Urban facades

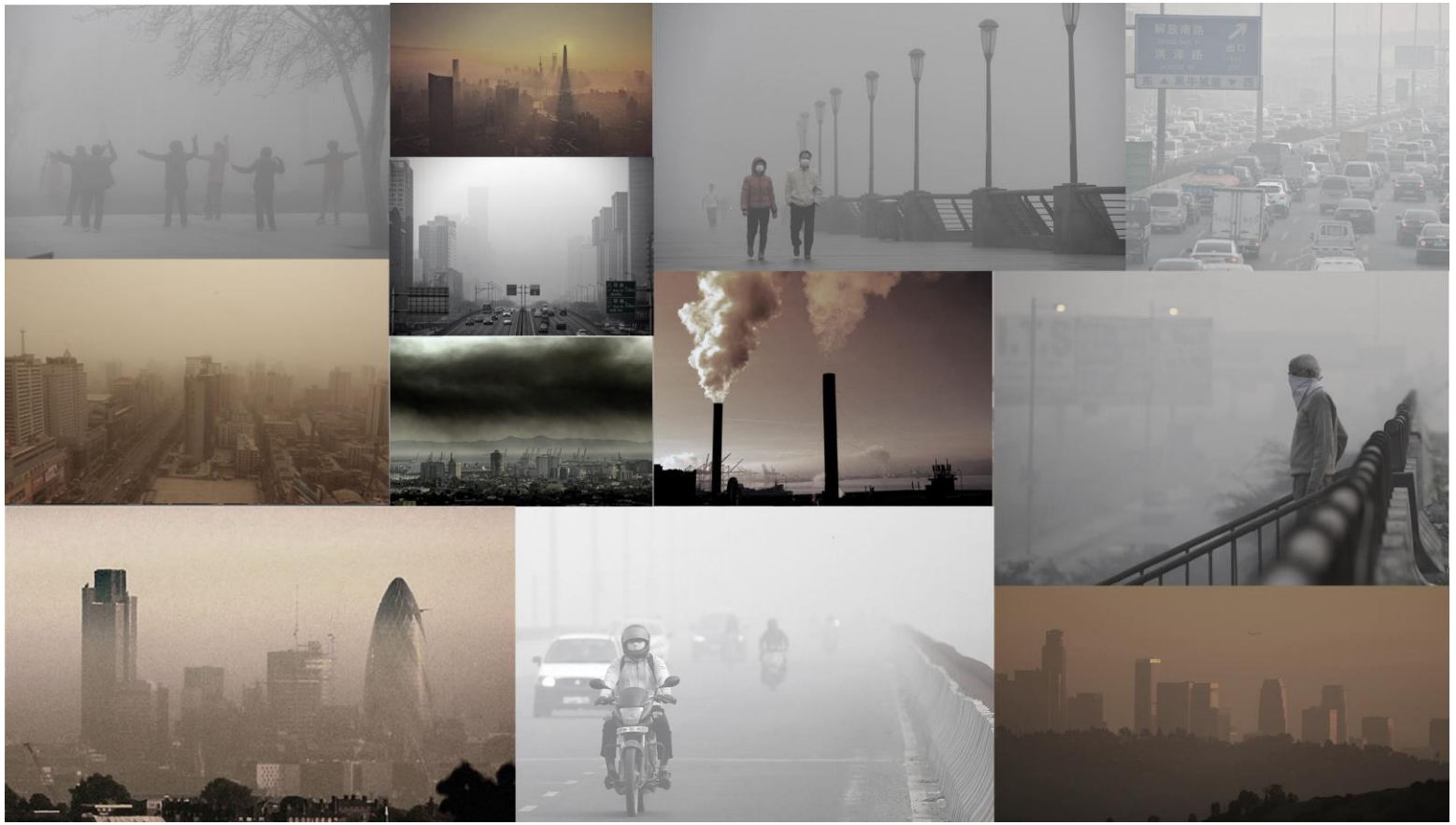
Photocatalytic building skin for passive remediation of air pollution

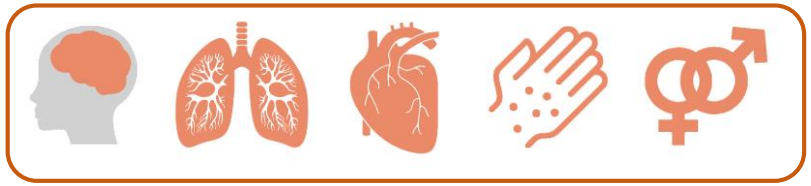
Yamuna Sakthivel

4738578

MSc Building Technology : P5 - Presentation

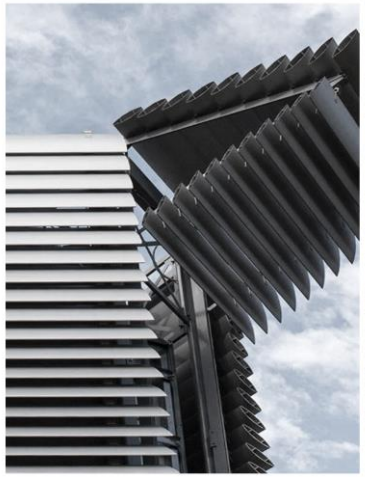
Air Pollution

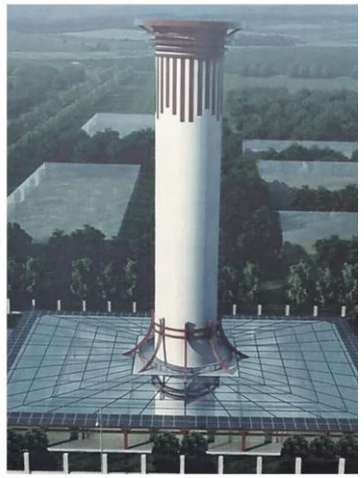




Potential Measures

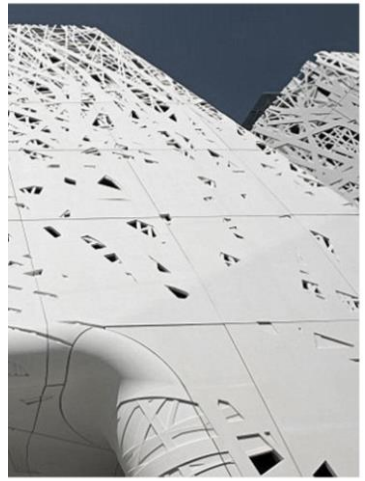
Active Measures





Passive Measures

Green Facades



Photocatalytic building materials

Potential Measures

Active Measures

Passive Measures

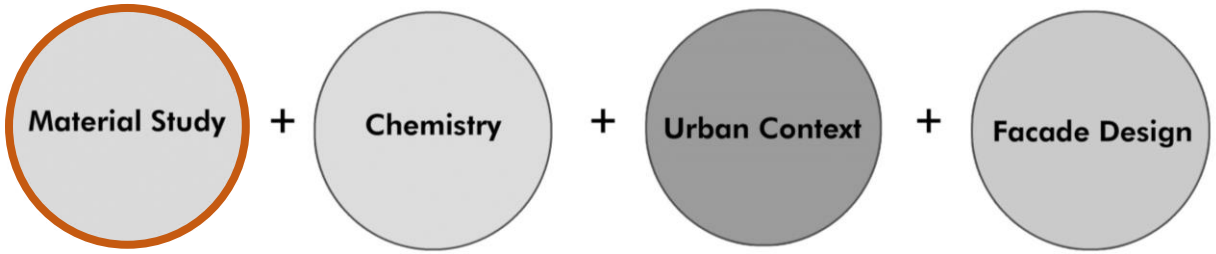
Green Facades

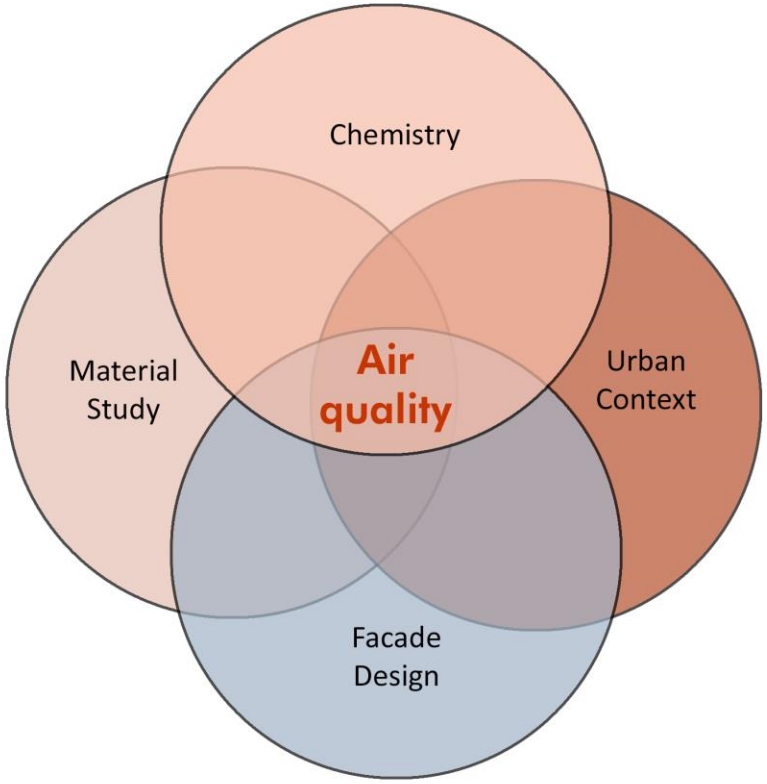
- One time investment
- No maintenance
- Suitability for all climates

Photocatalytic building materials

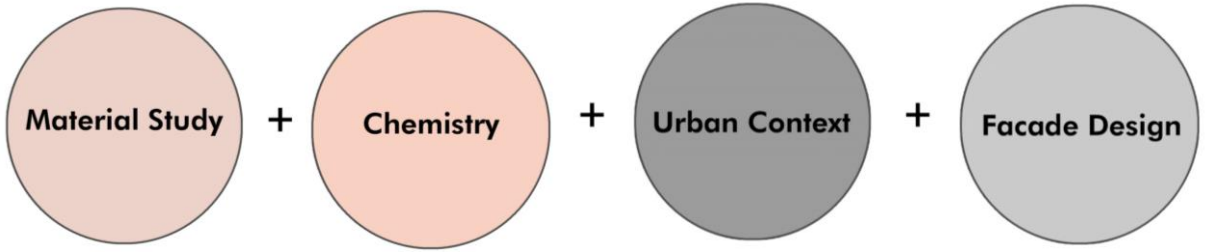
Structure of the Thesis

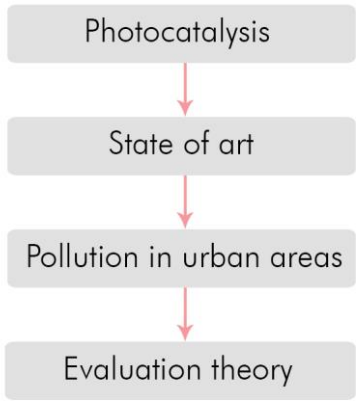
Integration of photocatalytic materials in urban environment.

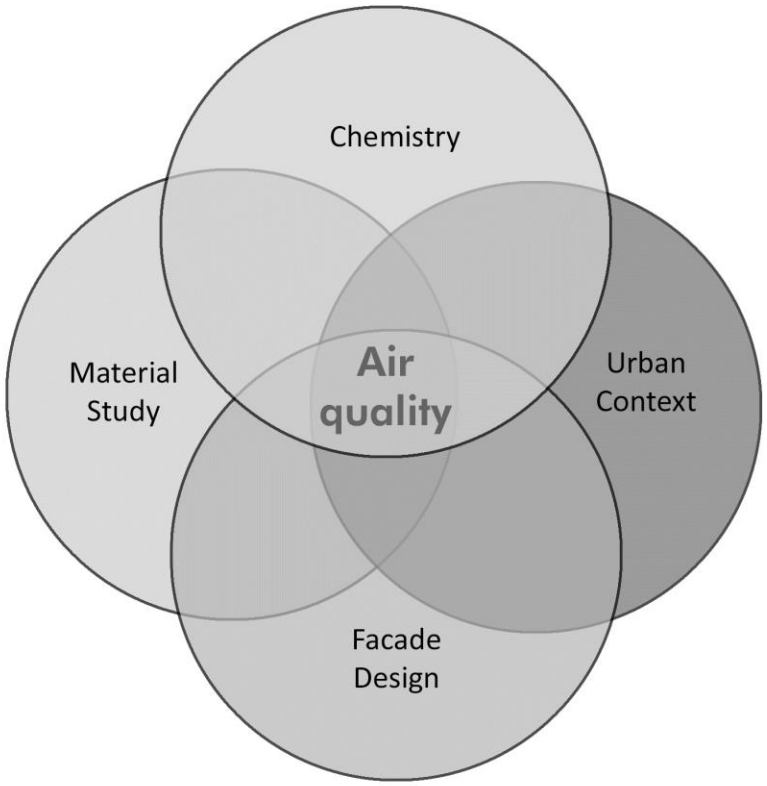




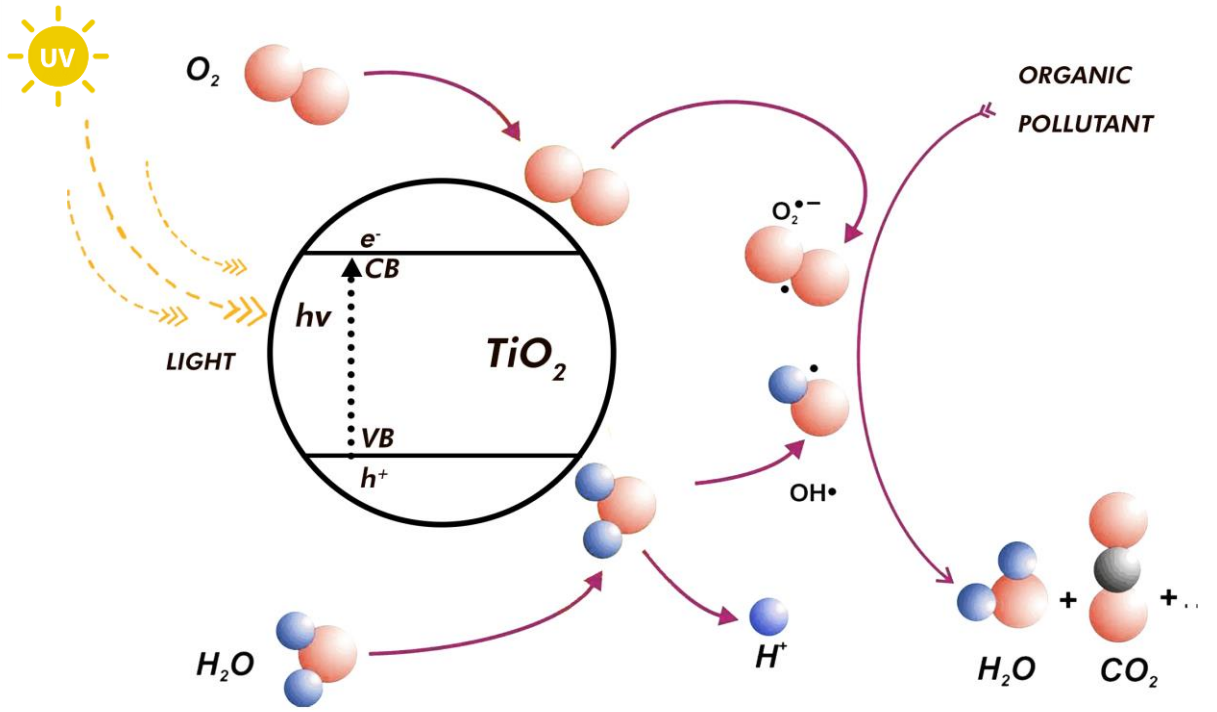
What is Photocatalysis mechanism, Operating conditions & their scope in pollutant degradation?





