Adaptive Façade

For Windload reduction in High-rise

Building Technology Track
Graduation studio

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Mentors
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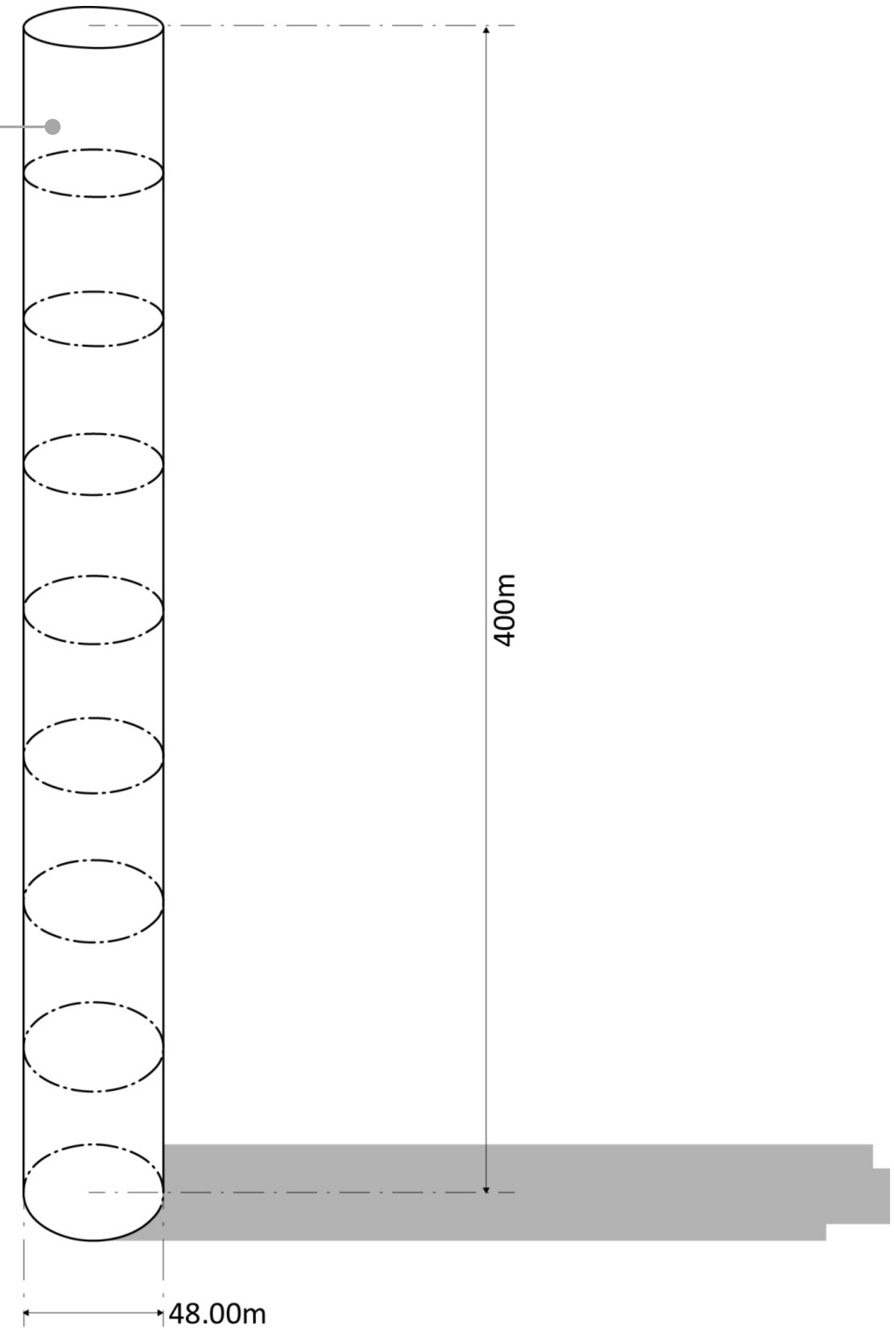
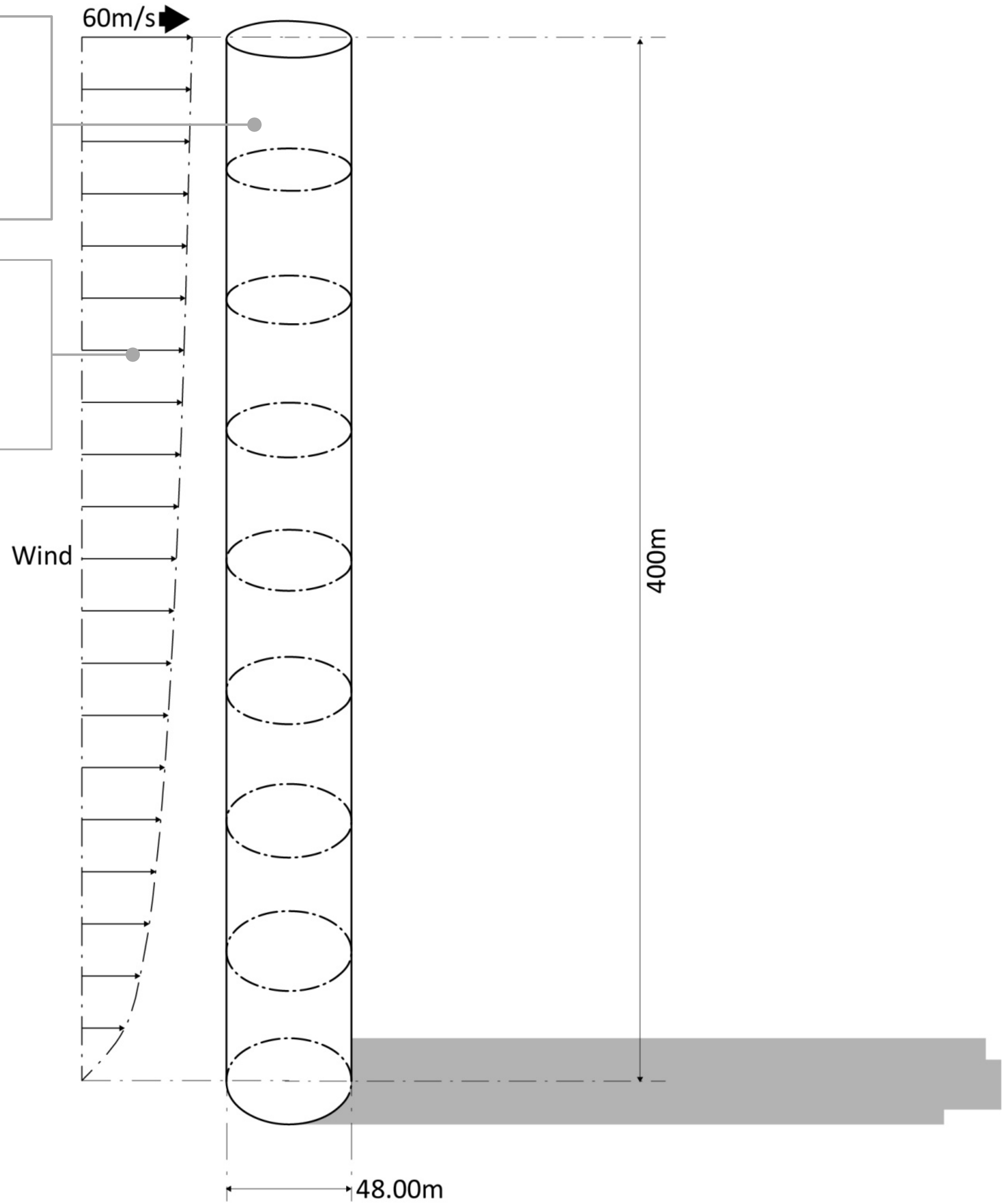
Highrise
Height: 400m
Size: 48m
N. Floor: 92 floors



Highrise
Height: 400m
Size: 48m
N. Floor: 92 floors

Basic wind speed
48.50 m/s
At 10m



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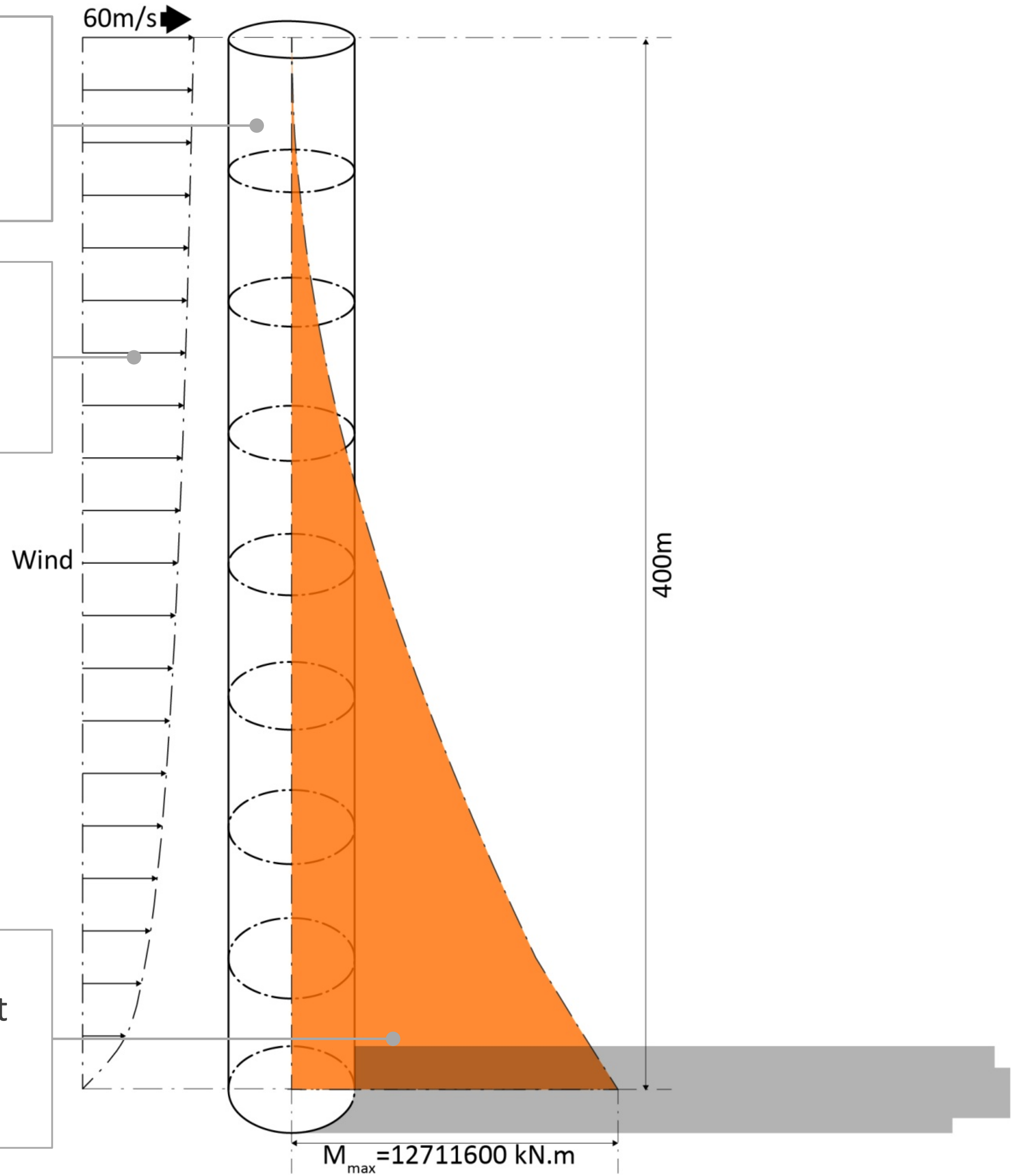

Windload + Height
High bending moment
High bending stress
Require big structure

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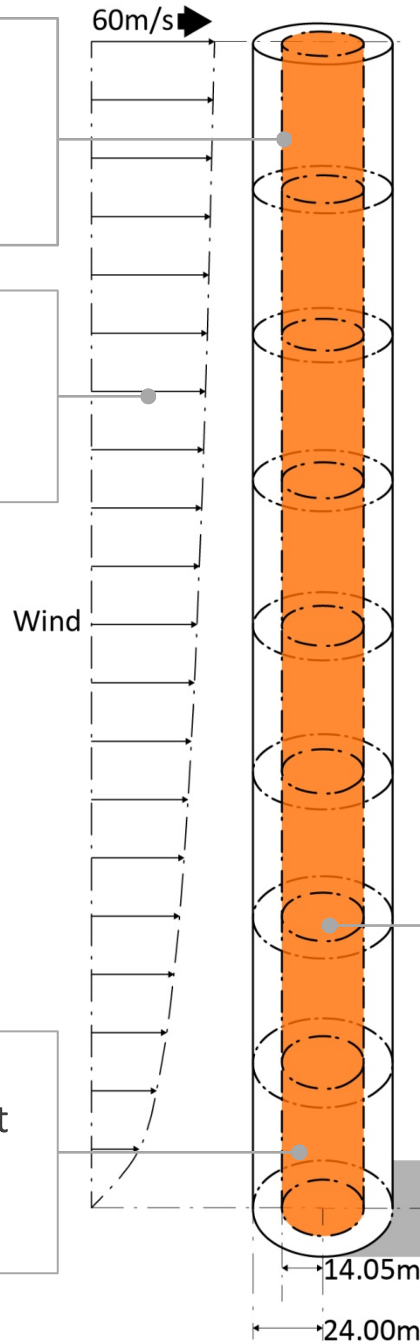
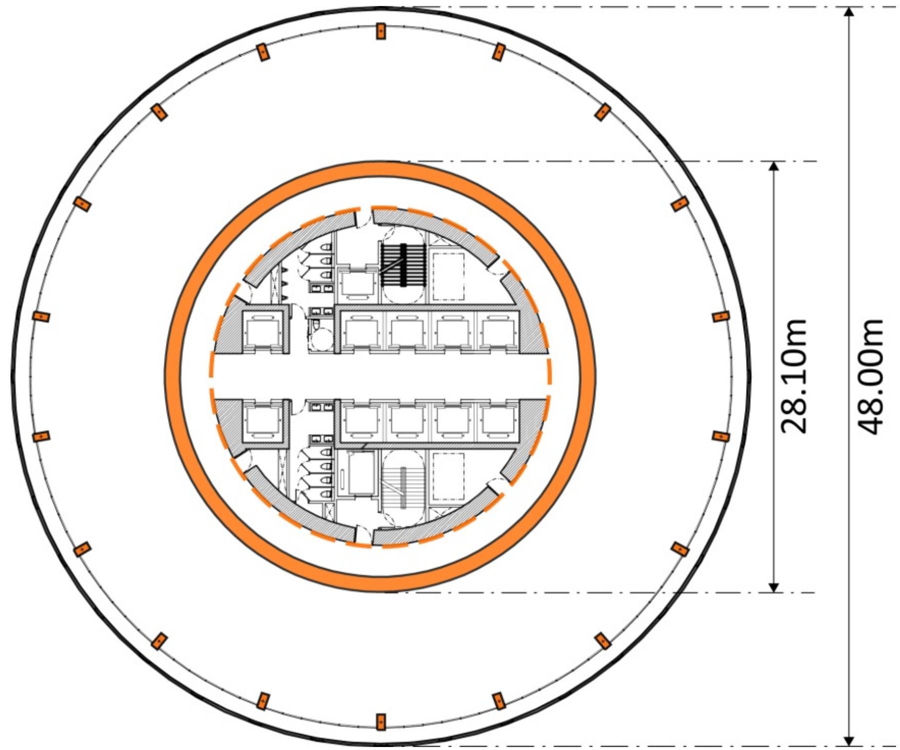


Windload + Height
High bending moment
High bending stress
Require big structure



Core Size Required for Windload
Ø(out) = 14.05m
Ø(in) = 13.05m
Cross-section area =**85.17 m^2**

Core Size Required for Normal load
Cross-section area =**30.00 m^2**
(include safety factor)

To solve a problem, do it at the cause, not at the end-result.

For the problems that are caused by the wind, the solution is at the wind

Create the building that less resistance to the wind

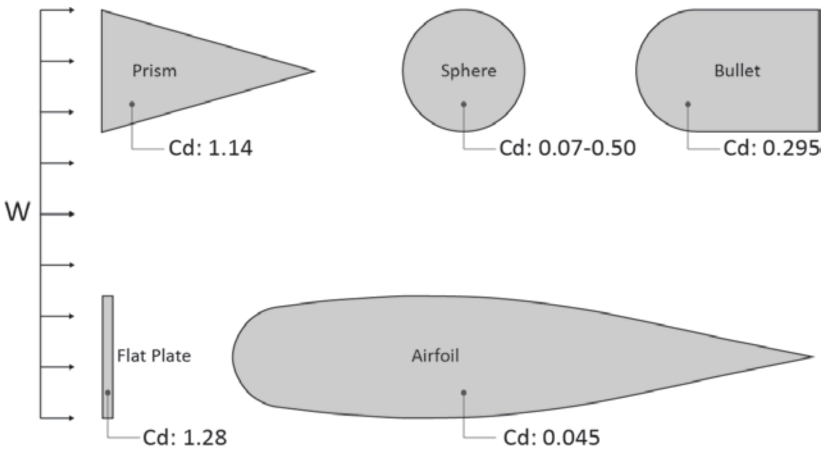
With

Adaptive Facade

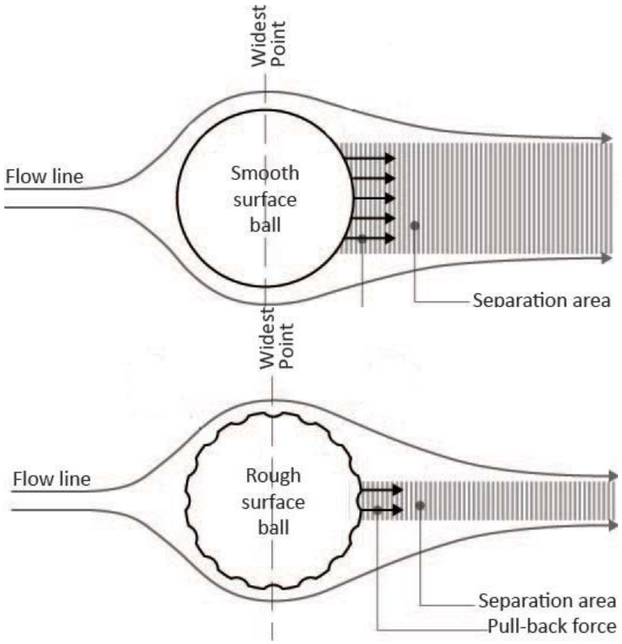
In what extend that adaptive building envelope can reduce wind loads in a high-rise with highest efficiency in reduction of structure material?

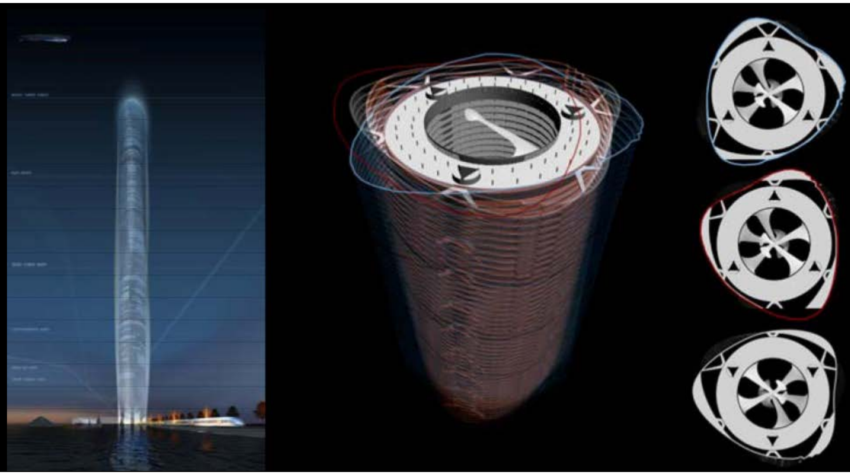
Wind force reduction

Object shape



Object surface





EVOLO Tower

Fastskins

Golfball

Basic wind effect to cylinder object

Wind Force

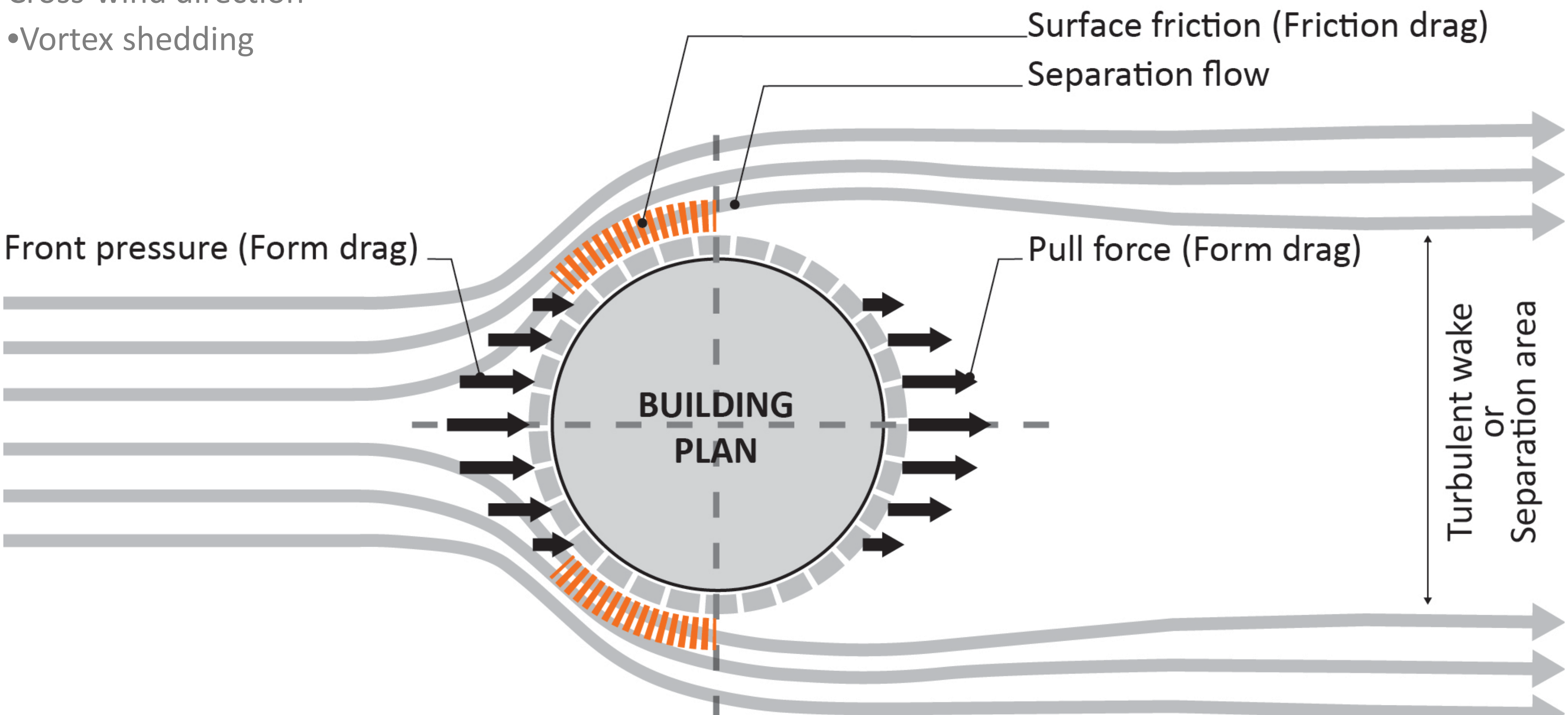
Along-wind direction

•Form drag

•Friction drag

Cross-wind direction

•Vortex shedding



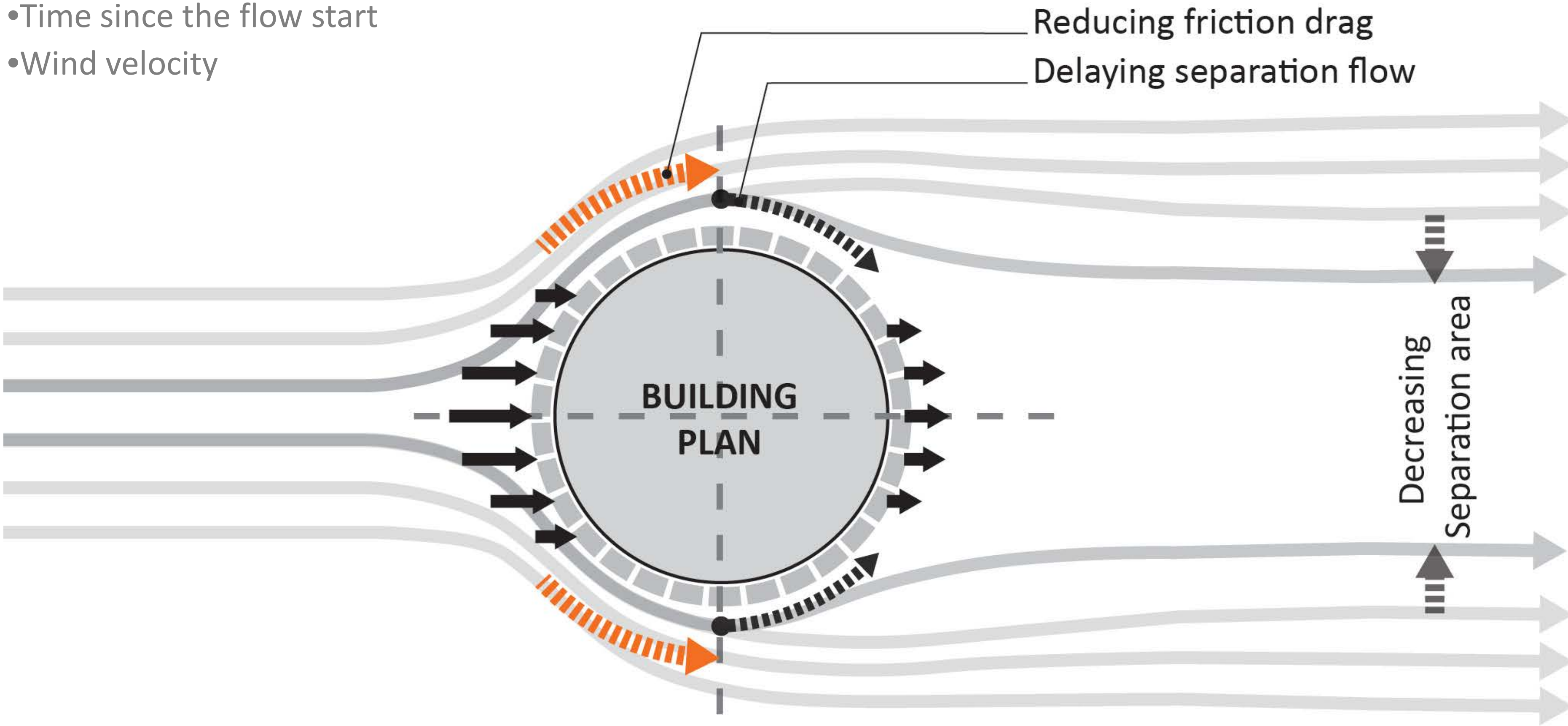
Design Objective

Reducing Wind Force

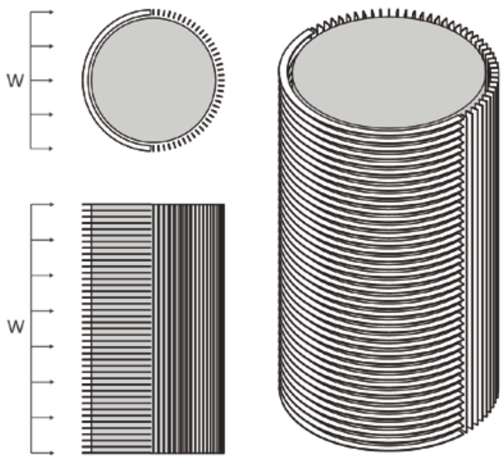
- Reduce friction drag
- Delay separation flow > smaller separation area > reduce pull-force

