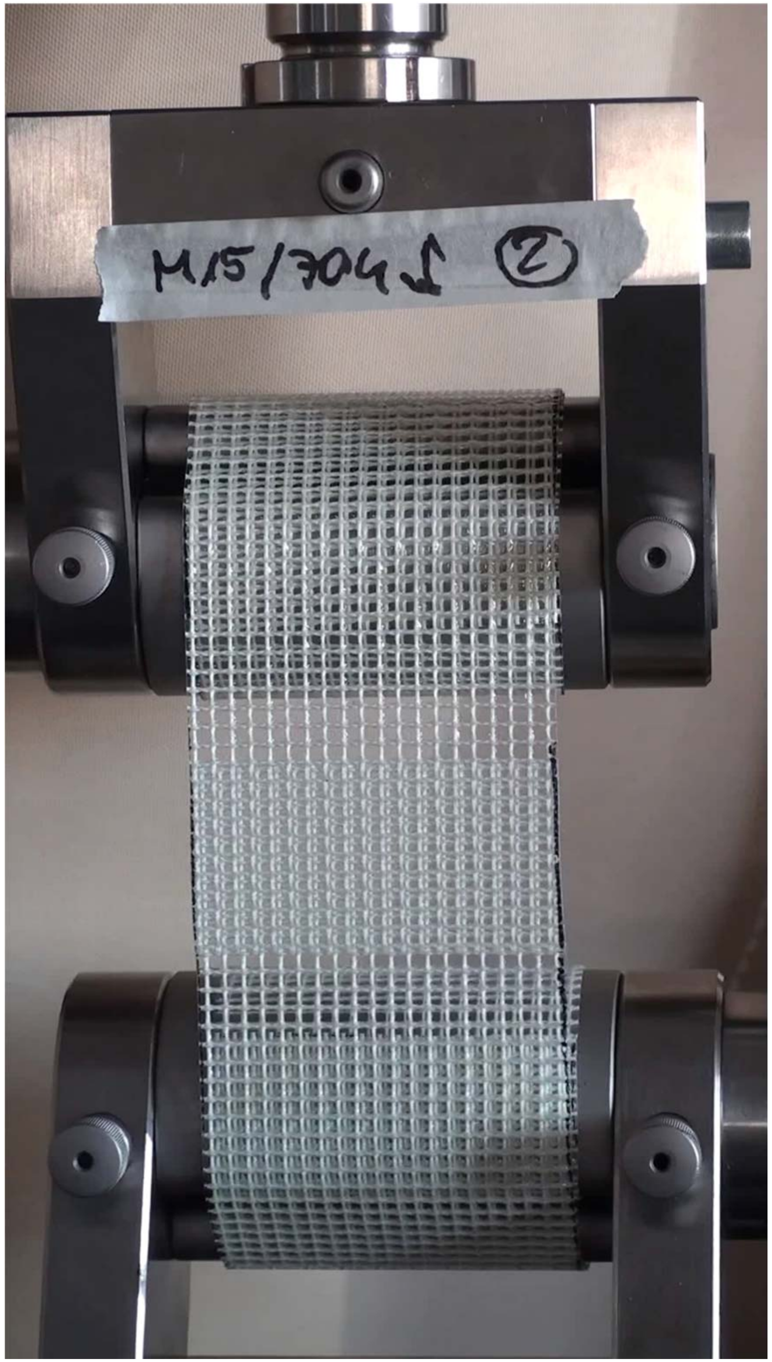
Test groups:

- Material
- Detail

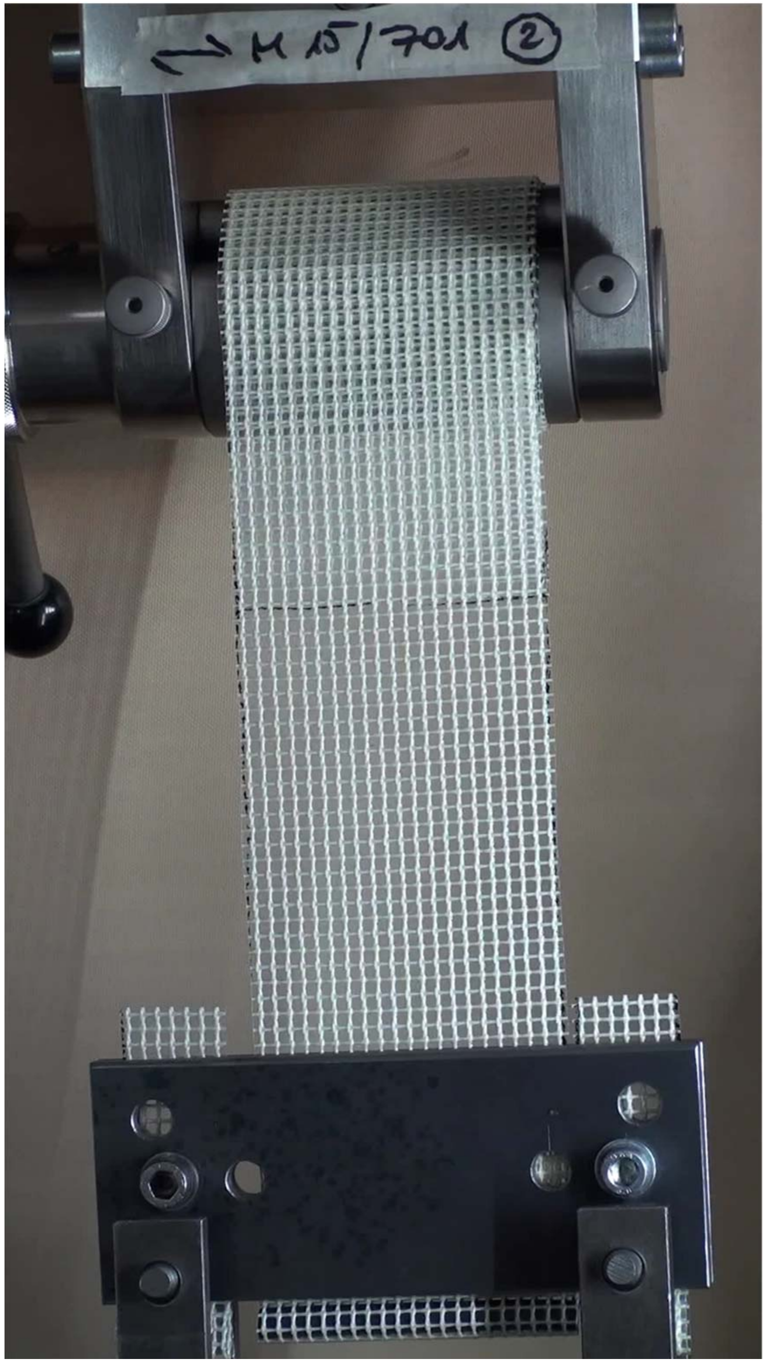
Detail

- Welding seam detail
- **Keder Pocket detail**
- **Cable pocket detail**


M15/699 3


M15/704 2

2. PROJECT FLOW & DESIGN STEPS / 7. MONOAXIAL tests & membrane verification



2. PROJECT FLOW & DESIGN STEPS / 7. MONOAXIAL tests & membrane verification

$$f_d = \frac{f_{tk}}{\gamma_m \gamma_f A_i} = \frac{f_{tk}}{A_{res}}$$

$$A_{res} = \gamma_m \gamma_f A_i$$

Permanent load situation: (LC11)

material: $A_{res} = \gamma_m \gamma_f A_0 A_1 A_2 A_3 = 1{,}4 * 1{,}5 * 1{,}1 * 1{,}6 * 1{,}15 * 1{,}2 = 5{,}10$

details: $A_{res} = \gamma_m \gamma_f A_0 A_1 A_2 A_3 = 1{,}5 * 1{,}5 * 1{,}1 * 1{,}6 * 1{,}15 * 1{,}2 = 5{,}46$

Wind storm combinations: (LC14; LC15; LC17)

material: $A_{res} = \gamma_m \gamma_f A_0 A_2 = 1{,}4 * 1{,}6 * 1{,}1 * 1{,}15 = 2{,}83$

details: $A_{res} = \gamma_m \gamma_f A_0 A_2 = 1{,}5 * 1{,}6 * 1{,}1 * 1{,}15 = 3{,}04$