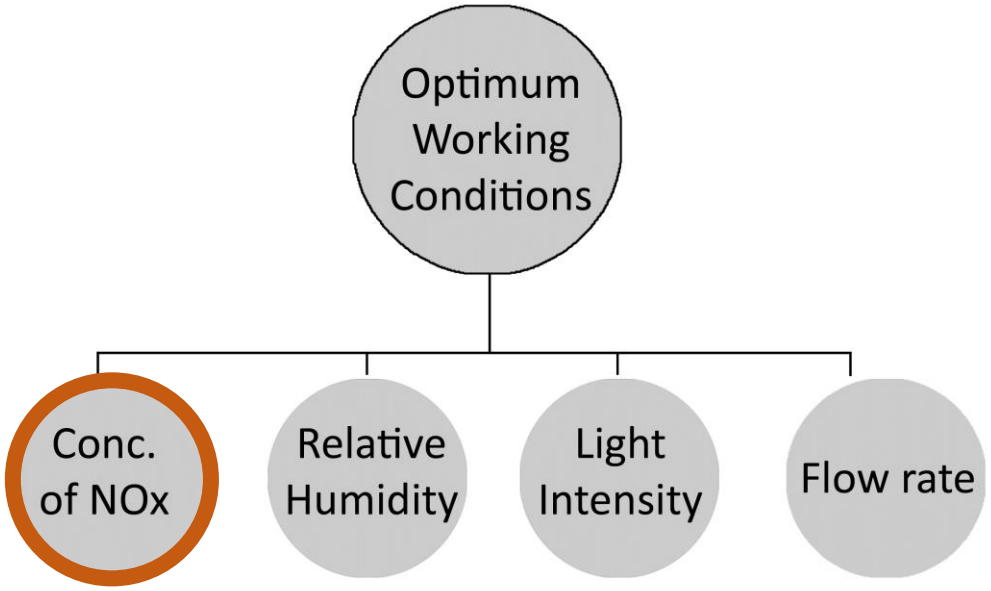


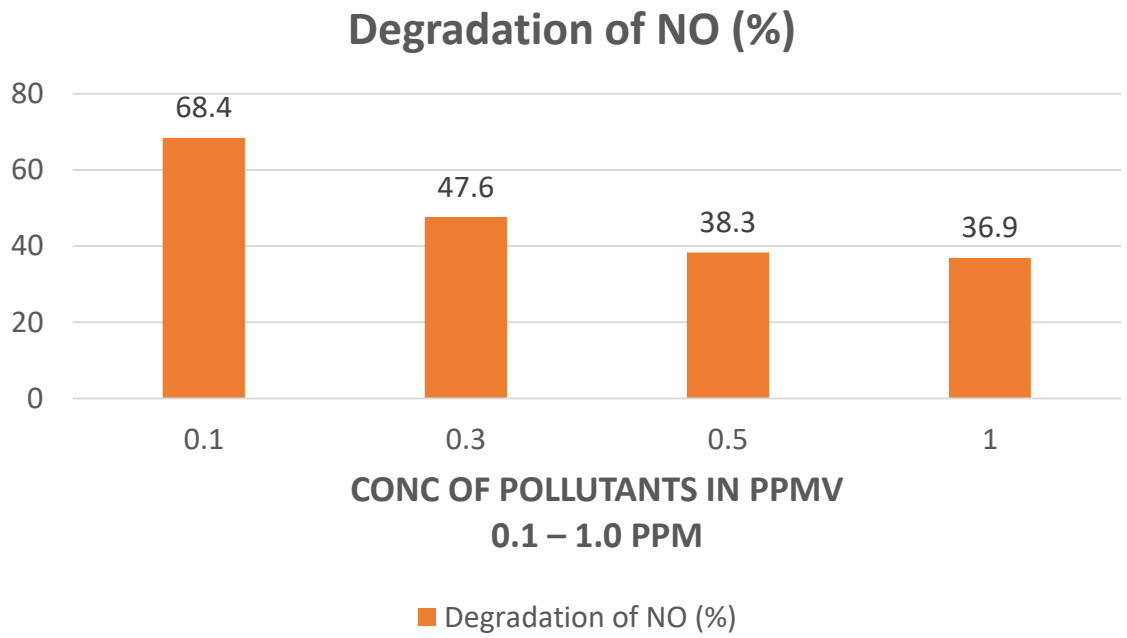
Photocatalysis



NO_X
SO_2
VOC's
CO

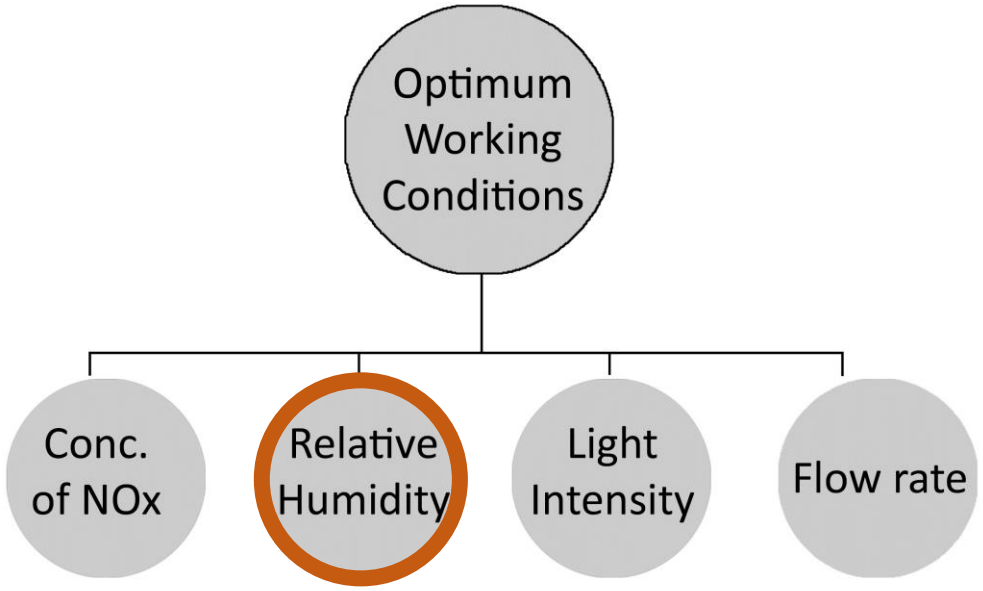
Operating Conditions

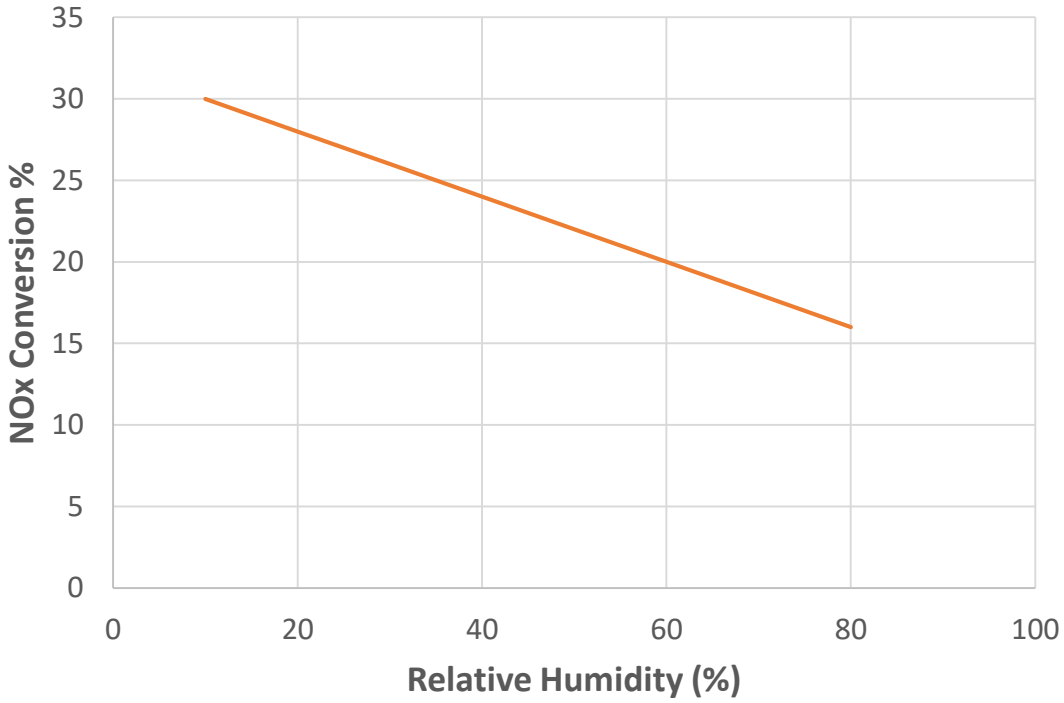




Increased surface area of active sites

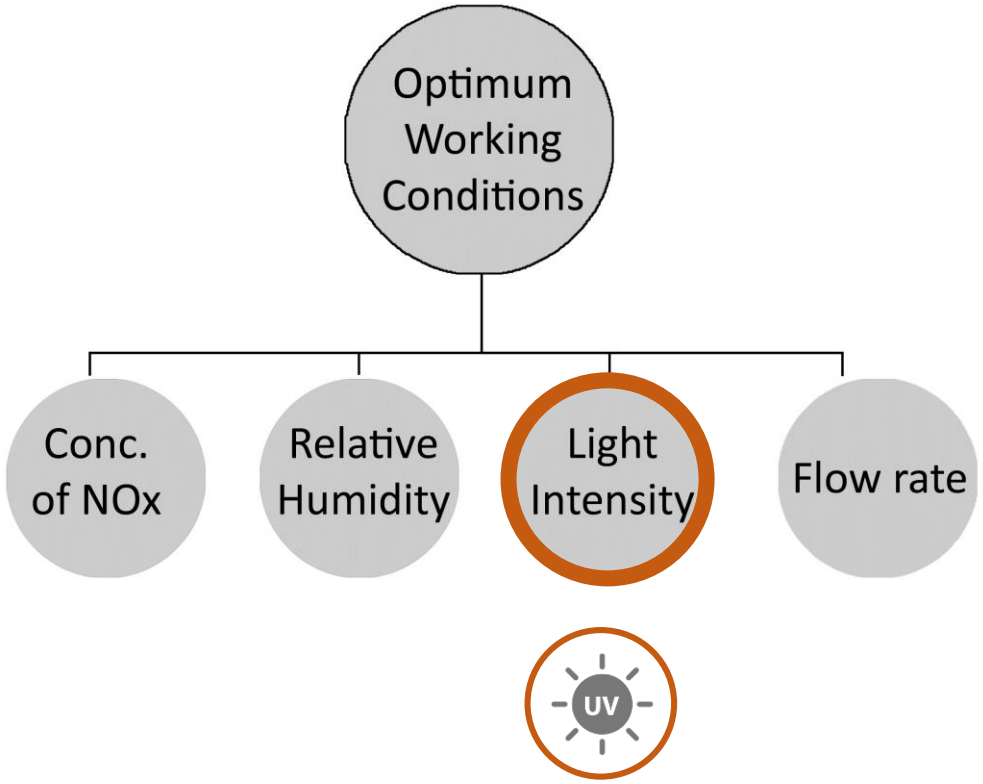
Operating Conditions



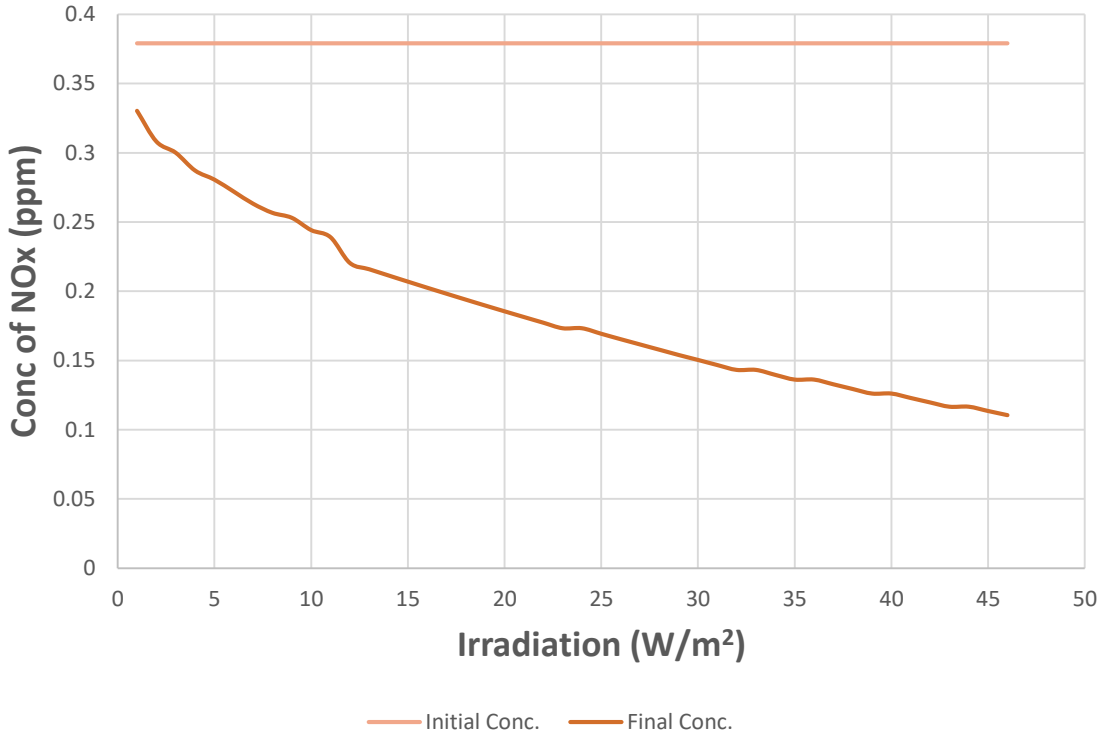


RH 40% : most favorable condition

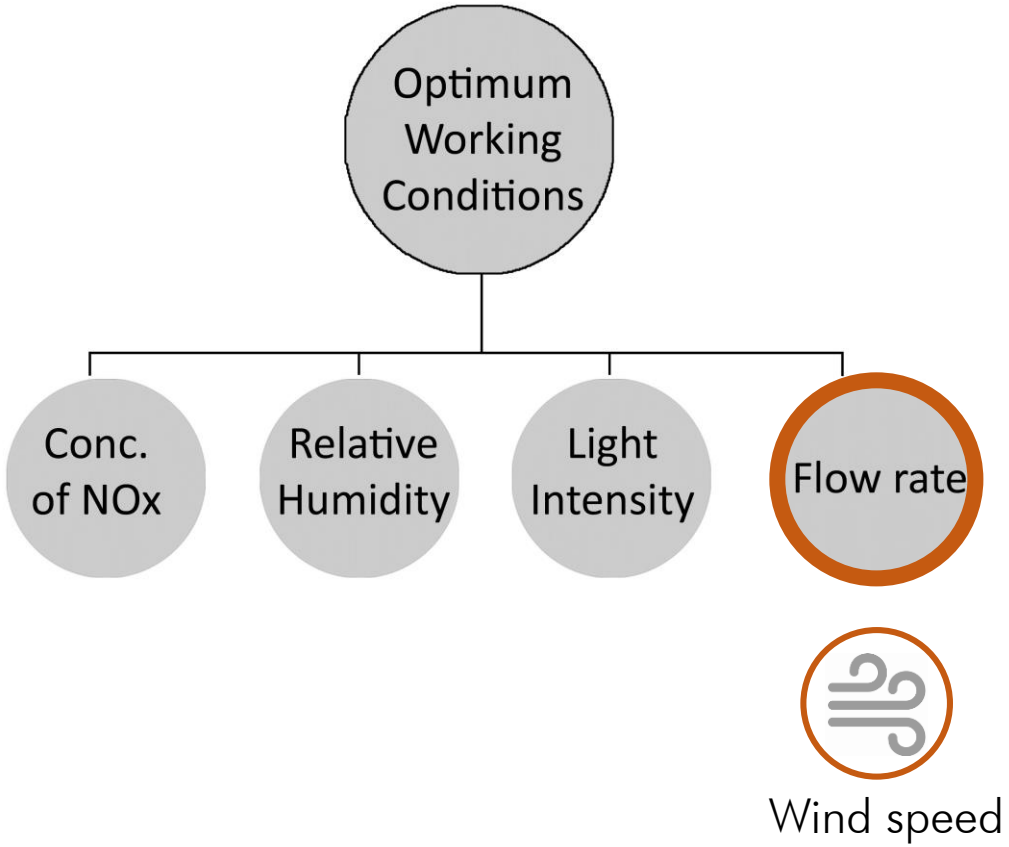
Operating Conditions

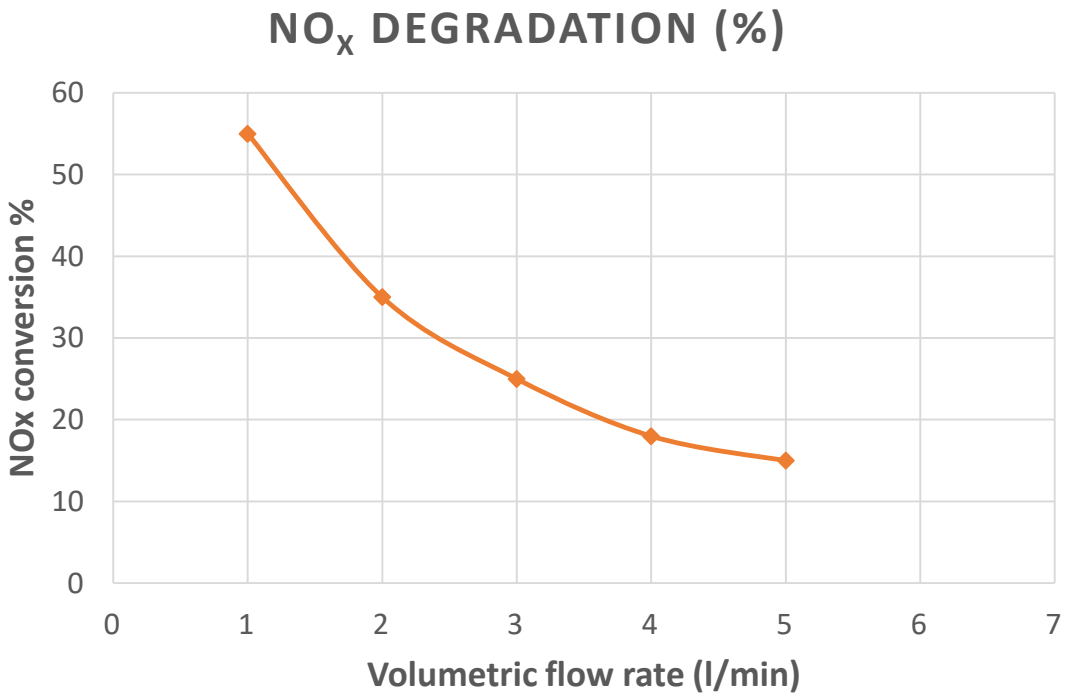


UV-A irradiation



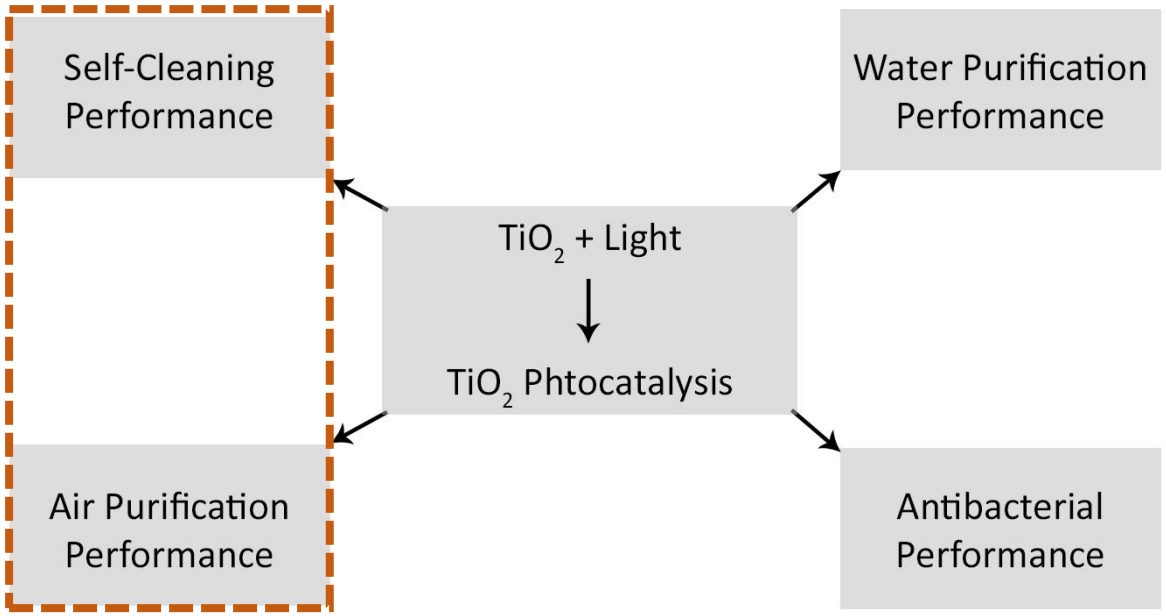
Operating Conditions





Less flow rate, more is the conversion

State of Art



Leopold Tunnel, Brussels

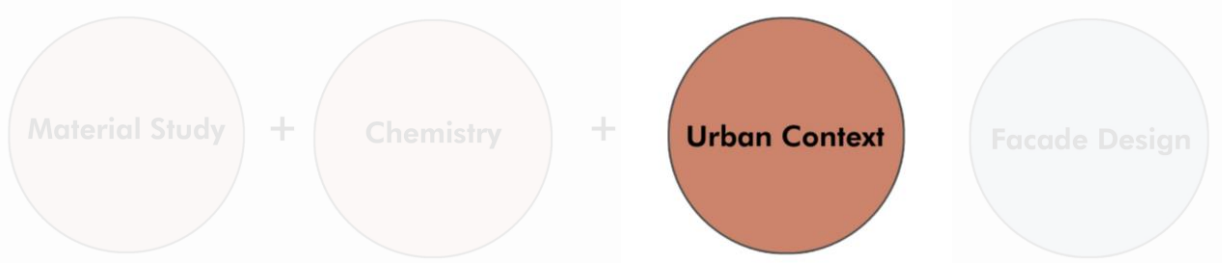
	Light Irradiation (UV)	Relative Humidity (%)	Wind Speed
Onsite Conditions	4 W/m2	70 %	> 3m/s
Proposed Conditions	**10 W/m2 (UV light)**	**<60 %**	**0.3 to 1.5 m/s**

Research Question

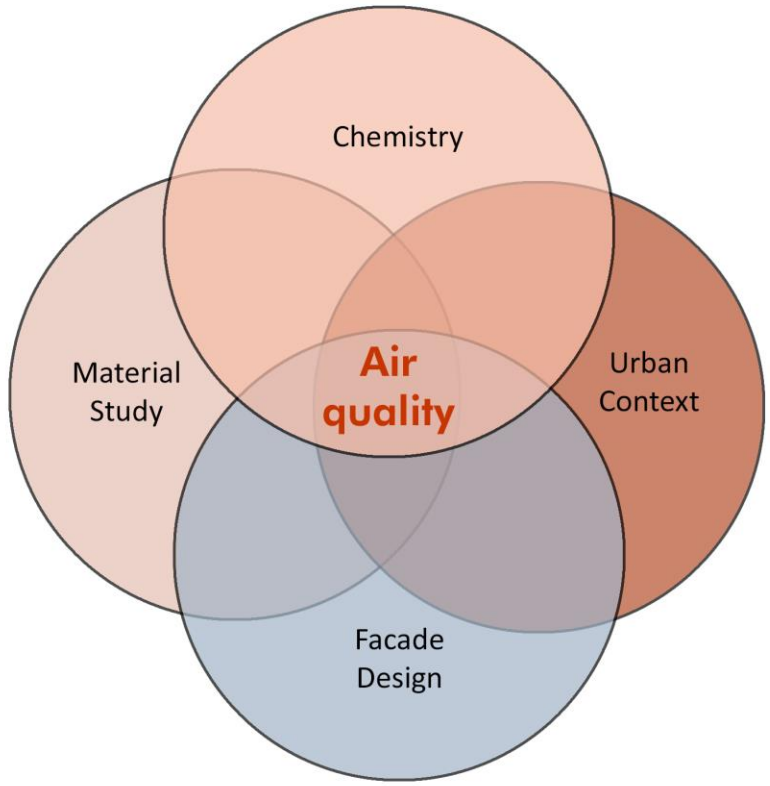
How can façade cladding panels with photocatalytic coating be designed to increase the active surface area for pollutant degradation in response to performance inhibiting factors in urban environments and what would be their effect in improving the air quality?

Urban Context

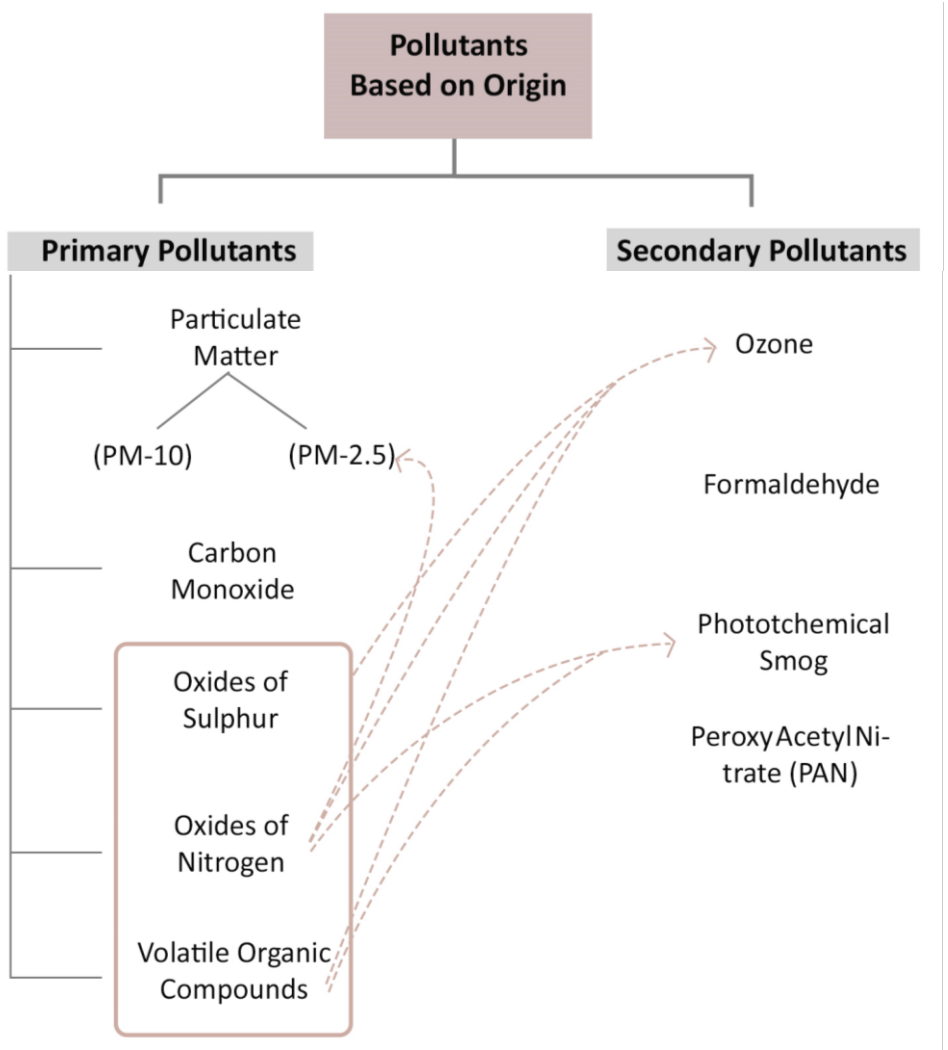
What is the role of façade in pollution abatement ?