Location of separation flow

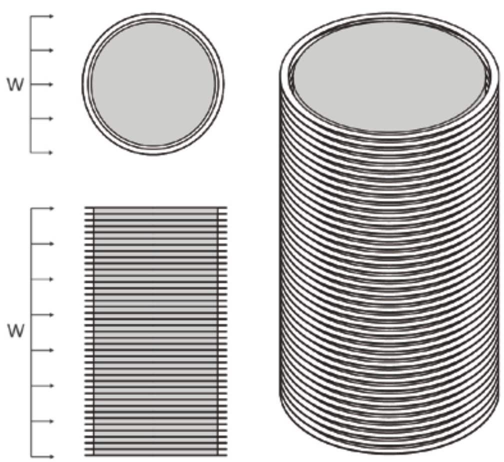
- Time since the flow start
- Wind velocity



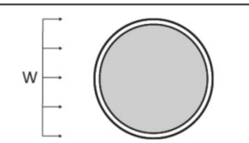
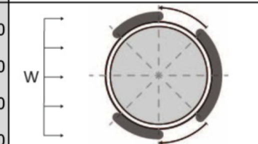
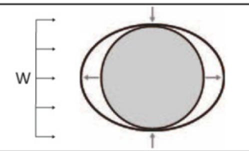
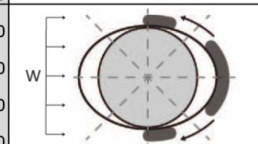
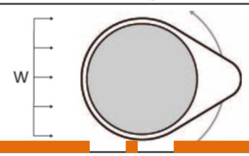
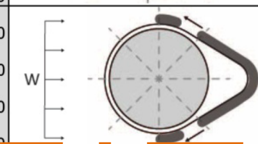
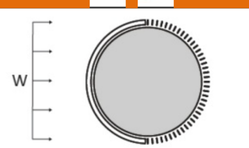
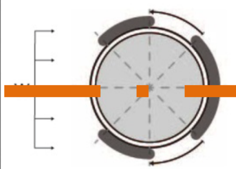
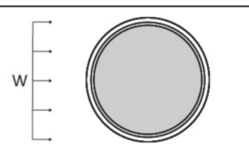
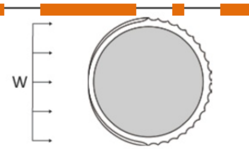
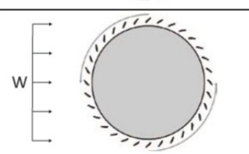
Possible Design Choices



Design 03



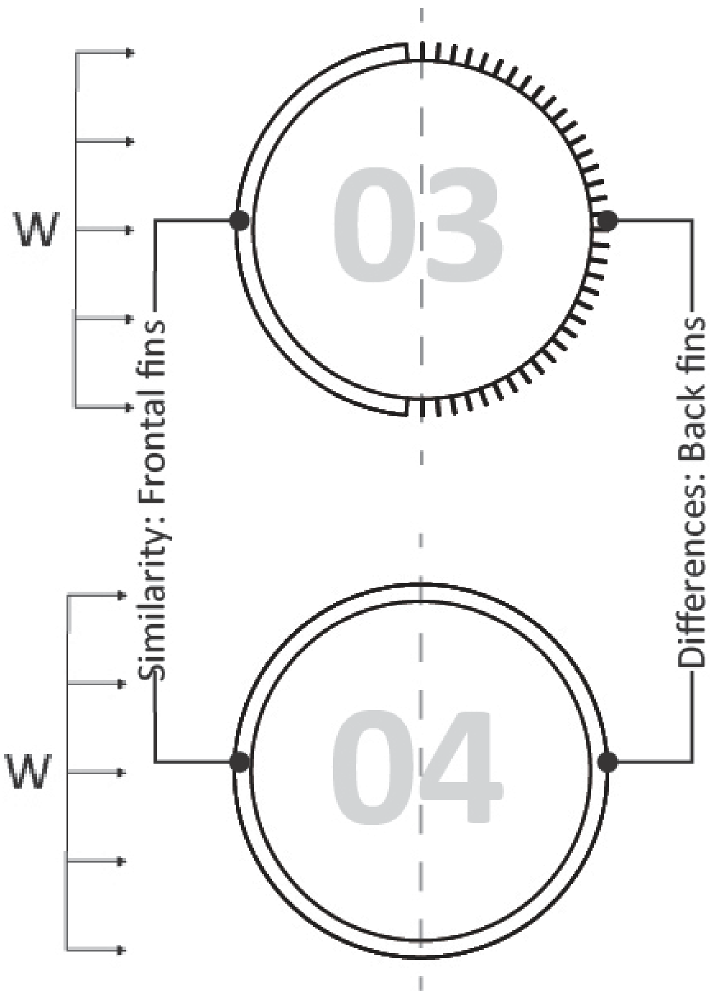
Design 04

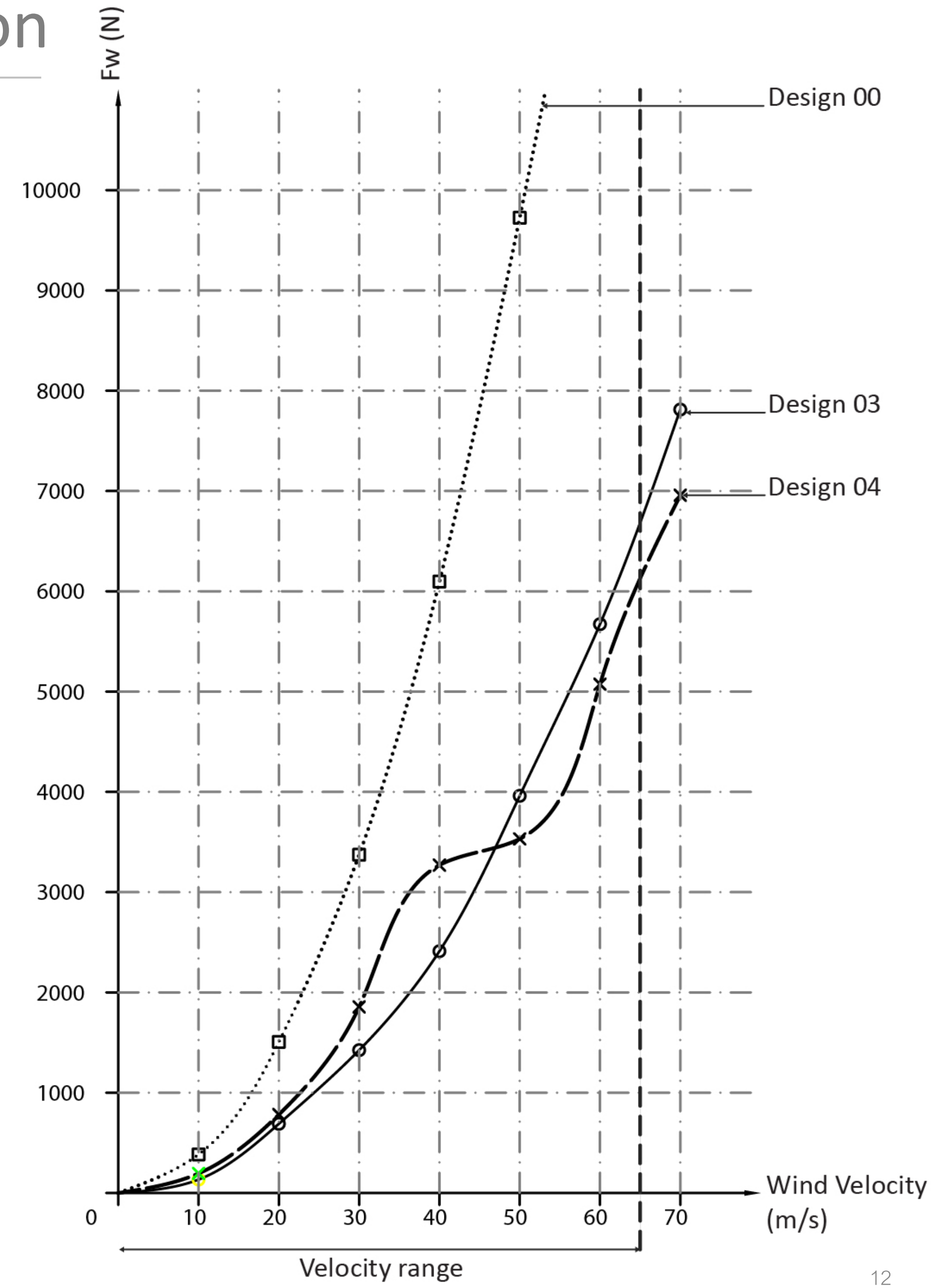
System	Design	Testing time (00.00 minute)	Result: Possitive peak pressure (pa)	Result: Negative peak pressure (pa)	Result: Highest velocity (m/s)	Result: Drag coefficient	Result: Development of negative pressure	Result: Aerodynamic property
0 Circular building with second skin		00.04 00.08 00.12 001.6	724.131 795.220 847.218 832.406	-1002.685 -1234.066 -917.309 -799.699	63.427 57.663 50.127 50.357	2.250 1.680 1.830 1.720		I
1 Shape changing envelope		00.04 00.08 00.12 001.6	589.869 704.225 736.986 757.348	-713.649 -899.610 -1251.849 -1208.508	68.578 70.026 70.889 66.257	1.440 1.290 1.060 1.120		II
2 Rotatable aerodynamic shape envelope		00.04 00.08 00.12 001.6	588.204 665.621 694.376 657.007	-830.256 -949.792 -1098.631 -1507.728	63.731 66.486 53.613 56.498	1.590 1.440 0.930 0.690		IIIII
3 Adaptable fins outer envelope 1 (two directions)		00.04 00.08 00.12 001.6	662.678 790.809 839.304 822.325	-932.782 -1239.290 -888.135 -775.536	65.674 60.053 49.734 50.253	0.190 0.140 0.140 0.130		IIIIIII
4 Adaptable fins outer envelope 2 (horizontal directions)		00.04 00.08 00.12 001.6	694.525 879.972 845.762 862.510	-790.782 -1228.723 -1063.581 -941.902	82.919 79.939 69.424 69.382	0.200 0.180 0.140 0.140		IIIIII
5 Adaptable surface roughness by using membrane		00.04 00.08 00.12 001.6	671.297 804.011 824.068 834.649	-940.604 -1183.865 -1115.886 -903.878	71.098 60.039 49.937 49.643	1.920 1.550 1.400 1.480		III
6 Virtical axis wind turbine envelope		00.04 00.08 00.12 001.6	662.352 790.073 841.876 817.566	-933.667 -1206.572 -943.068 -991.029	65.486 58.593 50.680 50.467	1.280 0.980 1.050 0.950		IIII

Selected Design Investigation

Performance in different velocities

Wind speed: 10m/s – 70m/s





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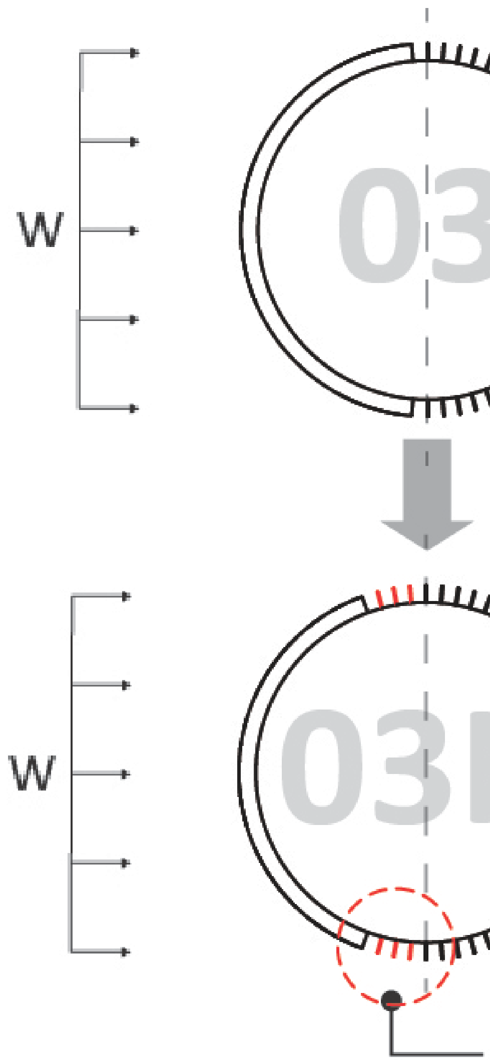
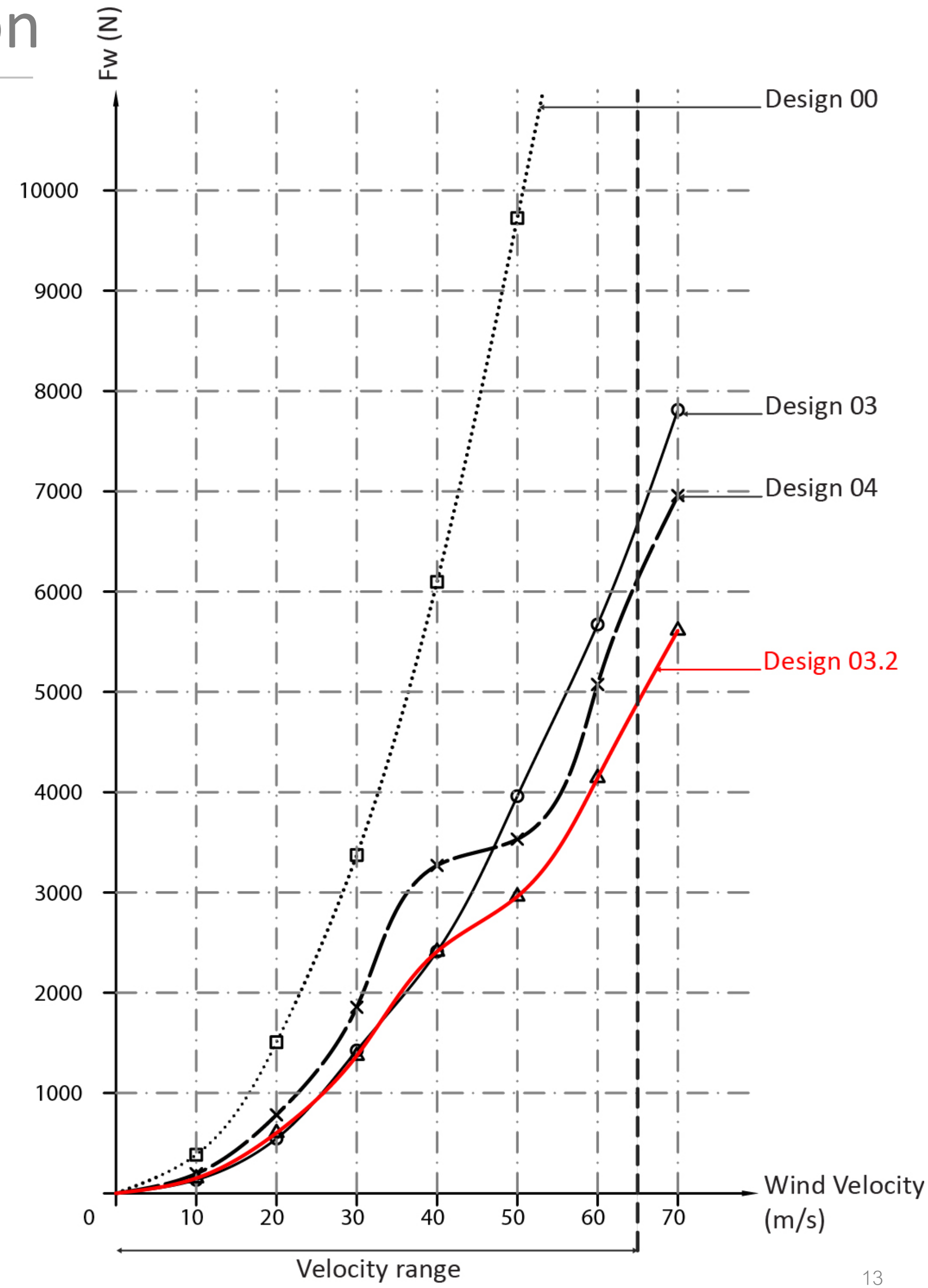




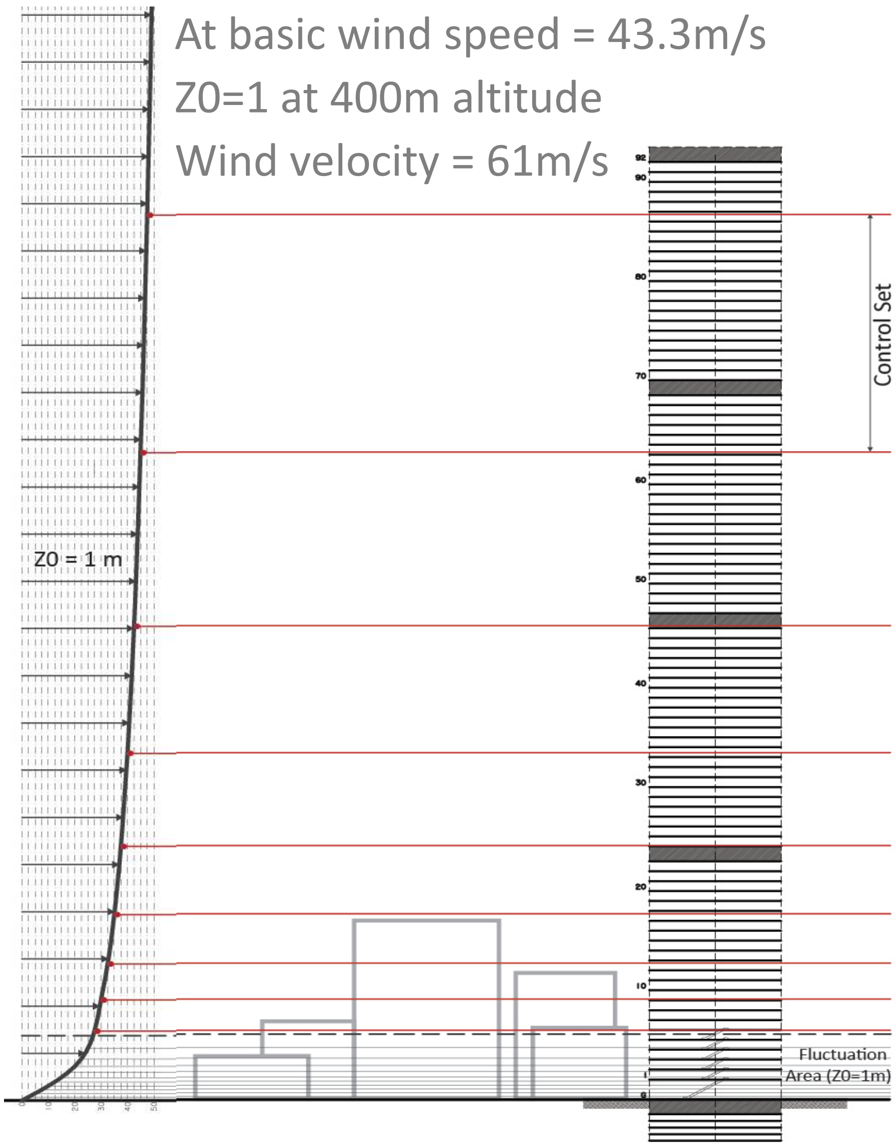
Relation to Height

Different in wind profile & sets of movement

At basic wind speed = 43.3m/s

Z0=1 at 400m altitude

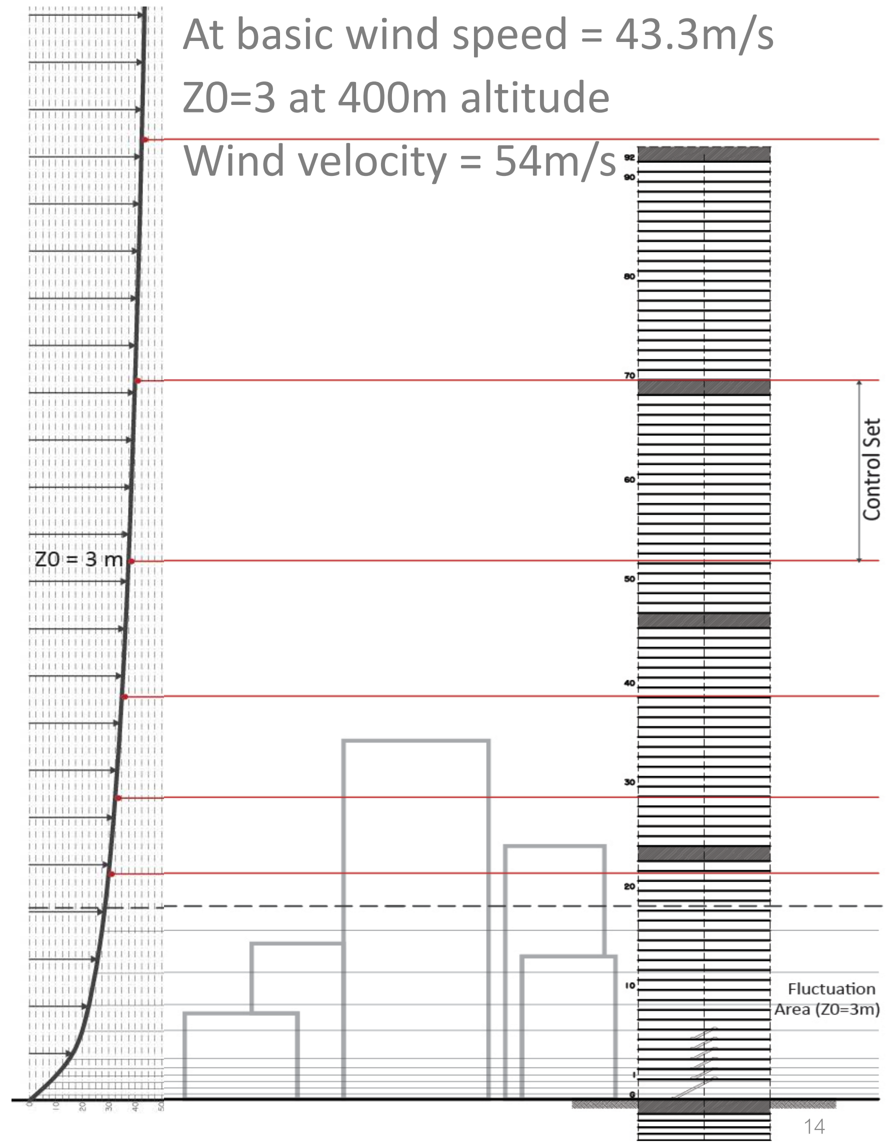
Wind velocity = 61m/s



At basic wind speed = 43.3m/s

Z0=3 at 400m altitude

Wind velocity = 54m/s



3 input data

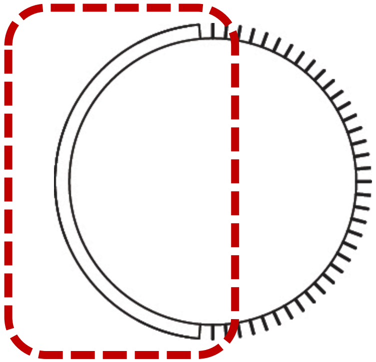
Wind direction
Wind speed
Time

Selected Design Investigation

Front horizontal riblets façade

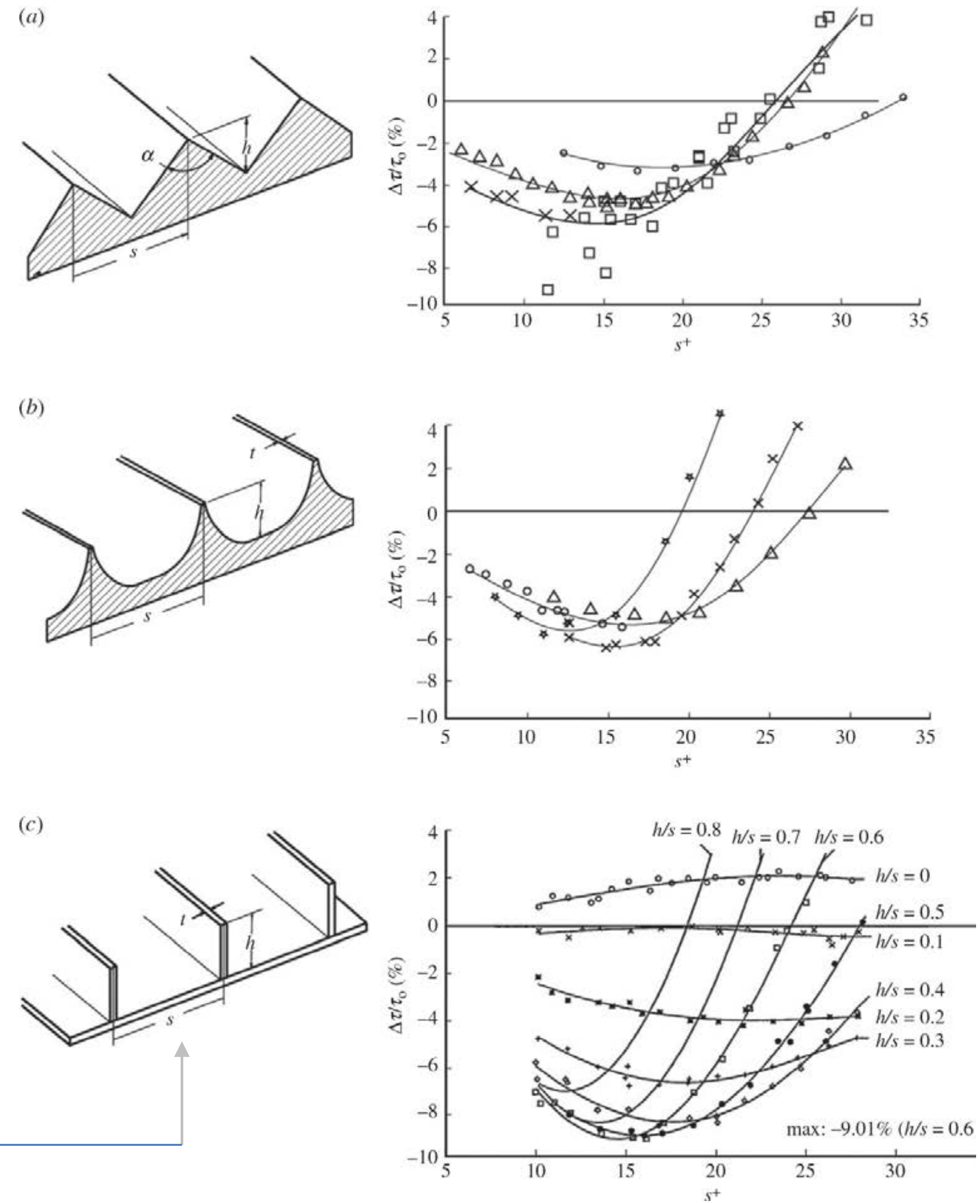
Friction drag reduction

Preventing cross wind turbulence



Performance :

- Ratio of height/space between riblets
  h/s= 1
- Ratio of riblets width/building width
  k/D= 1/20 or bigger