Maximum snow combinations: (LC12; LC13; LC16)

material: $A_{res} = \gamma_m \gamma_f A_0 A_1 A_2 = 1{,}4 * 1{,}5 * 1{,}1 * 1{,}6 * 1{,}15 = 4{,}25$

details: $A_{res} = \gamma_m \gamma_f A_0 A_1 A_2 = 1{,}5 * 1{,}5 * 1{,}1 * 1{,}6 * 1{,}15 = 4{,}55$

NAME	BREAKING STRESS [kN/m]	AVERAGE VALUE [kN/m]	5% FRACTILE f_{tk}[kN/m]	SLS		A res γm*γf*Σai (SLS)	MAXIMAL ALLOWABLE TENSION [kN/m]	MAXIMAL TENSION FROM STATICAL ANALYSIS [kN/m]	USAGE [%]	VERIFICATION (if usage < 100%)
			A			B	C=A/B	D	D/C*100	
MATERIAL-WARP-01	53,67			PERMANENT	LC11	5,10	10,28	1,17	11,4	OK
MATERIAL-WARP-02	53,92	54,21	52,44	WIND	LC14,15,17	2,83	18,51	13,33	72,0	OK
MATERIAL-WARP-03	55,04			SNOW	LC12,13,16	4,25	12,34	10,96	88,8	OK
MATERIAL-FILL-01	52,50			PERMANENT	LC11	5,10	9,04	1	11,1	OK
MATERIAL-FILL-02	60,05	58,61	46,10	WIND	LC14,15,17	2,83	16,27	6,7	41,2	OK
MATERIAL-FILL-03	63,27			SNOW	LC12,13,16	4,25	10,85	5,39	49,7	OK
				PERMANENT	LC11	5,46	9,55	1,17	12,2	OK
KEDER DETAIL-WARP-02	52,80	53,05	52,20	WIND	LC14,15,17	3,04	17,19	13,33	77,5	OK
KEDER DETAIL-WARP-03	53,30			SNOW	LC12,13,16	4,55	11,46	10,96	95,6	OK
				PERMANENT	LC11	5,46	9,08	1	11,0	OK
KEDER DETAIL-FILL-02	50,72	50,47	49,63	WIND	LC14,15,17	3,04	16,35	6,7	41,0	OK
KEDER DETAIL-FILL-03	50,23			SNOW	LC12,13,16	4,55	10,90	5,39	49,5	OK
WELDING DETAIL-WARP-01	54,55			PERMANENT	LC11	5,46	9,52	1,17	12,3	OK
WELDING DETAIL-WARP-02	58,11	56,28	52,05	WIND	LC14,15,17	3,04	17,14	13,33	77,8	OK
WELDING DETAIL-WARP-03	56,19			SNOW	LC12,13,16	4,55	11,43	10,96	**95,9**	**OK**
WELDING DETAIL-FILL-01	55,46			PERMANENT	LC11	5,46	6,30	1	15,9	OK
WELDING DETAIL-FILL-02	41,99	50,34	34,41	WIND	LC14,15,17	3,04	11,33	6,7	59,1	OK
WELDING DETAIL-FILL-03	53,58			SNOW	LC12,13,16	4,55	7,56	5,39	71,3	OK
CABLE DETAIL-WARP-01	56,90			PERMANENT	LC11	5,46	9,87	1,17	11,9	OK
CABLE DETAIL-WARP-02	55,73	55,97	53,93	WIND	LC14,15,17	3,04	17,77	13,33	75,0	OK
CABLE DETAIL-WARP-03	55,27			SNOW	LC12,13,16	4,55	11,84	10,96	92,5	OK
CABLE DETAIL-FILL-01	57,18			PERMANENT	LC11	5,46	10,12	1	9,9	OK
CABLE DETAIL-FILL-02	59,33	58,03	55,29	WIND	LC14,15,17	3,04	18,21	6,7	36,8	OK
CABLE DETAIL-FILL-03	57,57			SNOW	LC12,13,16	4,55	12,14	5,39	44,4	OK

2. PROJECT FLOW & DESIGN STEPS / 7. MONOAXIAL tests & membrane verification

$$f_d = \frac{f_{tk}}{\gamma_m \gamma_f A_i} = \frac{f_{tk}}{A_{res}}$$

$$A_{res} = \gamma_m \gamma_f A_i$$

Permanent load situation: (LC11)

material: $A_{res} = \gamma_m \gamma_f A_0 A_1 A_2 A_3 = 1{,}4 * 1{,}5 * 1{,}1 * 1{,}6 * 1{,}15 * 1{,}2 = 5{,}10$

details: $A_{res} = \gamma_m \gamma_f A_0 A_1 A_2 A_3 = 1{,}5 * 1{,}5 * 1{,}1 * 1{,}6 * 1{,}15 * 1{,}2 = 5{,}46$

Wind storm combinations: (LC14; LC15; LC17)

material: $A_{res} = \gamma_m \gamma_f A_0 A_2 = 1{,}4 * 1{,}6 * 1{,}1 * 1{,}15 = 2{,}83$

details: $A_{res} = \gamma_m \gamma_f A_0 A_2 = 1{,}5 * 1{,}6 * 1{,}1 * 1{,}15 = 3{,}04$

Maximum snow combinations: (LC12; LC13; LC16)

material: $A_{res} = \gamma_m \gamma_f A_0 A_1 A_2 = 1{,}4 * 1{,}5 * 1{,}1 * 1{,}6 * 1{,}15 = 4{,}25$

details: $A_{res} = \gamma_m \gamma_f A_0 A_1 A_2 = 1{,}5 * 1{,}5 * 1{,}1 * 1{,}6 * 1{,}15 = 4{,}55$

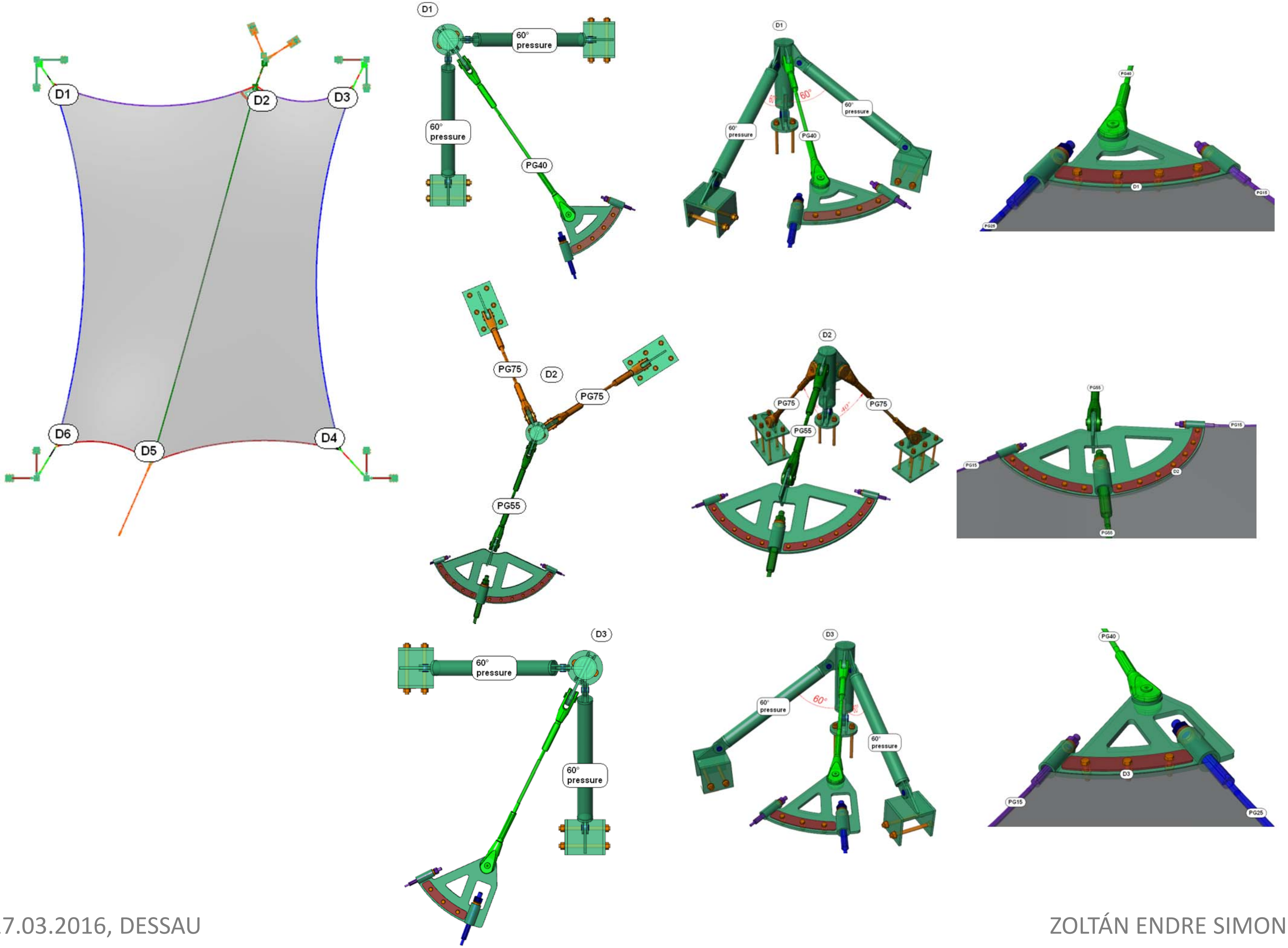
<u>Breaking loads from the datasheet:</u>