- Climatic Context
- Identifying Parameters
- Tools for analysis
- Design Situations



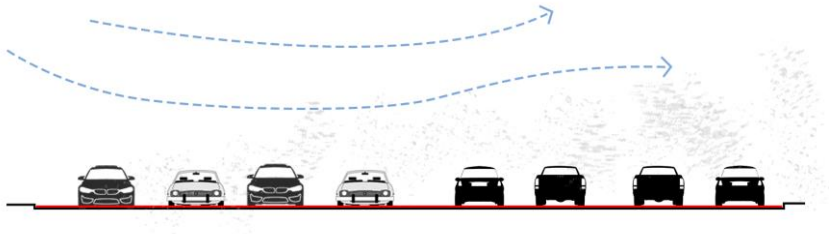
Pollution in Urban areas



Targets of Photocatalysts

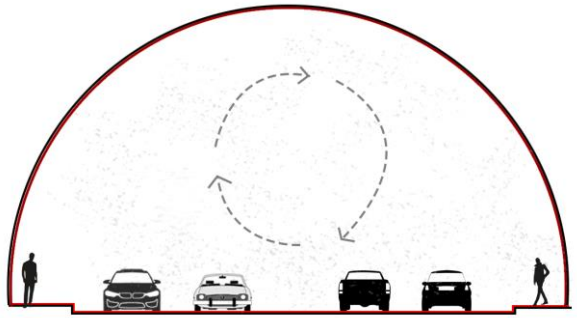
Pollutant dispersion

1. Open Sprawl



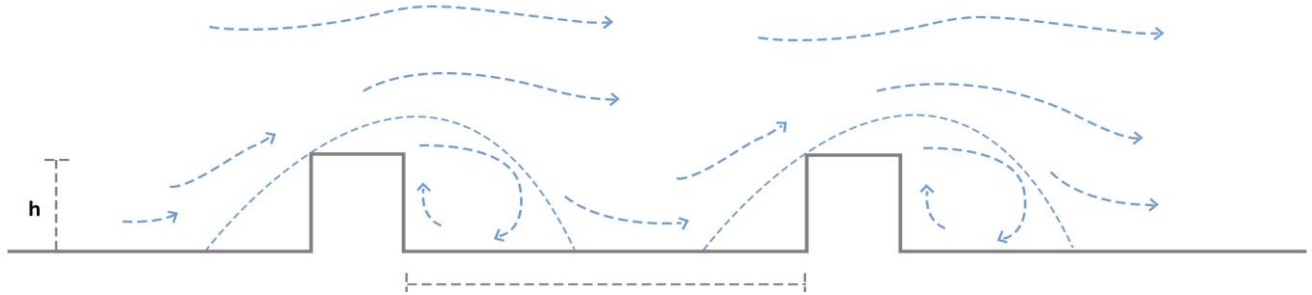
Quick dispersion of pollutants

2. Closed Space

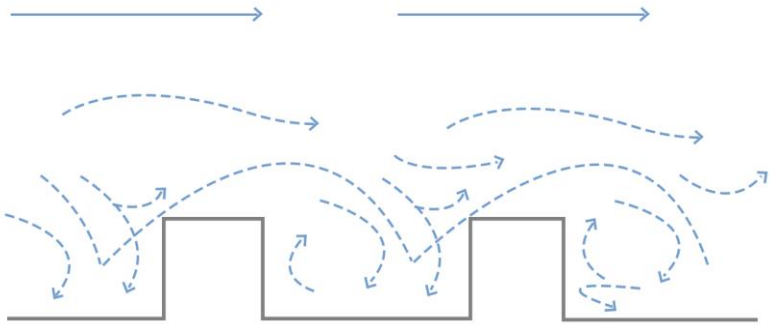


Stagnation or recirculation of pollutants

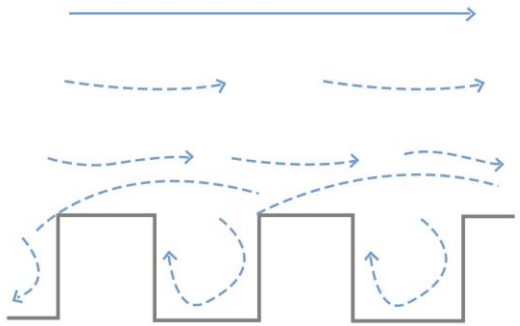
3. Semi-Confined Spaces



Isolated Roughness flow



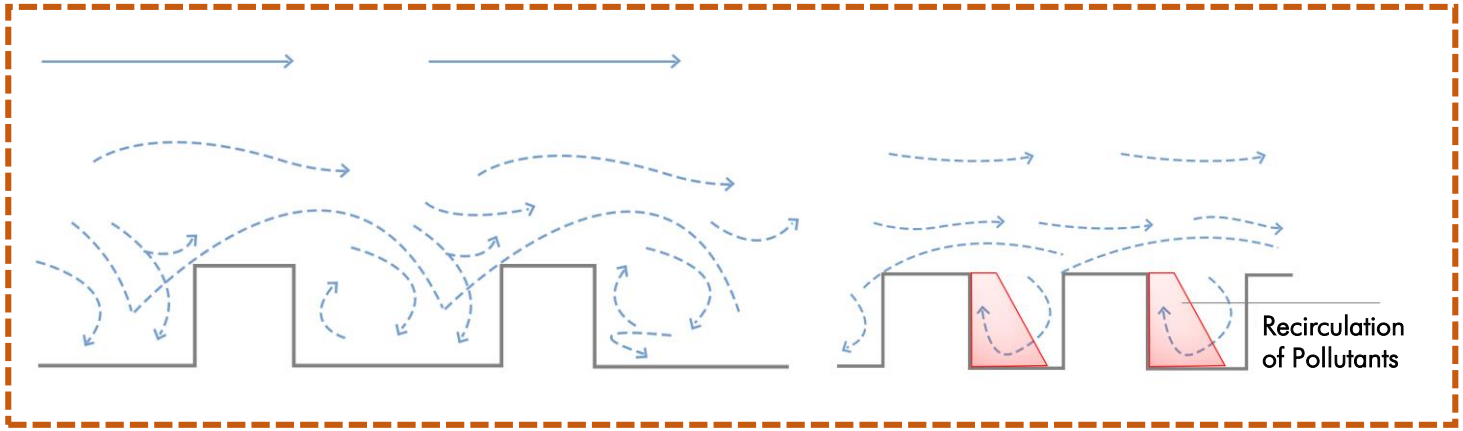
Wake interference flow



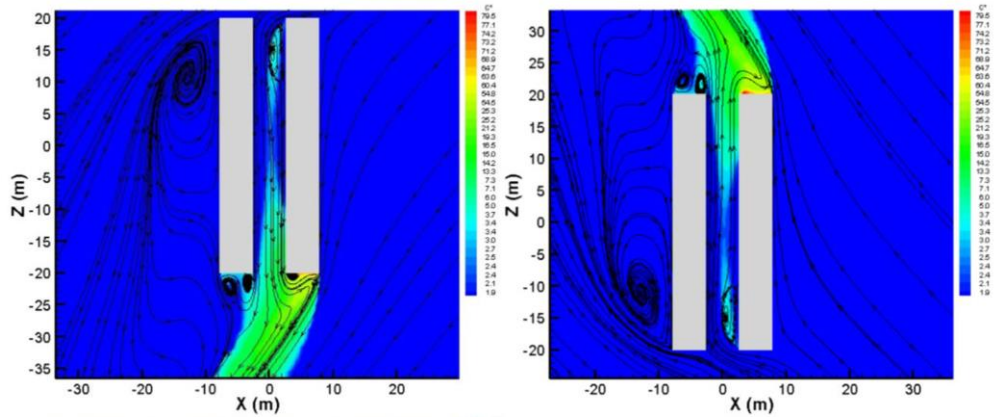
Skimming flow

Pollutant dispersion

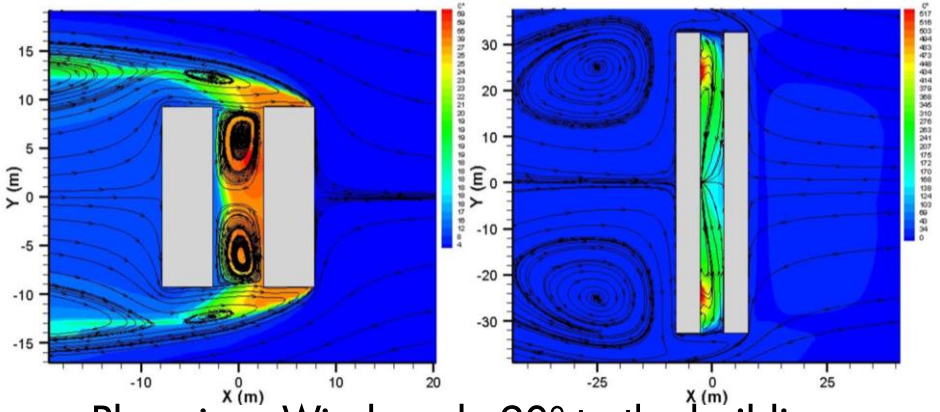
Leeward Side: Pollution receptors



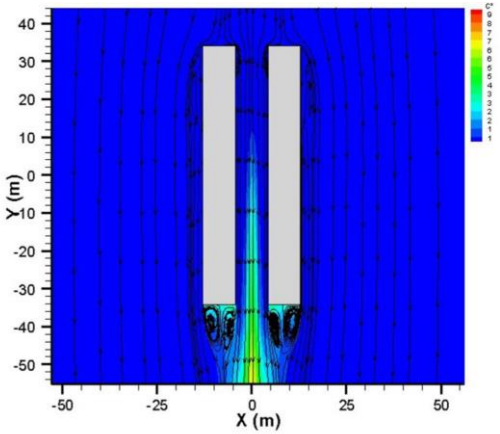
Pollutant dispersion



Plan view: Wind angle 45° to the building



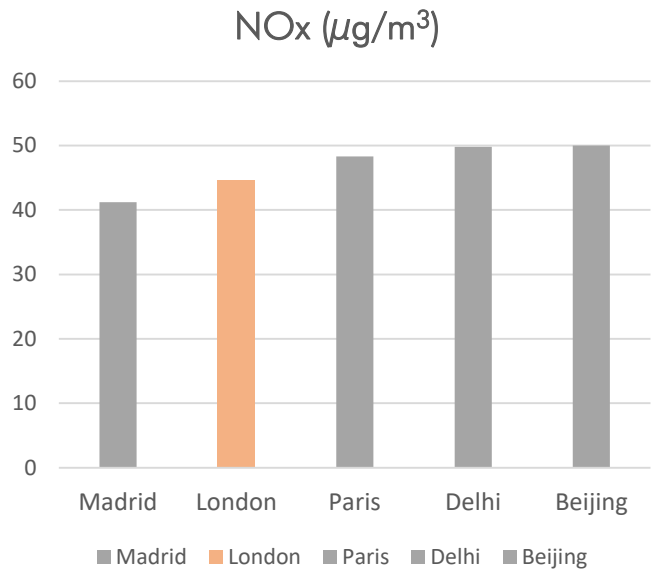
Plan view: Wind angle 90° to the building

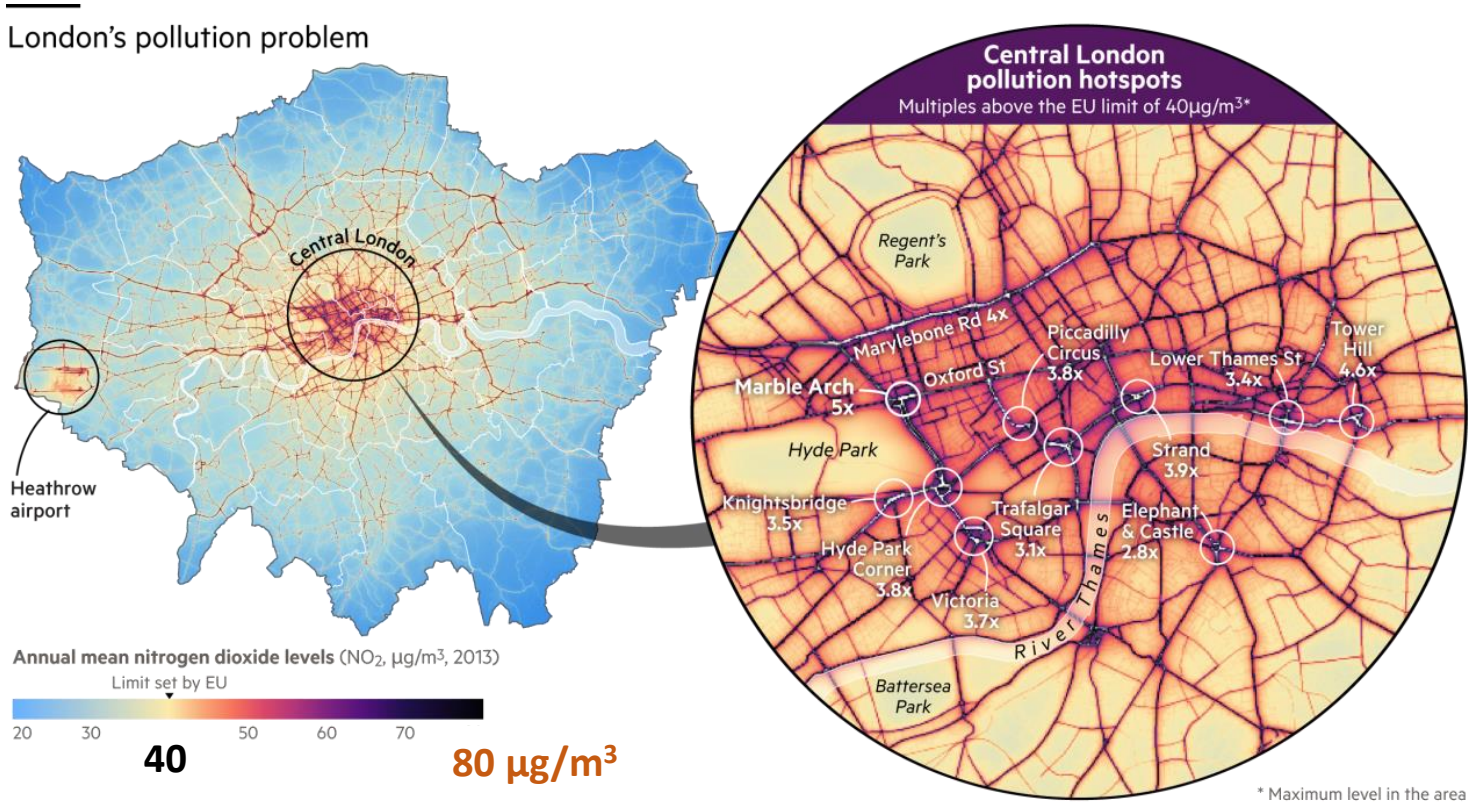


Top view: Wind parallel to the building

Pollutant dispersion fields CFD MIMO Analysis – PICADA Project

Urban Context : Site

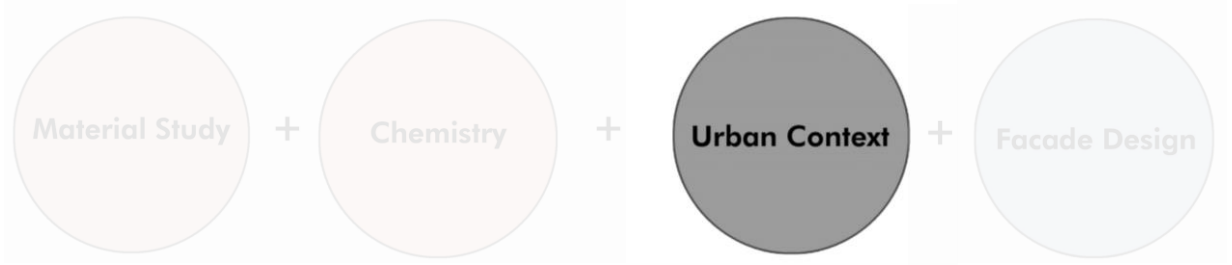


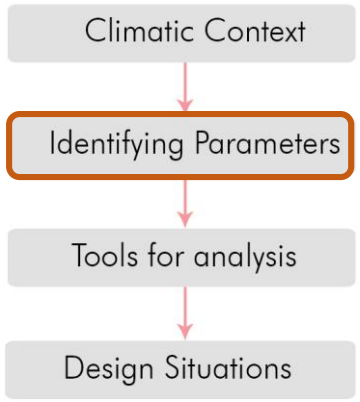


80 μg/m³

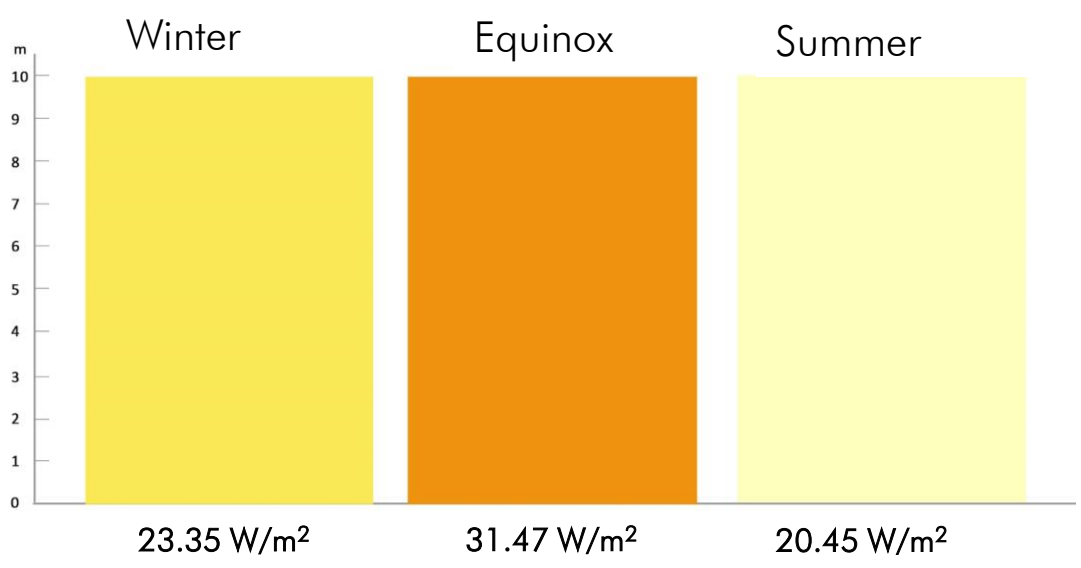
Urban Context

What are the parameters and constraints driving the design of the façade panels?