Match with Design 03 and 04

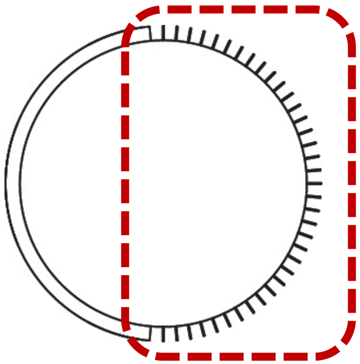
Selected Design Investigation

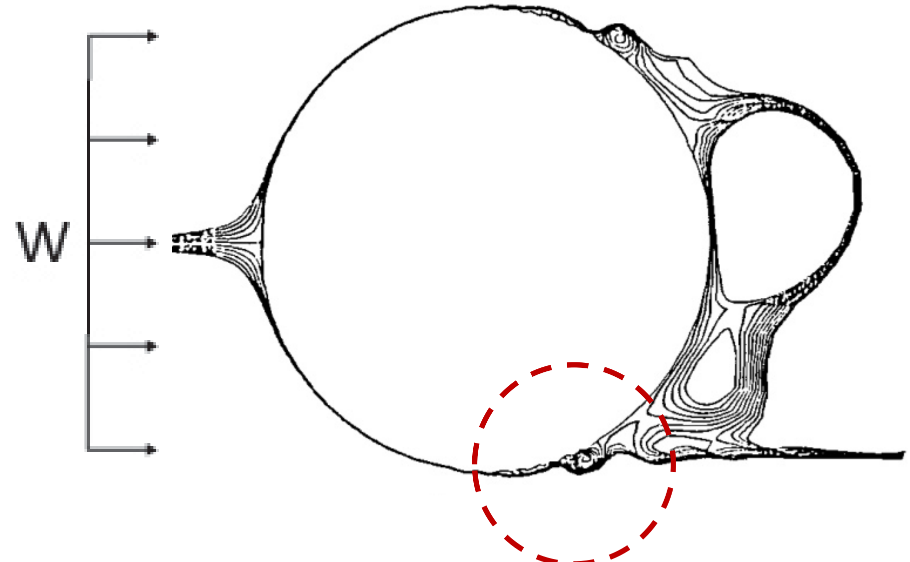
Back vertical riblets façade

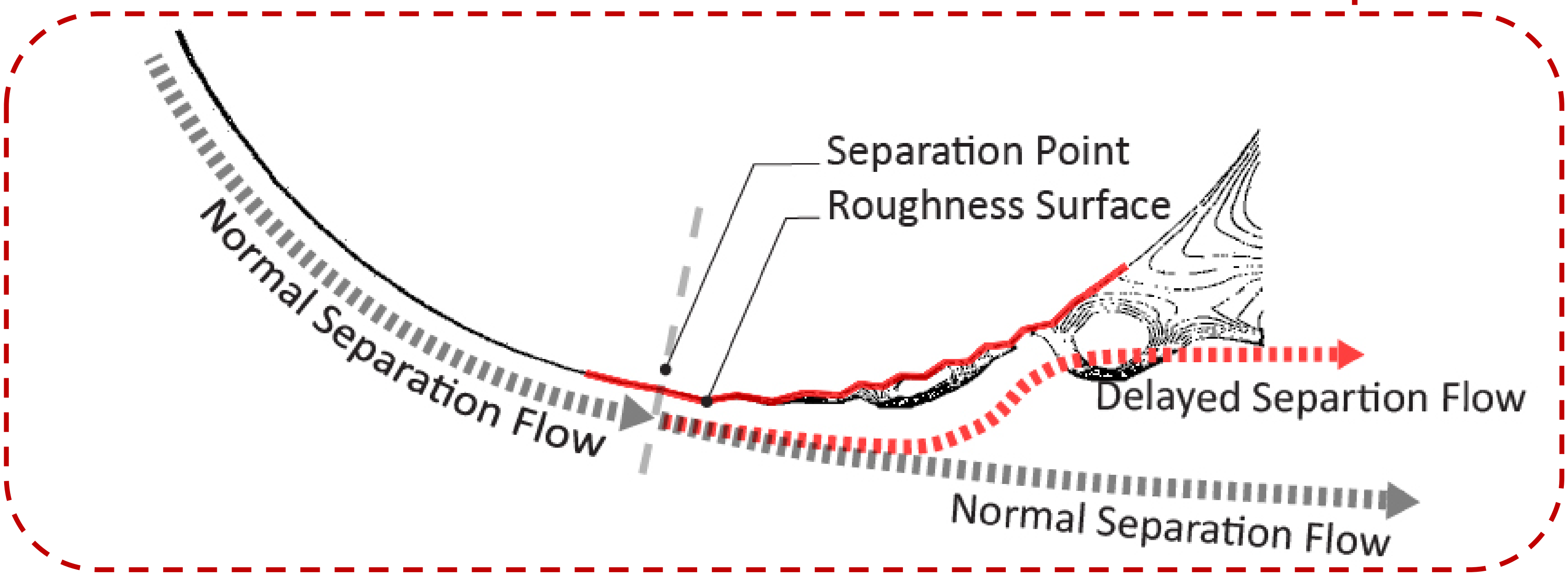
Delay the separation flow

Smaller the turbulent wake

And reduce pull-force







Selected Design Investigation

Back vertical riblets façade : Wind tunnel test

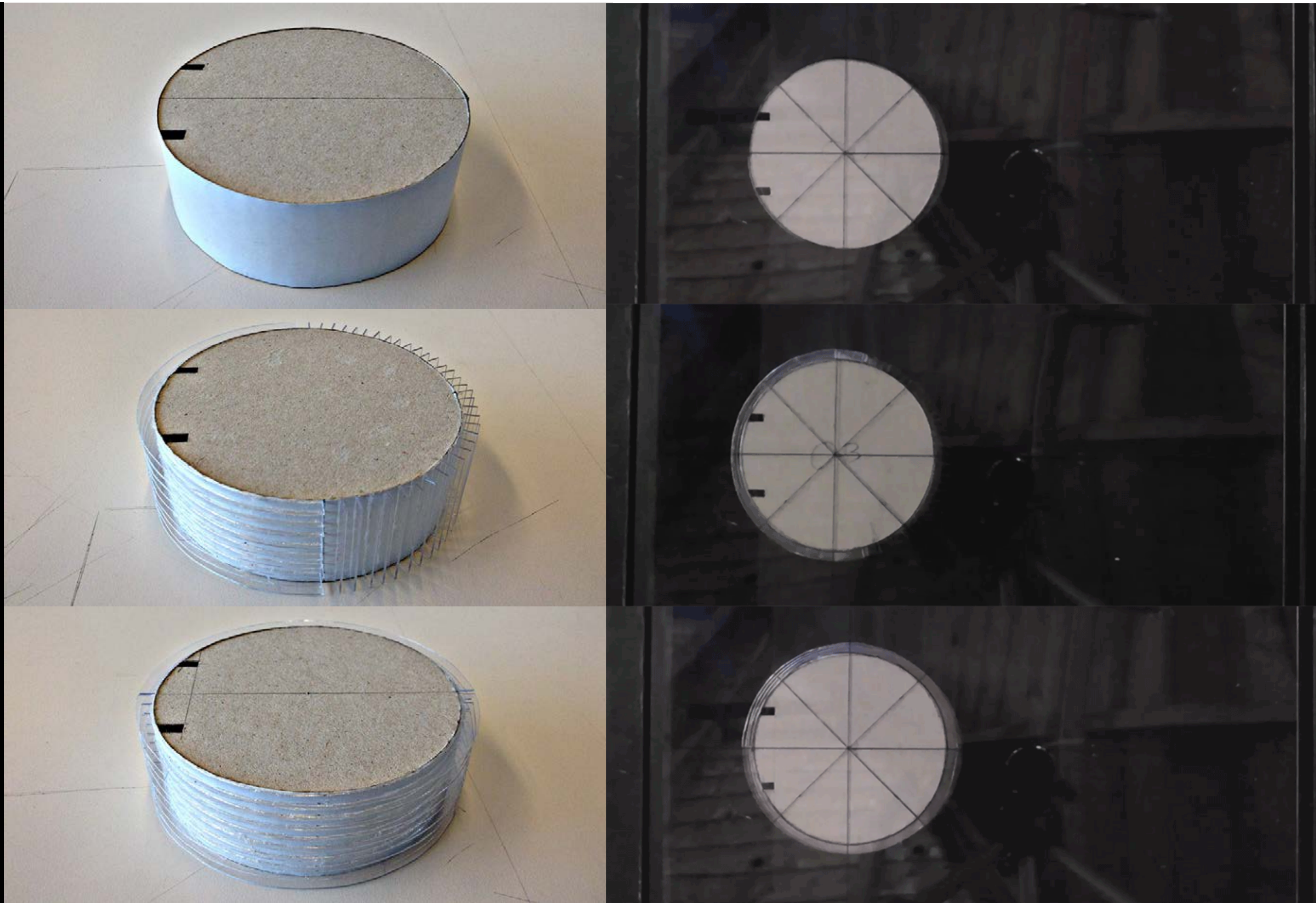
Selected Design Investigation

Back vertical riblets façade : Wind tunnel test

Design 00

Design 03

Design 04



Design Direction

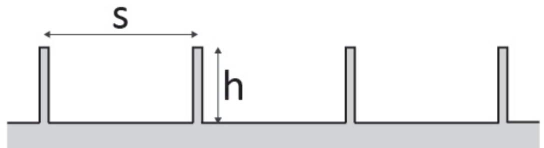
Original basic and adapted position

Original
Horizontal riblets

→

Adaptive
Horizontal riblets at the back are changed to vertical riblets.

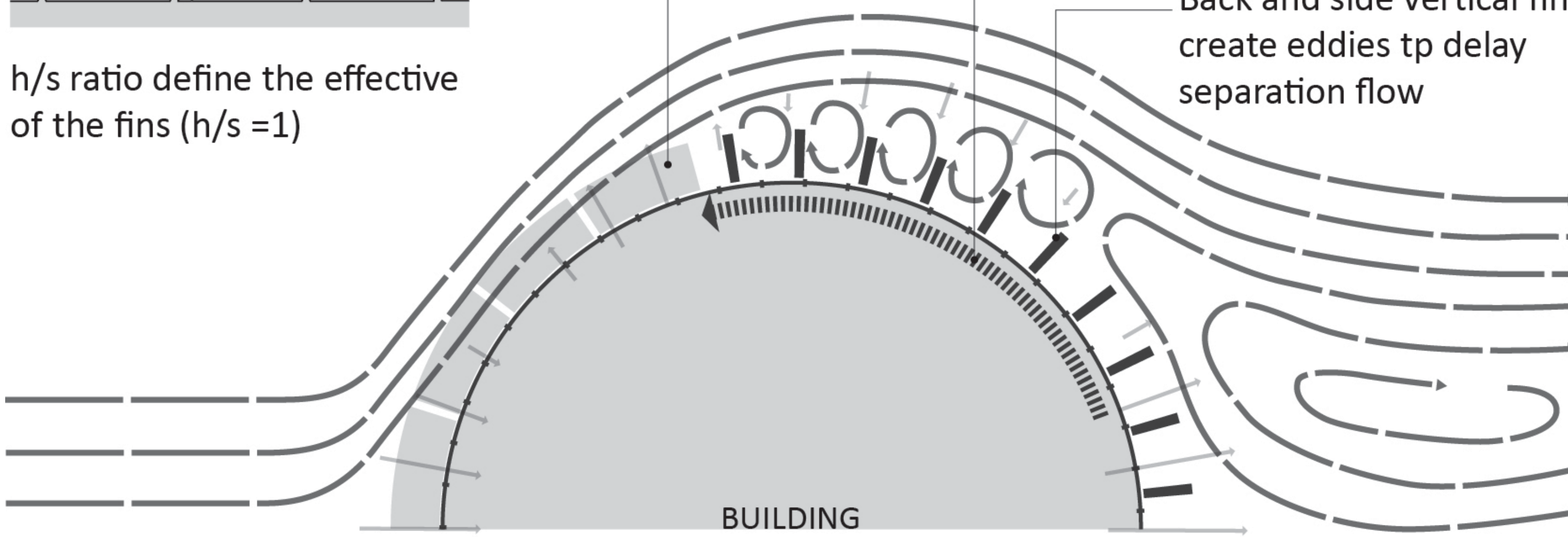
The frontal horizontal fins reduce friction drag



h/s ratio define the effective of the fins (h/s =1)

Fins change the position alone the location of separation flow

Back and side vertical fins create eddies tp delay separation flow



Designing

of

Wind Adaptive Facade

Design Direction

Transformation of horizontal - vertical riblets

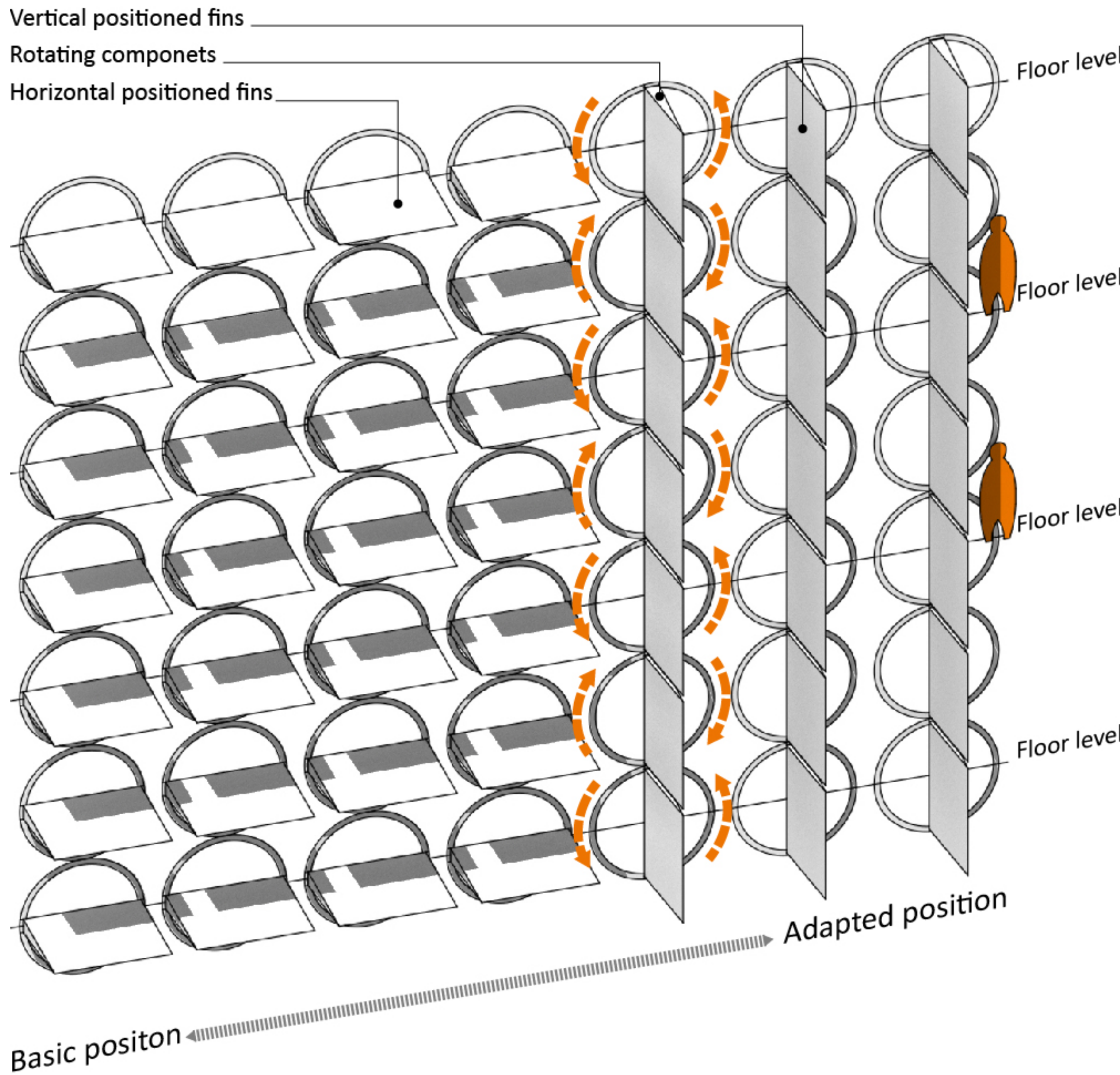
Rotatable Fins

Pros

- Set control system
- Simple mechanism
- Adjusting of h/s ratio without effect to floor height

Cons

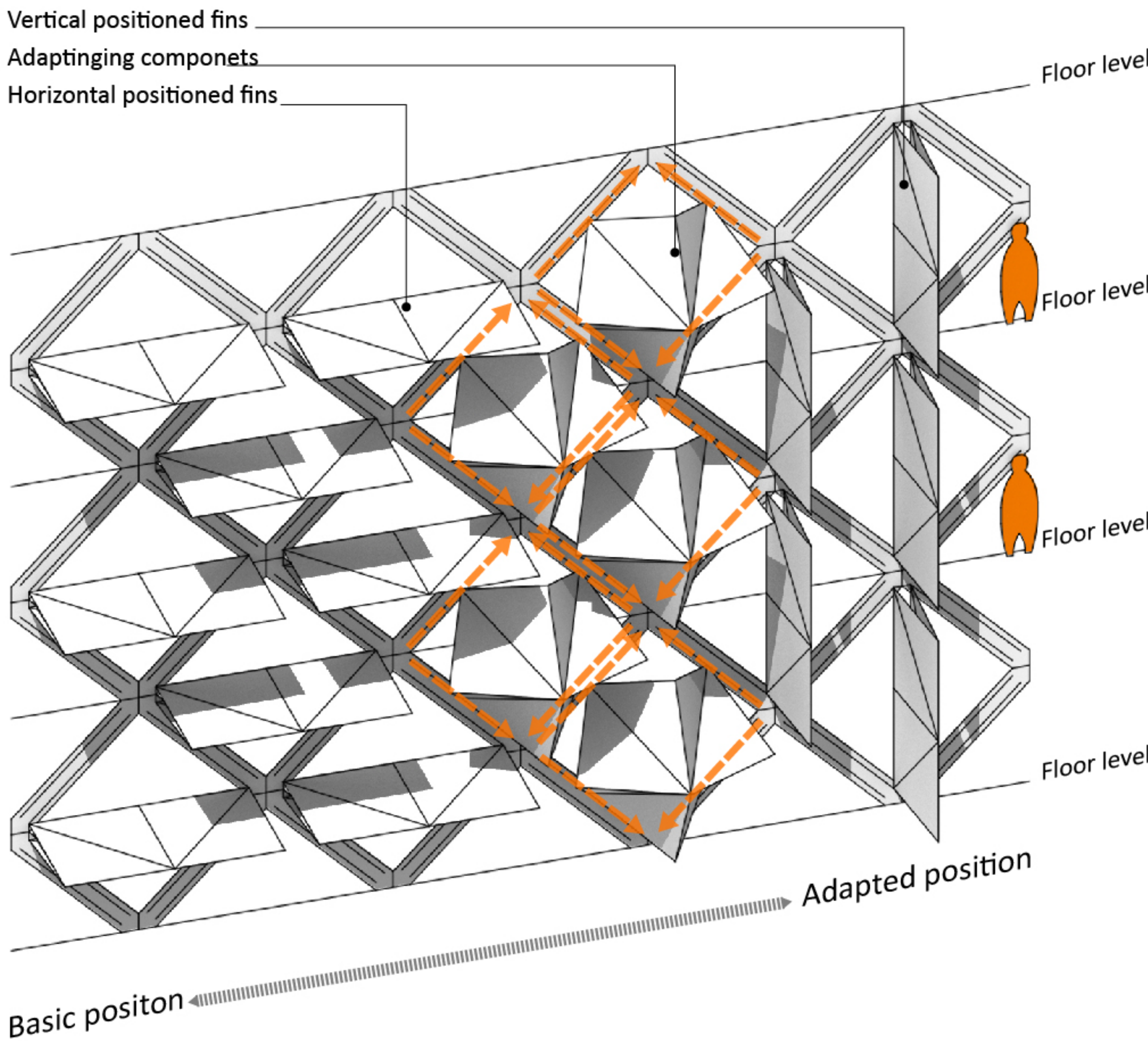
- Lack of structure integrated
- Visual disturbance



Design Direction

Transformation of horizontal - vertical riblets

Origami foldable fins
with Rhombus frame



Pros
- Possibly both set and individual control system
- Structure integrated
- Attractive

Cons
- Possible complicate mechanism
- The size relate to floor height
- Visual disturbance

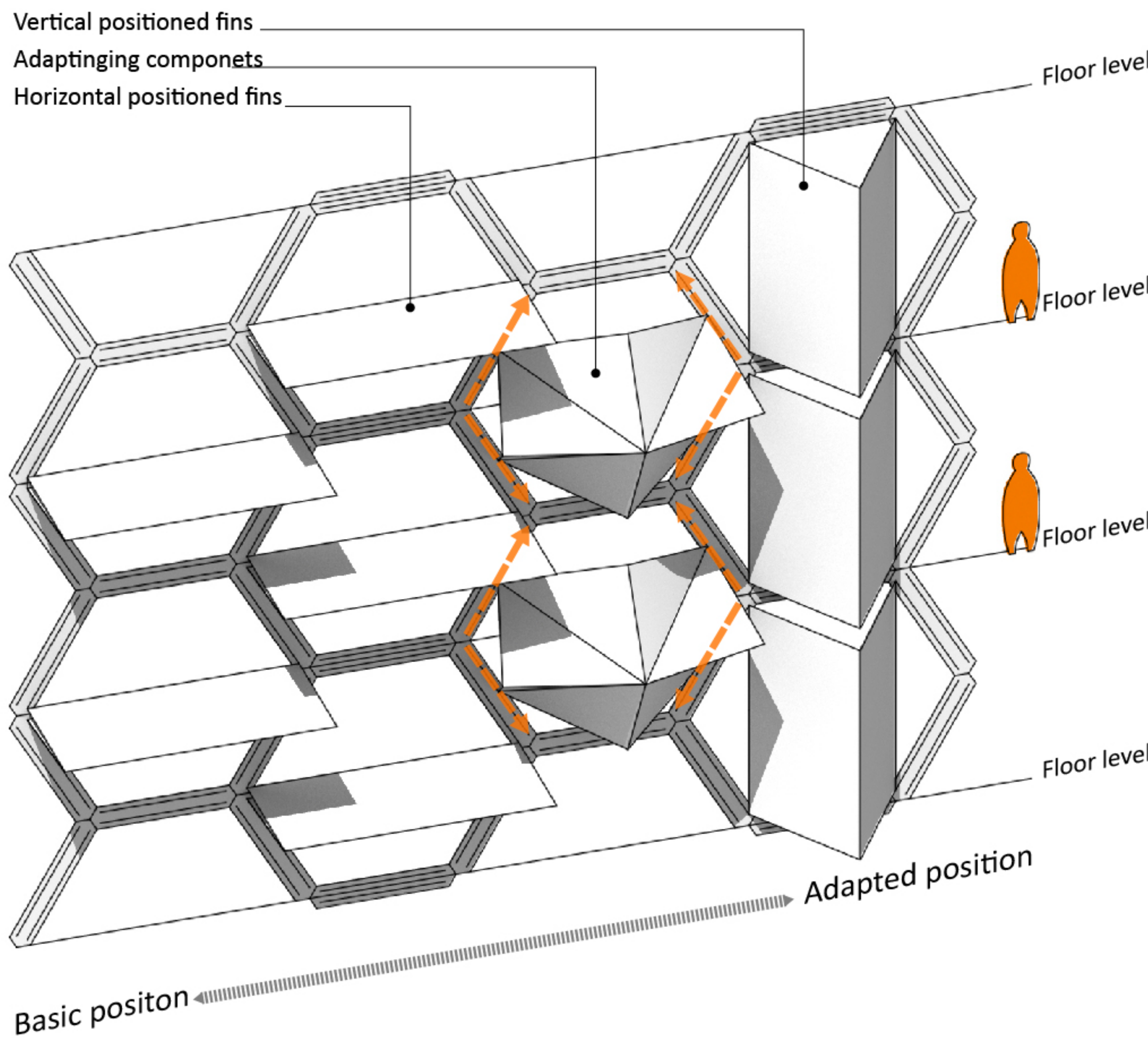
Design Direction

Transformation of horizontal - vertical riblets

Origami foldable fins
with Hexagonal frame

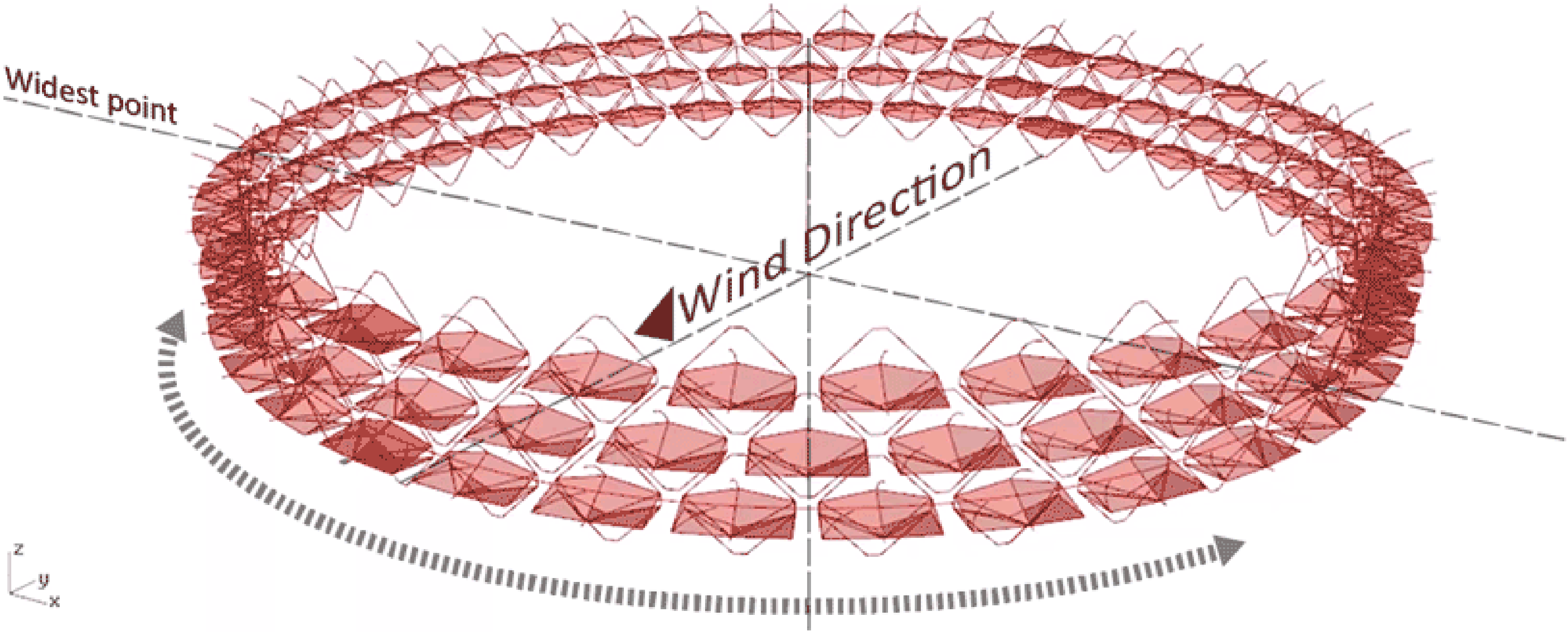
Pros
•Possibly both set and individual control system
•Structure integrated
•Attractive