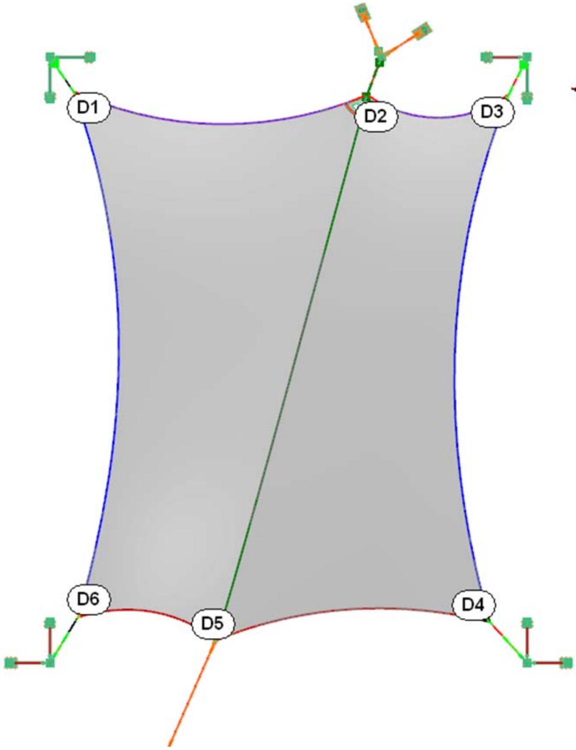
ftk (warp/fill) = 60/60 kN/m

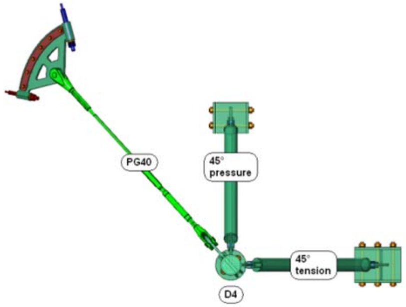
Name	BREAKING STRESS (datasheet) f_{tk}[kN/m]	SLS		A res γm*γf*Σai (SLS)	MAXIMAL ALLOWABLE TENSION [kN/m] C=A/B	MAXIMAL TENSION FROM STATICAL ANALYSIS [kN/m]	USAGE [%]	VERIFICATION (if usage < 100%)
	A			B	C	D	D/C*100	
MATERIAL-WARP	60,00	PERMANENT	LC11	5,10	11,76	1,17	9,95	OK
		WIND	LC14,15,17	2,83	21,17	13,33	62,95	OK
		SNOW	LC12,13,16	4,25	14,12	10,96	77,64	OK
MATERIAL-FILL	60,00	PERMANENT	LC11	5,10	11,76	1,37	11,65	OK
		WIND	LC14,15,17	2,83	21,17	7,42	35,04	OK
		SNOW	LC12,13,16	4,25	14,12	8,35	59,15	OK
DETAIL-WARP	60,00	PERMANENT	LC11	3,64	16,47	1,17	7,10	OK
		WIND	LC14,15,17	1,90	31,62	13,33	42,16	OK
		SNOW	LC12,13,16	3,04	19,76	10,96	55,46	OK
DETAIL-FILL	60,00	PERMANENT	LC11	3,64	16,47	1,37	8,32	OK
		WIND	LC14,15,17	1,90	31,62	7,42	23,47	OK
		SNOW	LC12,13,16	3,04	19,76	8,35	42,25	OK

The membrane usage in case of tests is much higher. The difference is about 20%.

2. PROJECT FLOW & DESIGN STEPS / 8. Steel details & verifications




D1
D2
D3
D6
D5
D4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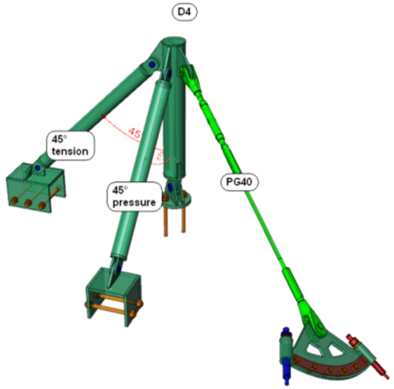
45°
pressure
45°
tension
D4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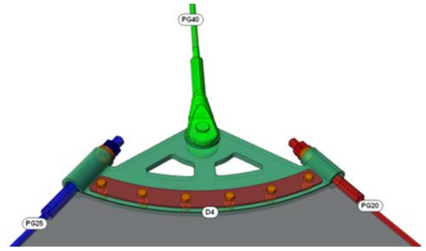
45°
tension
45°
pressure
PG40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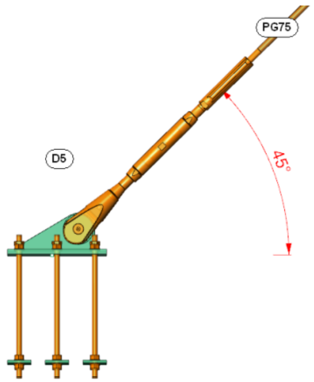
D4
PG20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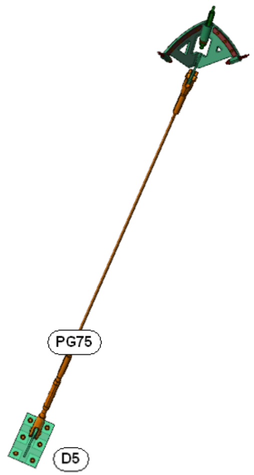
D5
45°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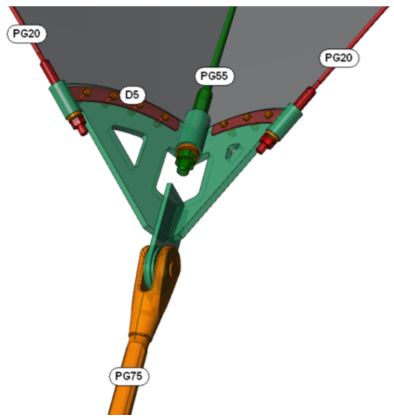
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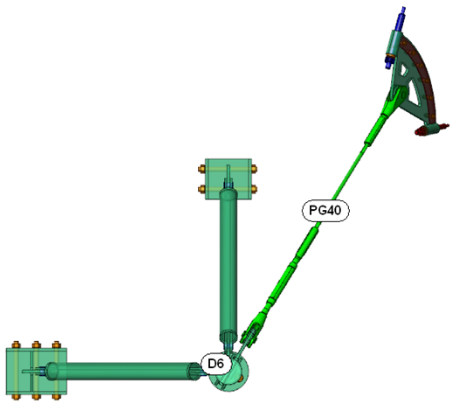
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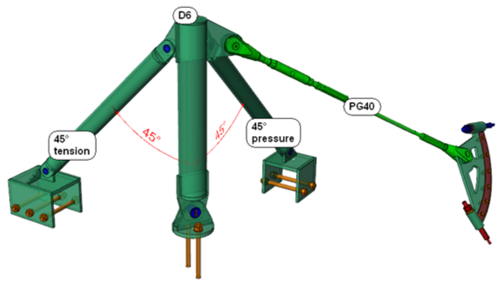
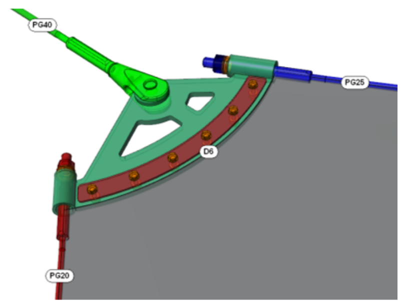