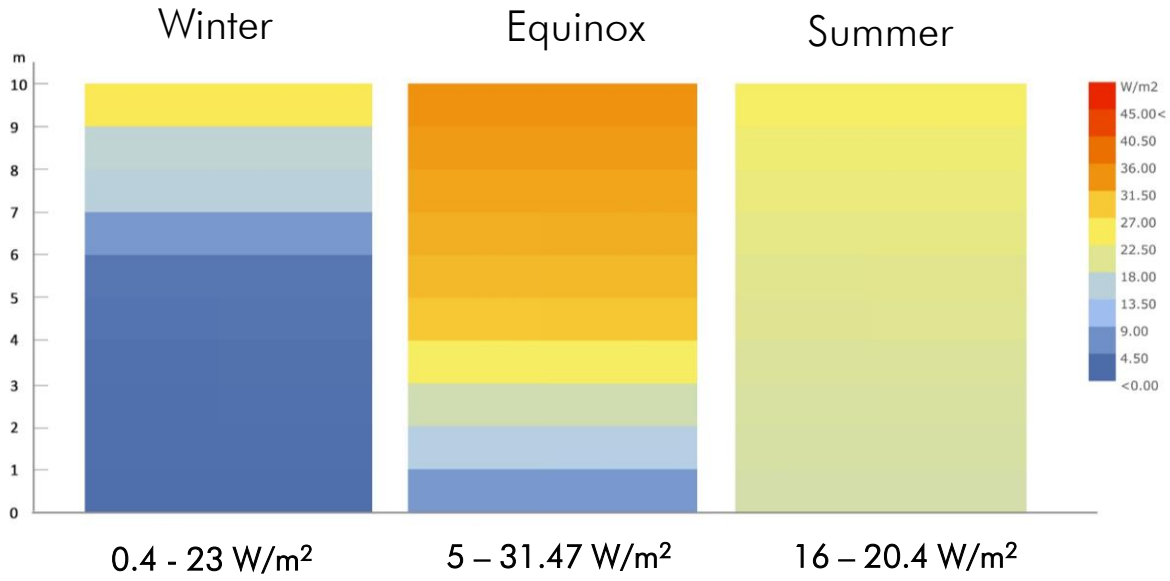




Translation of Parameters: UV Irradiance



Stand-alone building - South



Street Canyon – South Facade

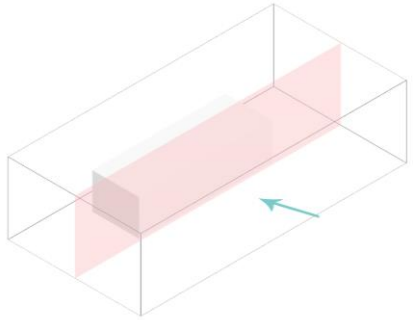
Lady-bug

UV

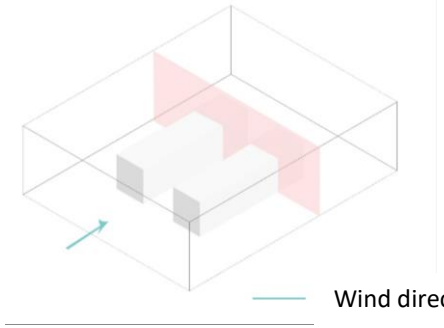
4.5% x Solar Irradiance

Façade Panel should have omnidirectional reception of light

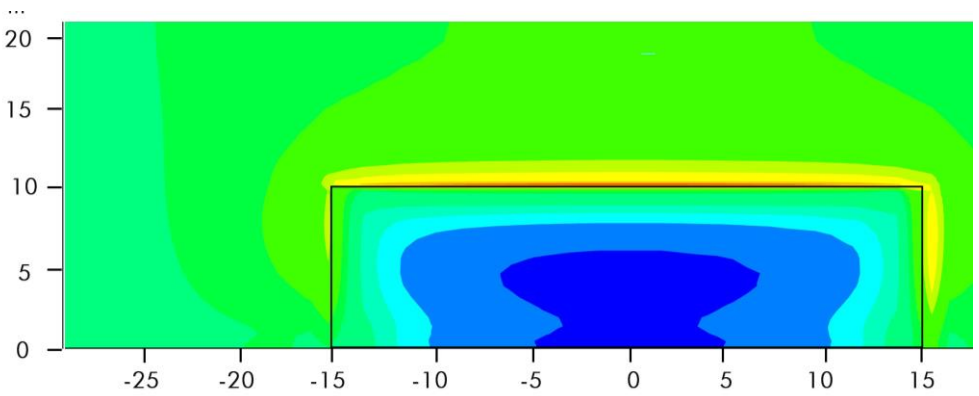
Translation of Parameters: Wind Velocity Field



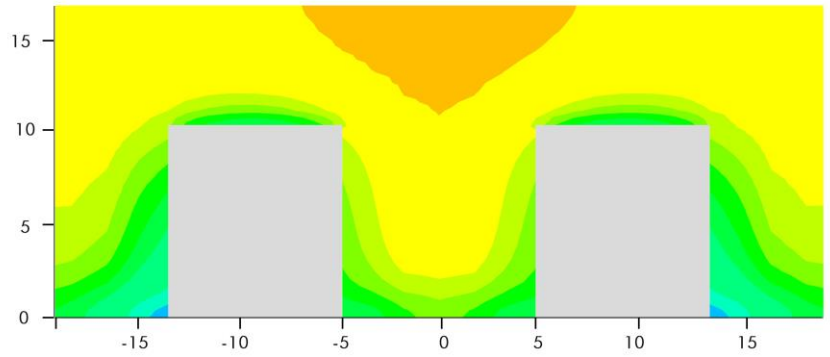
Computational domain in CFD



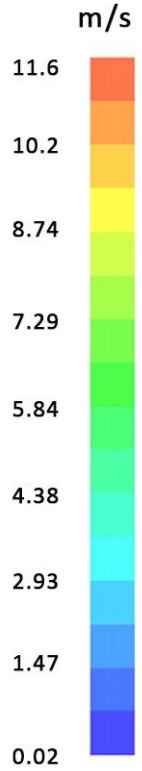
Wind direction



Wind perpendicular to the façade
Stand alone building



Wind parallel to the façade
Street Canyon

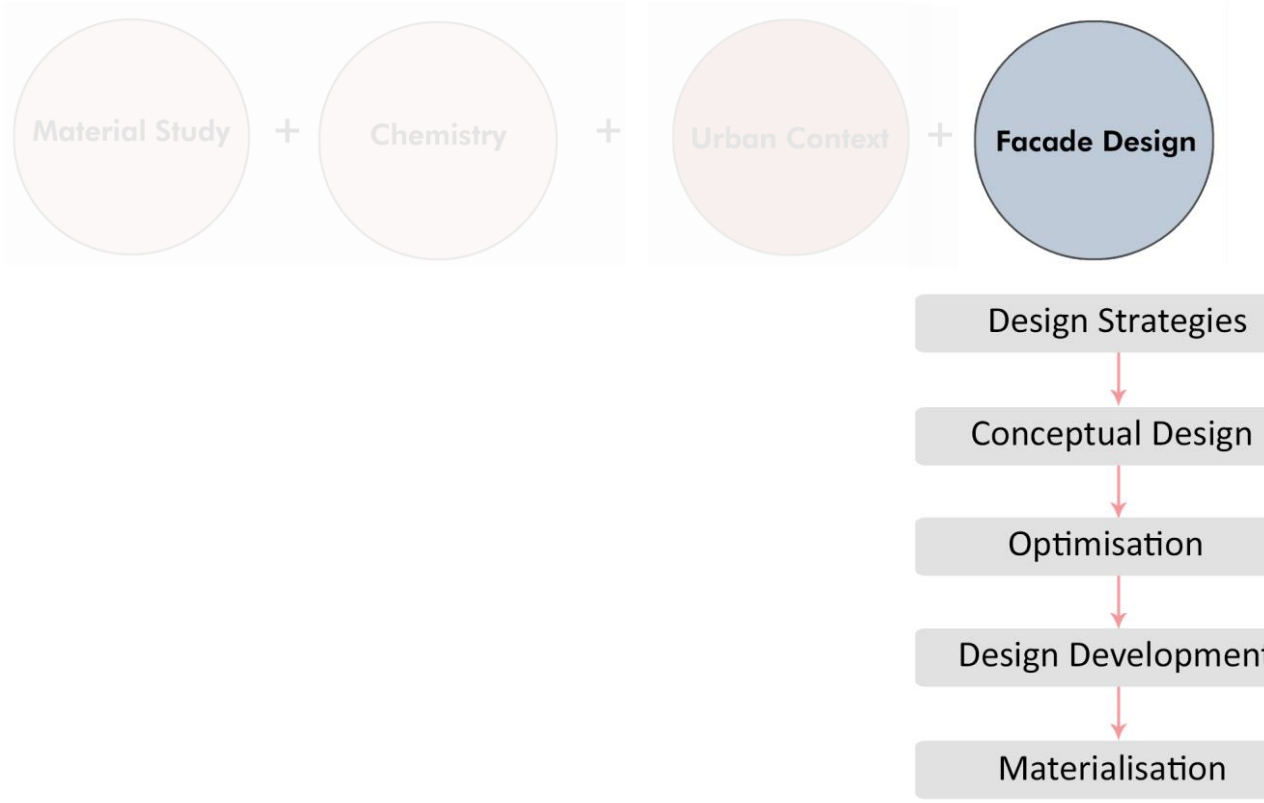


RhinoCFD

Velocity field
>1.7 m/s

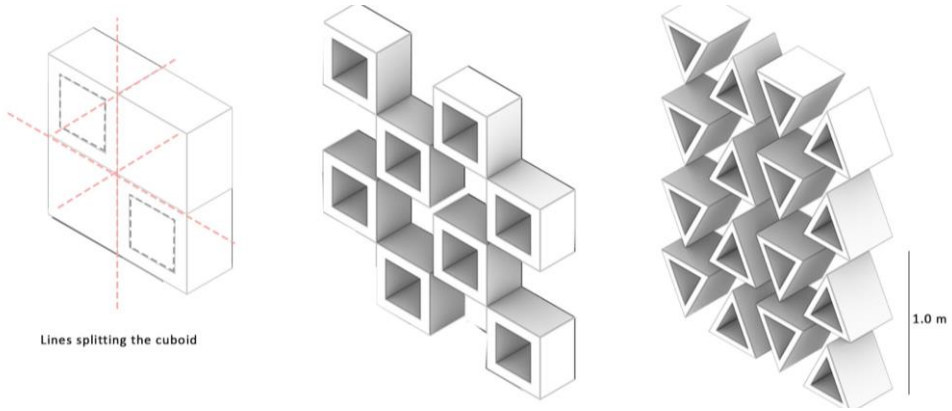
Reduction of Wind speed over the façade is necessary

Facade Design

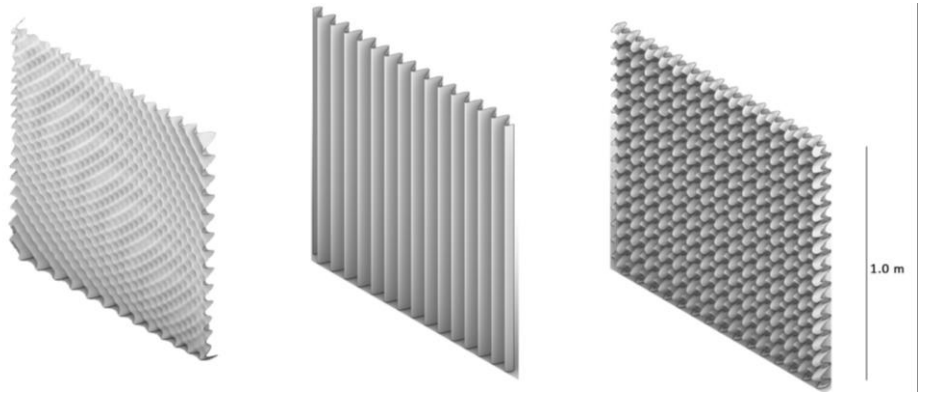


Design Strategies

Surface Enlargement



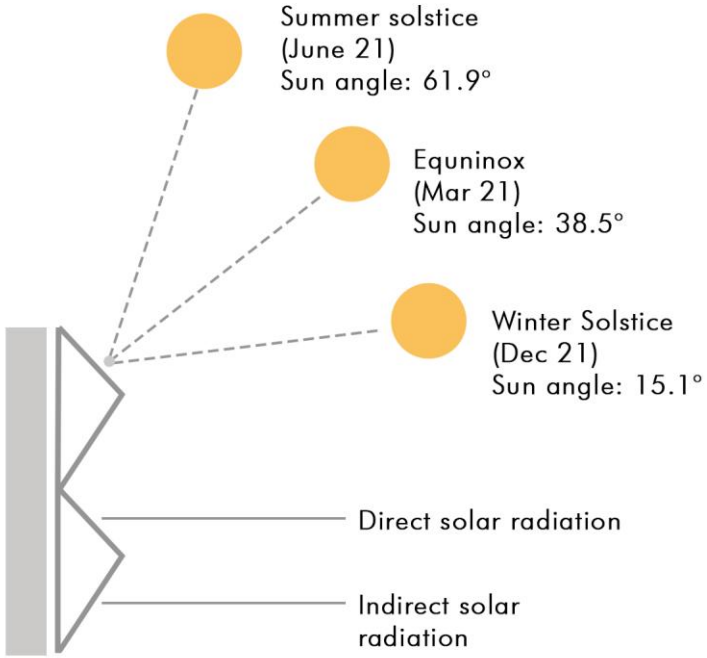
Splitting a volume
Surface enlargement: 1.9 – 2.27



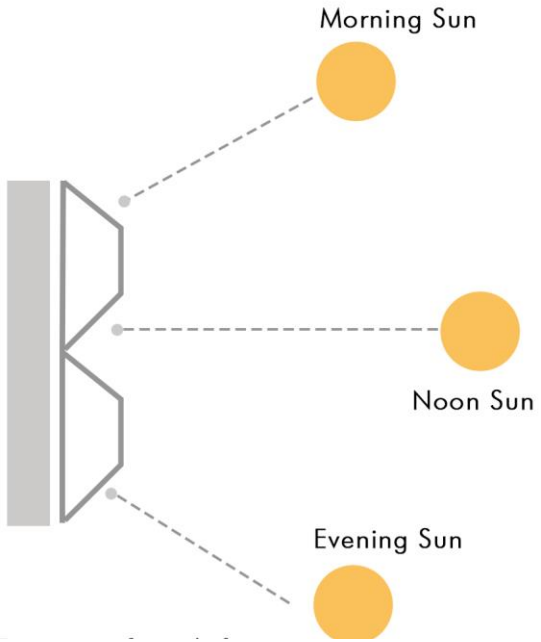
Sinusoidal manipulation
Surface enlargement: 1.6 – 3.5

Design Strategies

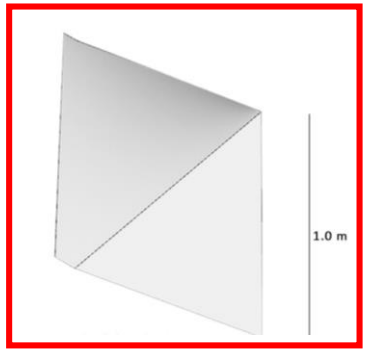
Surface Enlargement



Side view of south-facing facade



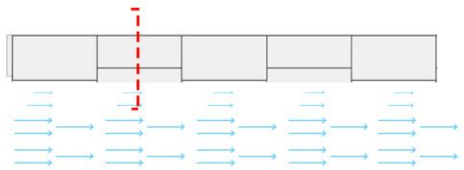
Top view of south-facing facade



Pyramidal manipulation
Surface enlargement: 1.4 – 1.9

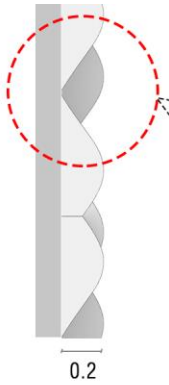
Design Strategies

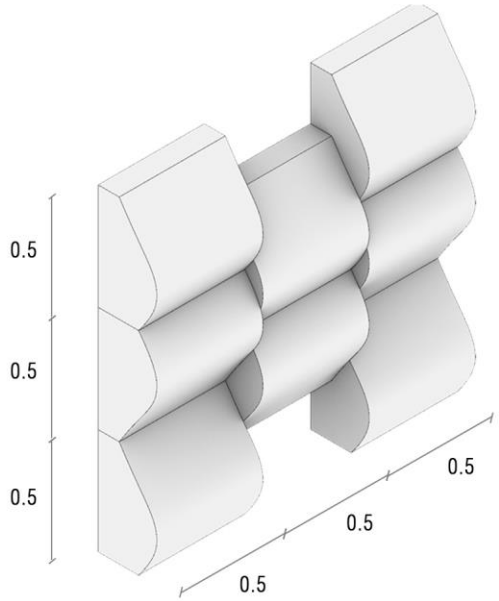
Surface Roughness : Strategy 1



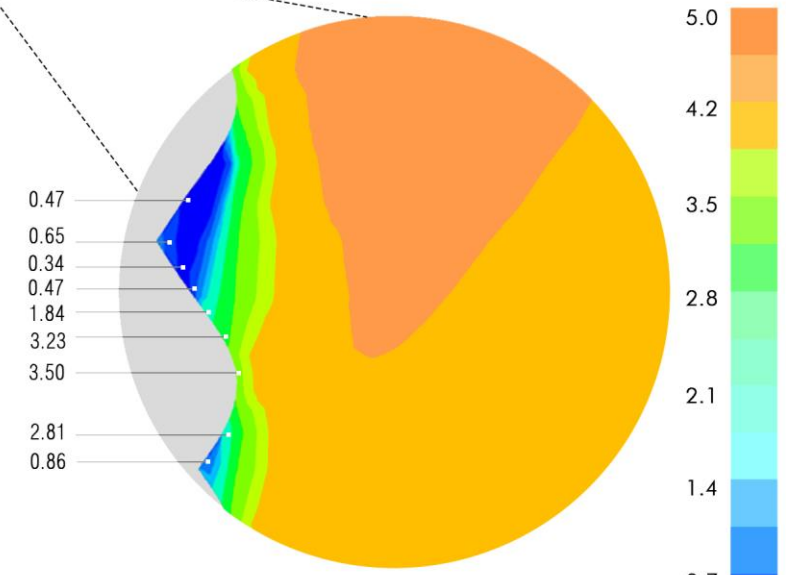
Top view of the panel

Wind flow parallel to the facade (5 m/s)





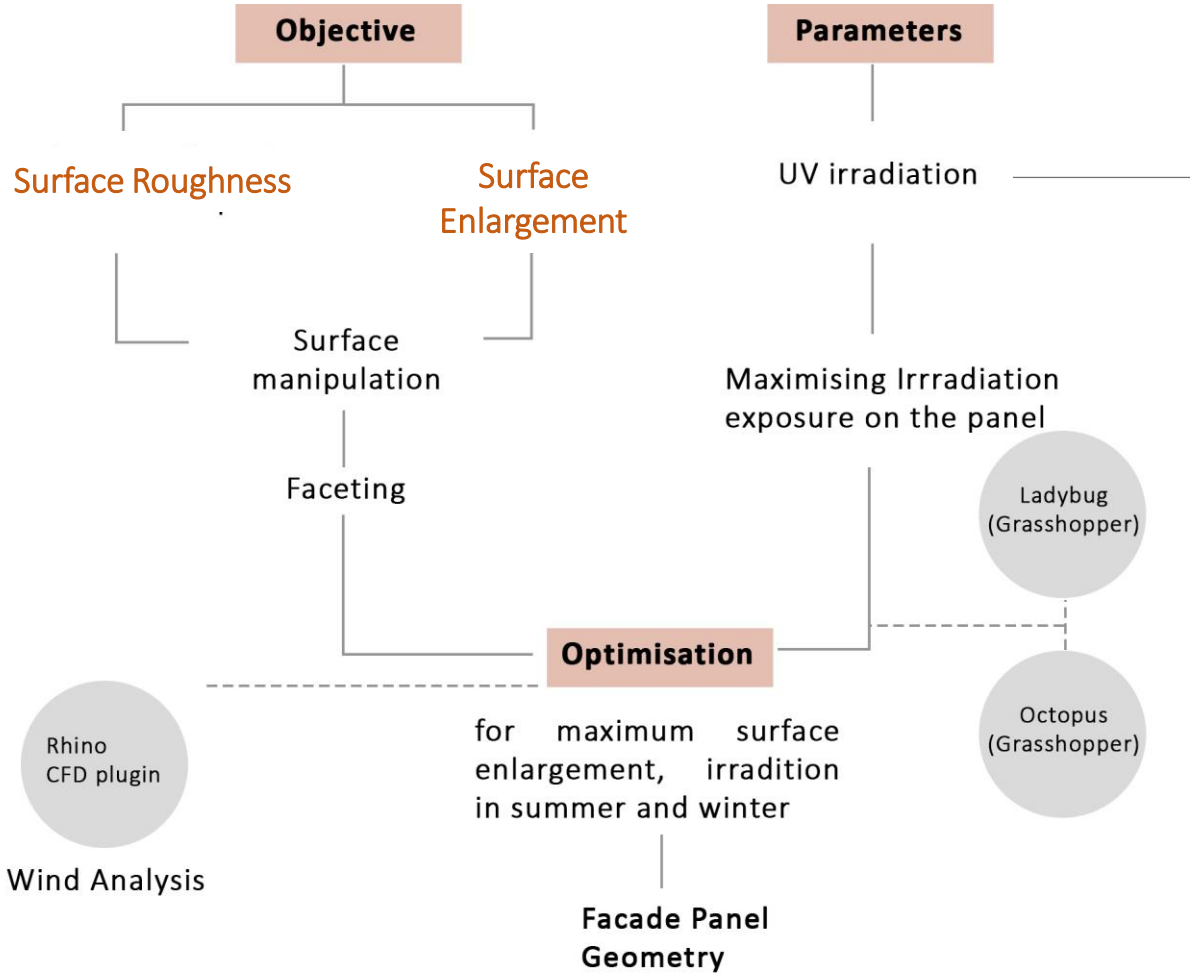
Arrangement of the panels



Velocity field at the surface of the facade panels at a height of 5 m from the base of the building

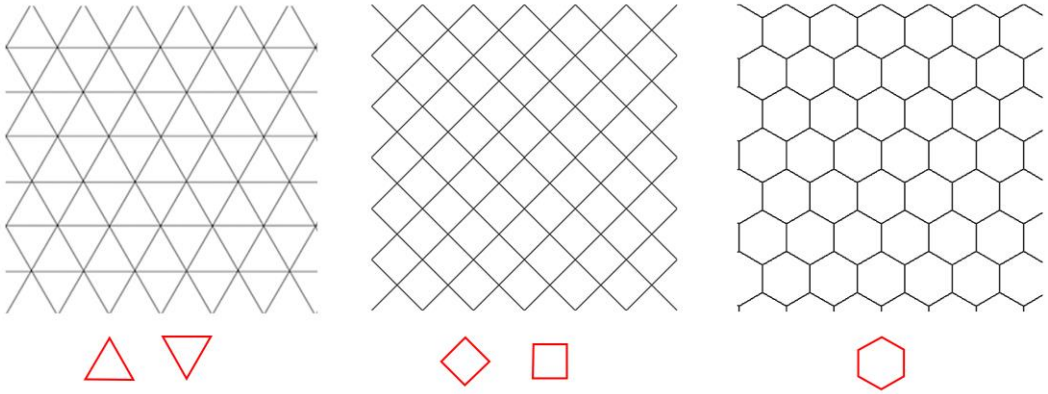
Alternating texture & Roughness elements with depth > 0.2 m is a variable for the façade geometry