Cons
•Possible complicate mechanism
•Optimization involve with building floor height
•Low drag reduction



Origami Foldable Fins

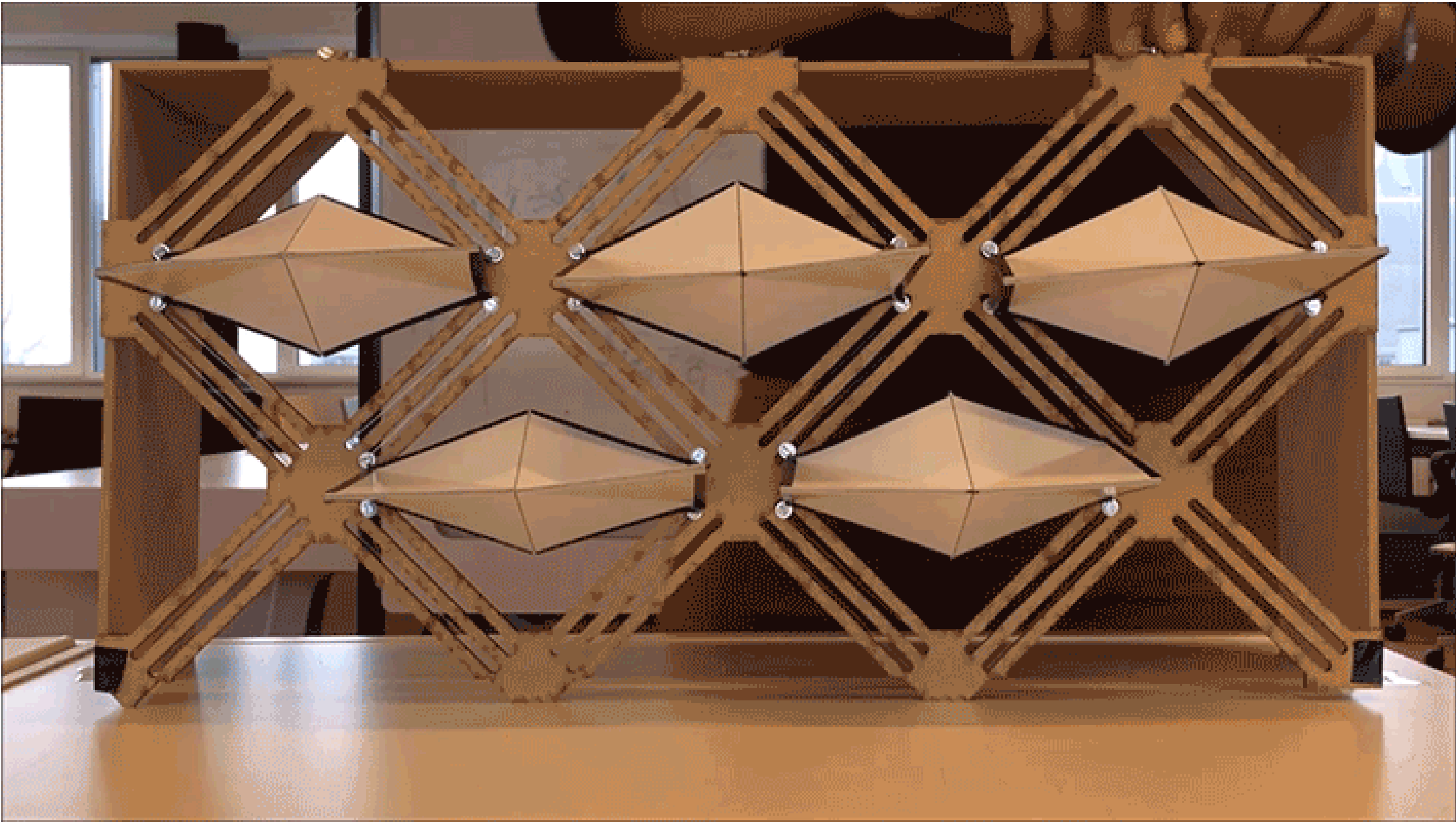
Morphing sequence



- •Following the location of separation flow which reach the widest point in 32 second
- •Start from the back of the building: depend on wind direction
- •The movement of one fin also move the fins next to it

Selected System : Origami Foldable Fins

Mock-up test



Moving Mechanism

Origami Foldable Fins

Operating system : Schematic 1

Cable

Pros

•One motor control multiple units

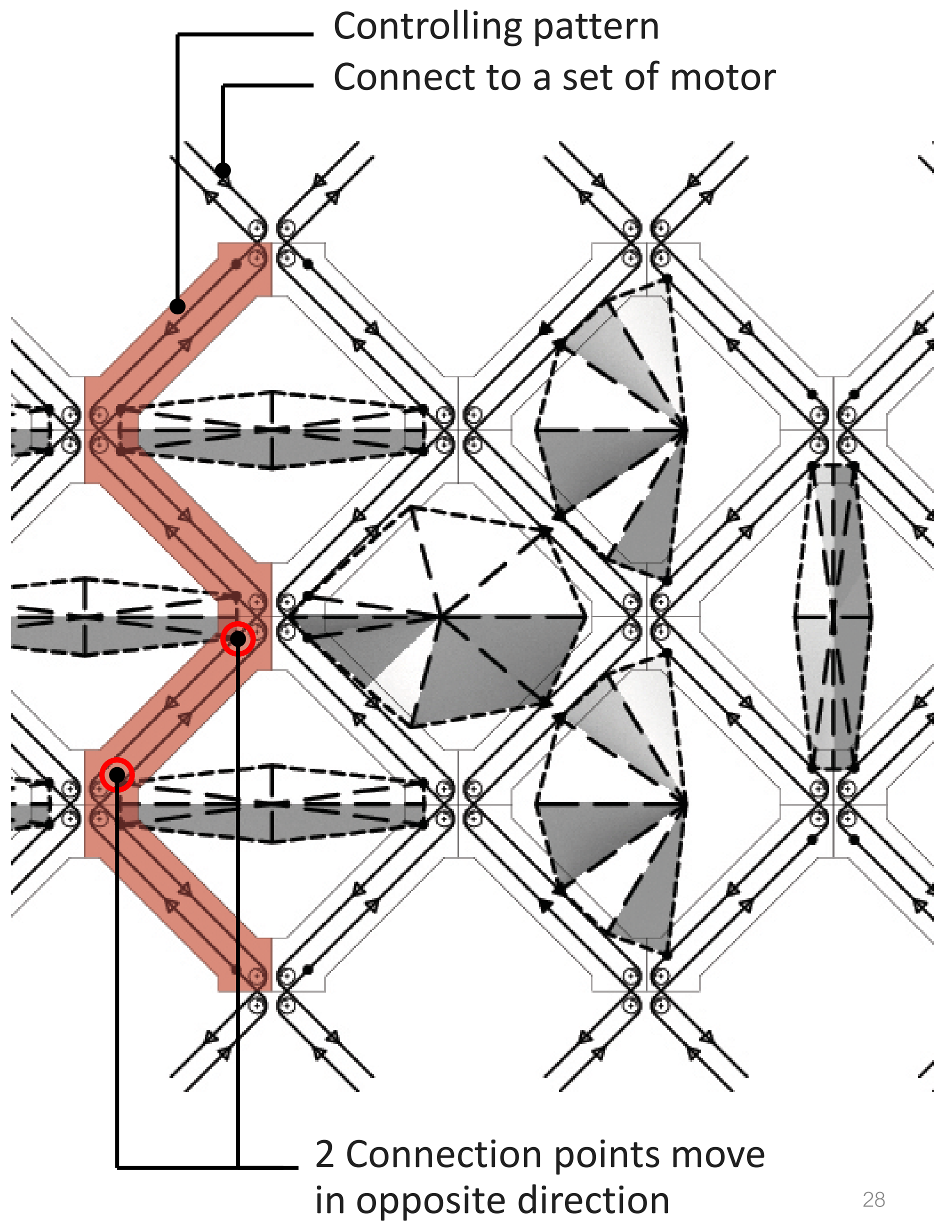
•Possible lower budget option

Cons

•Require big and powerful motor

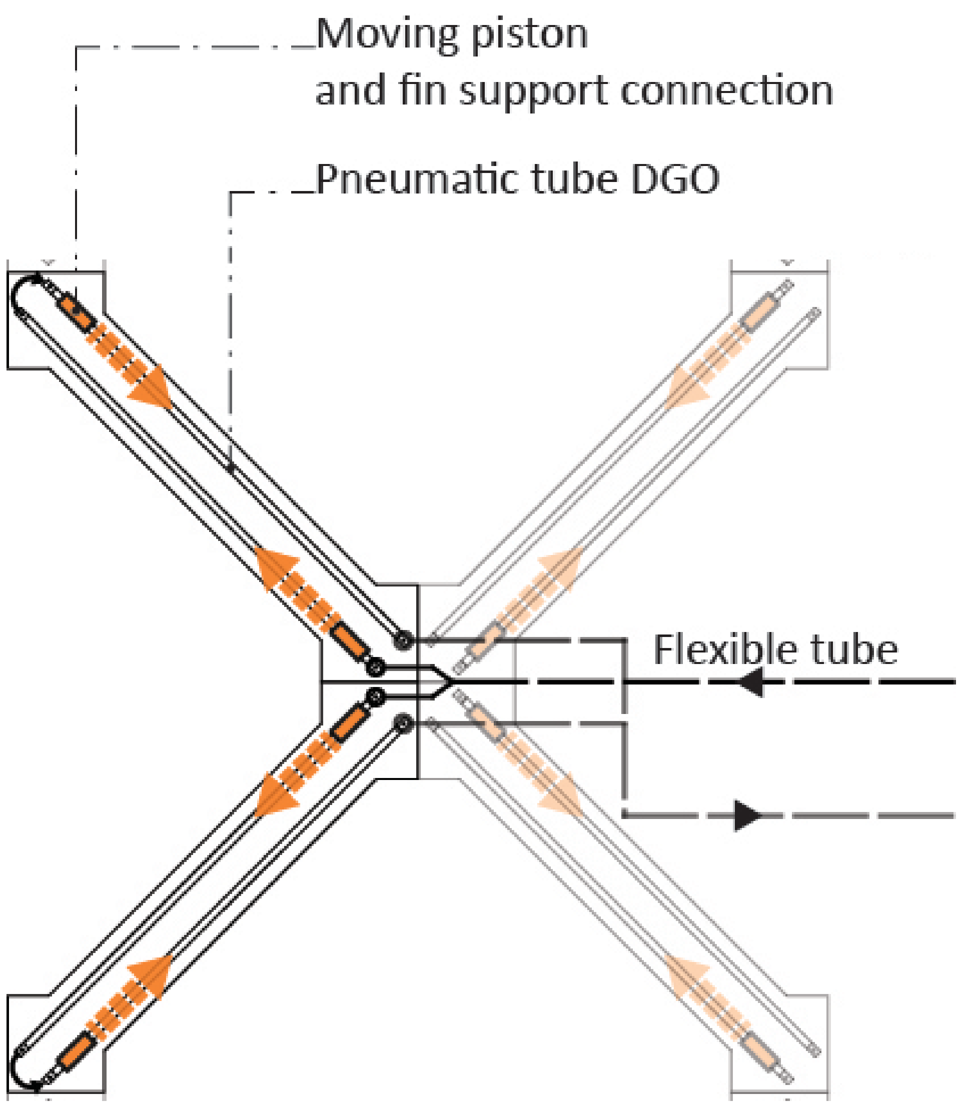
•High risk when one set fail

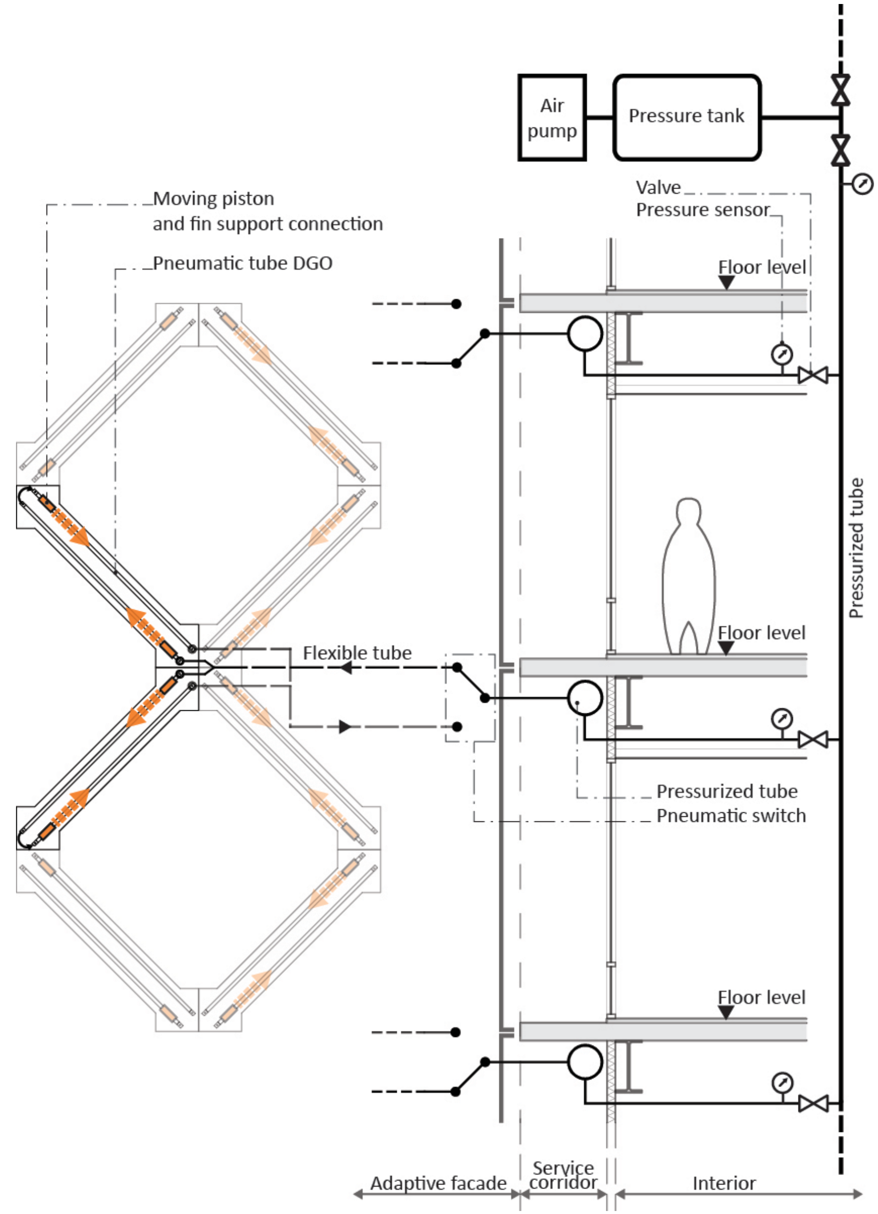
•High friction to the movement when the cable contain high tension



Origami Foldable Fins + Pneumatic Drive

Combination to Building System





Origami Foldable Fins

Operating system : Schematic 2

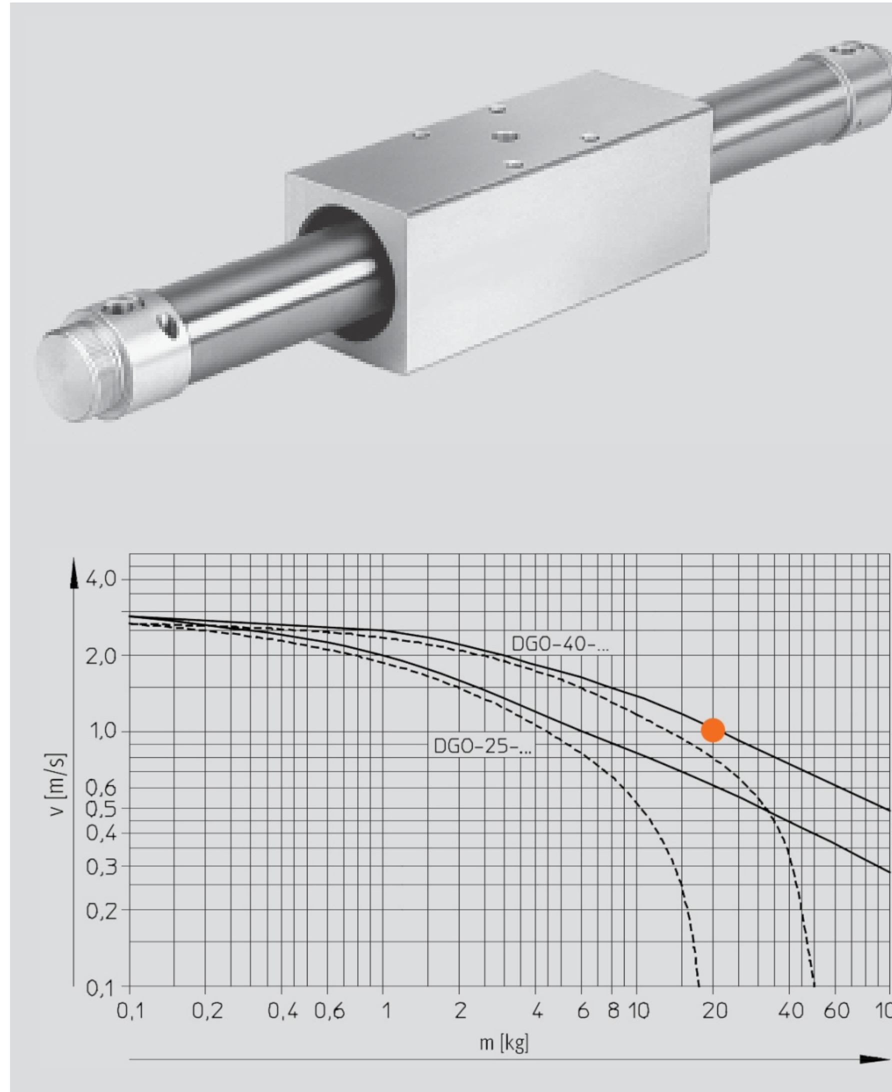
Pressurized air : Pneumatic

Pros

- Possible lower maintenance requirement
- Individual operated less effect when one system fail
- Require less energy when operating
- Less complex mechanism