D6
45°
tension
45°
45°
pressure
PG40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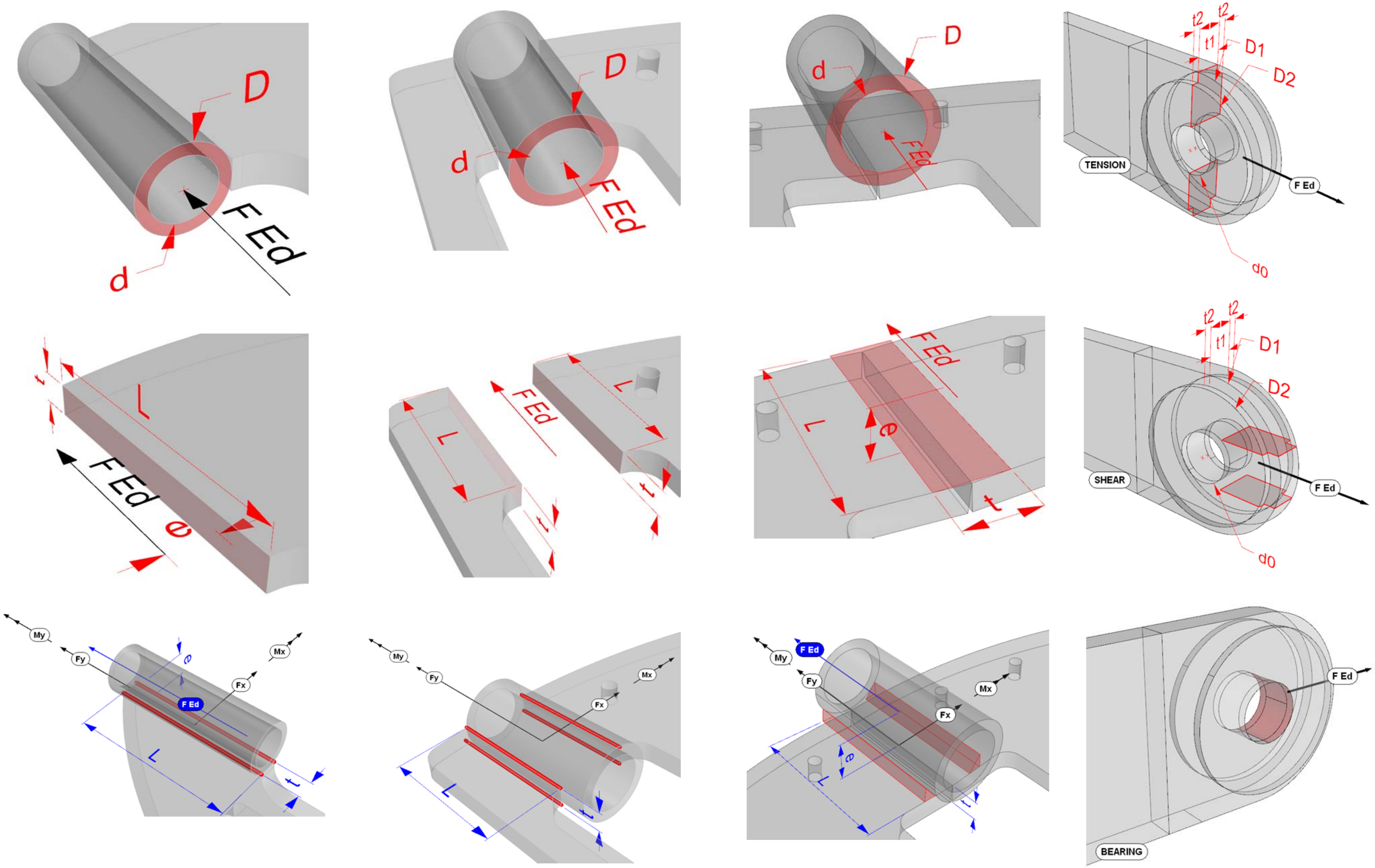
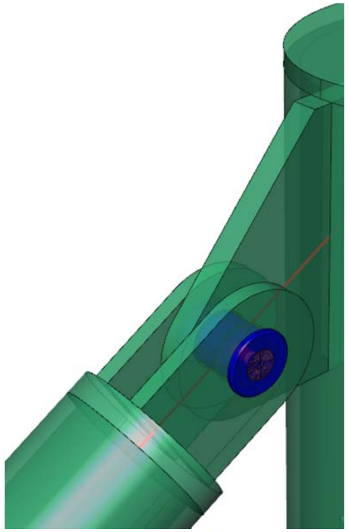
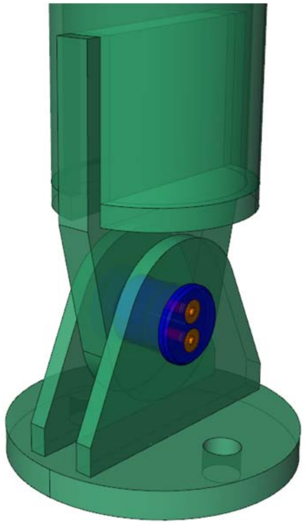
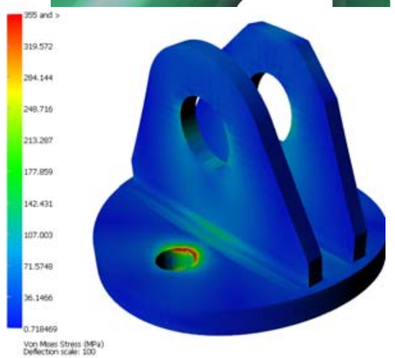
PG25
D6
PG20