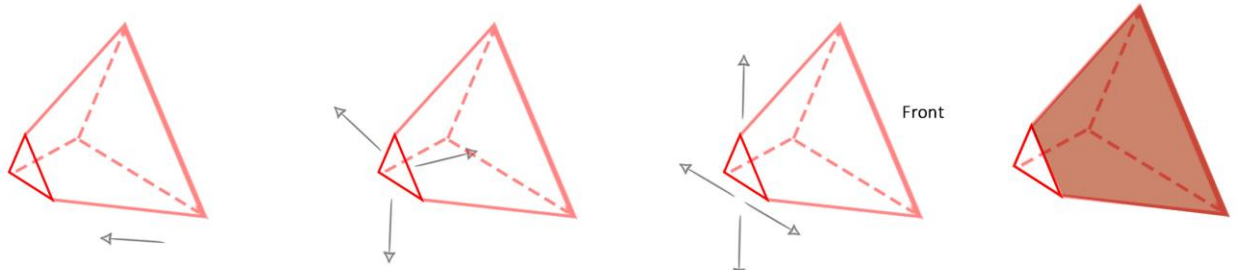
Conceptual Design



Amount of surface area with irradiation >10 W/m^2 over the sun hours

Conceptual Design





Design Goal: Maximizing radiation on the faces of the module

Variables

Depth : 0.1 – 0.5 m

along y direction

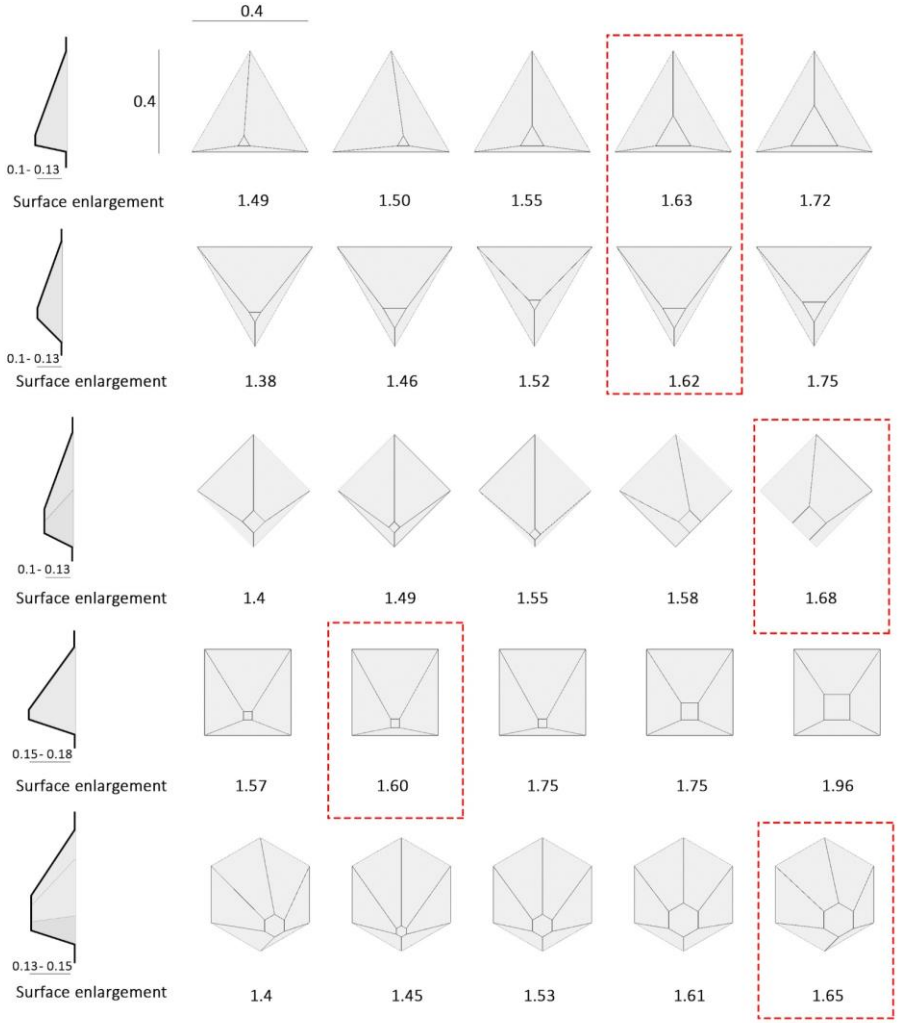
Scaling the tip

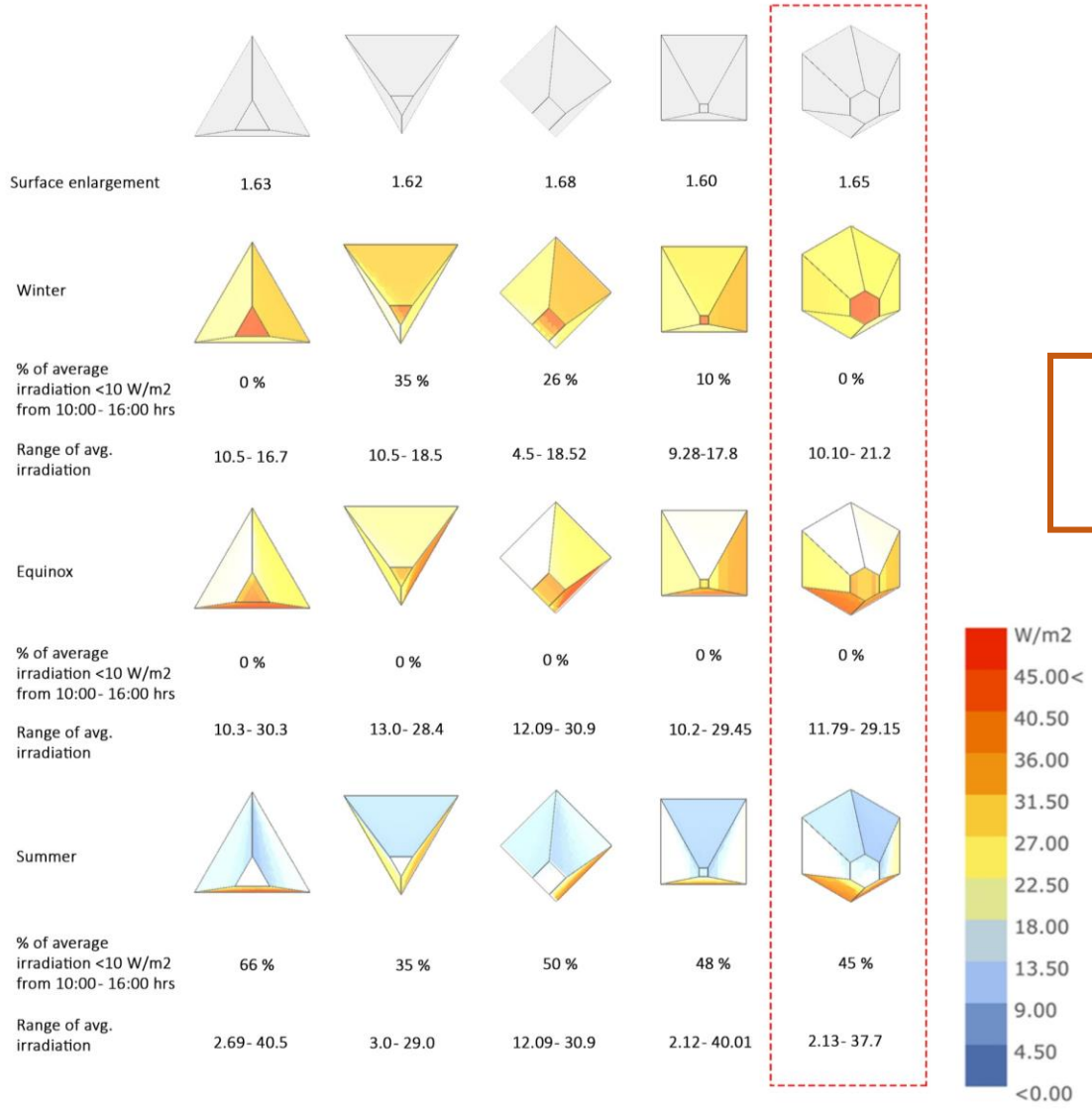
Movement along x, y & z axis

Resultant Change

Cardinal angles of the face

Conceptual Design

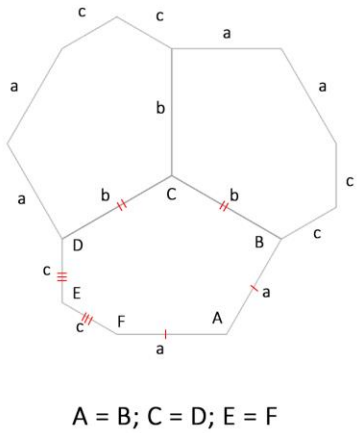




Hexagonal Geometry

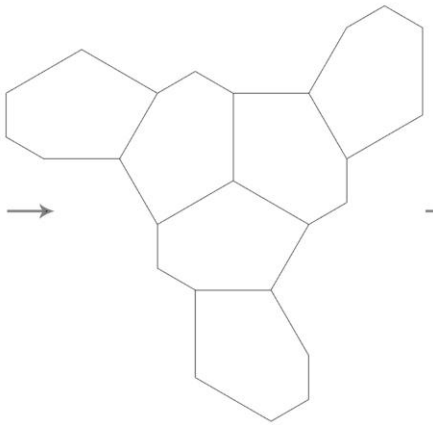
Conceptual Development

Façade tiling pattern

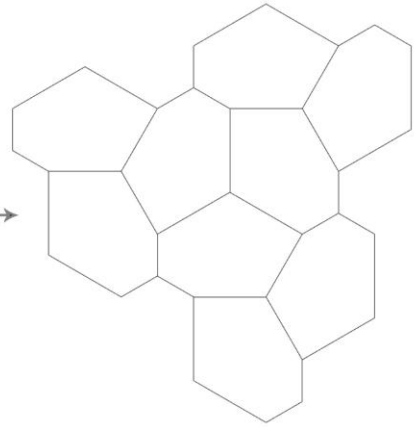


A = B; C = D; E = F

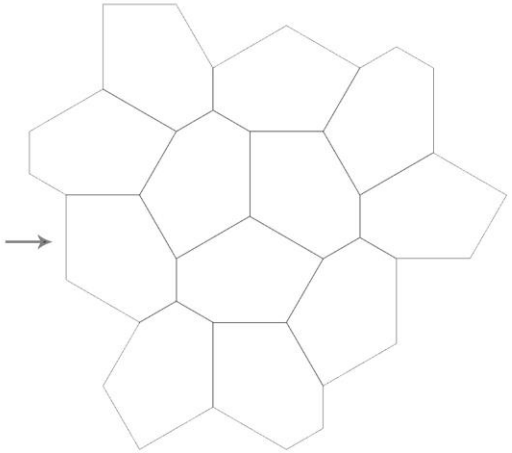
1 Hexagonal tile module



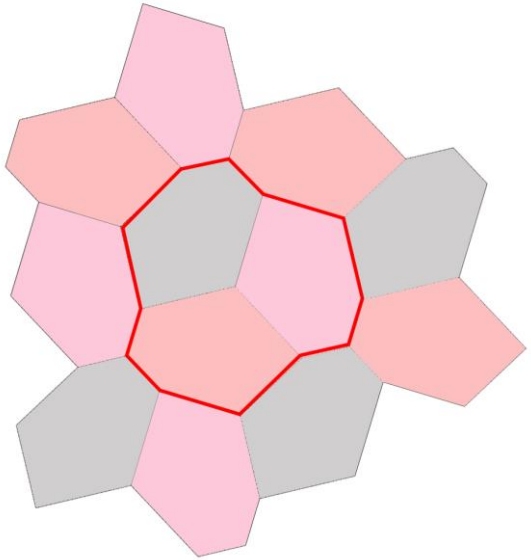
2 Rotation by 120°



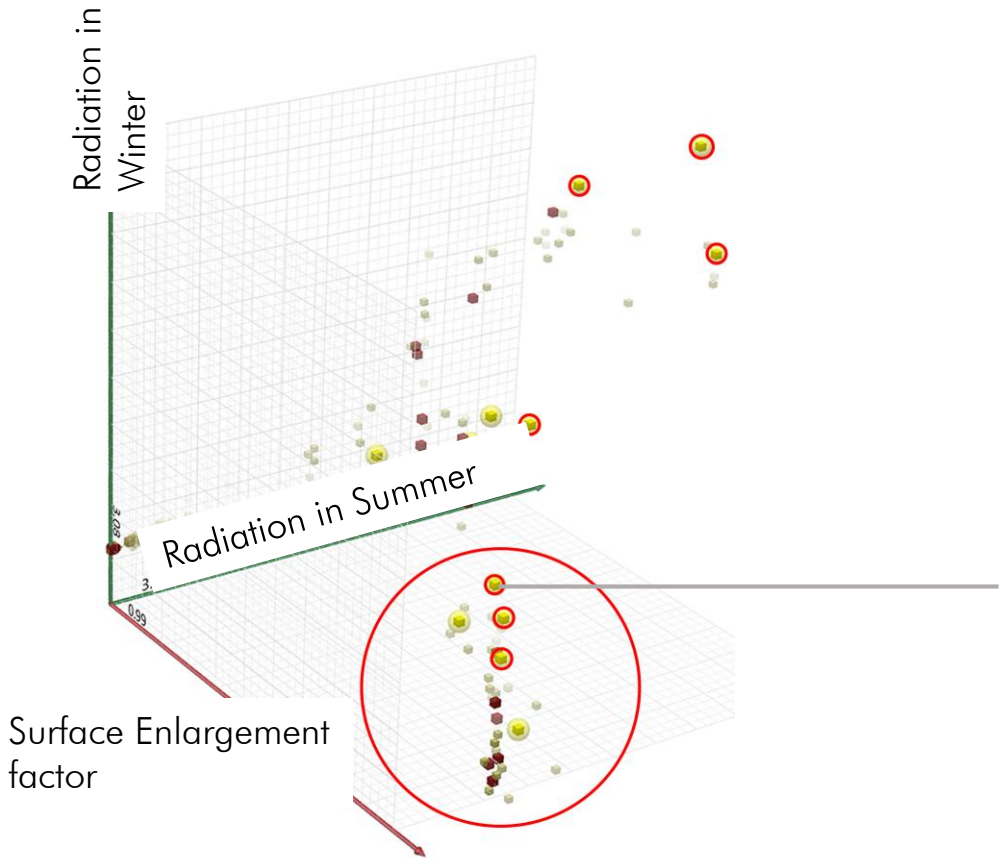
3



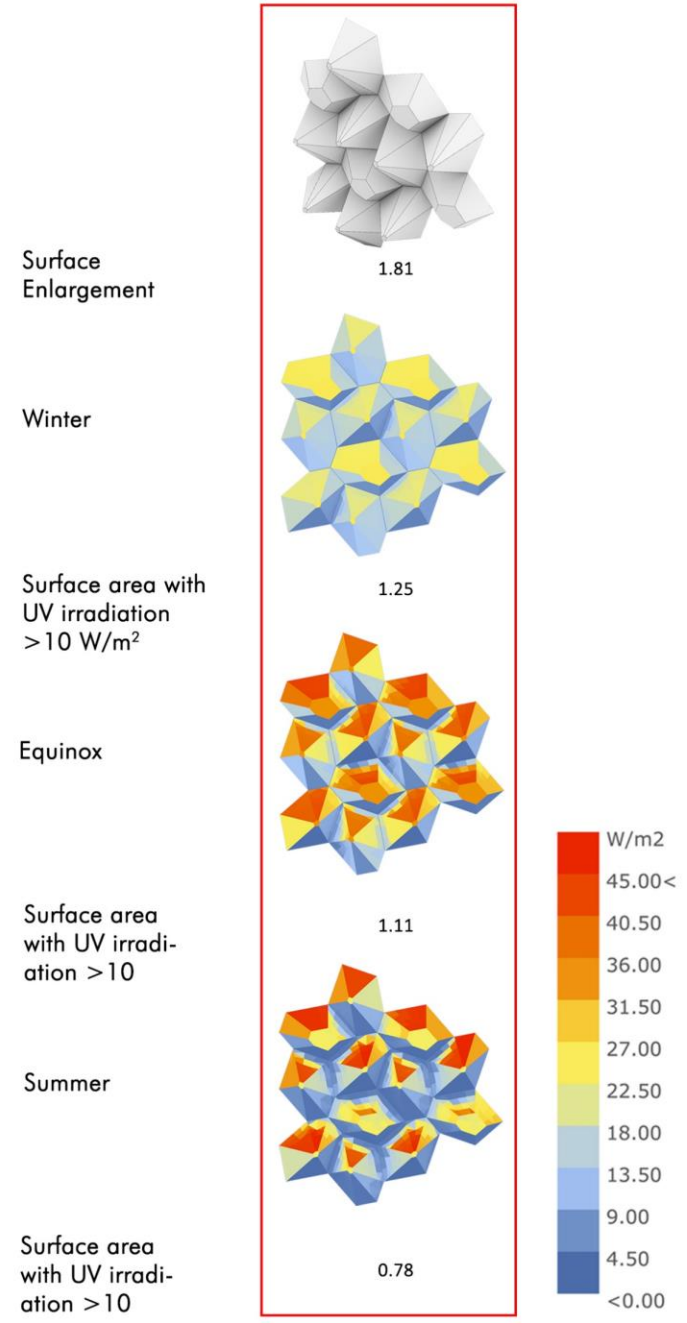
4



Optimization Results

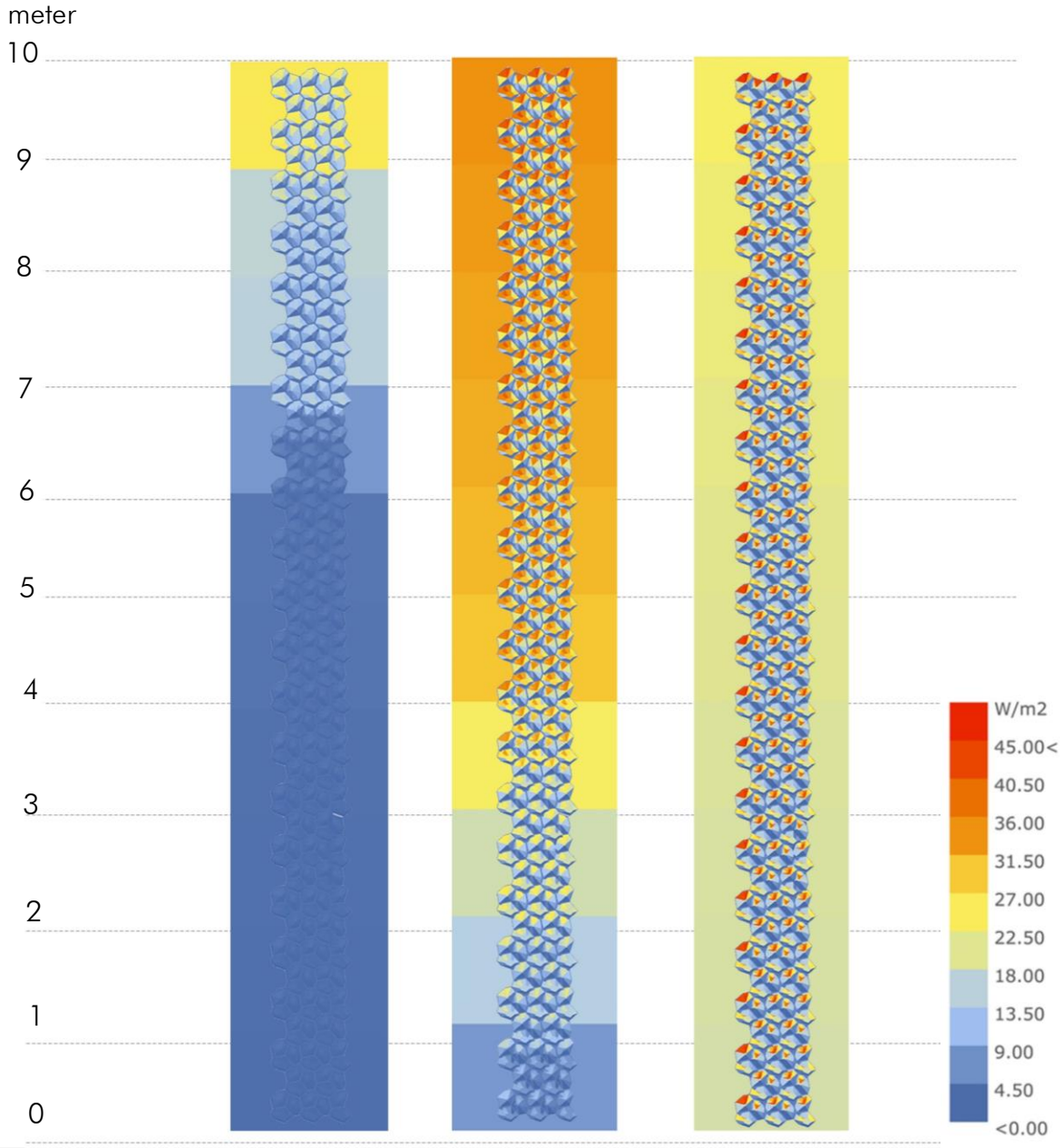


Optimization graph from Octopus

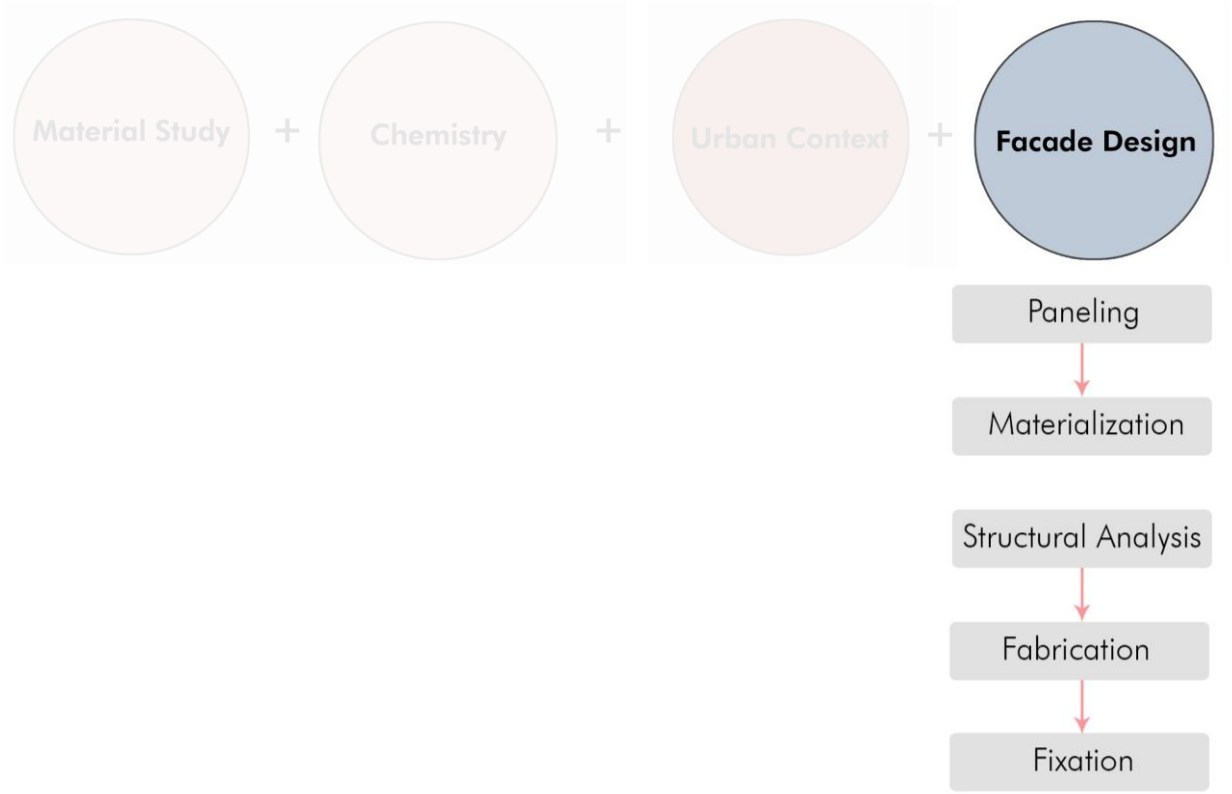