Cons

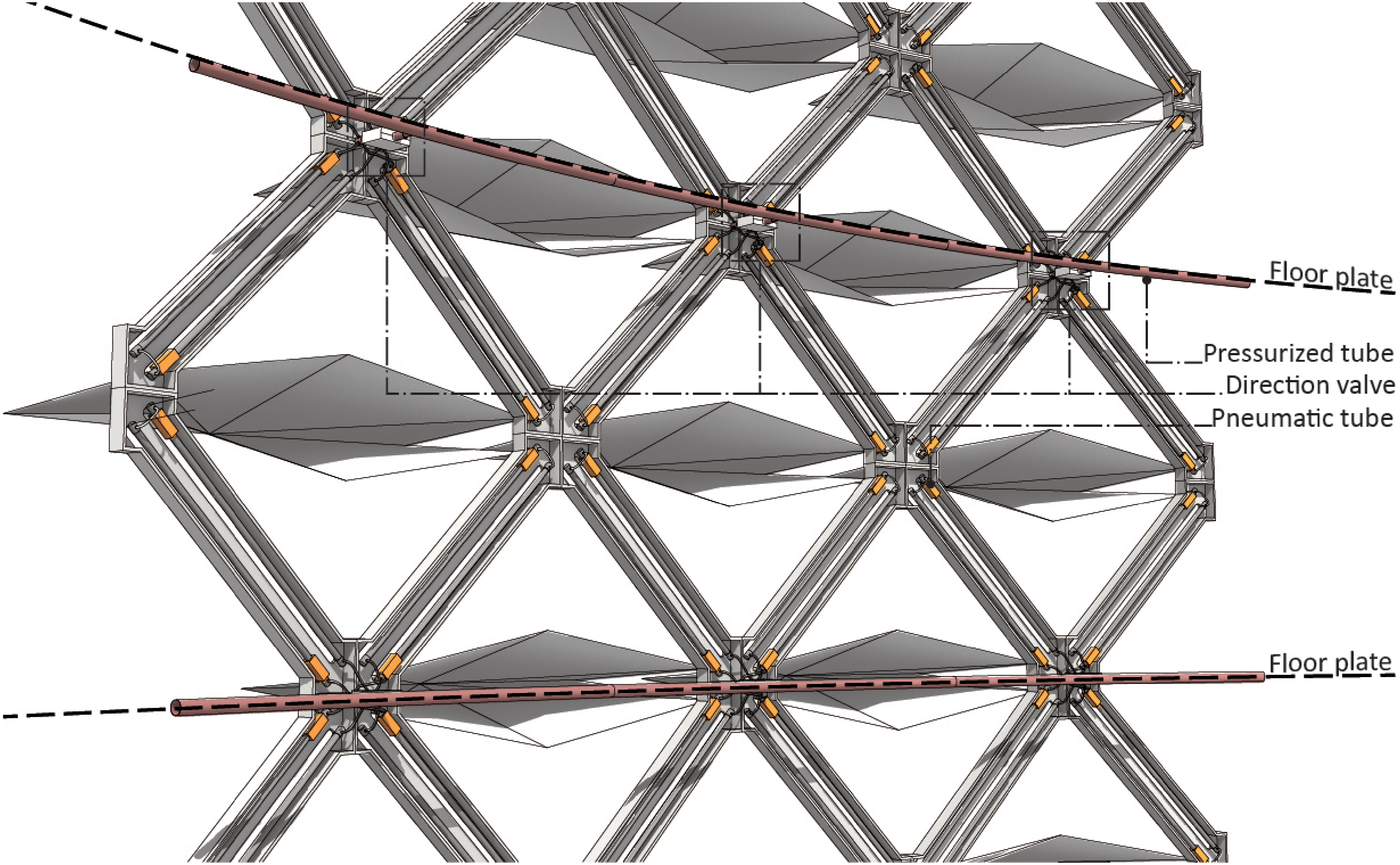
- High cost



FESTO: Pneumatic rodless cylinder drive

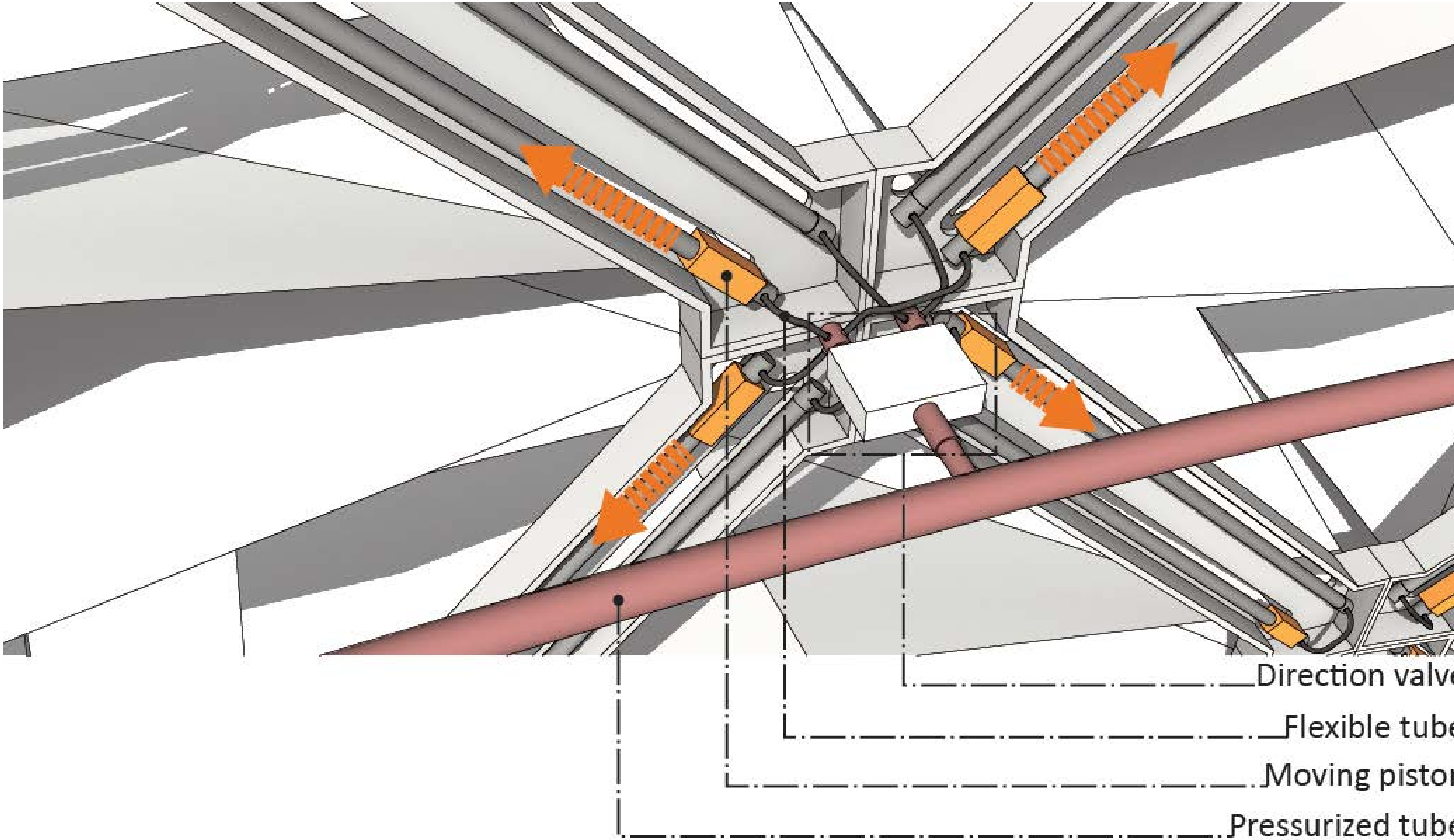
Origami Foldable Fins + Pneumatic Drive

Combination to Building System



Origami Foldable Fins + Pneumatic Drive

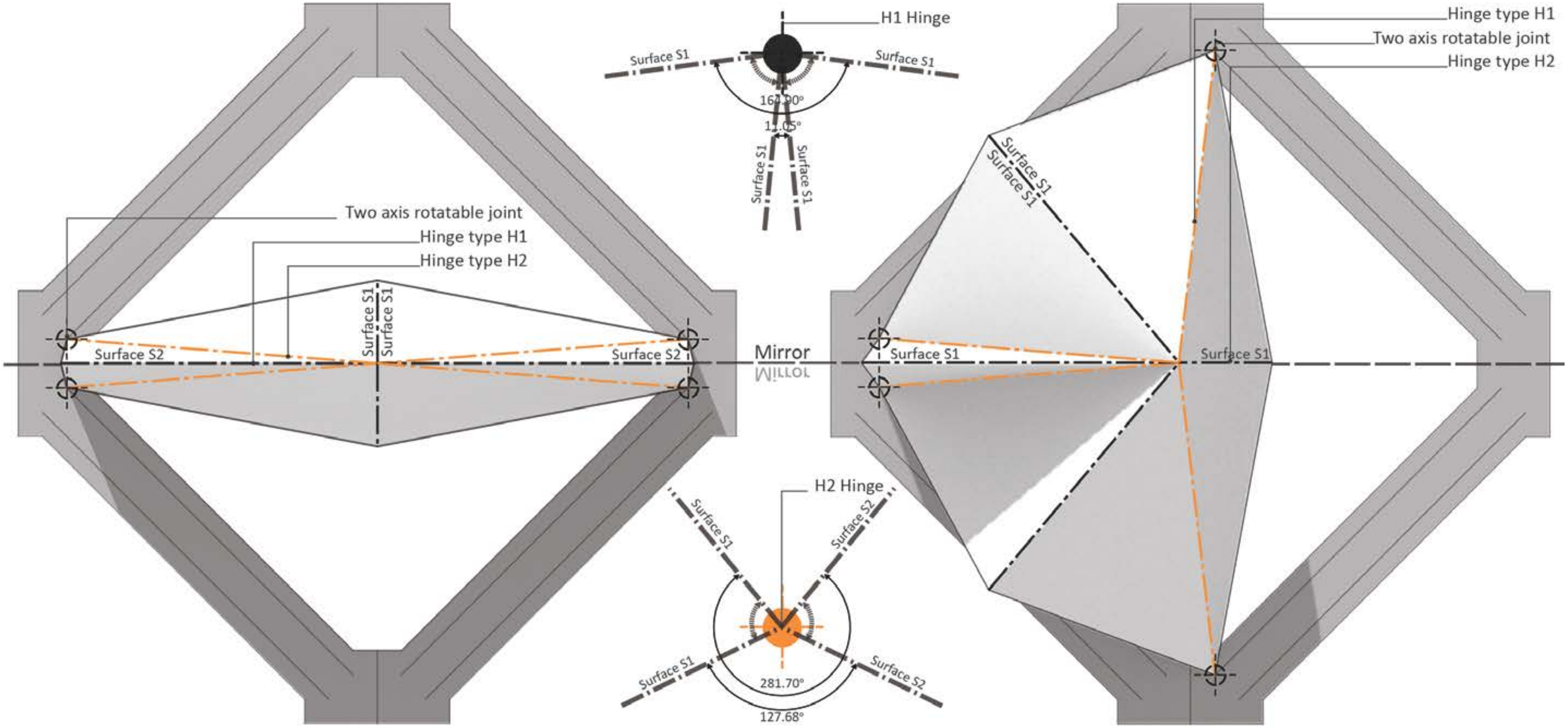
Combination to Building System



Details and Assembling

Origami Foldable Fins + Pneumatic Drive

Geometry Study : Define the critical angles

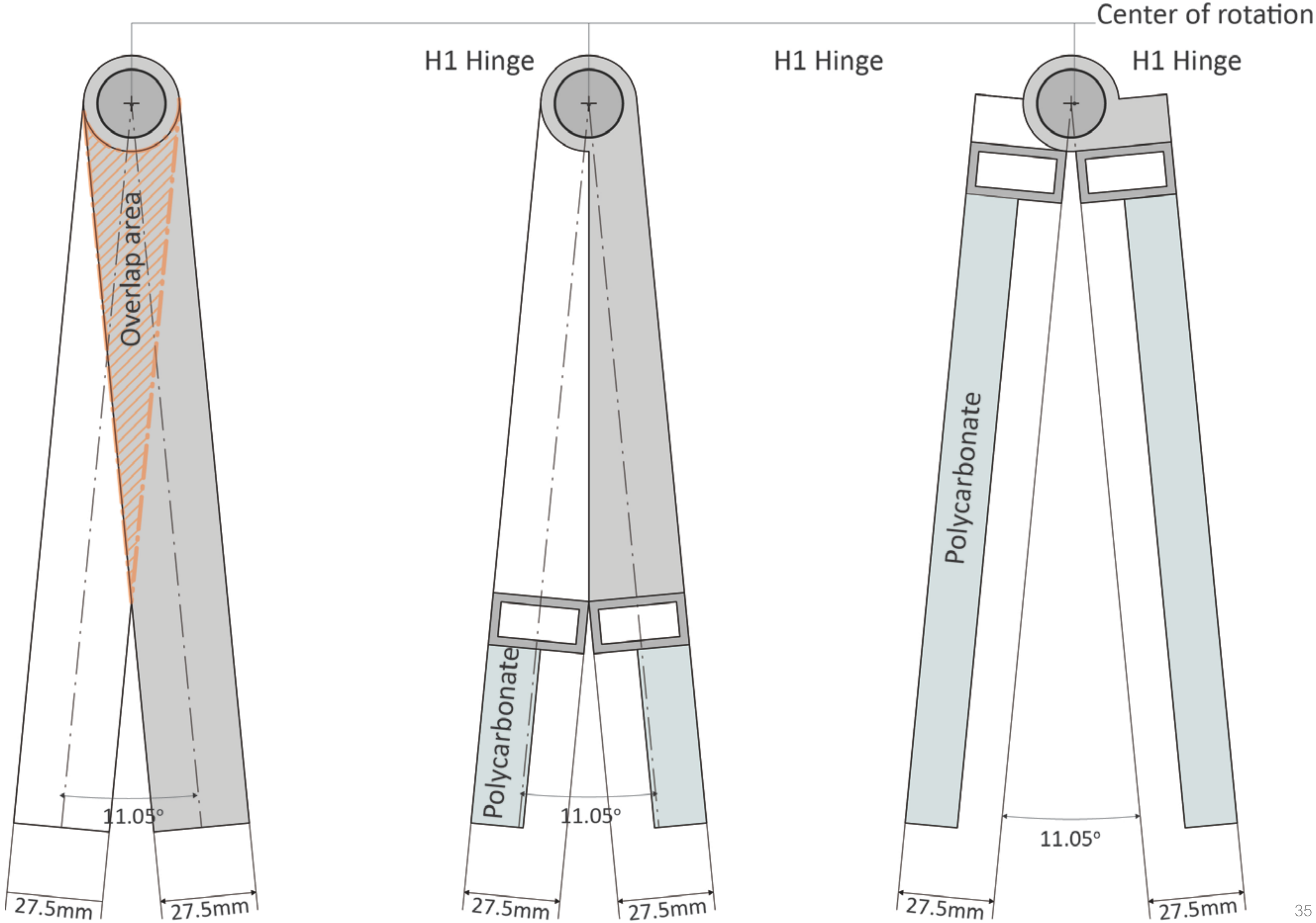


Basic Position

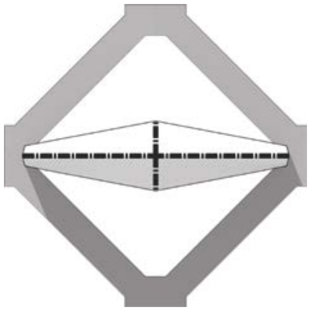
Adapting Position

Origami Foldable Fins + Pneumatic Drive

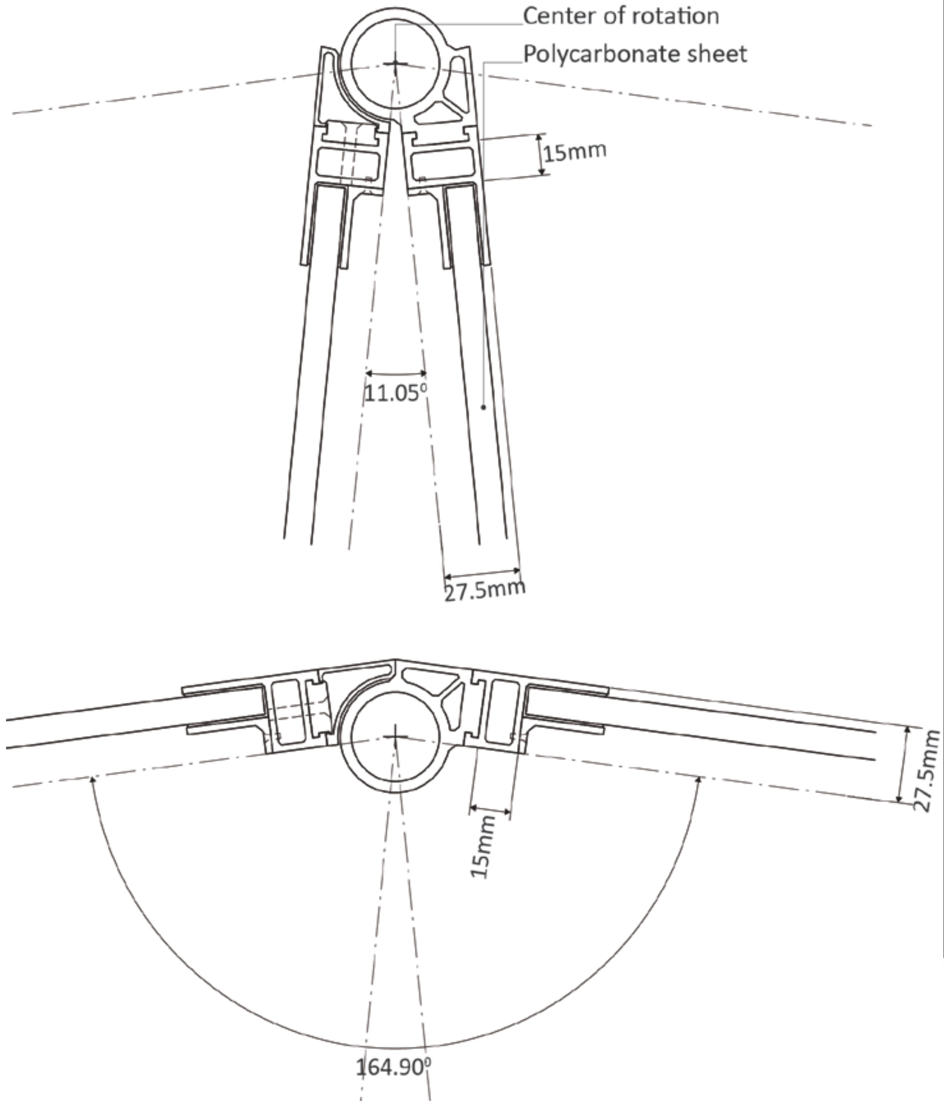
Geometry Study : Critical angles solutions

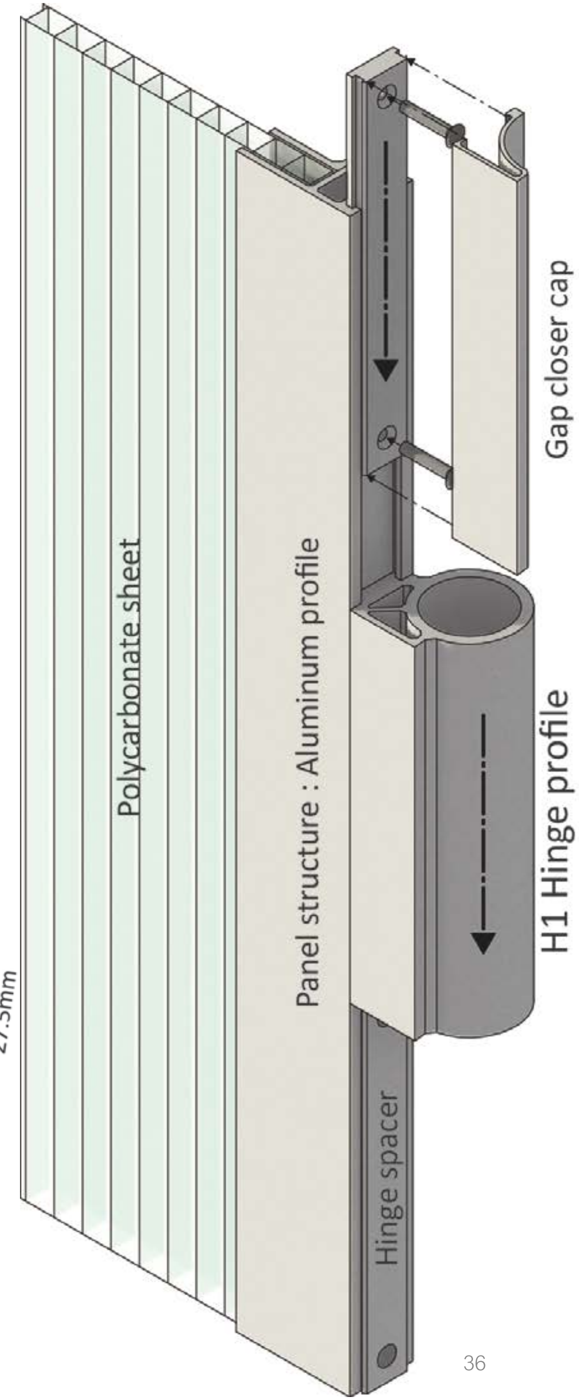


Origami Foldable Fins + Pneumatic Drive

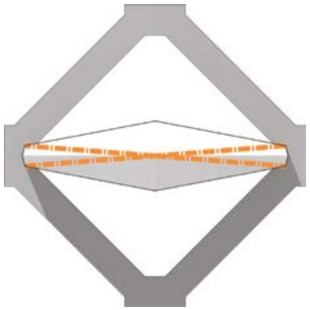


Detailing:
H1 hinge detail
and assembling

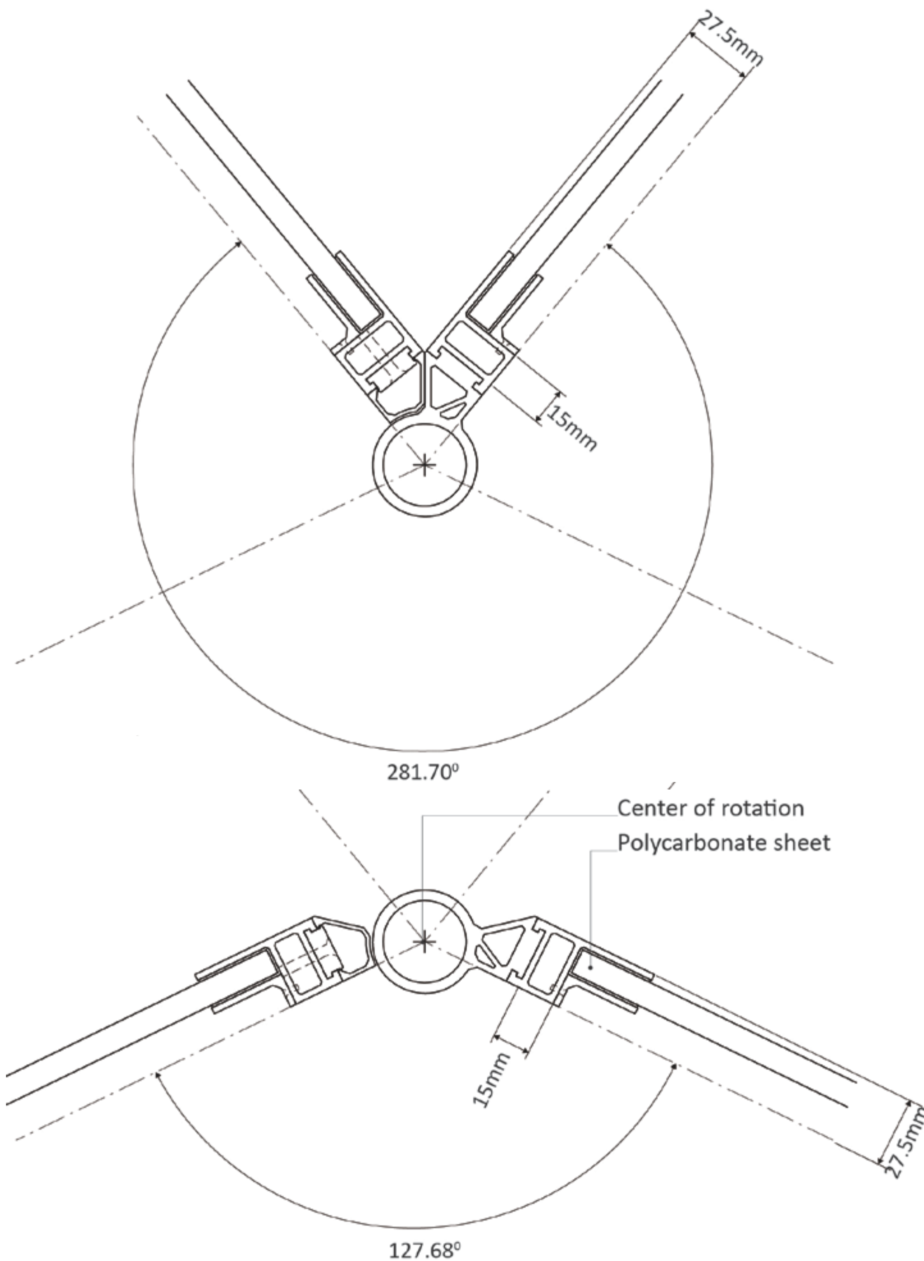


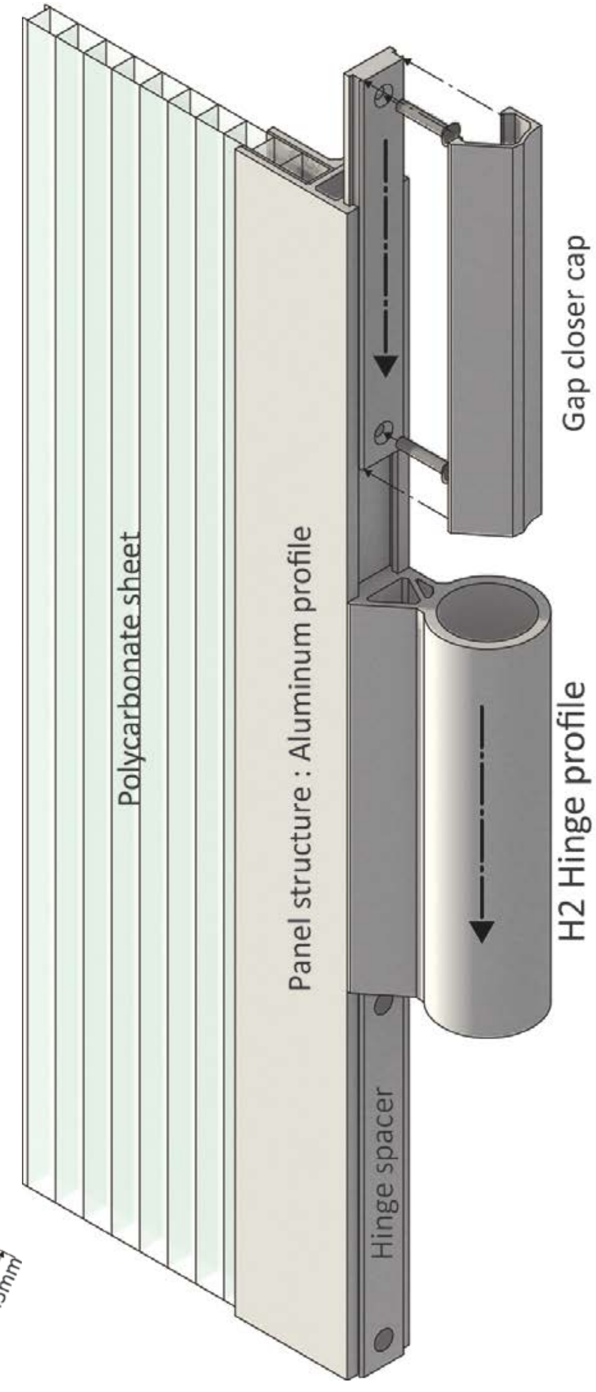


Origami Foldable Fins + Pneumatic Drive

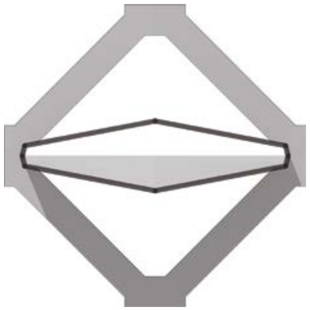


Detailing:
H2 hinge detail
and assembling

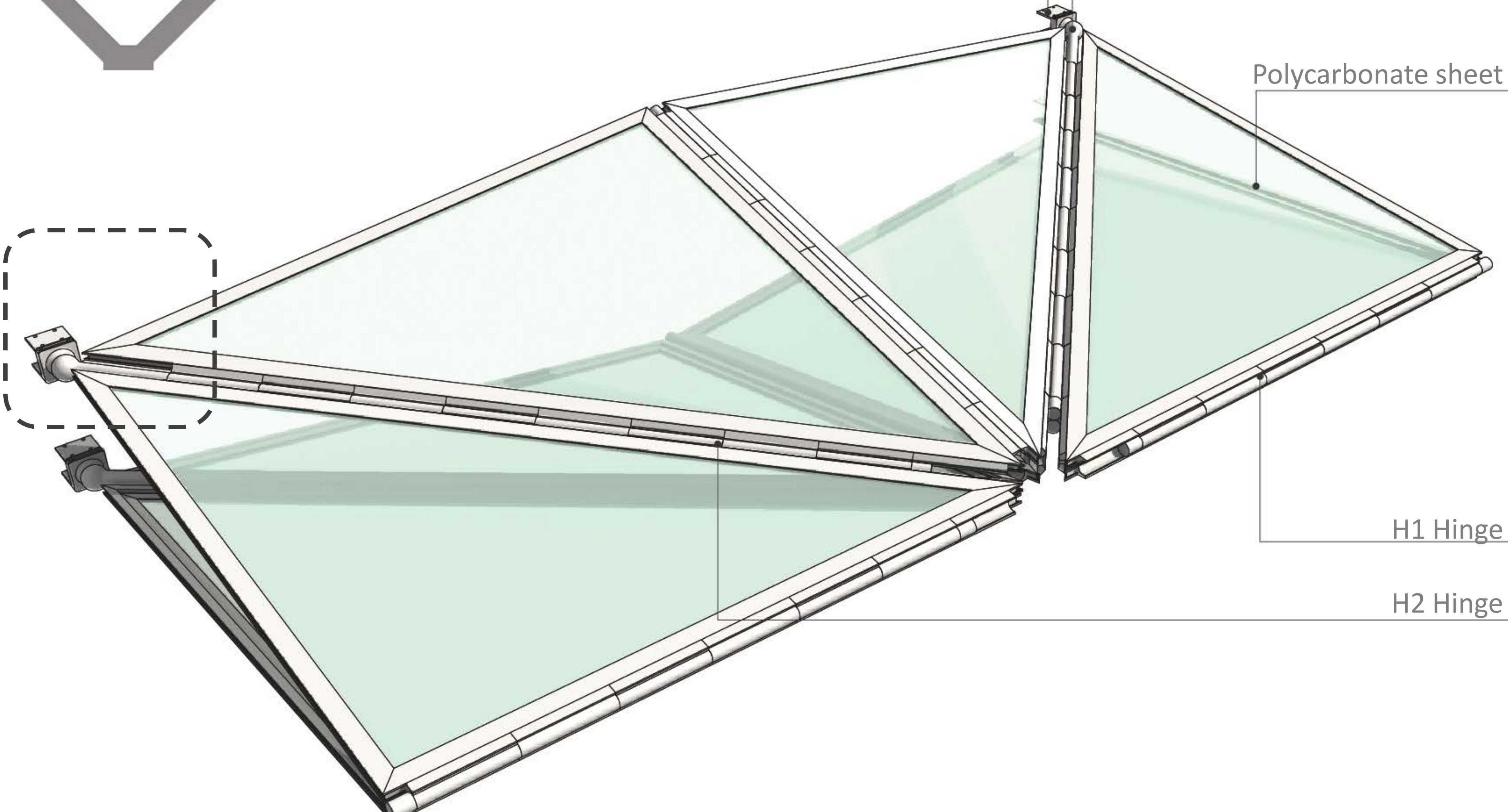




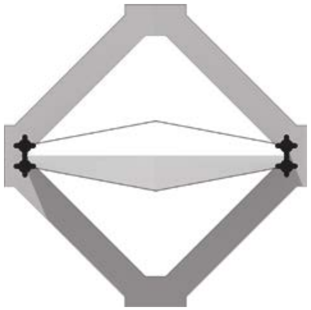
Origami Foldable Fins + Pneumatic Drive



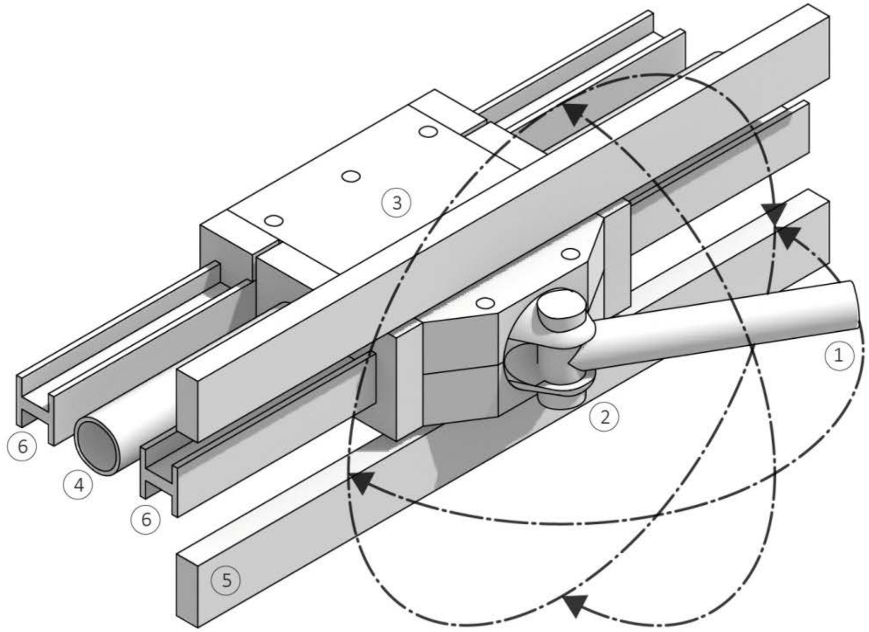
Detailing:
Completed fin

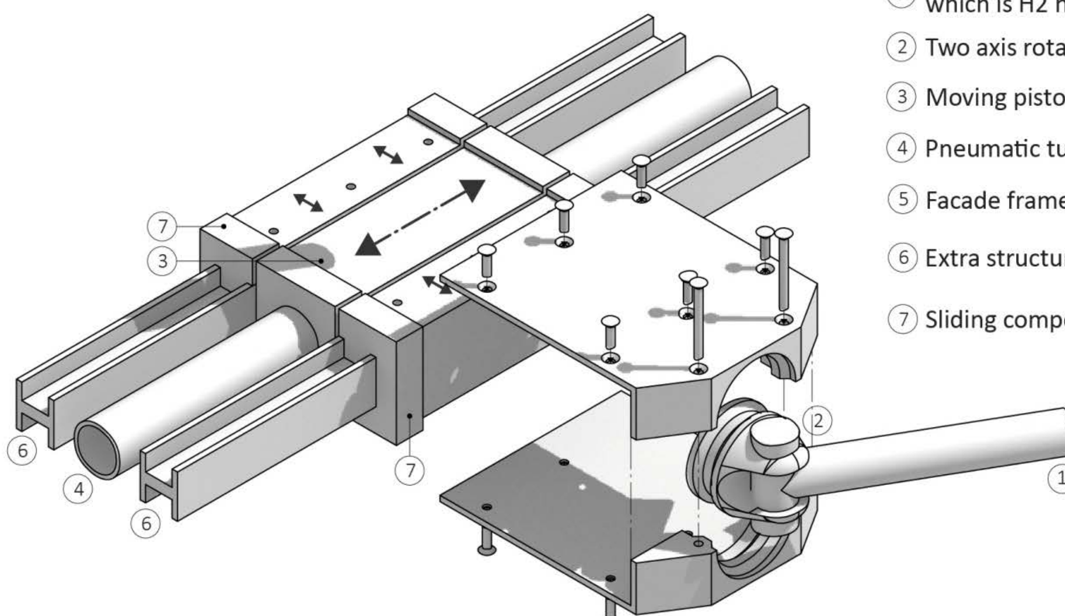


Origami Foldable Fins + Pneumatic Drive



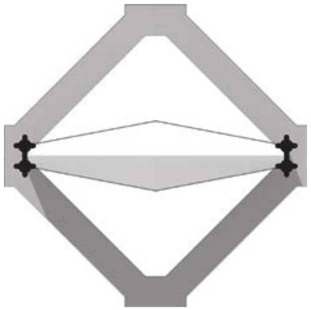
Detailing:
Two axis
rotatable joint
schematic 1