2. PROJECT FLOW & DESIGN STEPS / 8. Steel details & verifications

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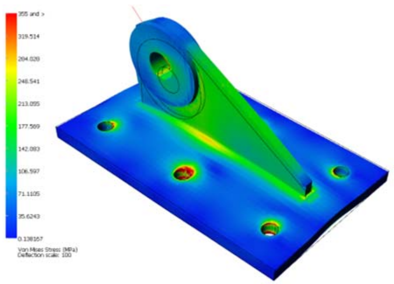
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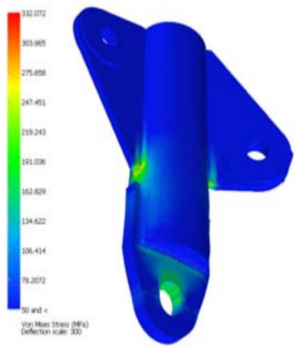
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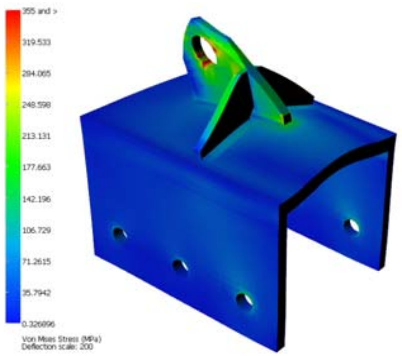
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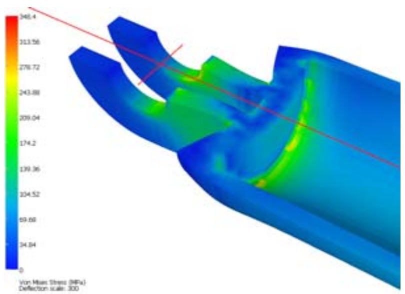
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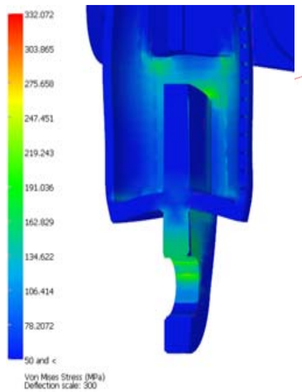
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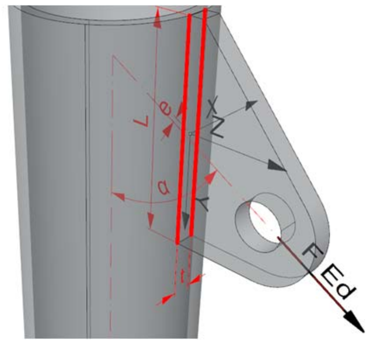
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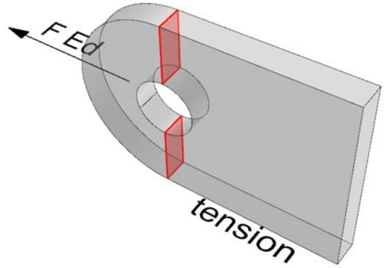
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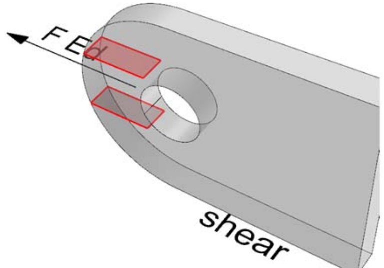
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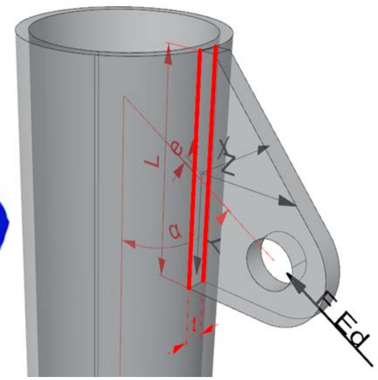
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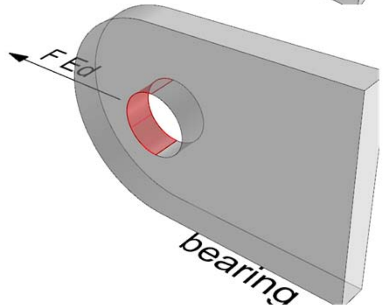
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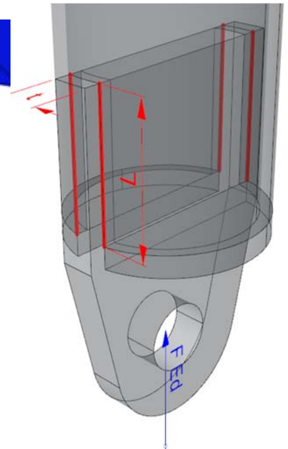
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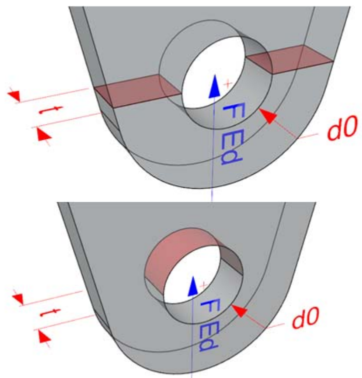
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F Ed
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SECTION A1-A1

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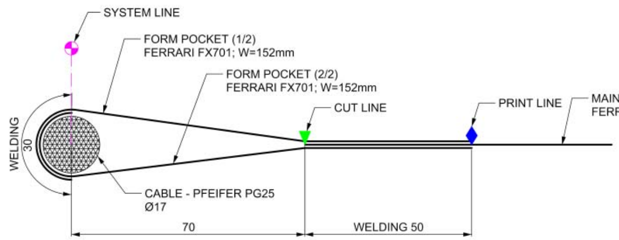
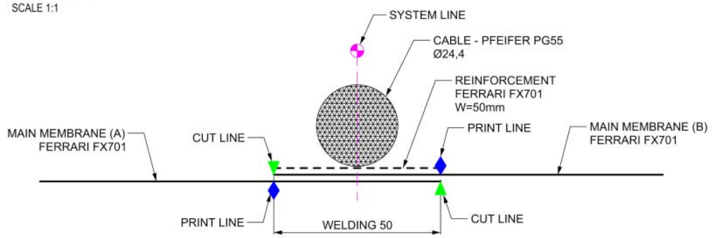