Application in Street Canyon

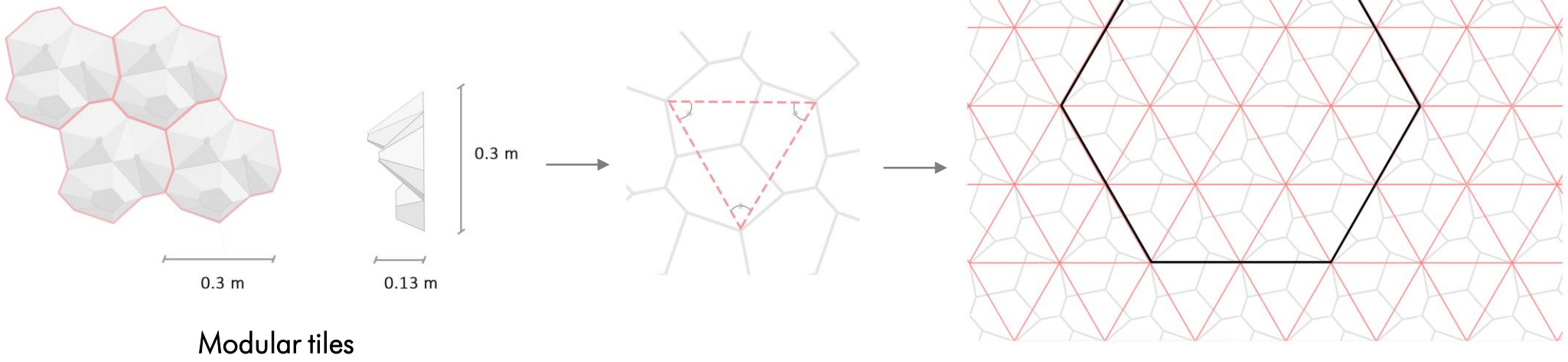
At the bottom most part of the street, a tile module has **35 – 40 % of surface area with twice the irradiance at that point on a flat facade**



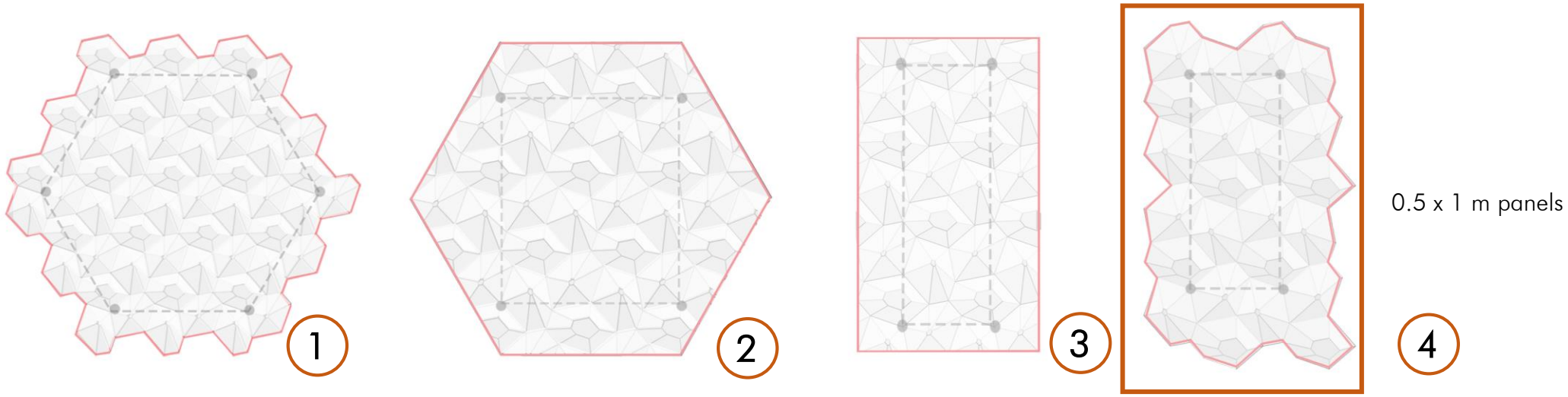
Design Development



Design Development

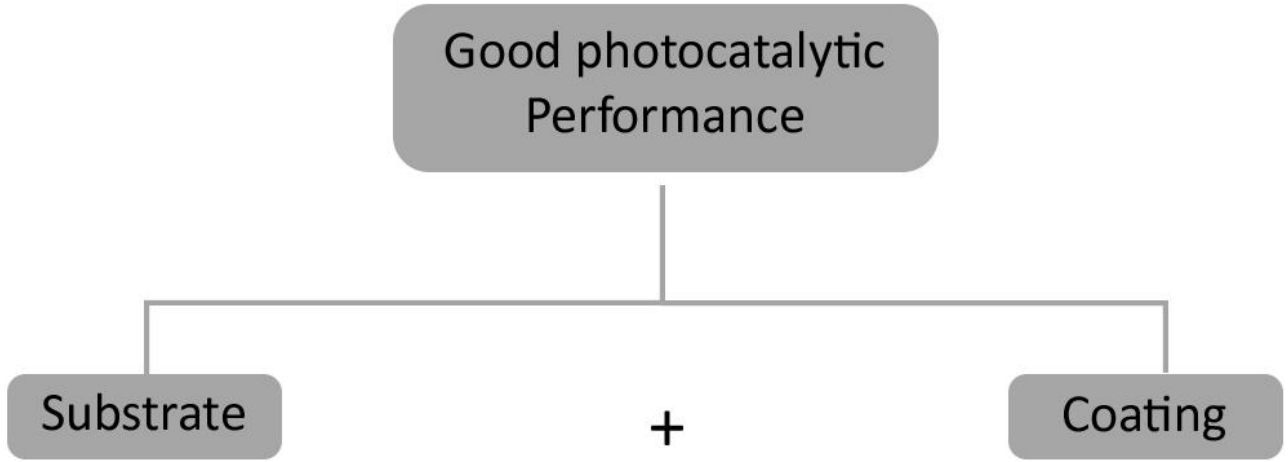


Modular tiles



0.5 x 1 m panels

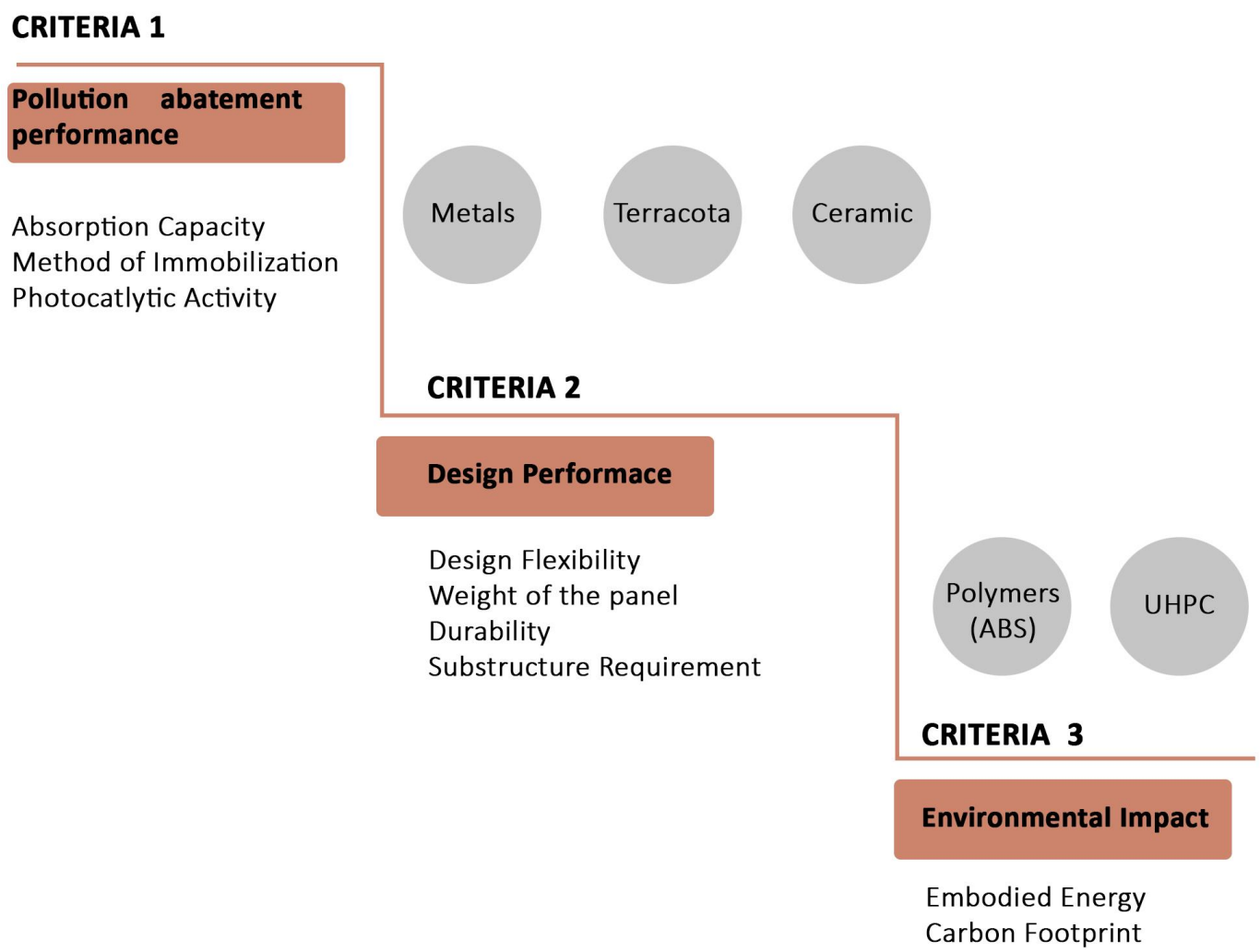
Materialization



- Non - reactive to TiO_2
- Good absorption capacity
- Geometry of the Substrate
- Highly durable

- Thickness of the film
- Technique of deposition (High temperature deposition inhibits photocatalysis)
- Highly durable

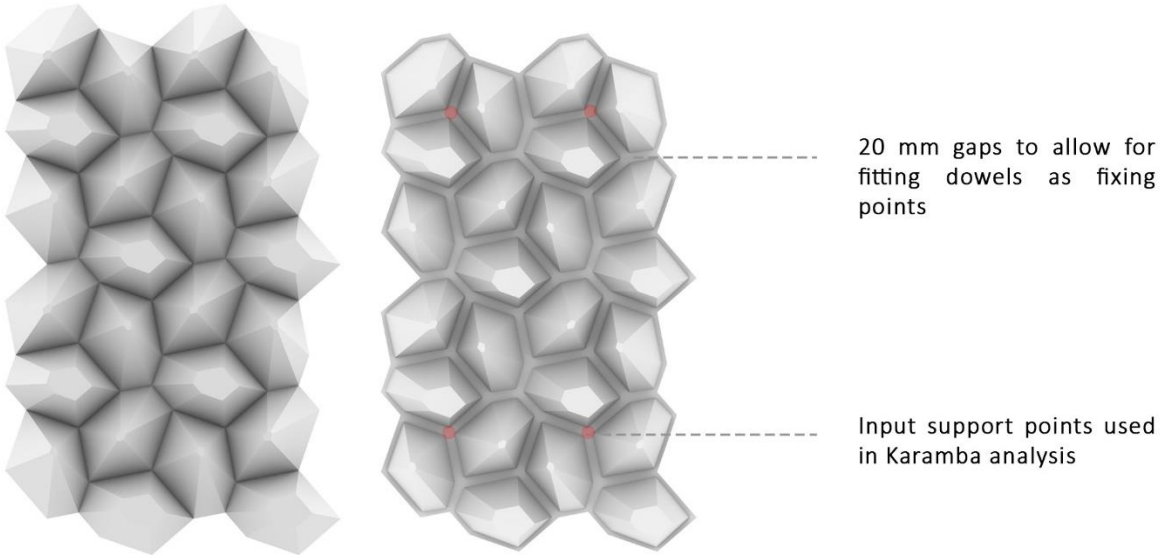
Materialization



** Acrylonitrile-butadiene-styrene*

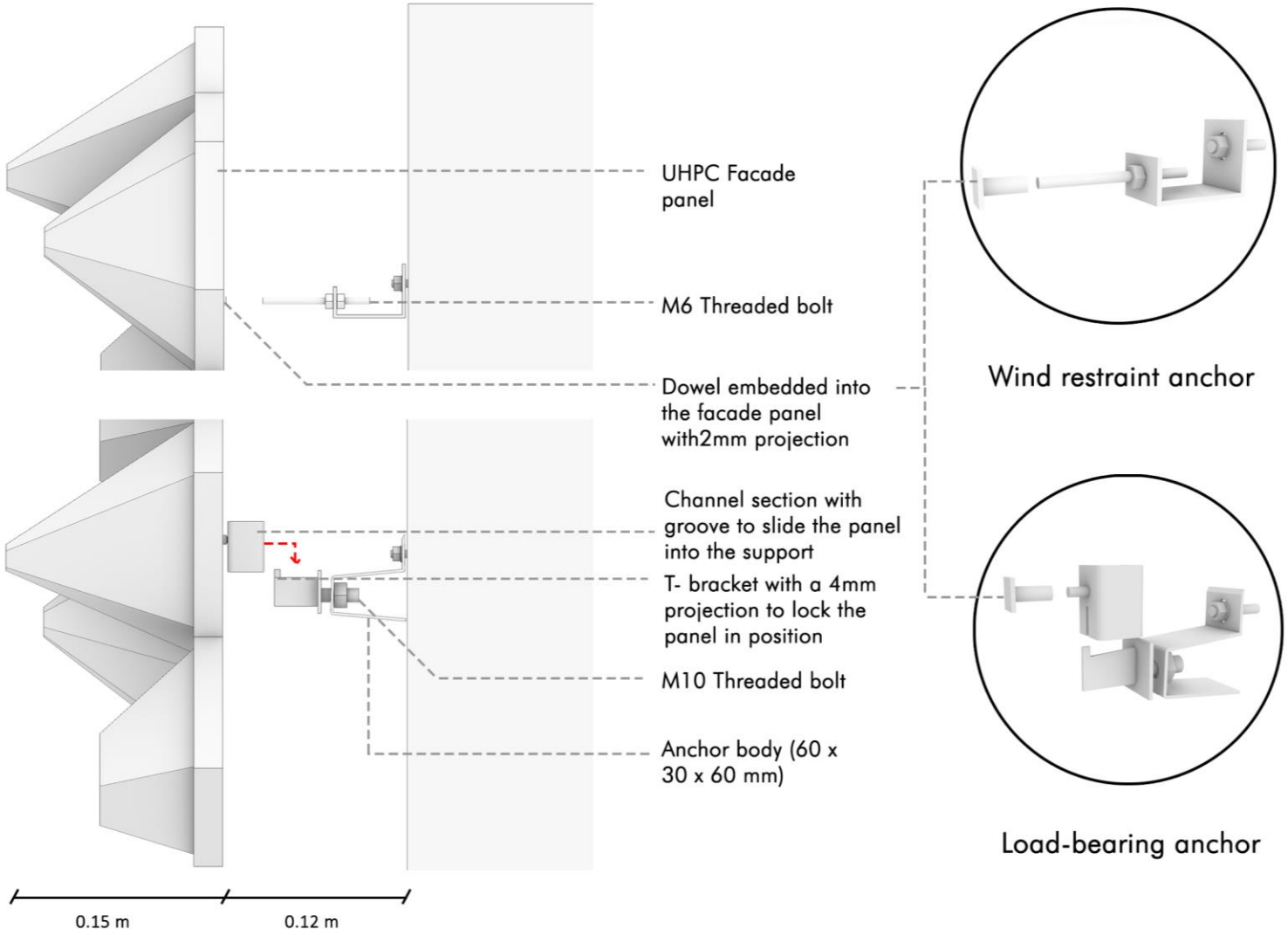
** UHPC : Ultra High Performing Concrete*

Materialization

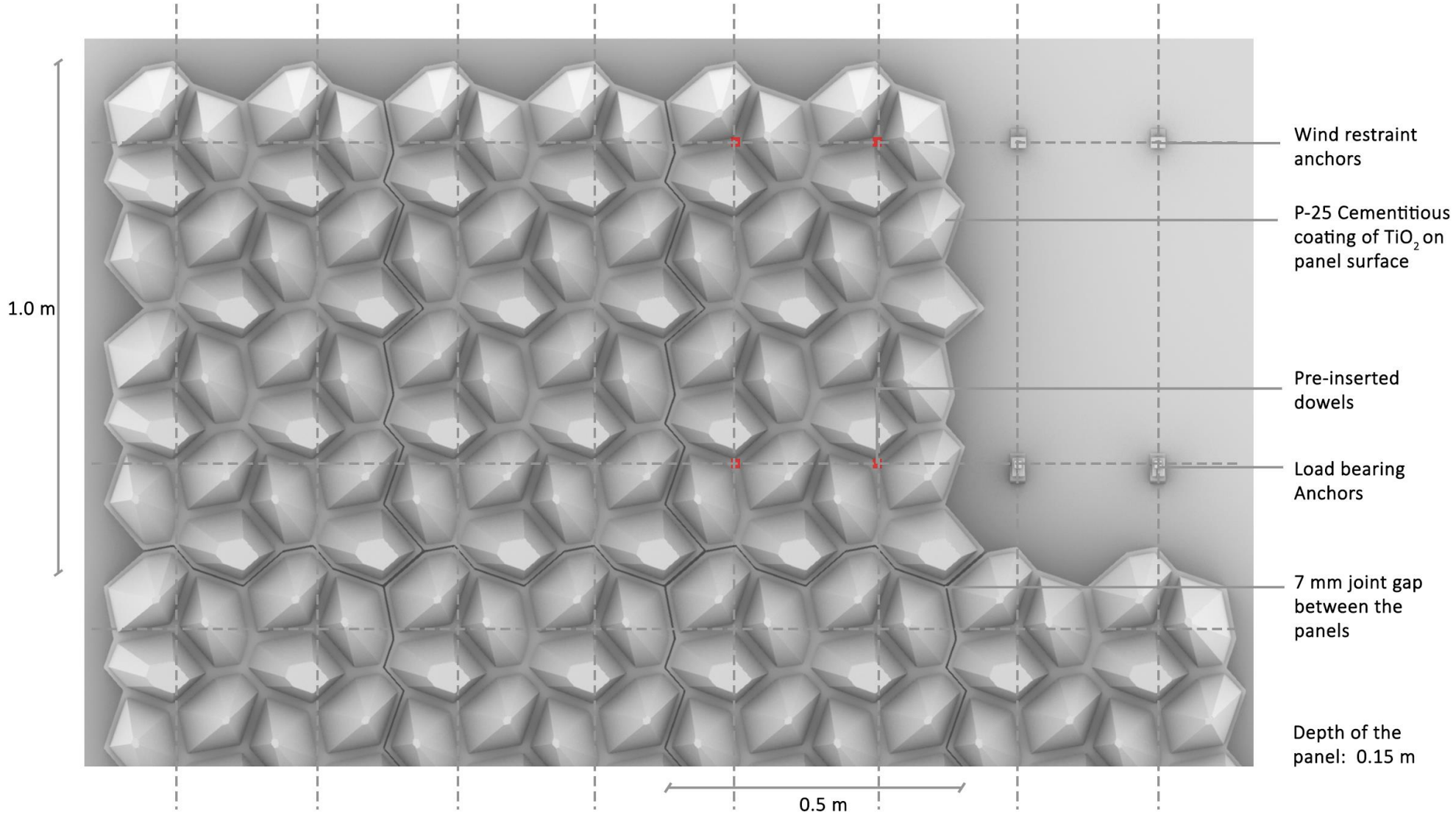


Material	UHPC	ABS Plastic
Thickness	15 mm	5 mm
Weight	35.45 Kg	**5.55 Kg**
Embodied energy	**275.75 MJ/Panel**	527.25 MJ/Panel