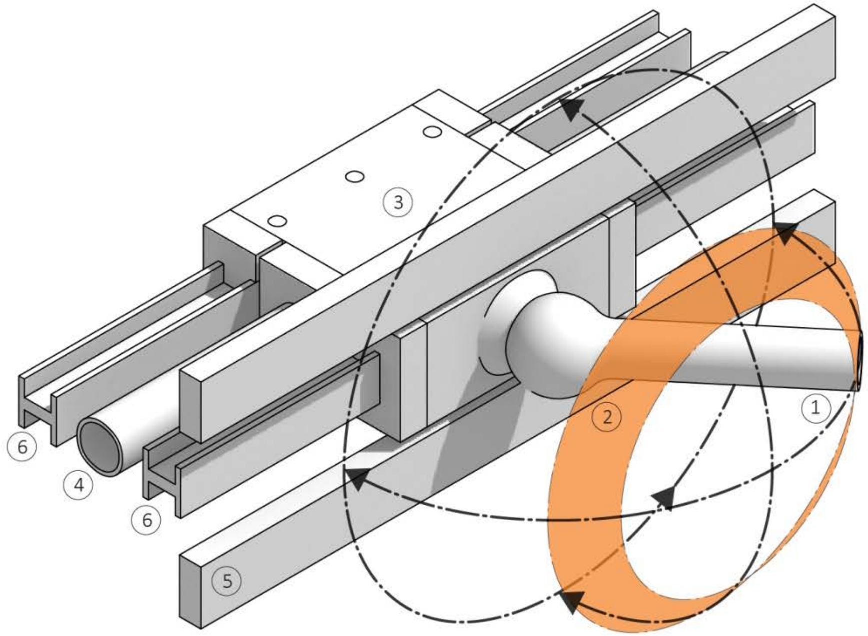


1. Circular beam which is H2 hinge
2. Two axis rotation joint
3. Moving piston
4. Pneumatic tube
5. Facade frame
6. Extra structure beam
7. Sliding component

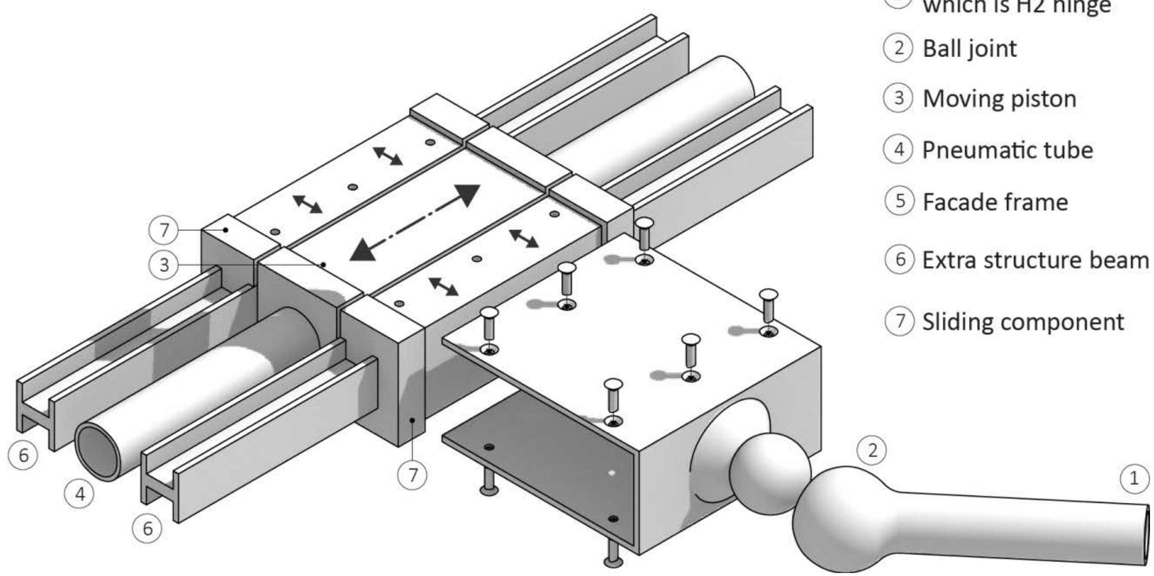
Origami Foldable Fins + Pneumatic Drive



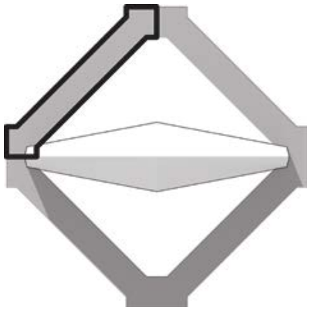
Detailing:
Two axis
rotatable joint
schematic 1



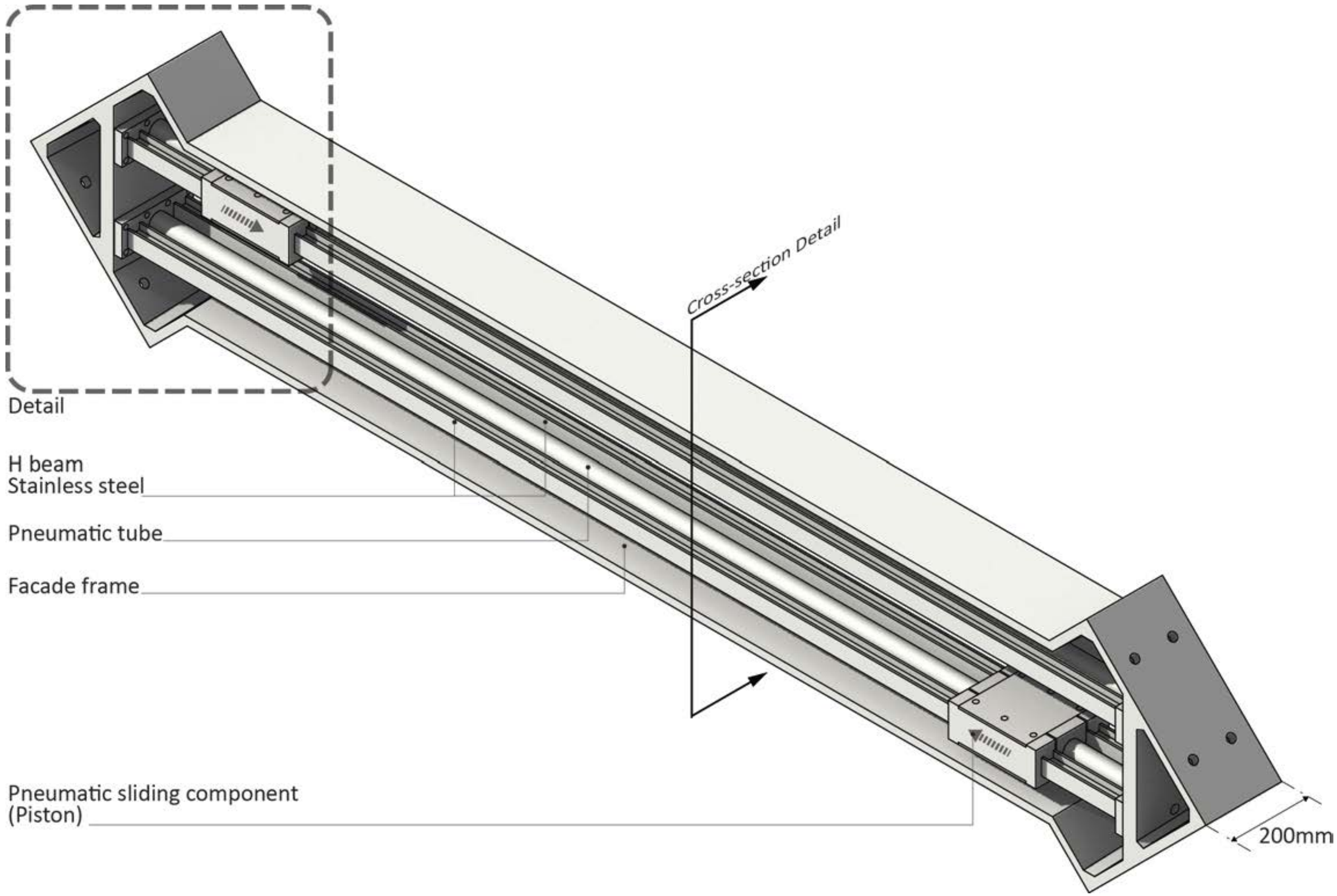
1. Circular beam which is H2 hinge
2. Ball joint
3. Moving piston
4. Pneumatic tube
5. Facade frame
6. Extra structure beam
7. Sliding component



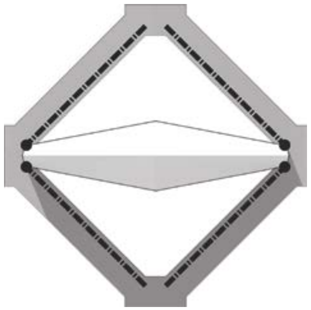
Origami Foldable Fins + Pneumatic Drive



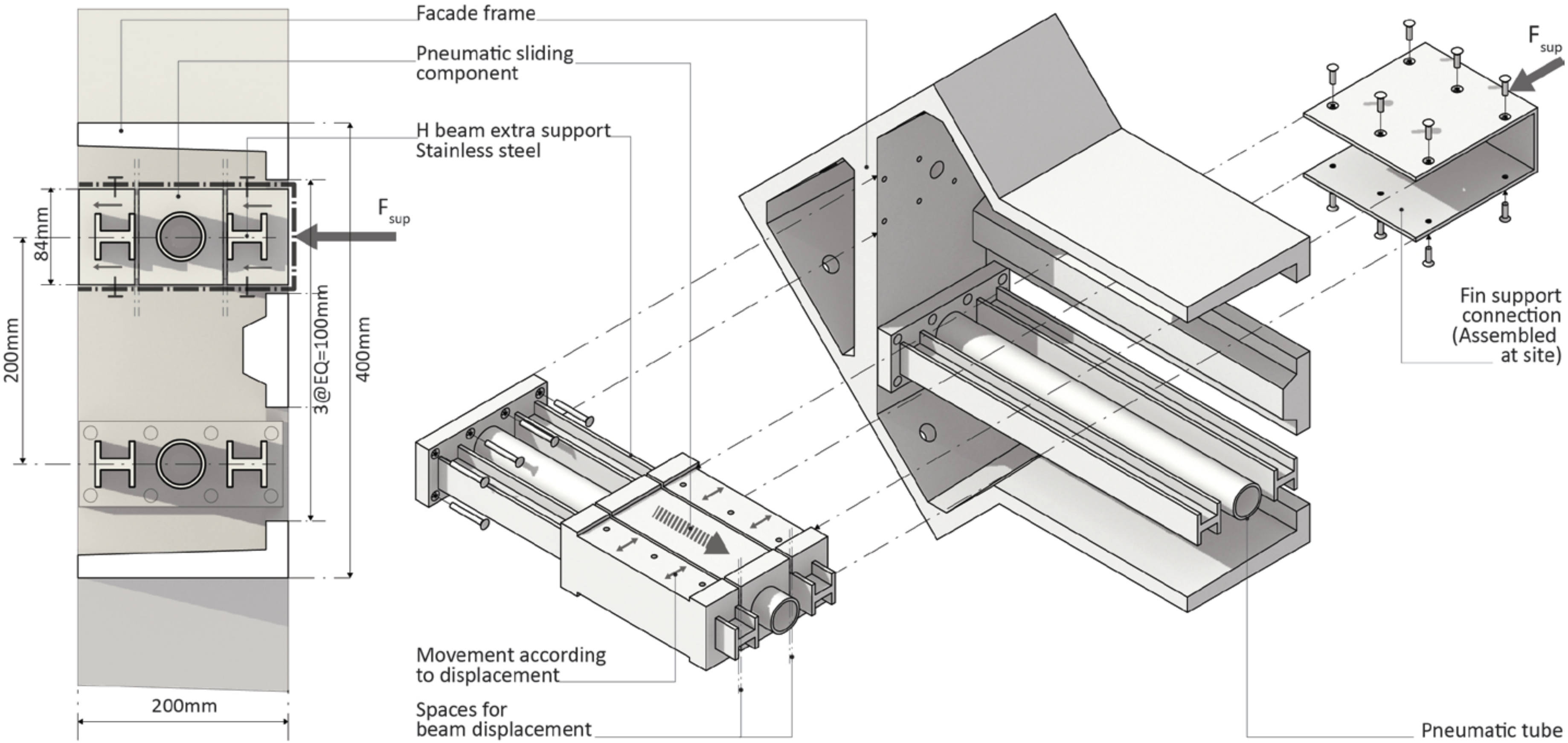
Detailing:
Façade frame
and pneumatic
tube



Origami Foldable Fins + Pneumatic Drive

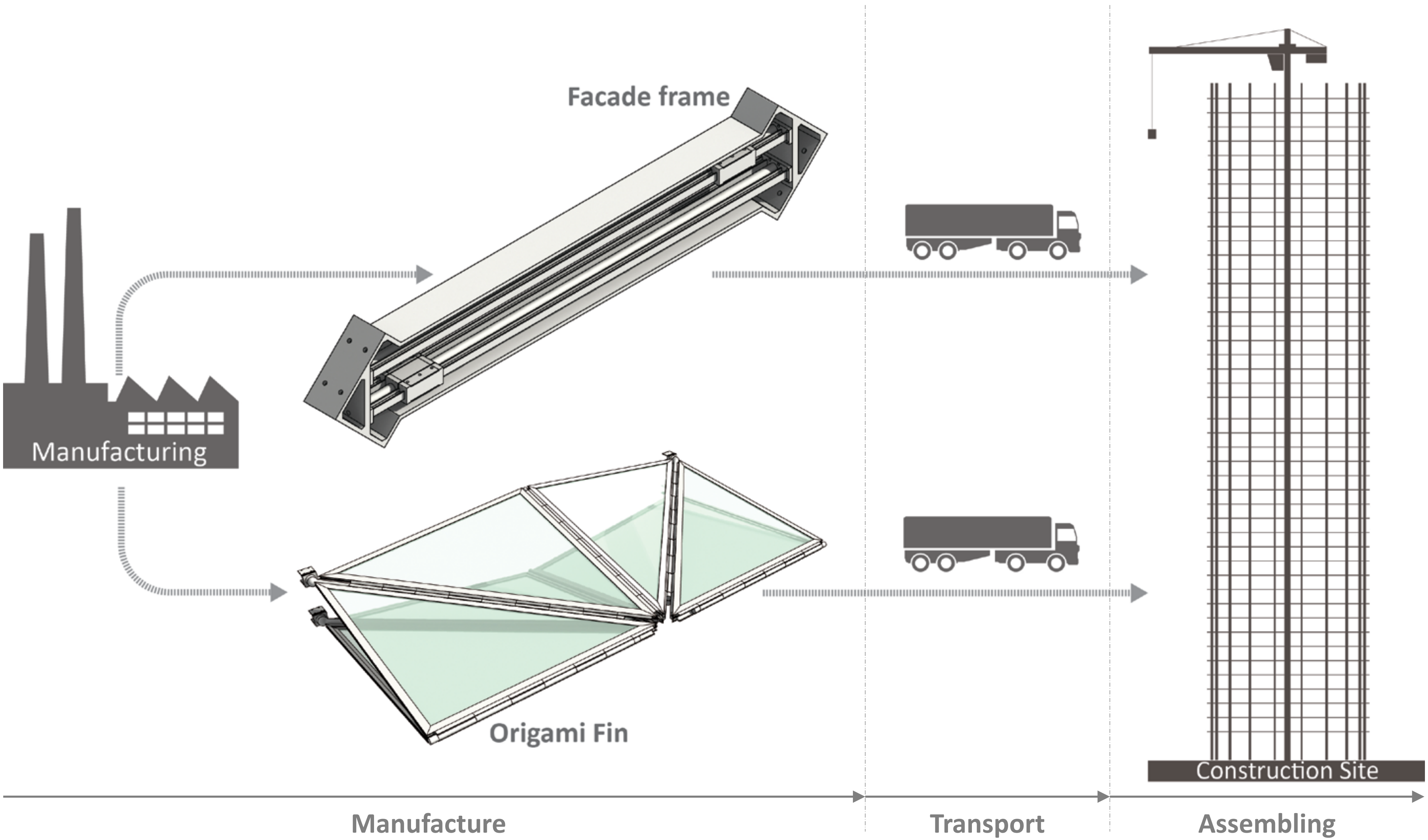


Detailing:
Pneumatic tube
extra support
beams

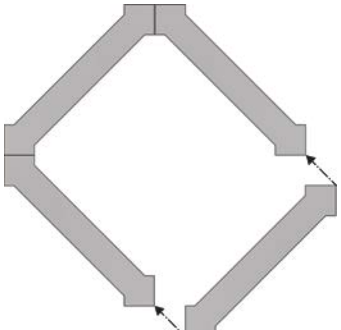


Origami Foldable Fins + Pneumatic Drive

Construction: Manufacture and transportation



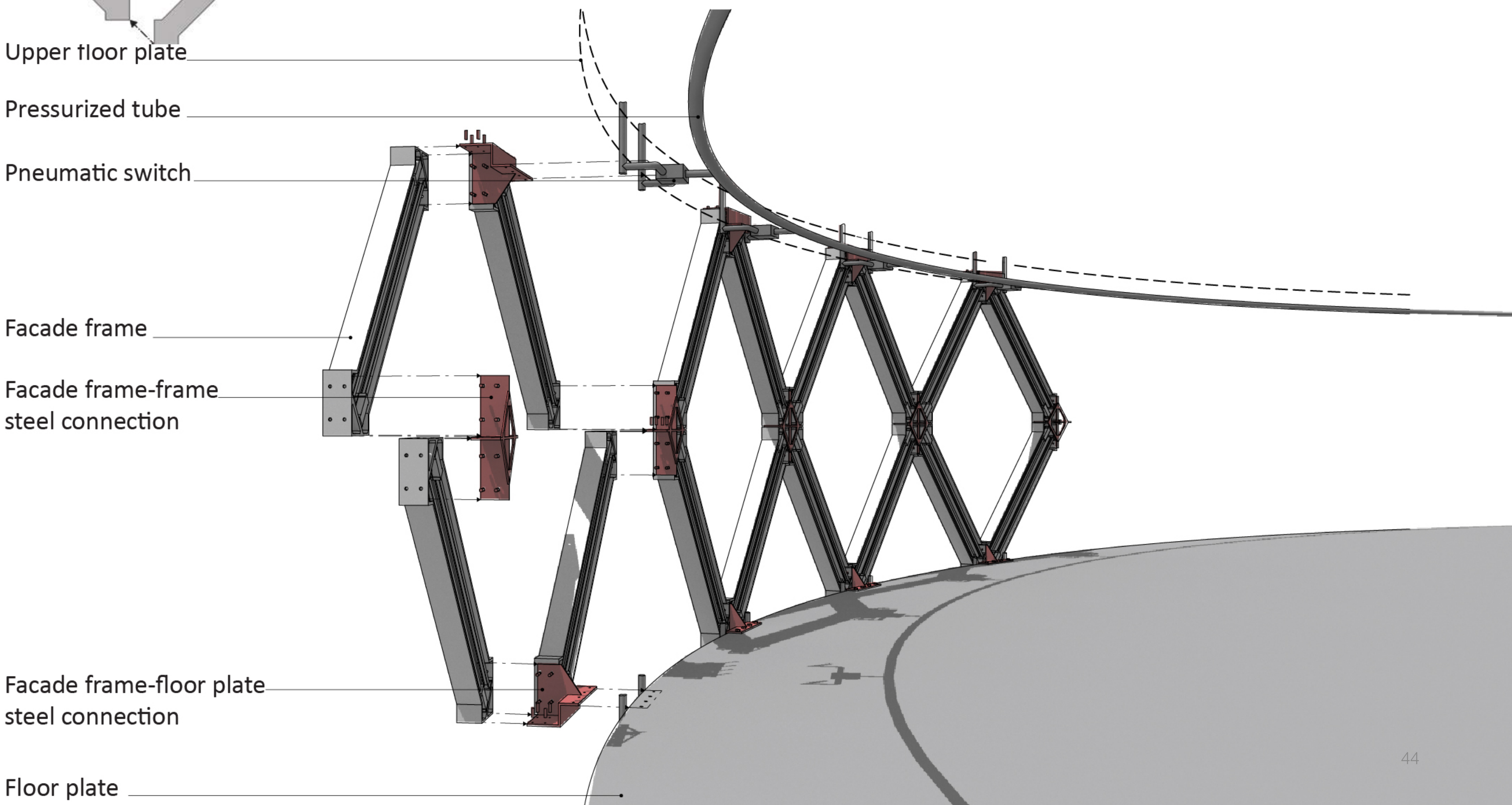
Origami Foldable Fins + Pneumatic Drive



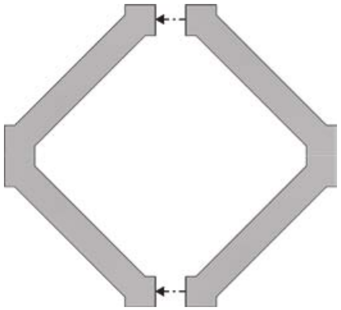
Construction:

Façade frame - floor plate assembling

Option 1



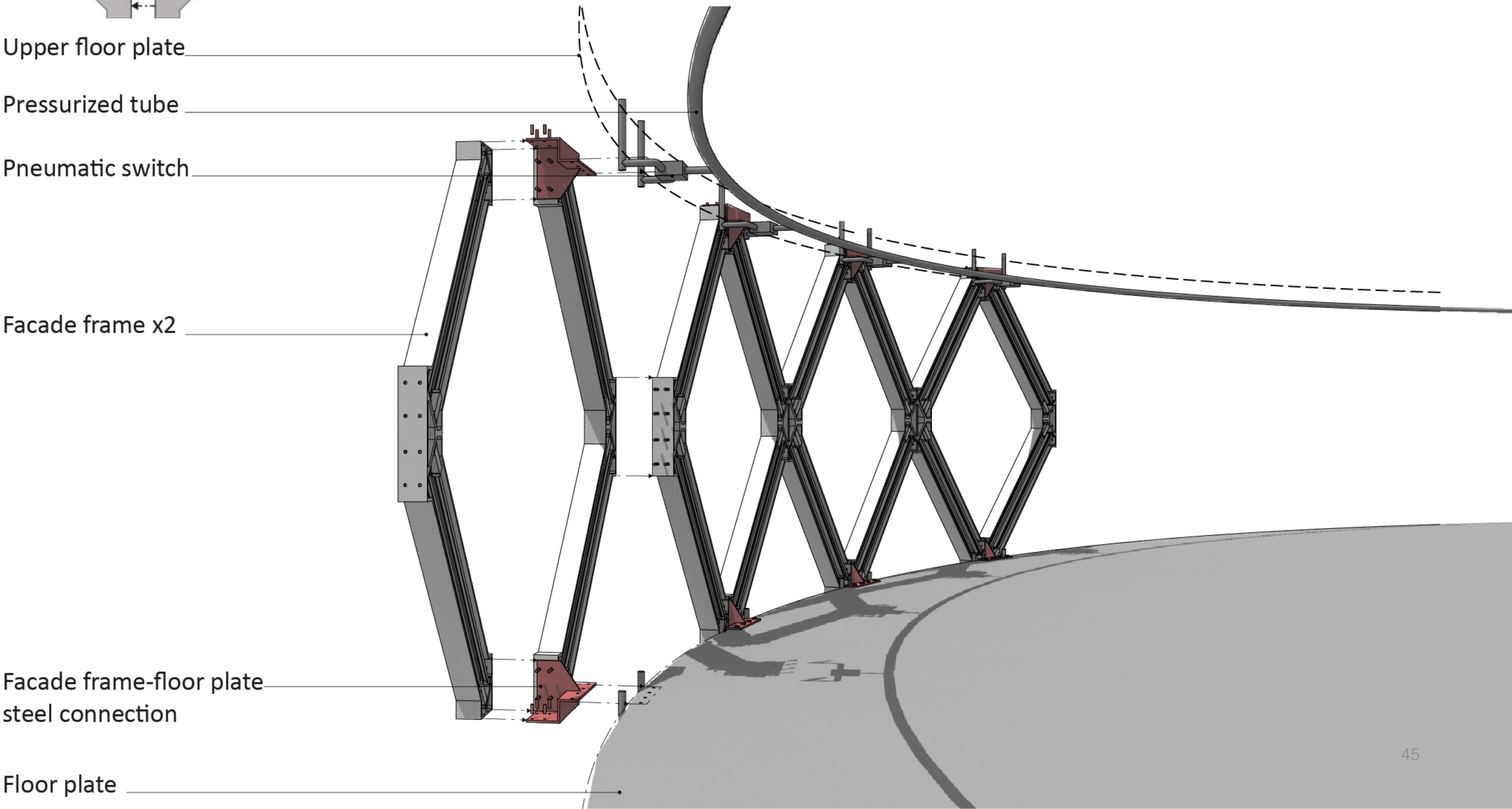
Origami Foldable Fins + Pneumatic Drive



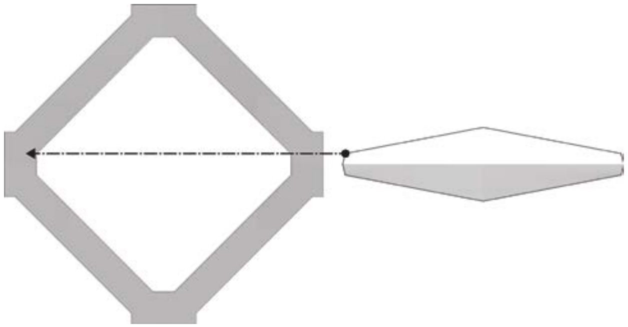
Construction:

Façade frame - floor plate assembling

Option 2

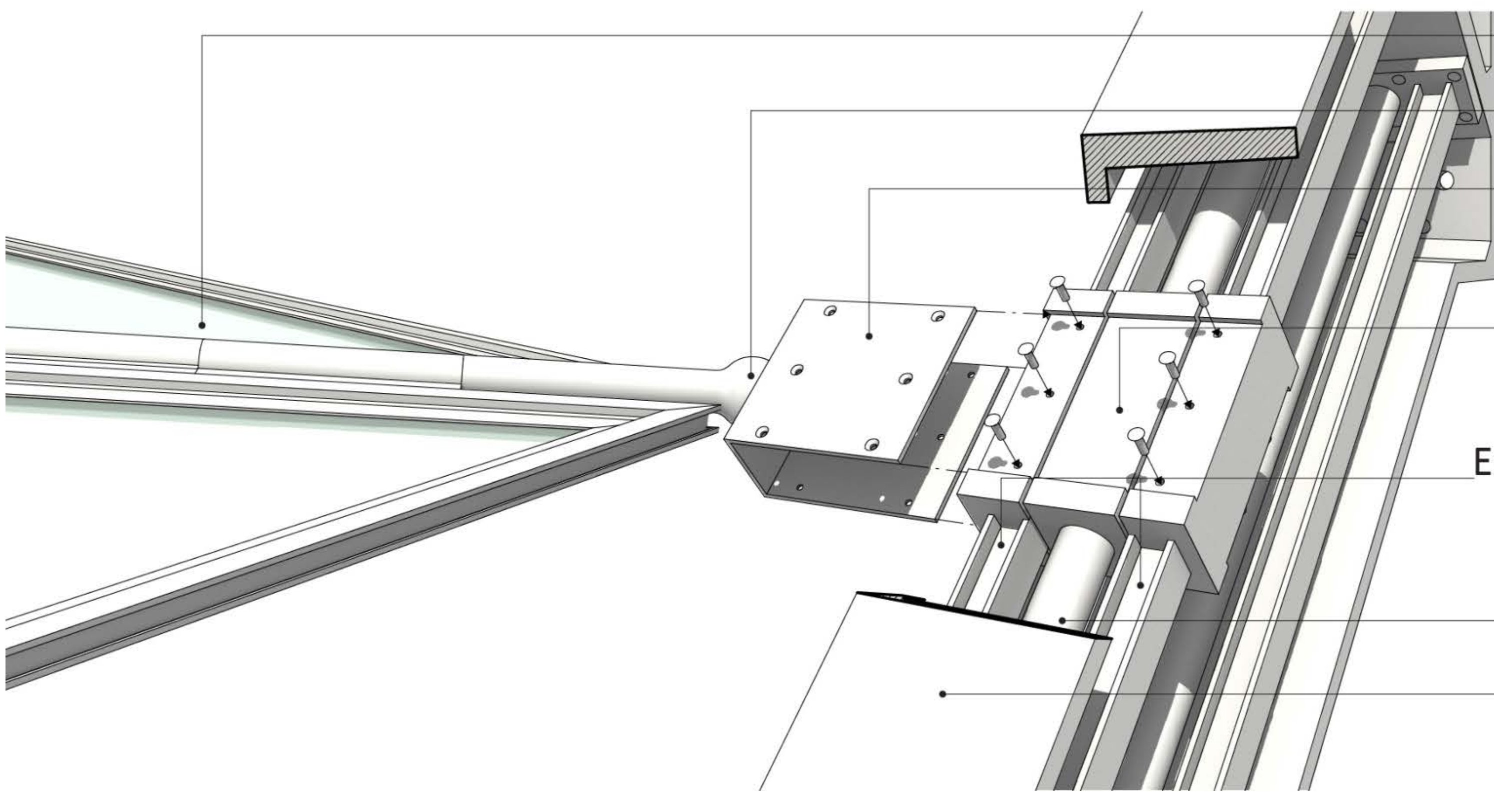


Origami Foldable Fins + Pneumatic Drive



Detailing :

Fin assembling to façade frame

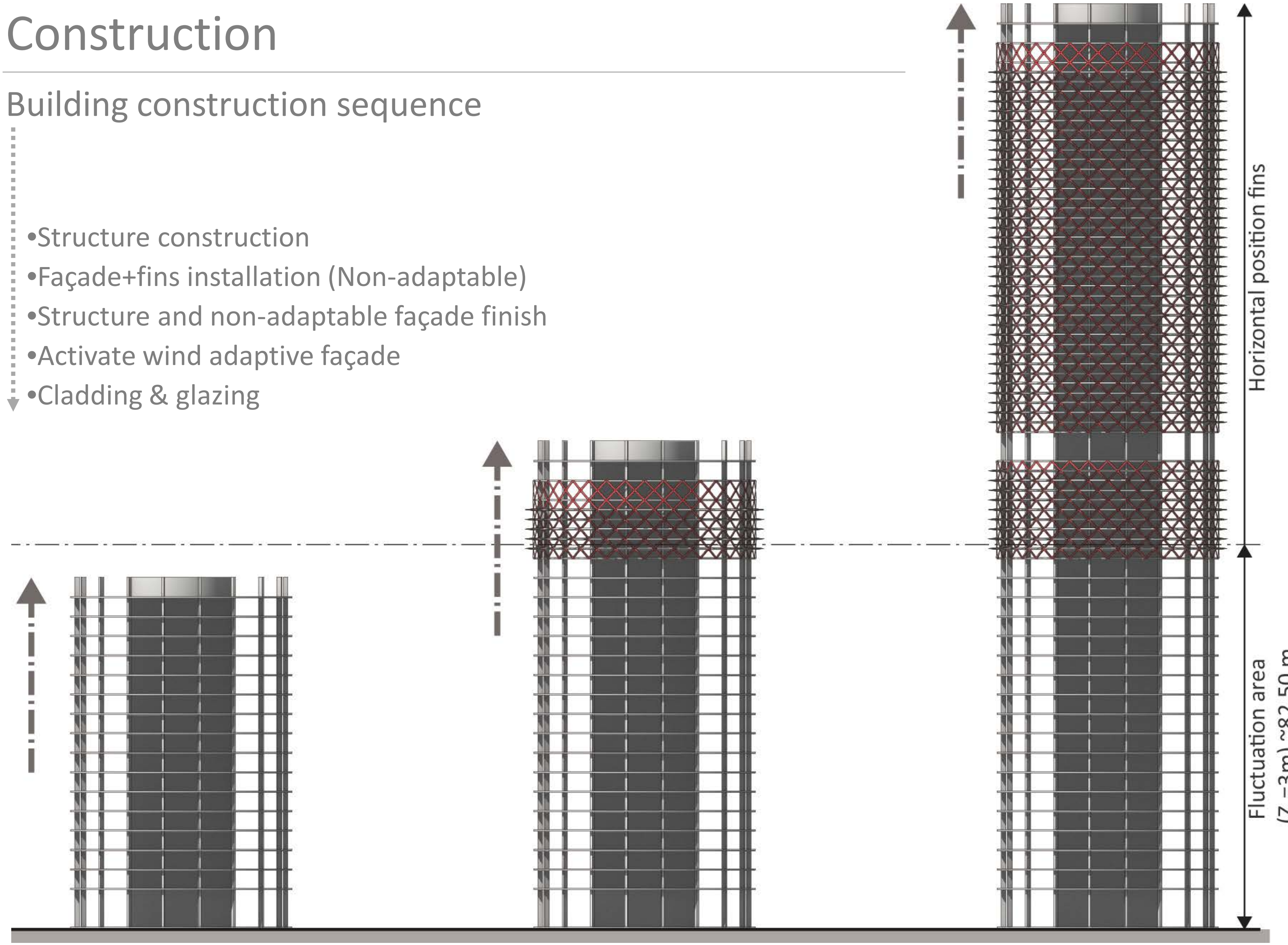


Construction and Maintenance

Construction

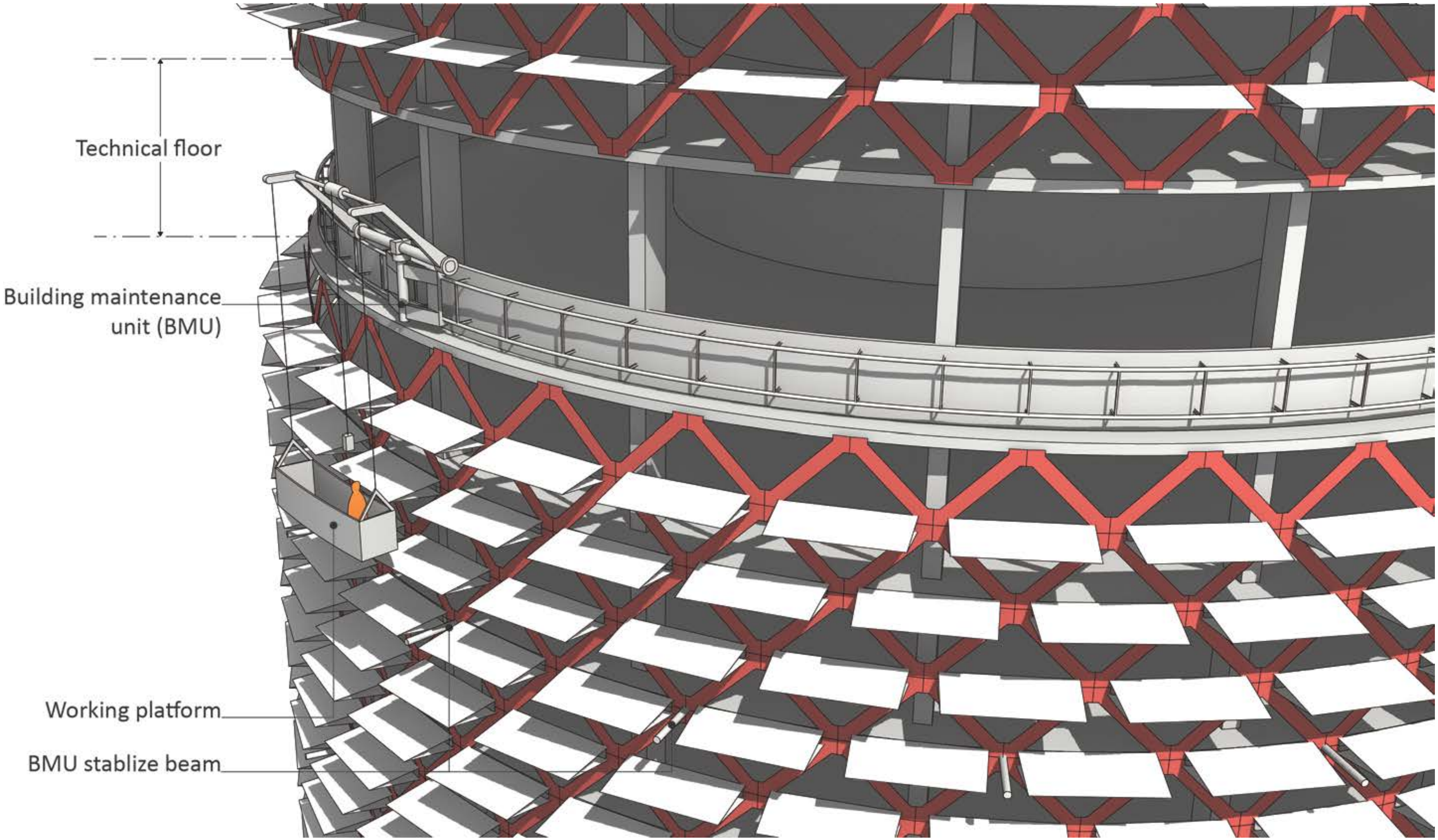
Building construction sequence

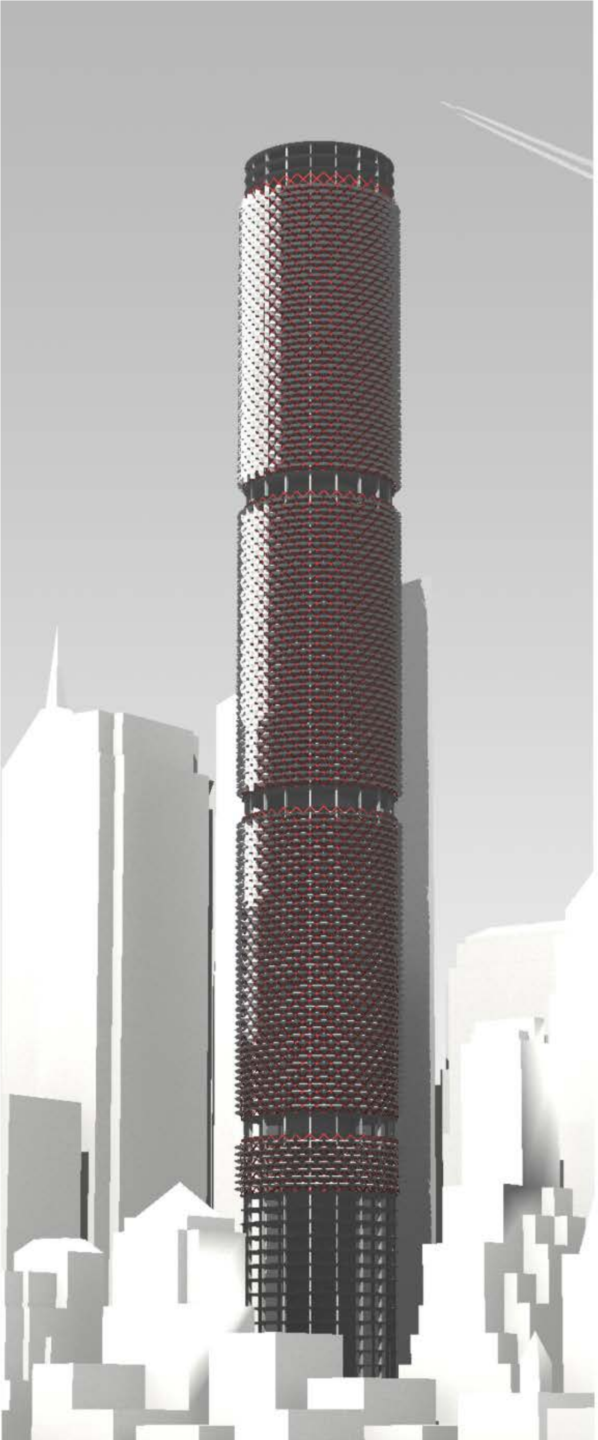
- •Structure construction
- •Façade+fins installation (Non-adaptable)
- •Structure and non-adaptable façade finish
- •Activate wind adaptive façade
- •Cladding & glazing

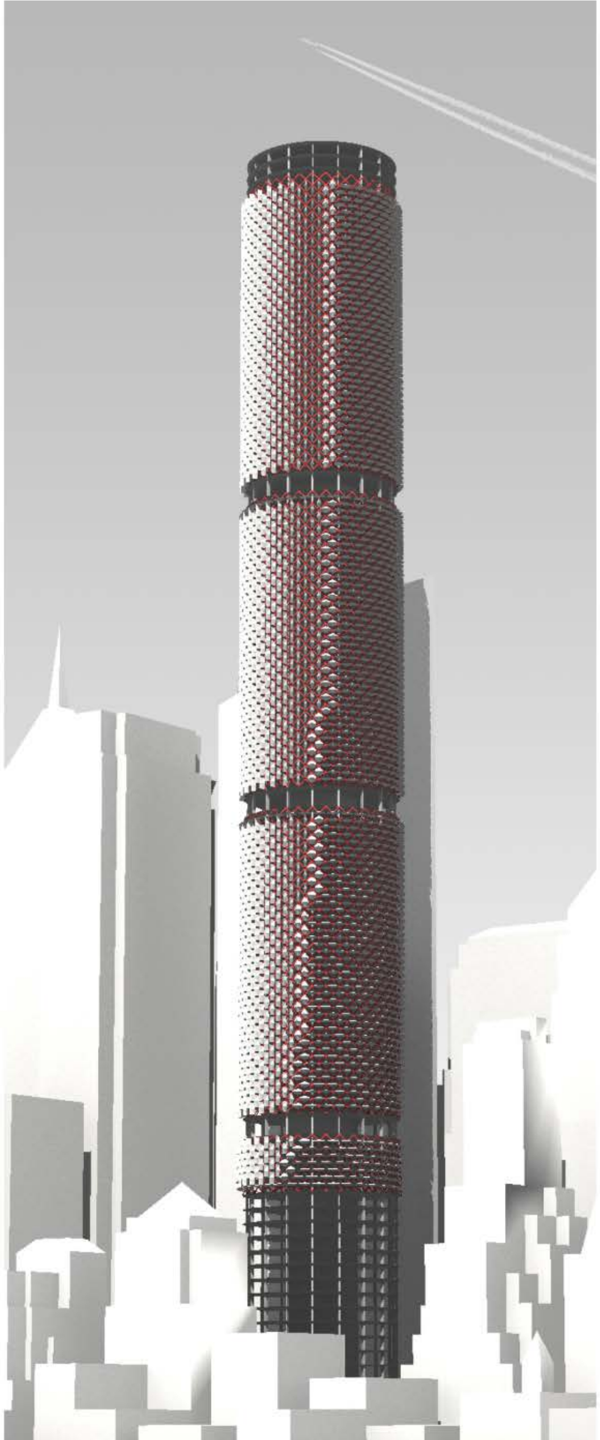


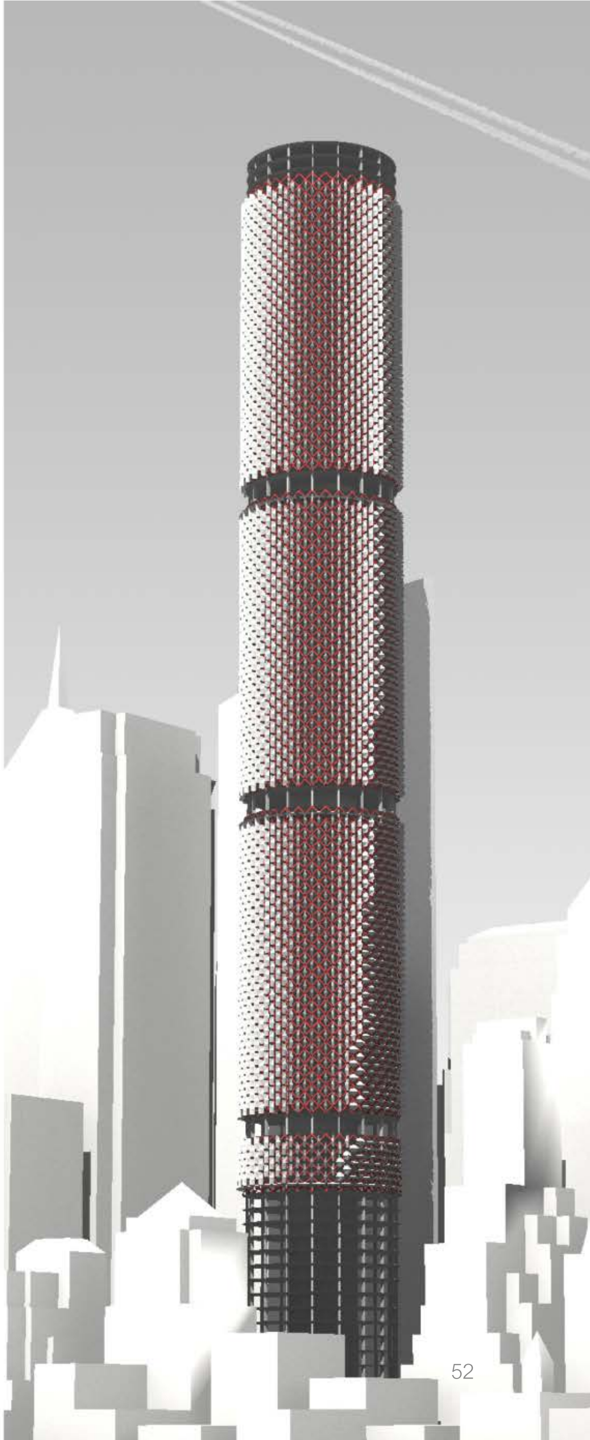
Maintenance and Safety

- Façade maintenance : BMU at every technical floor
- Safety in case of system fails : All façade change to horizontal position







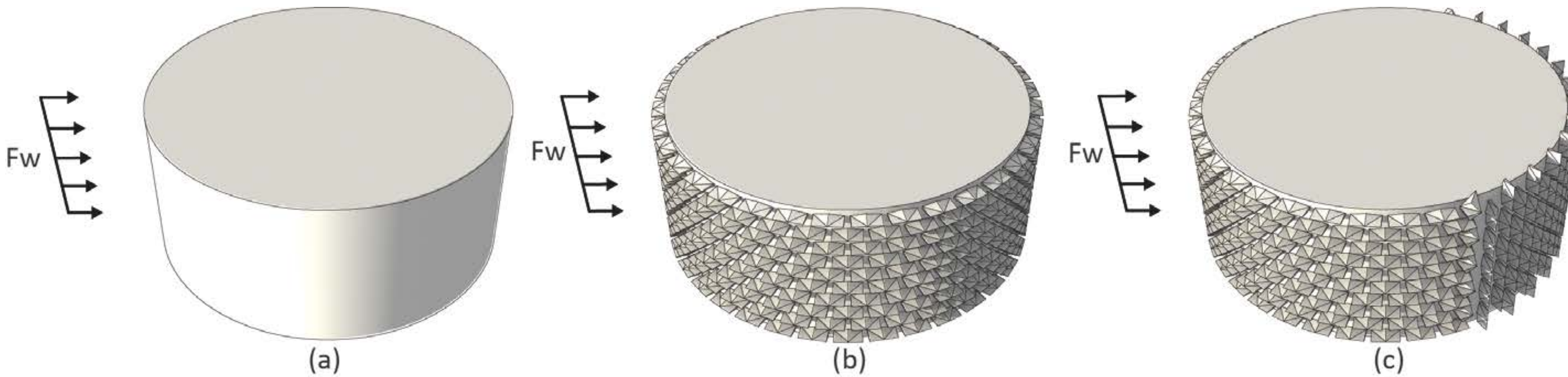


Conclusion

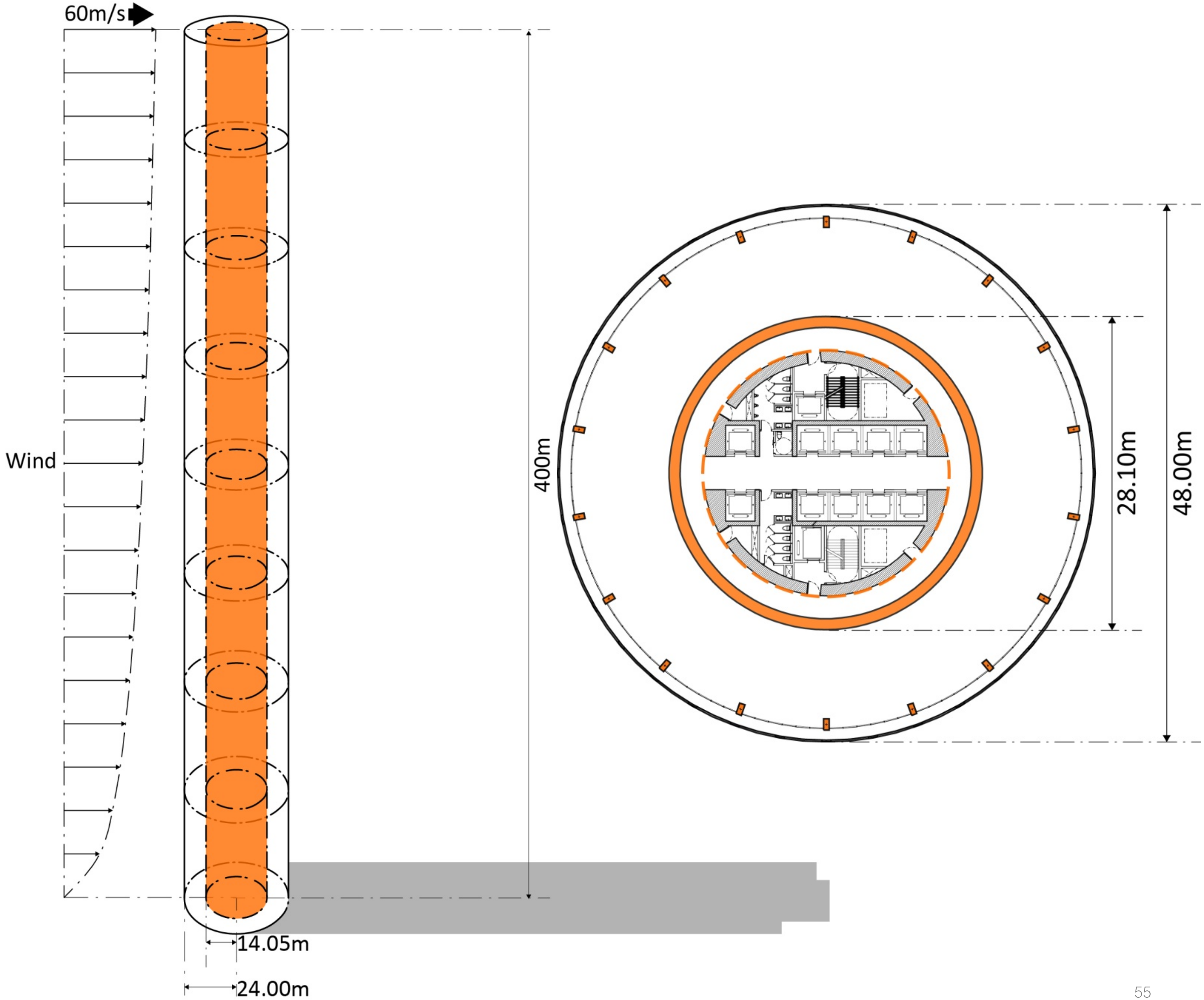
Drag Reduction

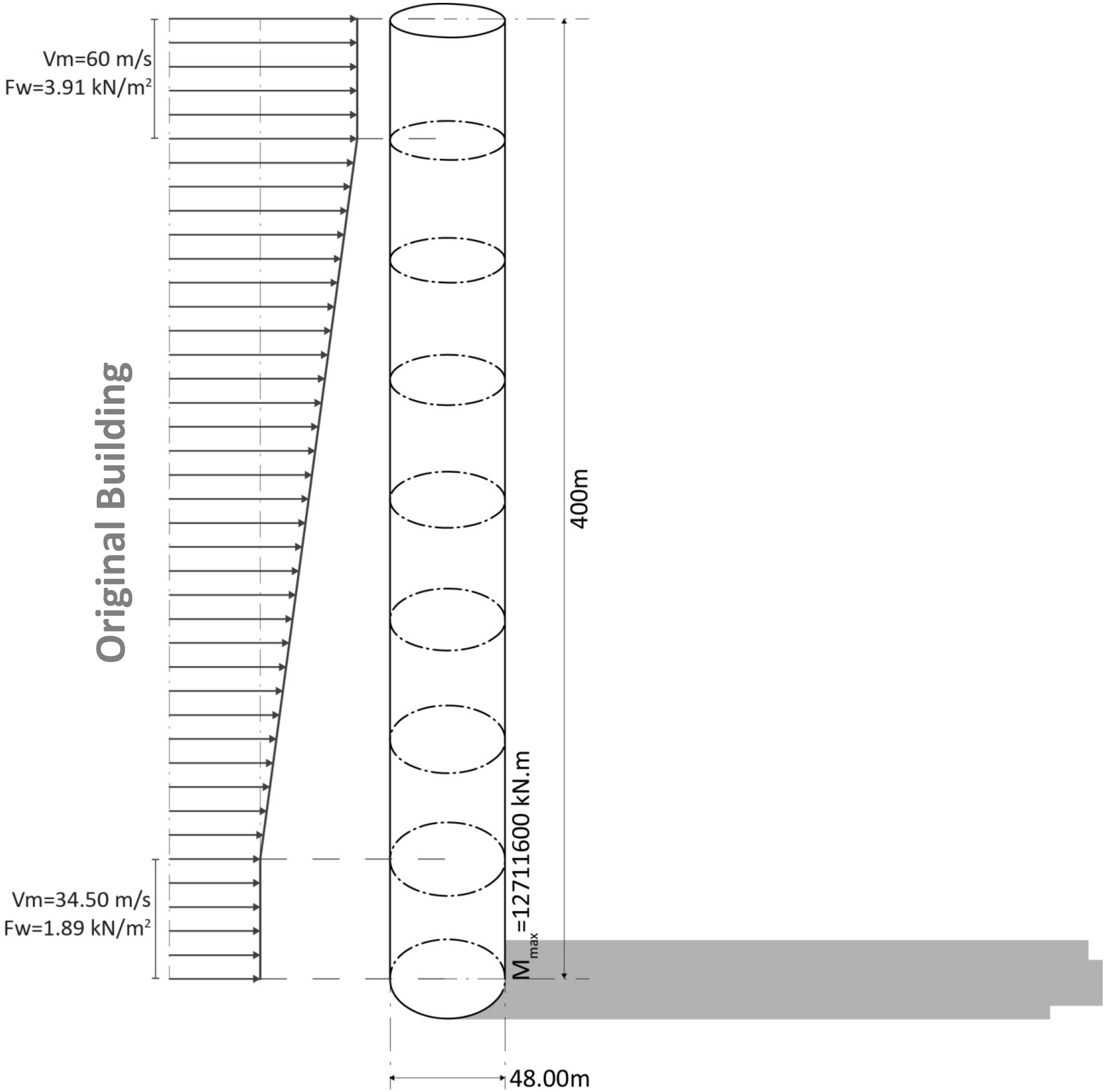
Experiment with final detail models

- Smooth surface building
- Building with only horizontal fins
- Building with horizontal and vertical (optimized) fins