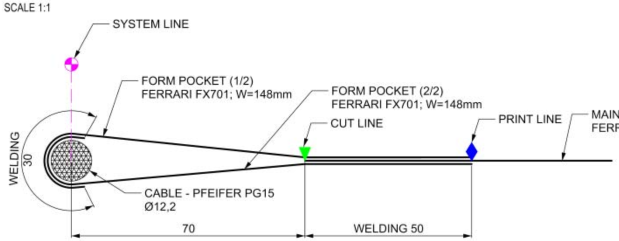
SECTION B-B

SCALE 1:1



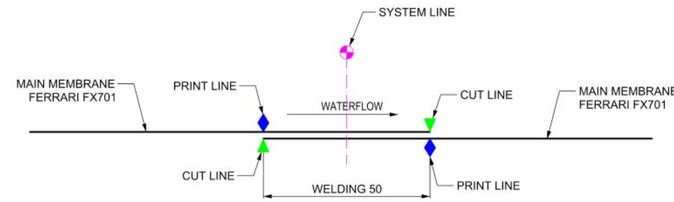
SECTION A2-A2

SCALE 1:1



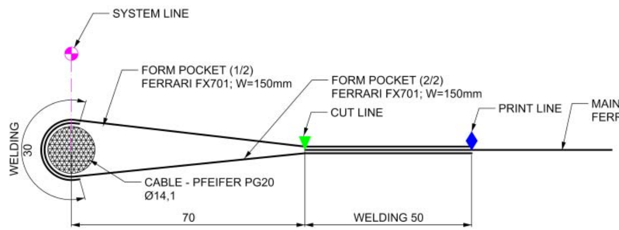
SECTION C-C

SCALE 1:1



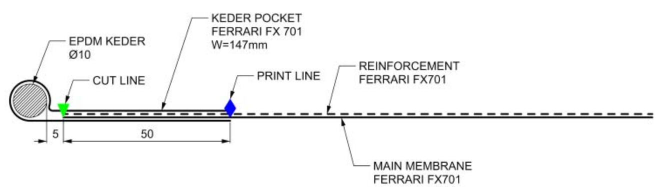
SECTION A3-A3

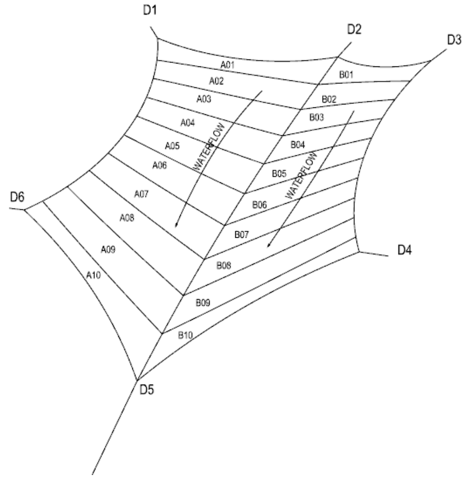
SCALE 1:1

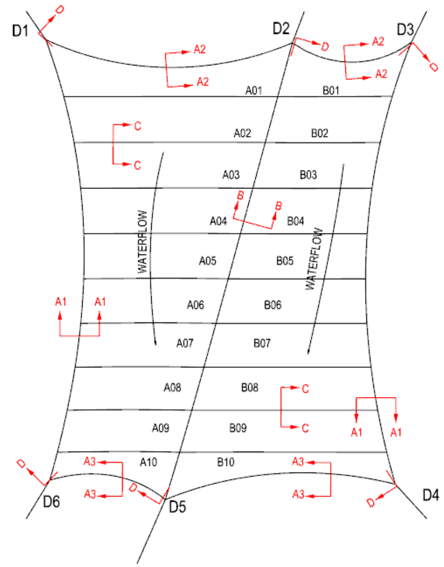


SECTION D-D

SCALE 1:1

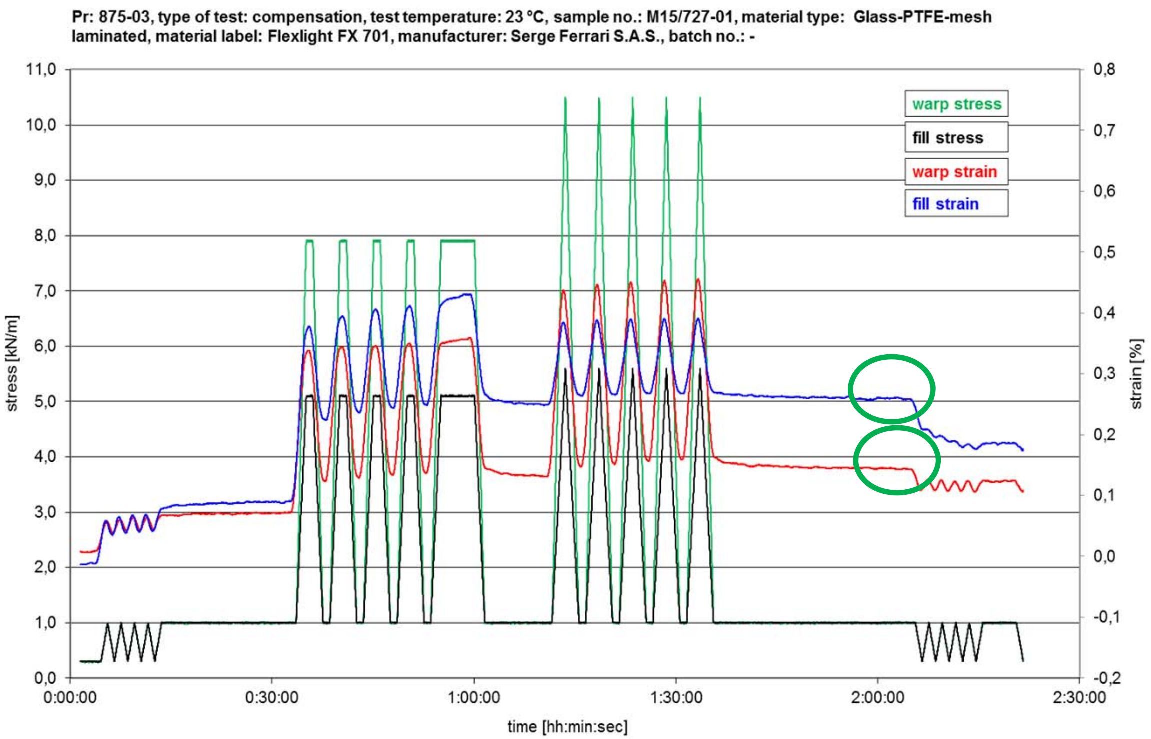






SLS	Warp Stress [kN/m]	Fill Stress [kN/m]
	Typical maximum	Typical maximum
LC11 (permanent)	1	1
LC12 (snow)	4,9	3
LC13 (snow)	7,9	4,5
LC14 (wind)	8,4	4,8
LC15 (wind)	9,2	5,2
LC16 (snow)	7,9	5,1
LC17 (wind)	10,5	5,6

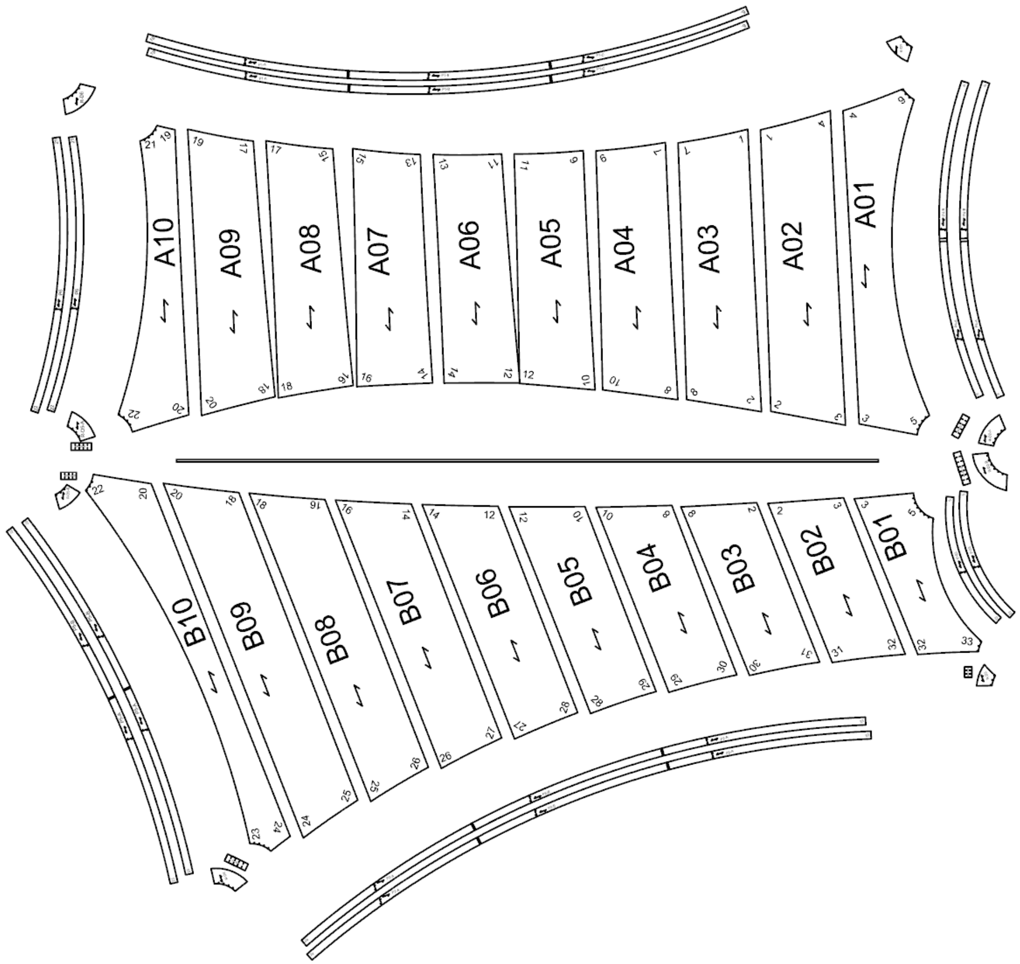
SLS	Warp Stress [kN/m]	Fill Stress [kN/m]
	Typical Max	Typical maximum
LC11 (permanent combination)	1	1
LC16 (maximal snow combination)	7,9	5,1
LC17 (wind combination)	10,5	5,6

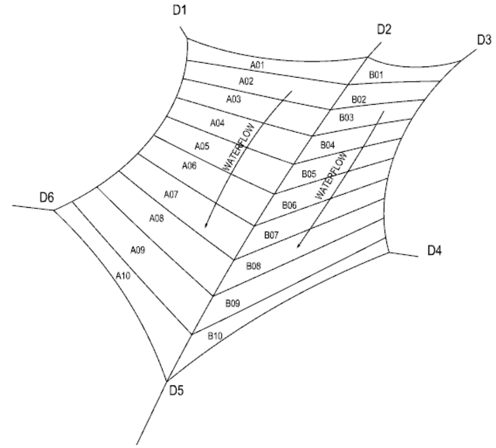


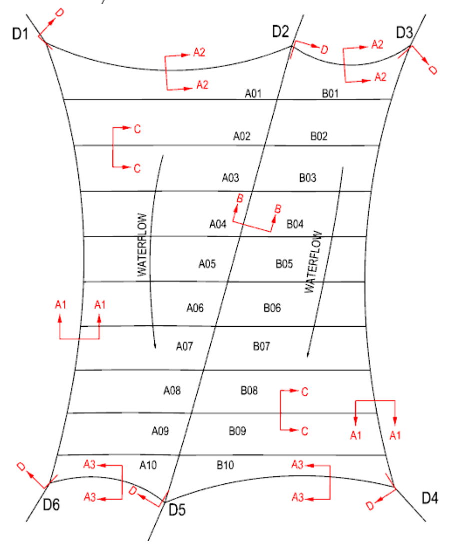
Defined compensation values:

in warp: 0,2% (2mm in 10m)

in fill: 0,3% (3mm in 10m)