Fixing Method

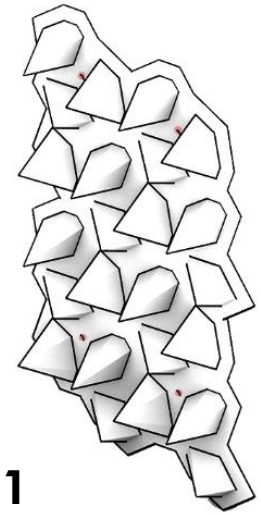


Fixing Method



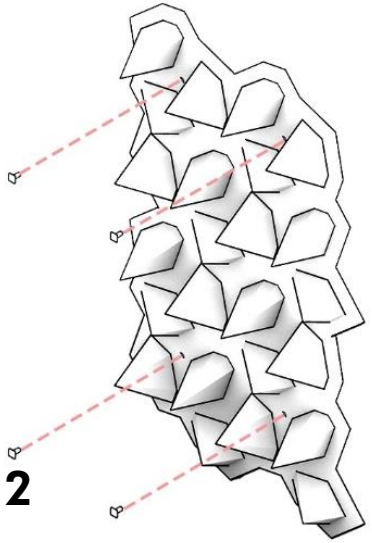
Fabrication Method

Injection Casting



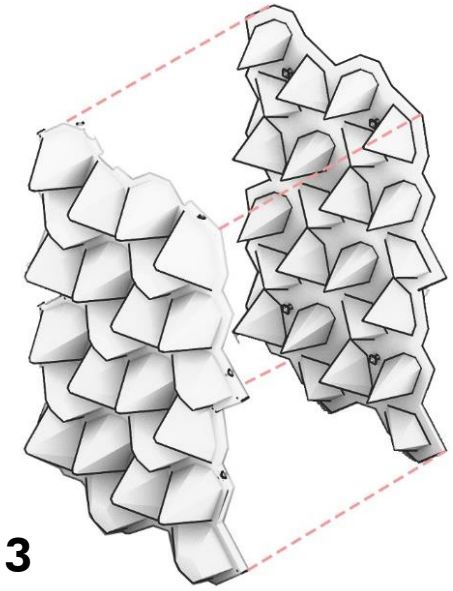
1

Holes are made in the mold



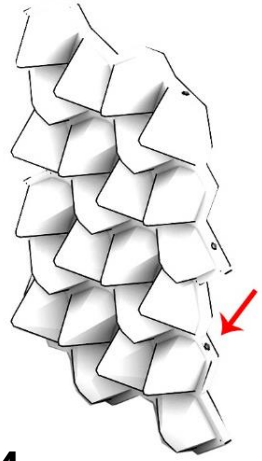
2

Dowels are fitted into the male mold.



3

Molds are clamped together



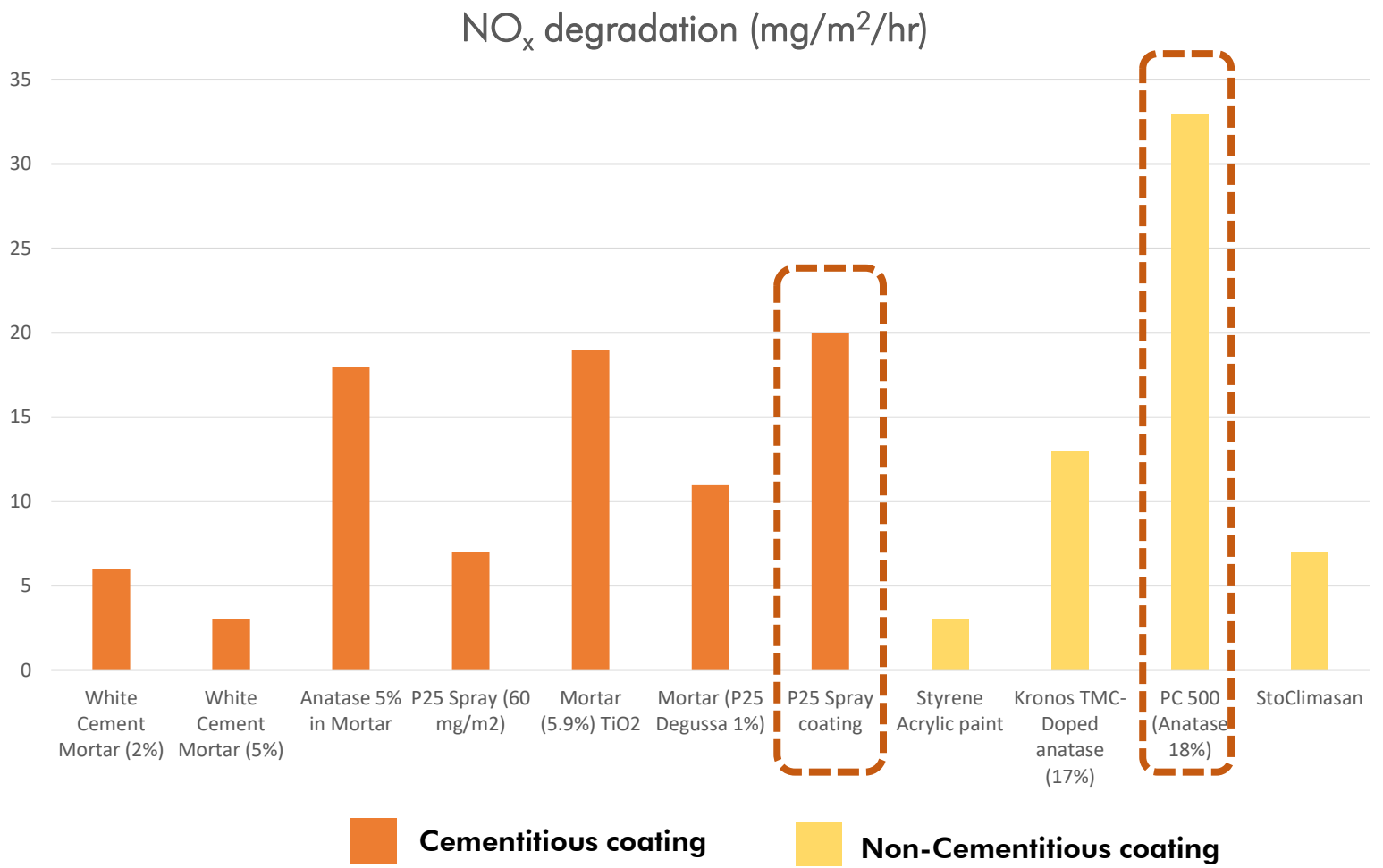
Free flowing UHPC is filled from below with using an upcrete peristaltic pump

4

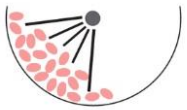
***Upcrete** is the name given to a method of pressure-filling a closed mould with concrete from the bottom to the top.*

Molds are clamped together

Surface Treatment



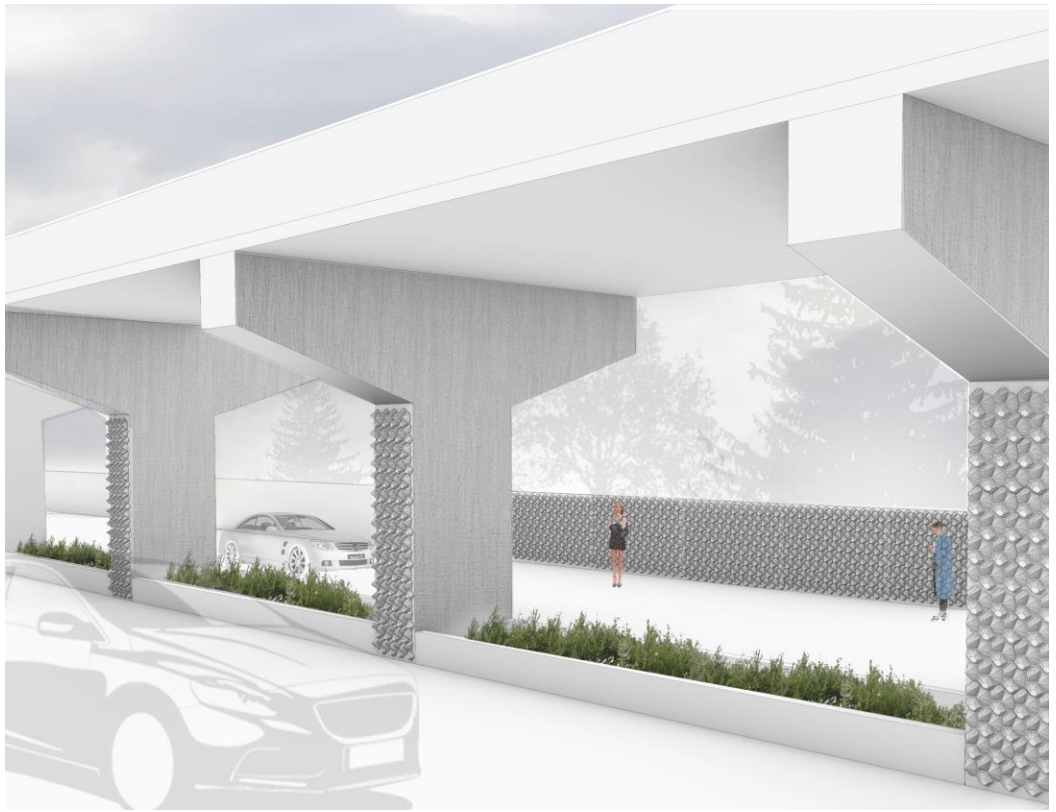
Types of TiO2 coating and their NO_x abatement performance



Facade panel is spray coated with TiO_2 PC500 (Anatase 18%) / P25 Spray coating

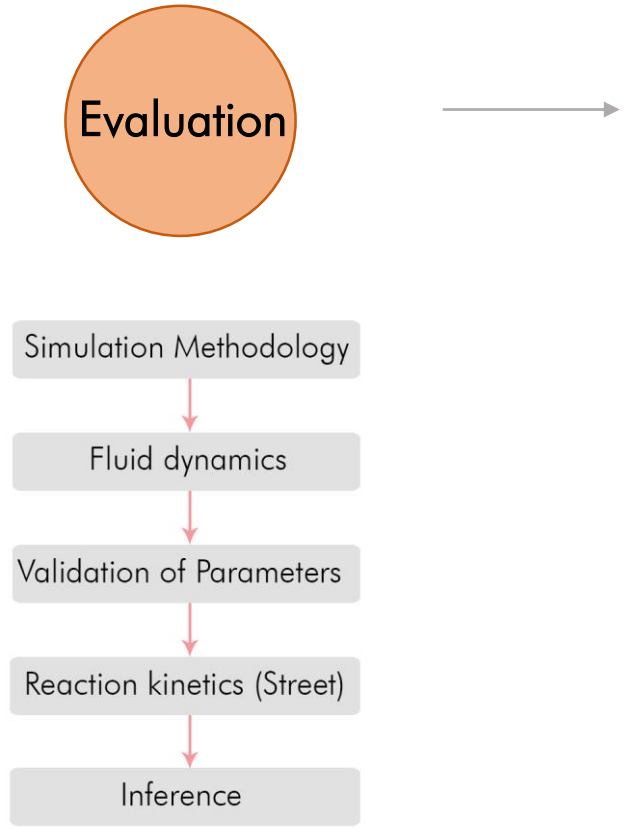
Application in Urban areas

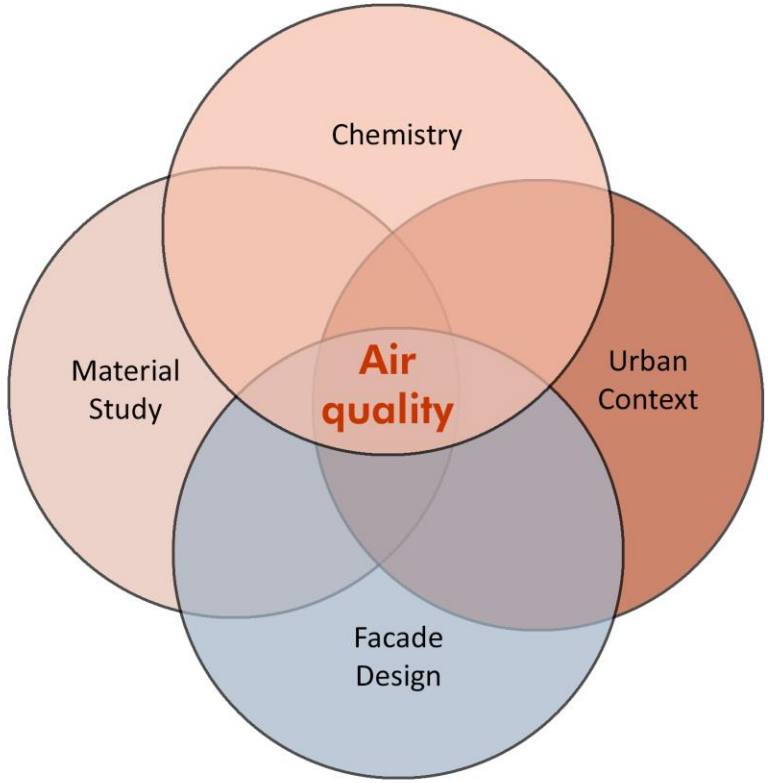
Elevation of a south facade



Application in roadways and acoustic barriers

Air Purification Effect





Langmuir-Hinshelwood Model

$$r_{NO} = -1 \frac{K_d C_{g(NO)}}{1 + K_d C_{g(NO)}} \alpha_1 \left(-1 + \sqrt{1 + \alpha_2 E}\right)$$

K_d ⟶  RH

Where r_{NO} is the reaction rate at the active surface for NO [mol/m^3/s]

k
is the **reaction rate constant** for the degradation of NO [mol/m^3/s]

K_d is the **effective adsorption equilibrium constant** for NO which is a function of RH at 50 % [m^3/mol]

C_{NO}
is the concentration of NO in the air over the active surface [mol/m3]

Langmuir-Hinshelwood Model

$$r_{NO} = -1 \frac{K_d C_{g(NO)}}{1 + K_d C_{g(NO)}} \alpha_1 \left(-1 + \sqrt{1 + \alpha_2 E}\right)$$

E ⟶ 

UV

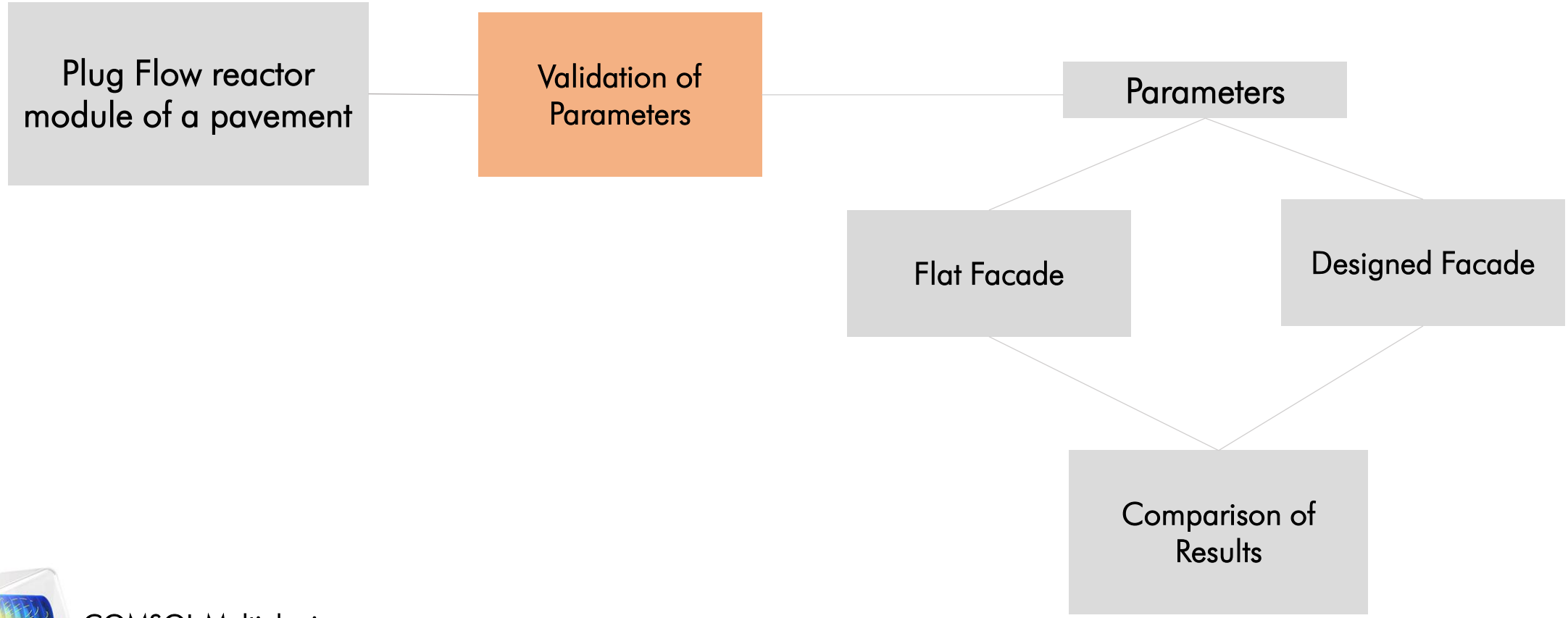
Where r_{NO} is the reaction rate at the active surface for NO [mol/m^3/s]

k
is the **reaction rate constant** for the degradation of NO [mol/m^3/s]

K_d is the **effective adsorption equilibrium constant** for NO which is a function of RH at 50 % [m^3/mol]

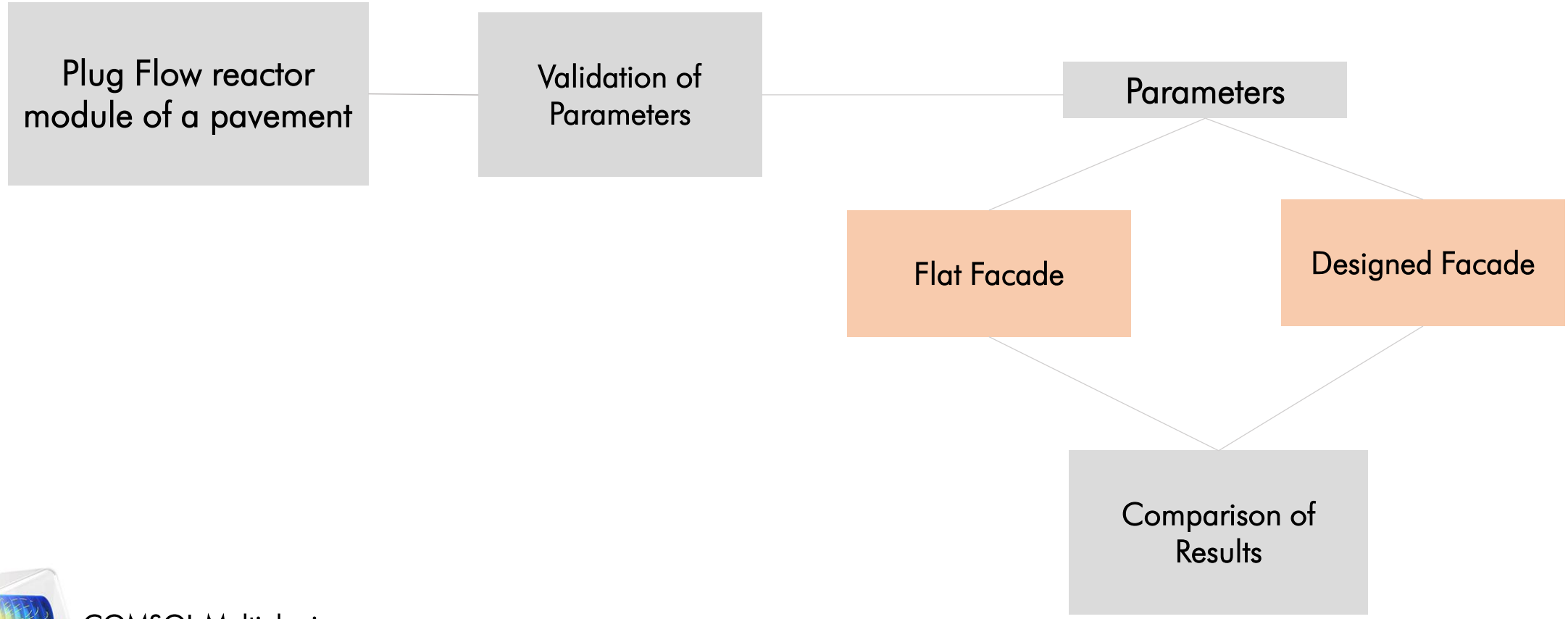
C_{NO}
is the concentration of NO in the air over the active surface [mol/m3]