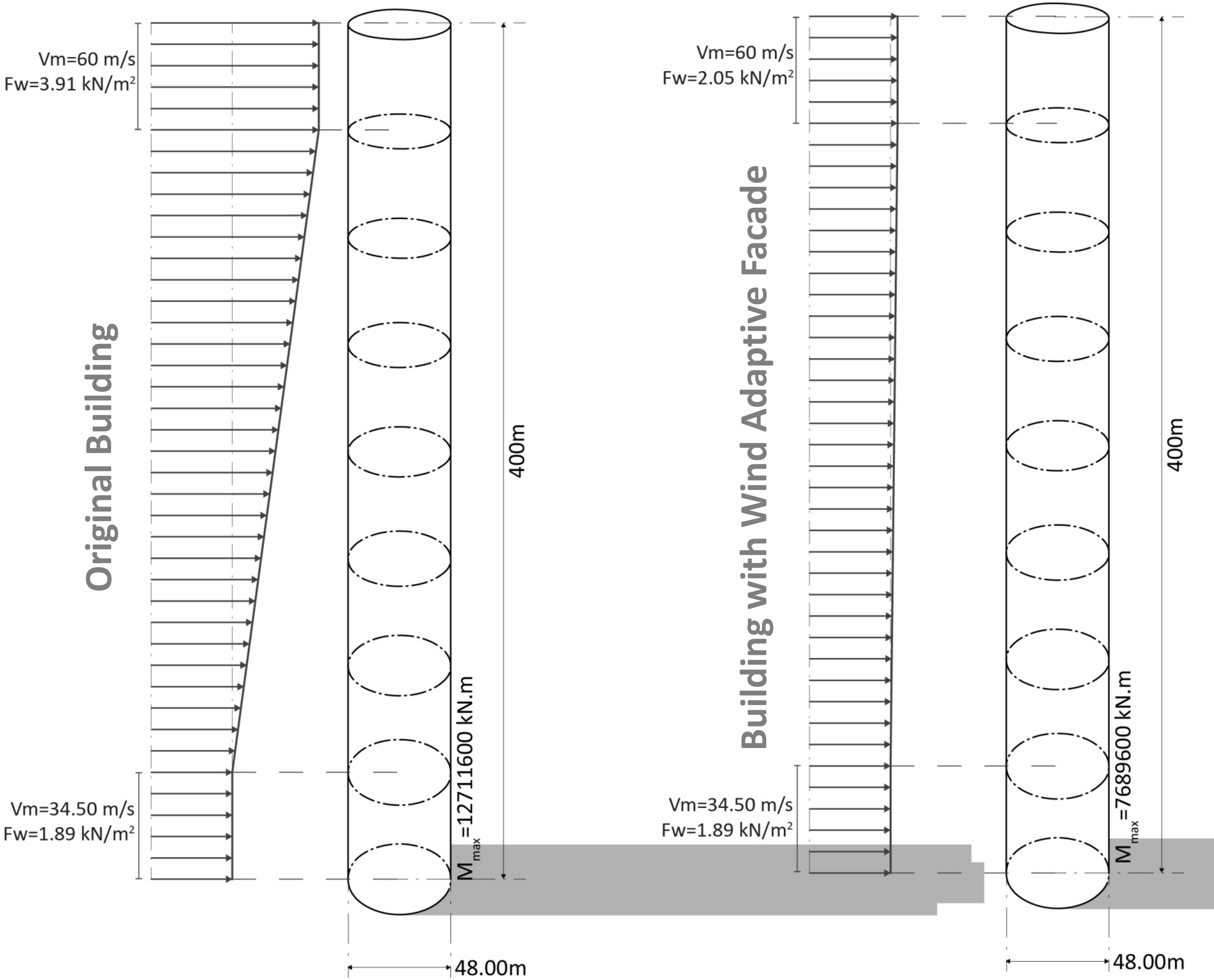


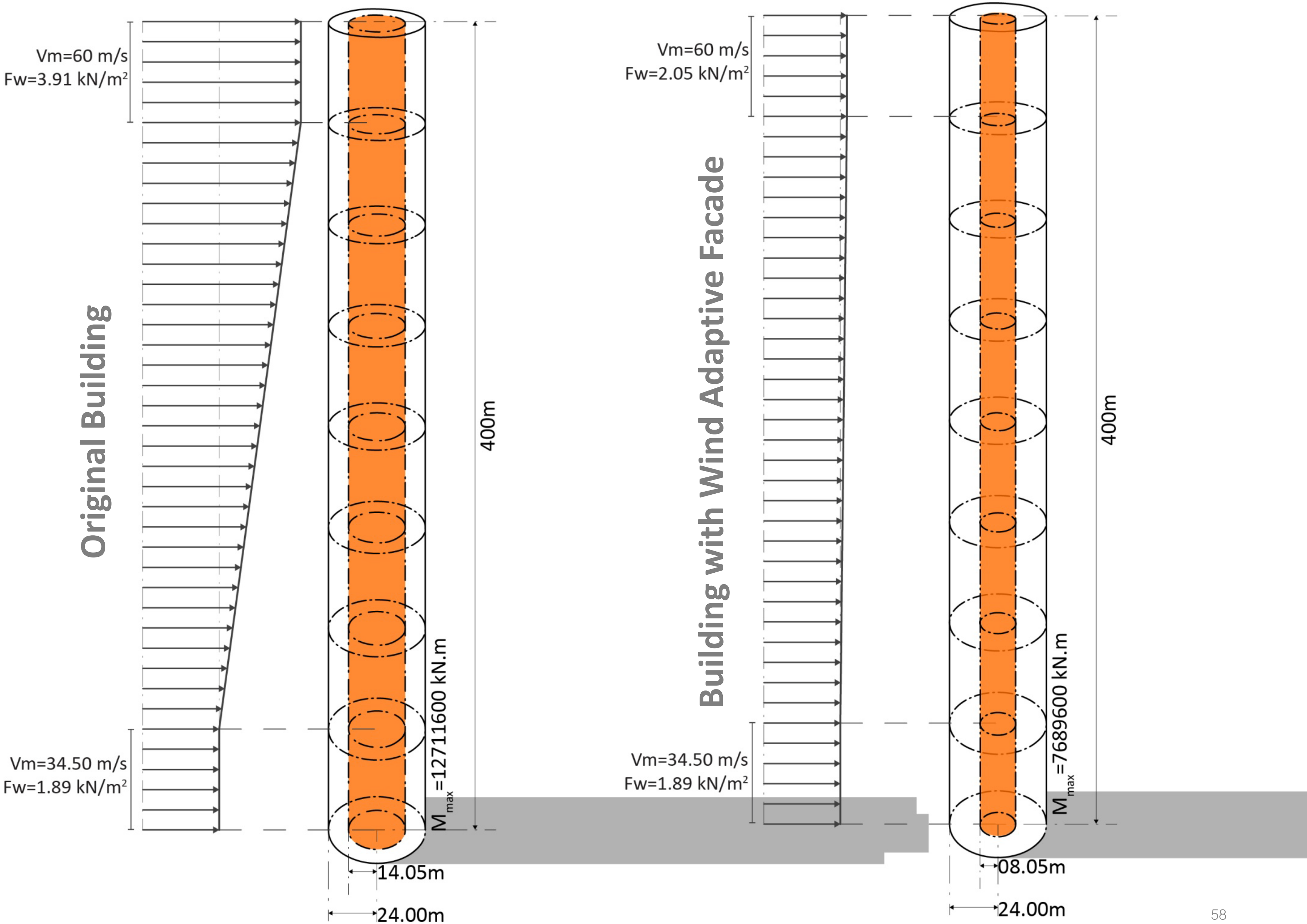
	Drag force (kN)	Drag force per area (kN/m^2)	Drag reduction (%)
Smooth model	3941.84	3.91	-
Horizontal fins model	2326.35	2.31	40.92
Horizontal + vertical fins model	2063.37	2.05	47.57

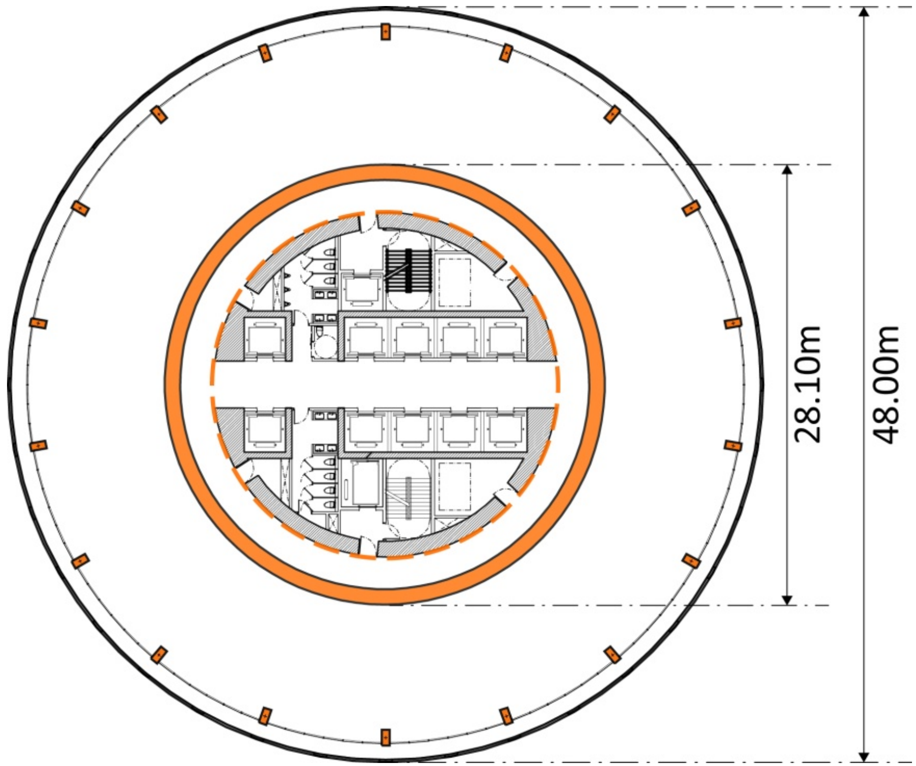

60m/s
Wind
400m
14.05m
24.00m
28.10m
48.00m



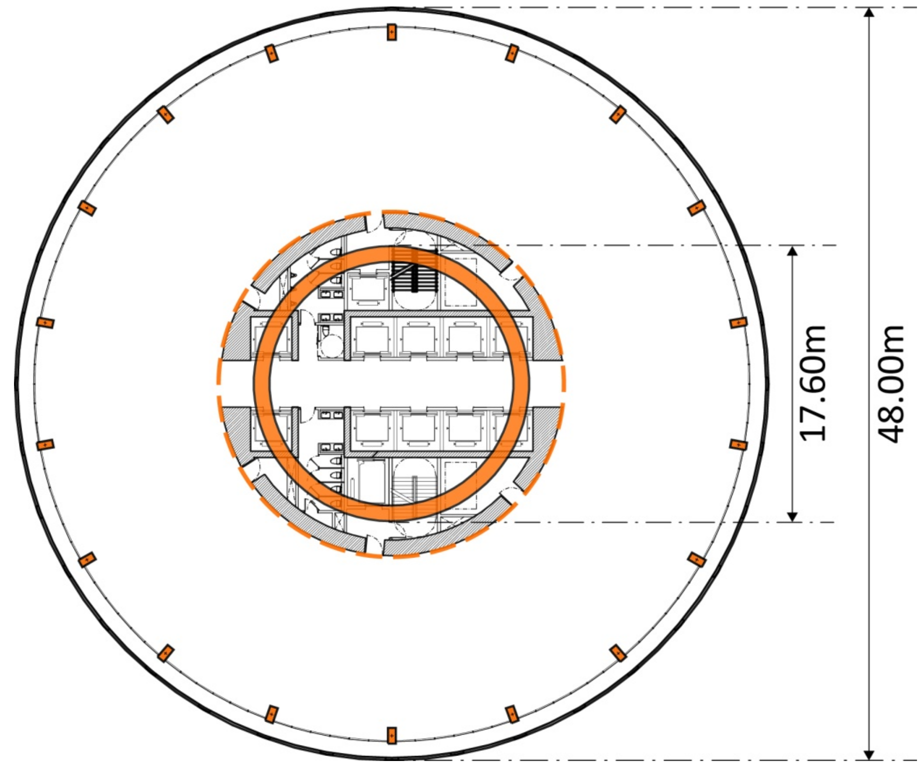
Original Building
Vm=60 m/s
Fw=3.91 kN/m²
Vm=34.50 m/s
Fw=1.89 kN/m²
400m
Mmax=12711600 kN.m
48.00m


Original Building
Vm=60 m/s
Fw=3.91 kN/m²
Vm=34.50 m/s
Fw=1.89 kN/m²
400m
Mmax=12711600 kN.m
48.00m
Building with Wind Adaptive Facade
Vm=60 m/s
Fw=2.05 kN/m²
Vm=34.50 m/s
Fw=1.89 kN/m²
400m
Mmax=7689600 kN.m
48.00m


Original Building
Vm=60 m/s
Fw=3.91 kN/m²
Vm=34.50 m/s
Fw=1.89 kN/m²
400m
Mmax=12711600 kN.m
14.05m
24.00m
Building with Wind Adaptive Facade
Vm=60 m/s
Fw=2.05 kN/m²
Vm=34.50 m/s
Fw=1.89 kN/m²
400m
Mmax=7689600 kN.m
08.05m
24.00m



Original Building



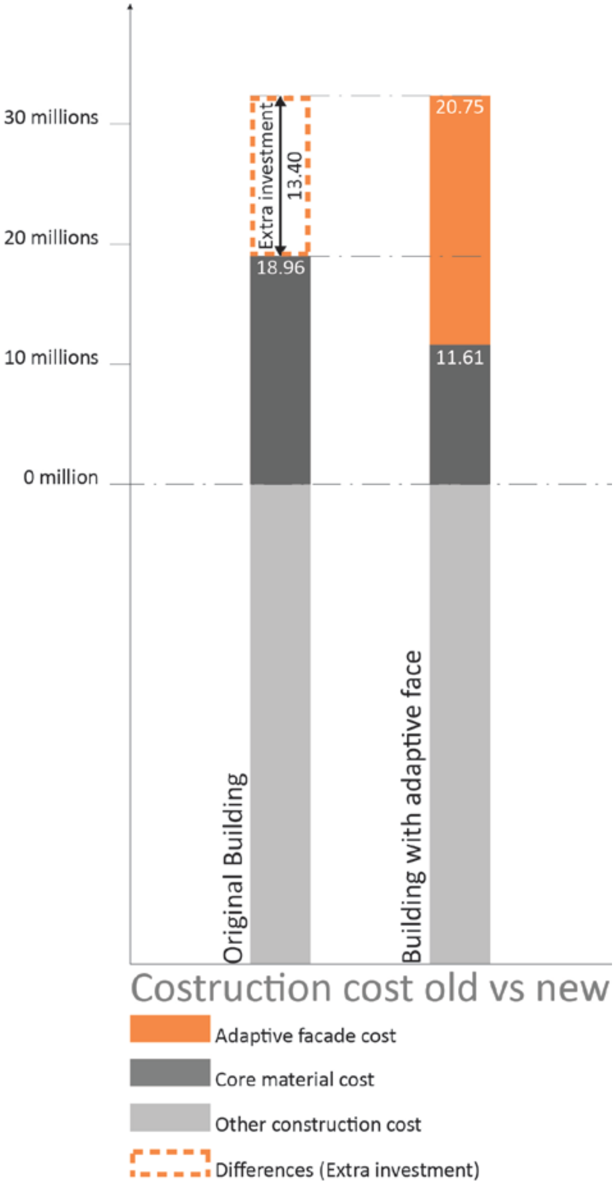
Building with Wind Adaptive Facade

Positive

•Drag reduction:		40%	by horizontal fin position
		47%	by adaptable fins
•Structure material reduction:		38.75%	by adaptable fins
•Increase rentable area	from	1012.97	m^2 per floor
	to	1389.84 m^2 per floor	
		137%	by adaptable fins

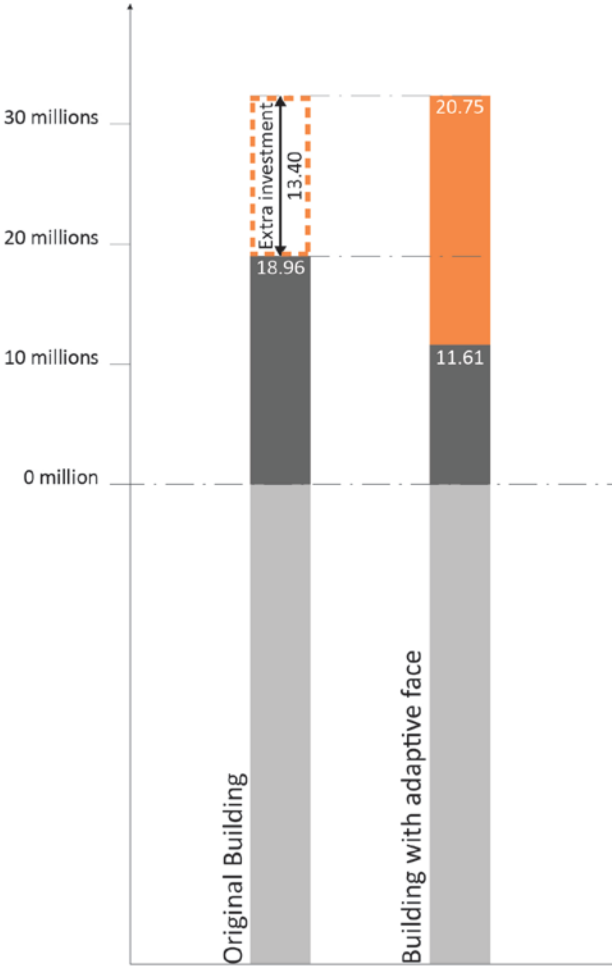
Feasibility

Cost calculation



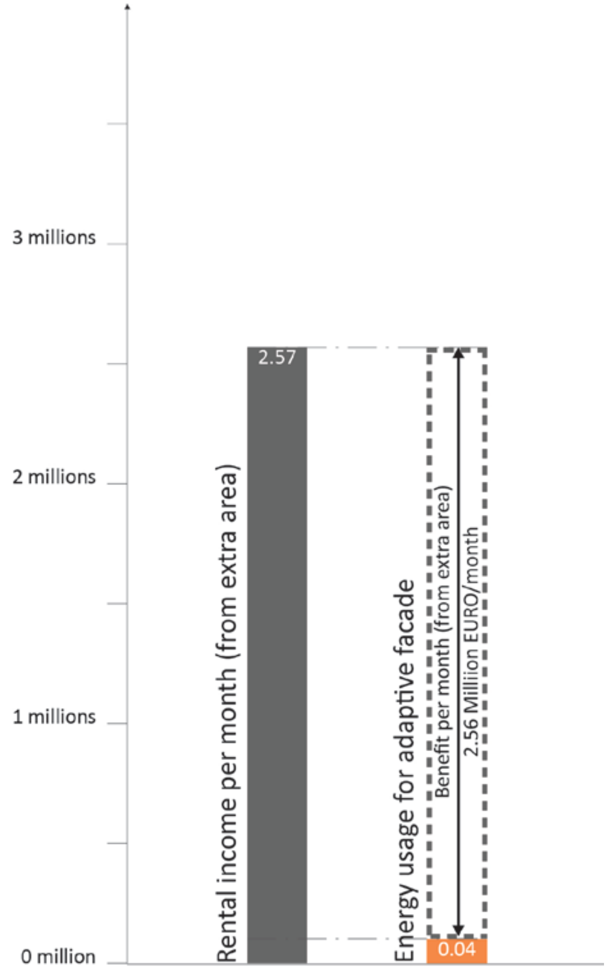
Feasibility

Cost calculation



Costruction cost old vs new

- Adaptive facade cost
- Core material cost
- Other construction cost
- Differences (Extra investment)

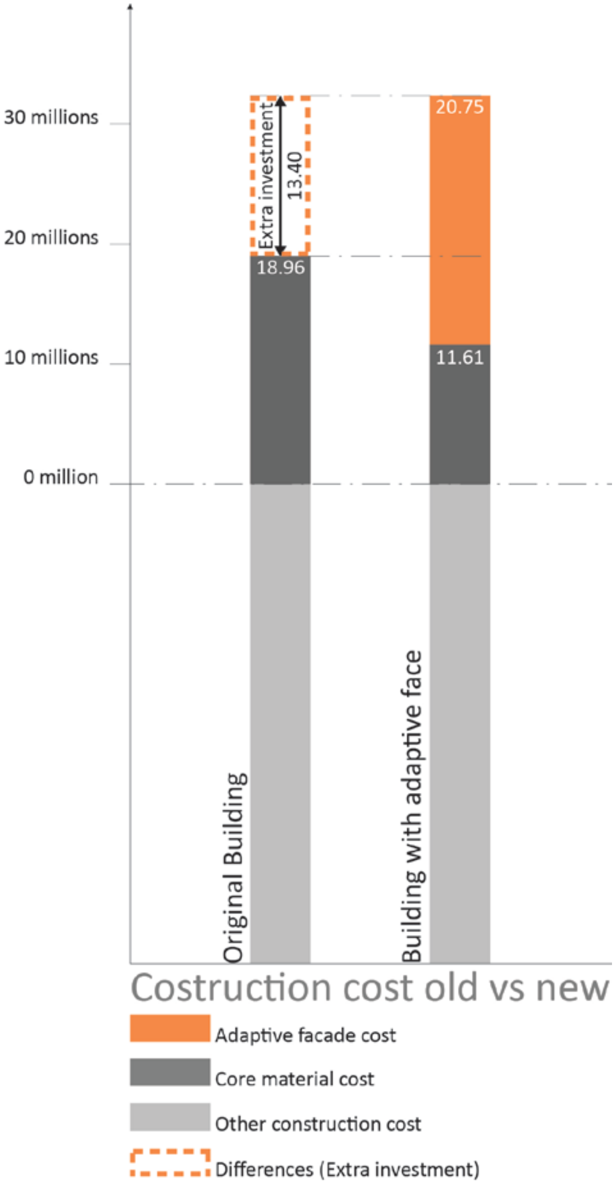


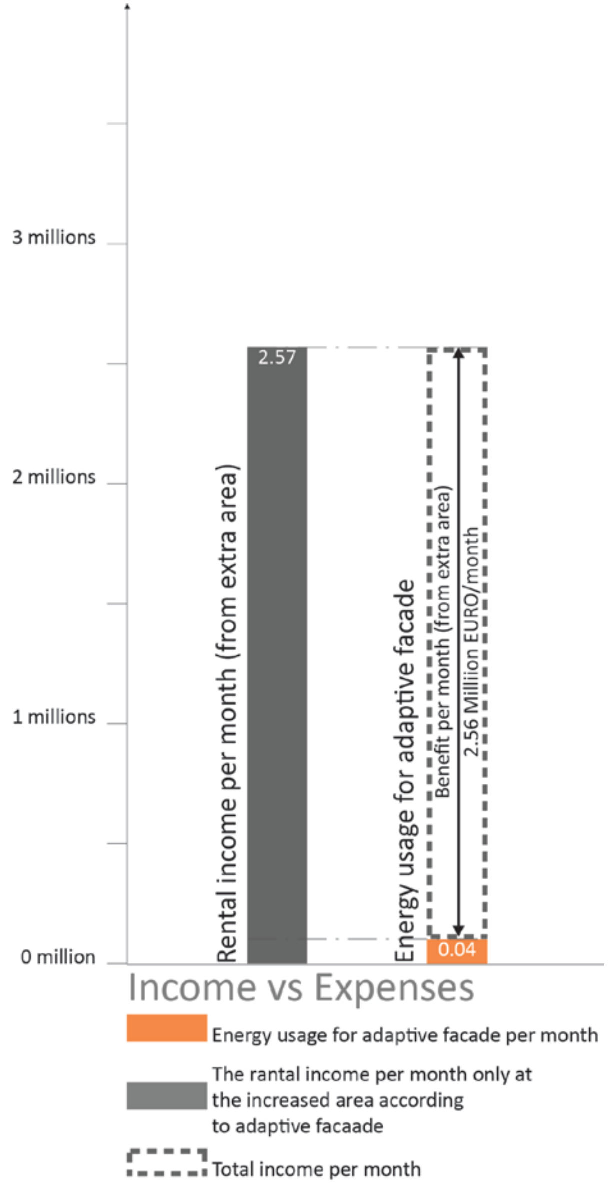
Income vs Expenses

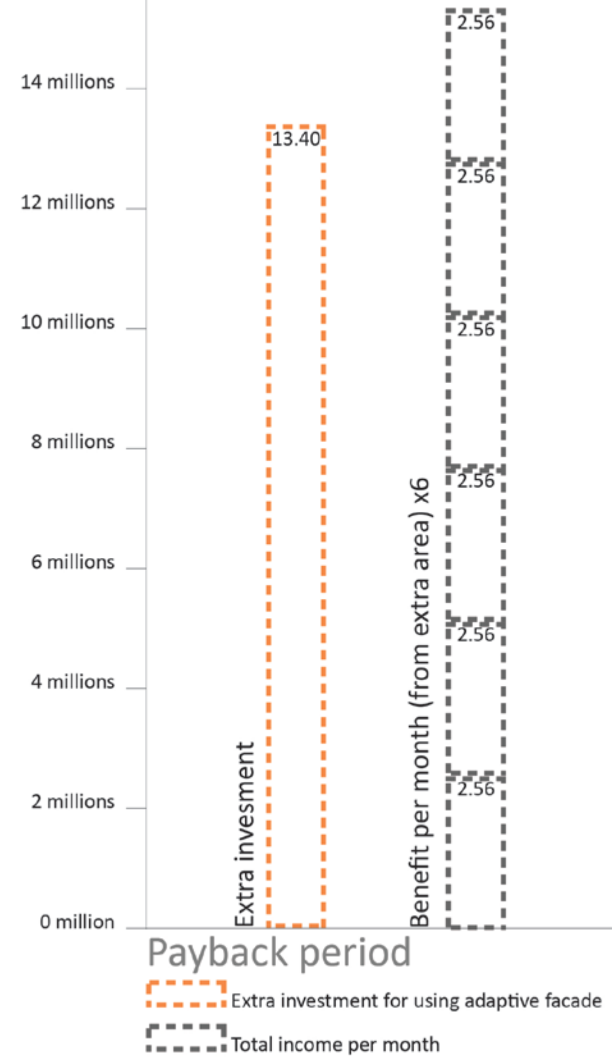
- Energy usage for adaptive facade per month
- The rantal income per month only at the increased area according to adaptive facaade
- Total income per month

Feasibility

Cost calculation







Conclusion

Recommended development

- Wind analysis by CFD and wind tunnel with higher accuracy
- The number of adapted vertical fins in each wind speed
- Vortex shedding should be taken into consideration.
- Safety factor, system energy supply
- Alternate function such as sun shading etc.

Possible suggestion

- Horizontal non-adaptive fins would be efficient enough for windload reduction.
  Only 7% of drag reduction different from the adaptive one.
  Require no energy and no mechanism.