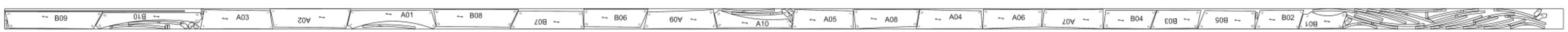






NESTING SUMMARY

total surface area of the membrane patterns (incl. pockets, reinforcements):	144 sqm
total usage area (gross area of the membrane roll):	186 sqm
wastage	22,5%



2. PROJECT FLOW & DESIGN STEPS / 10. Cost estimation

ENGINEERING	total cost	VAT
Preliminary proposal/static/BOQ/nesting	4400	
Approval Drawings	2200	
Membrane Details and Patterning	2200	
Statical Analysis/steel & steel shop rawings	6600	
Additional Works /Approval procedure	3300	
	18.700	3553

MEMBRANE (according offer of FLONTEX Europa /Poland)	total cost	VAT
Row Material	6510	
Delivery (France-Poland)	500	
Fabrication costs	2808	
Packing (wooden box + bubble foil)	440	
Delivery (Poland-Germany)	300	
Test Sample fabrication	195	
Test Sample delivery (Poland-Germany)	50	
	10.803	2053

TESTING (prices are estimated)	total cost	VAT
Monoaxial Material	250	
Monoaxial welding seam	250	
Monoaxial clamp sample	250	
Monoaxial cable pocket	250	
BIAX for E-value & compensation	600	
	1.600	304

CABLES (according to the offer of PFEIFER/Getrmany)	total cost	VAT
	4.942	939

Steel (according the offer of LANARO Ltd. / Italy)	total cost	VAT
Raw Material	992	
Manufacturing	3218	
Corrosion protection	334	
Fasteners	468	
Packing	98	
Delivery (Italy-Germany)	385	
	5.495	1044

Site works	total cost	VAT
Surway of the footings (1 day)	1000	
Driling+footing+ steel (2 days)		
Membrane preparation (1 day)	5600	
Membrane final position (1 days)		
Transportation (by car)	400	
Hotels	1120	
	8.120	1543

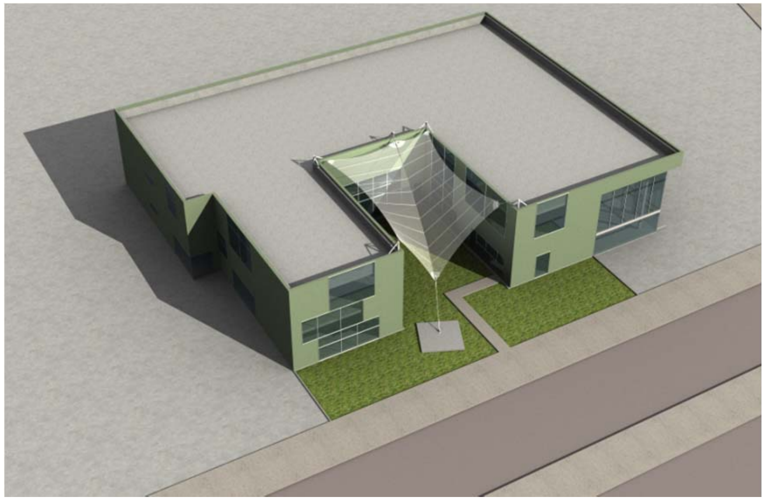
Project Management	total cost	VAT
Travelling	1200	
Hotel costs	340	
PM working hour	16200	
Purchsing (department)	1680	
Assistance	2520	
	21.940	4169

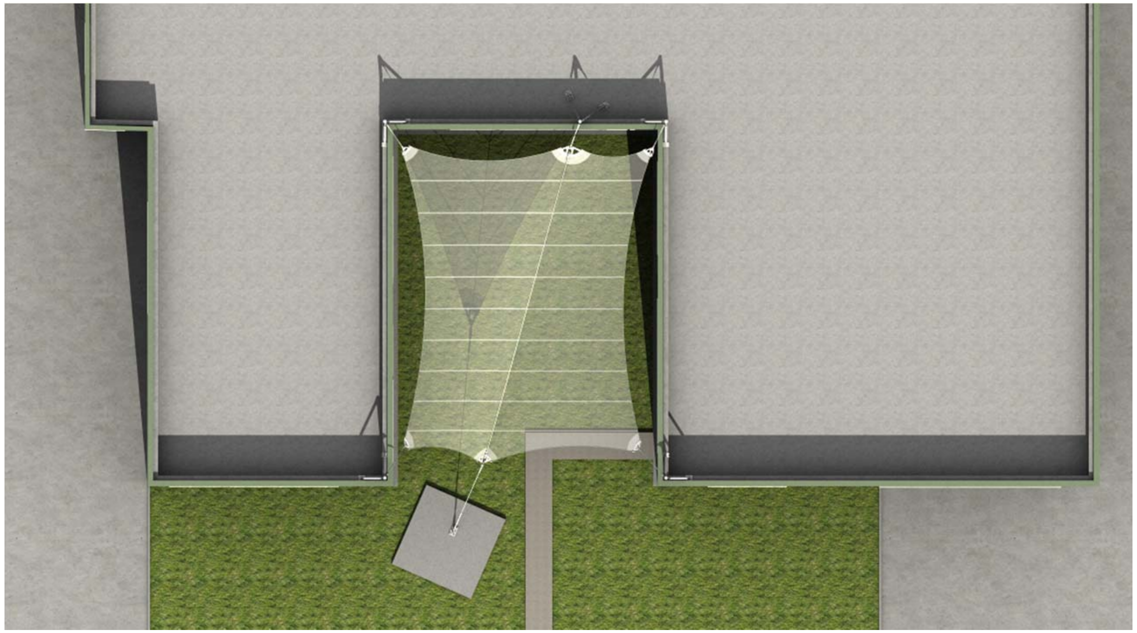
Finance bonds	total cost	VAT
performance bond	600	
advanced payment bond	0	
warrenty bond	400	
	1.000	190

Financing & Risk	total cost	VAT
financing (3%)	2.592	
risk factor (5%)	4.320	
	6.912	1313

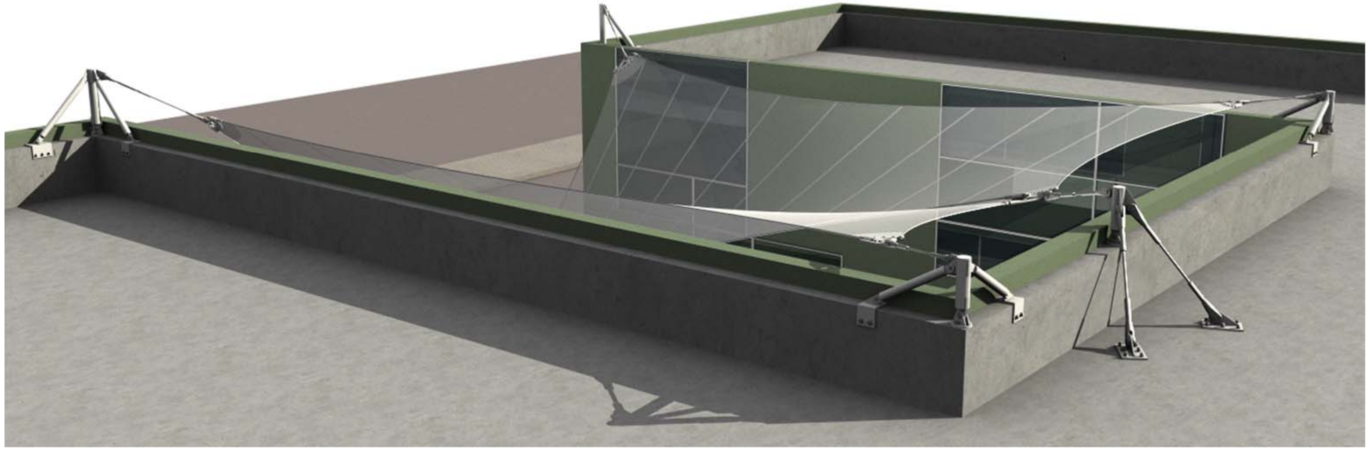
total costs (incl. VAT)	**94.619**
profit (10%)	9.462
contract volume (incl. VAT)	**104.081**

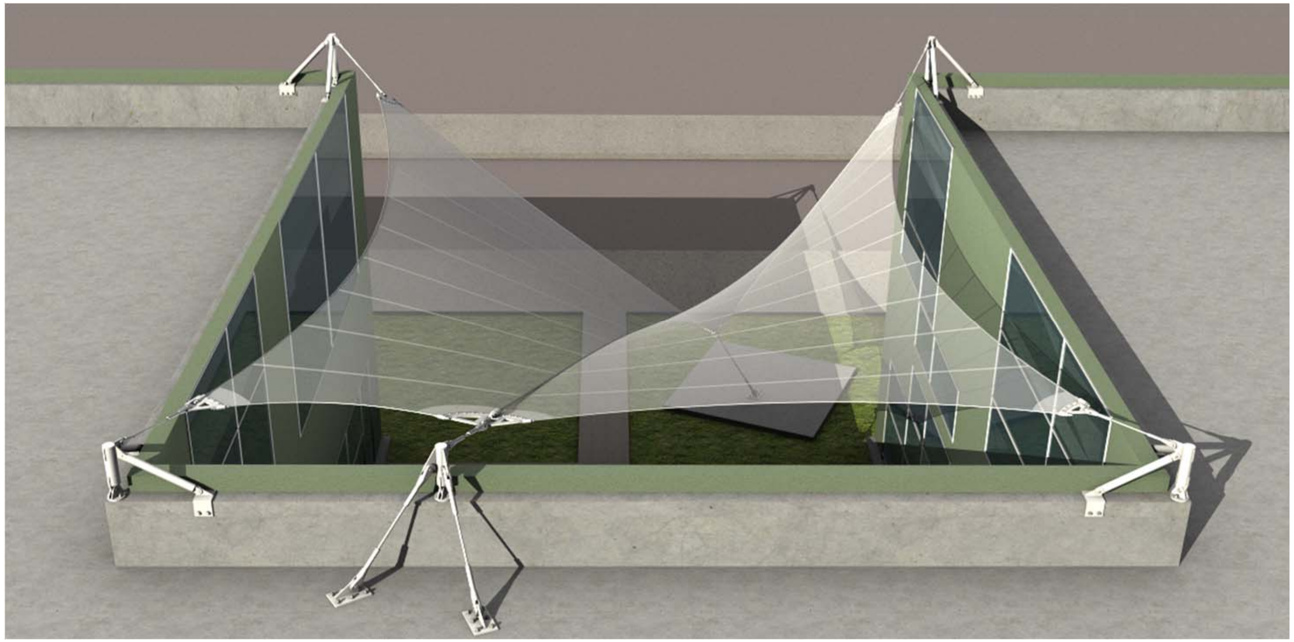
3. SUMMARY



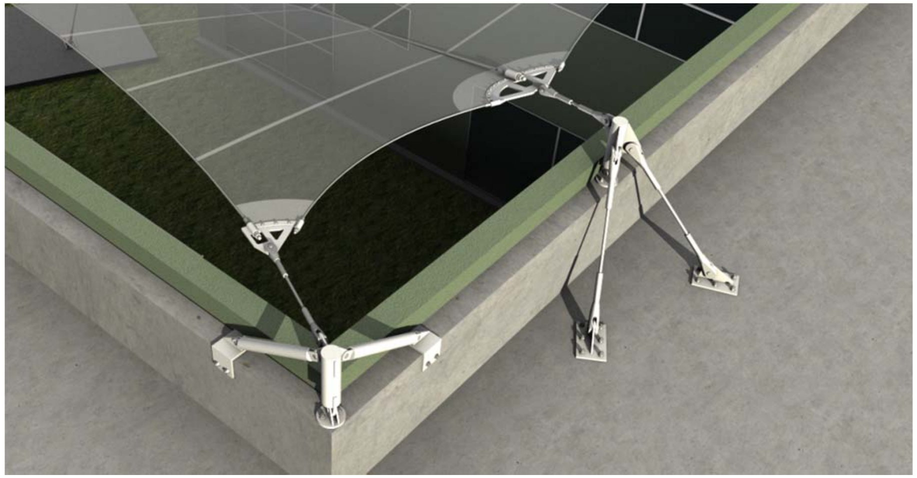


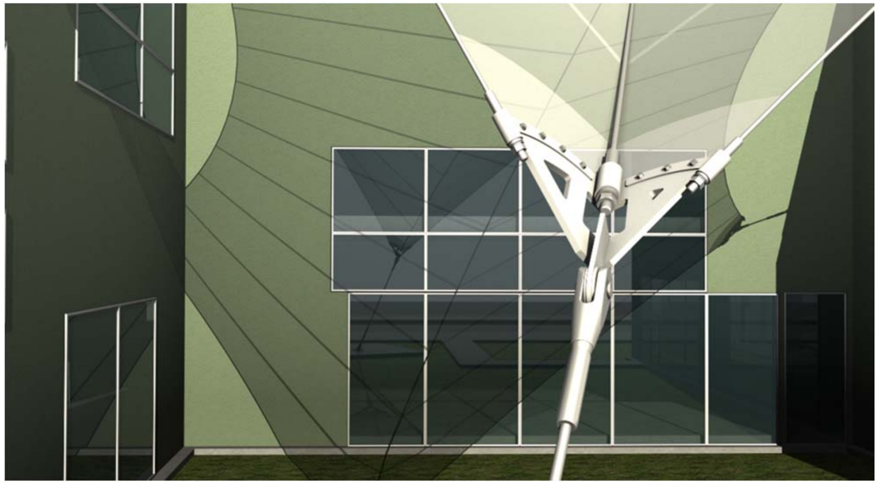
3. SUMMARY

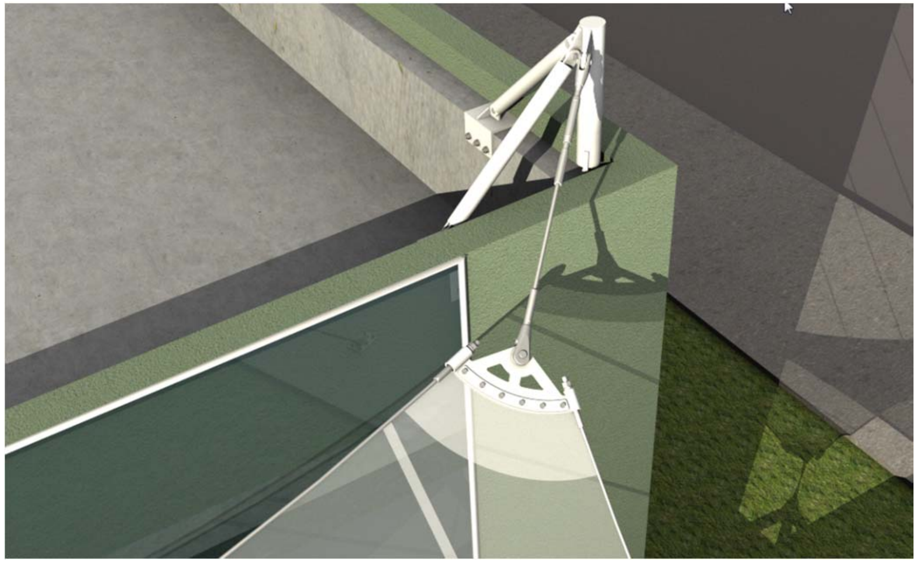




3. SUMMARY







3. SUMMARY