Evaluation Methodology



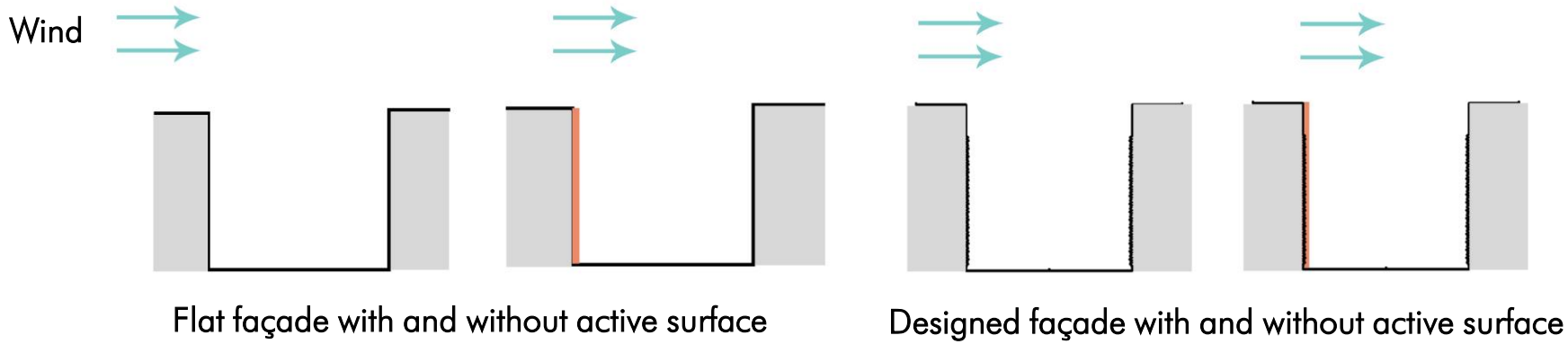
COMSOL Multiphysics

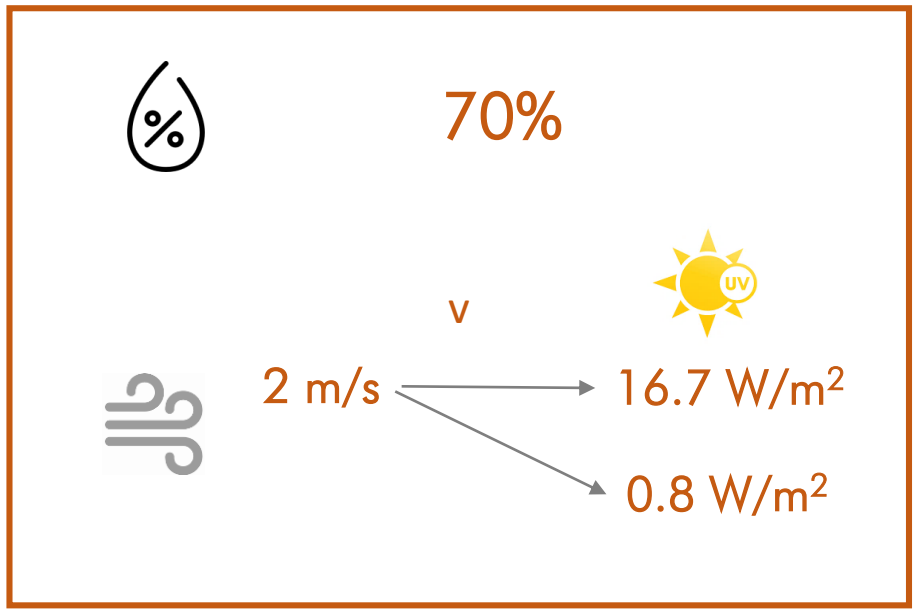
Evaluation Methodology

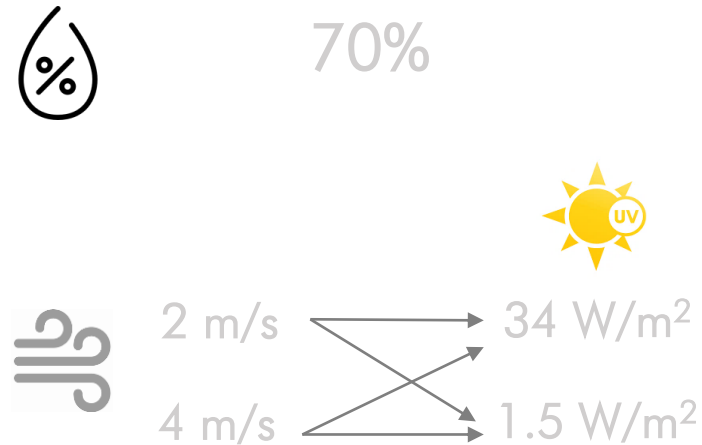


COMSOL Multiphysics

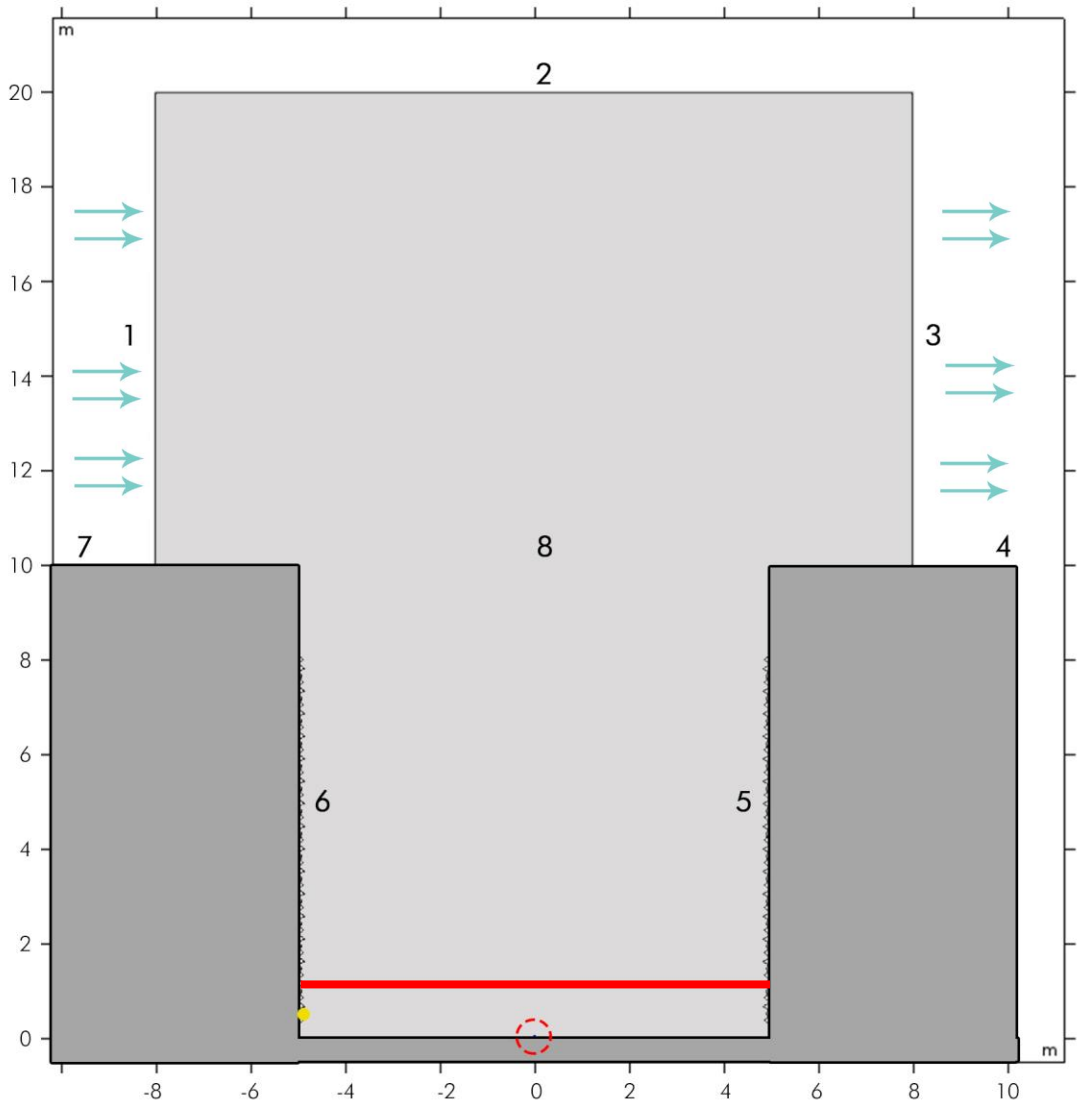
Analysis Scenarios for the street

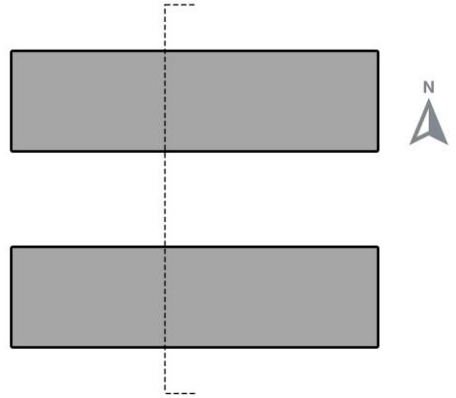






Street Model

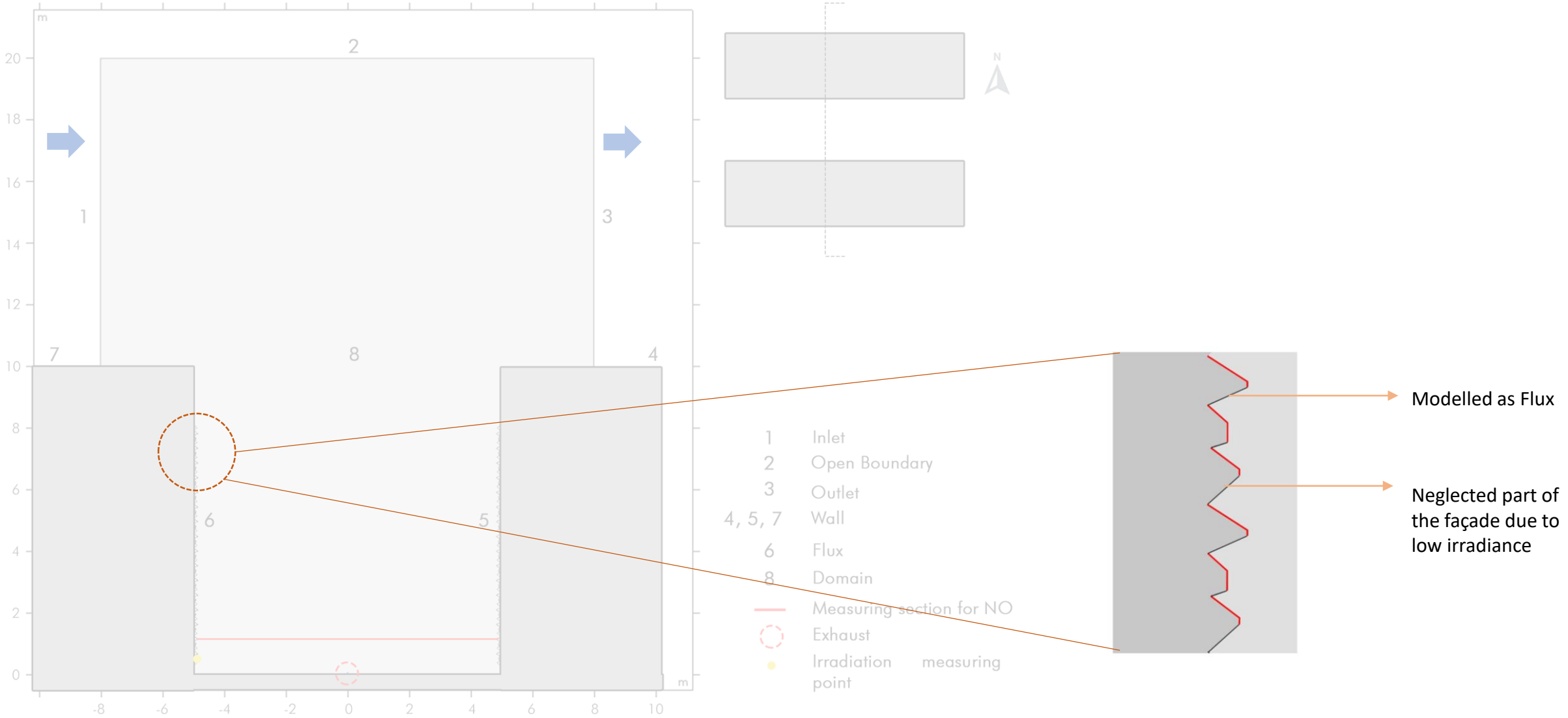




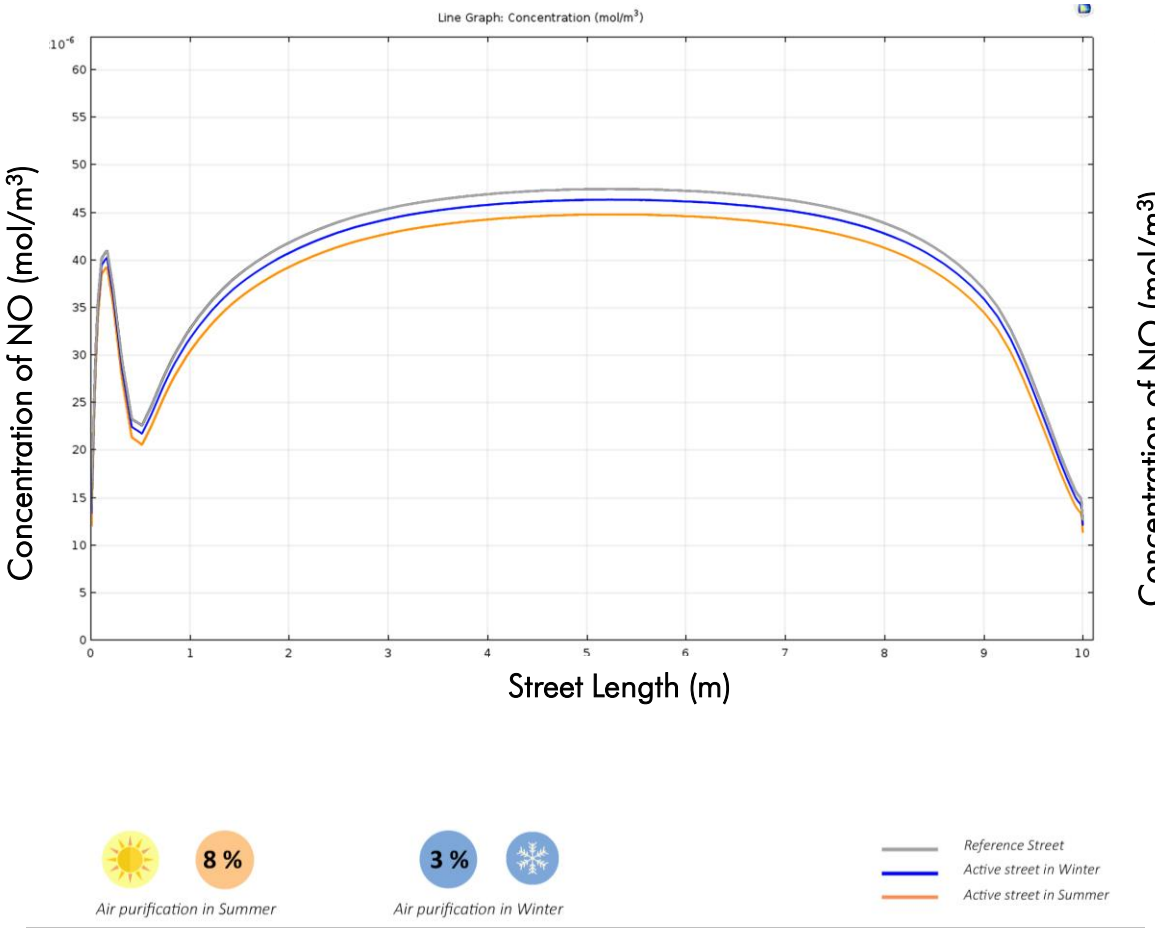
Top view of the street

1	Inlet
2	Open Boundary
3	Outlet
4, 5, 7	Wall
6	Flux
8	Domain
—	Measuring section for NO
○	Exhaust
●	Irradiation measuring point

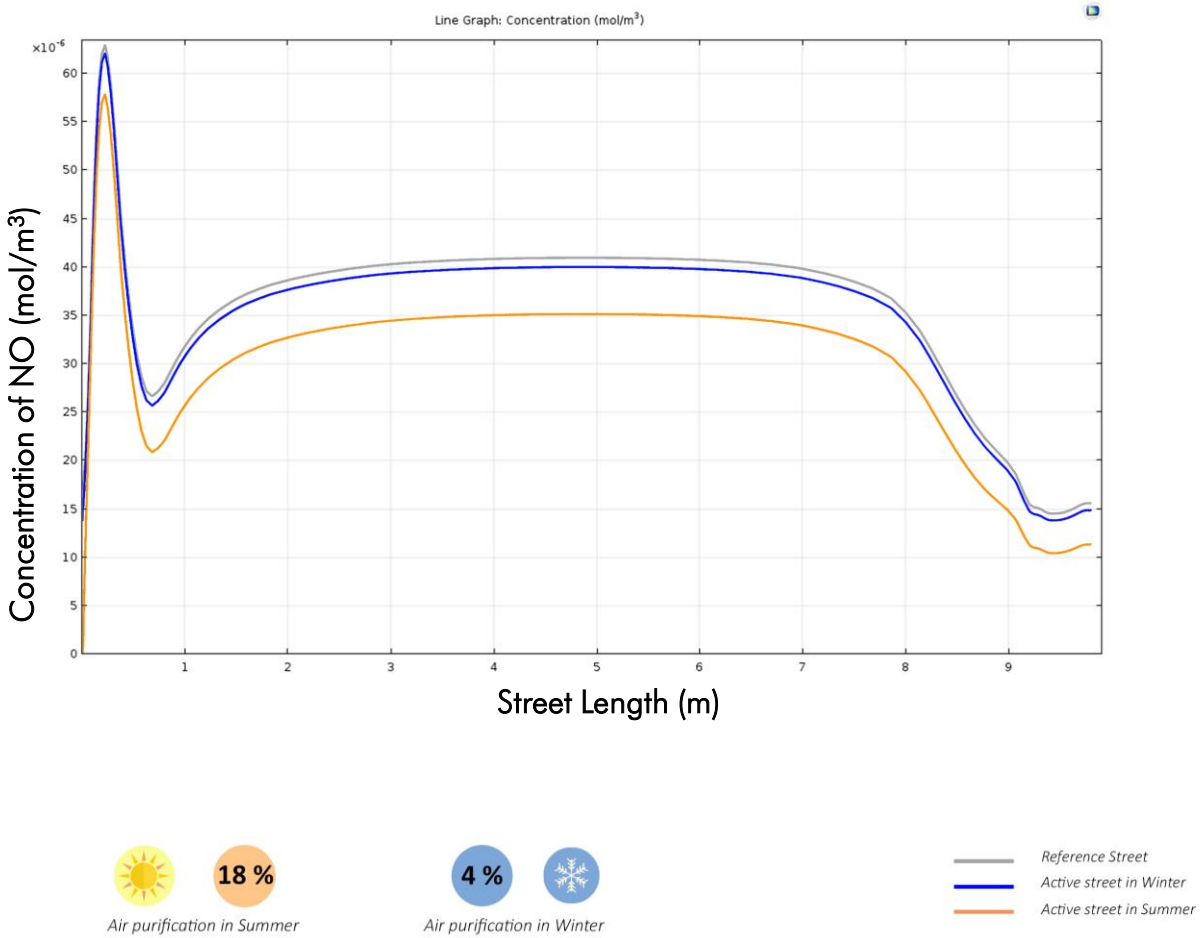
Street Model



Comparison of a flat and designed panel

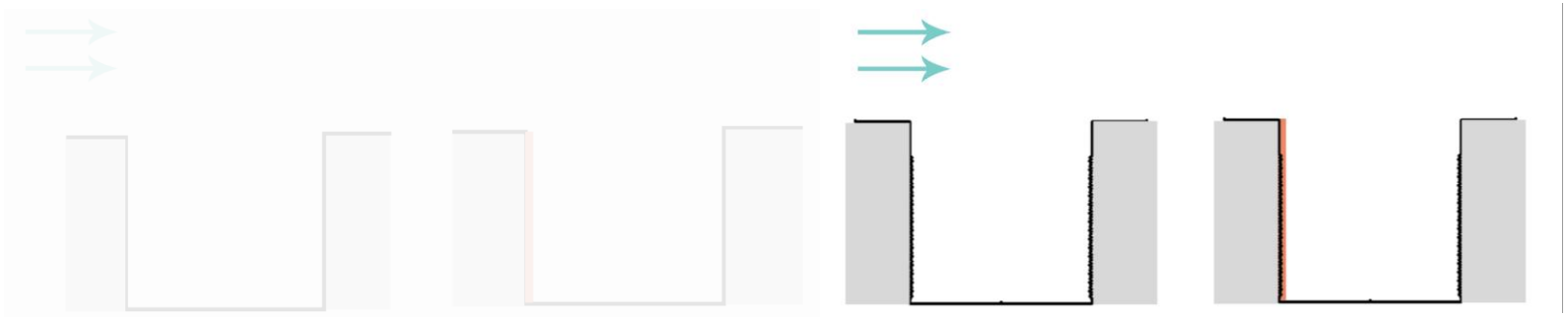


NOx abatement results for the flat panel



NOx abatement results for the designed panel

Analysis Scenarios for the street



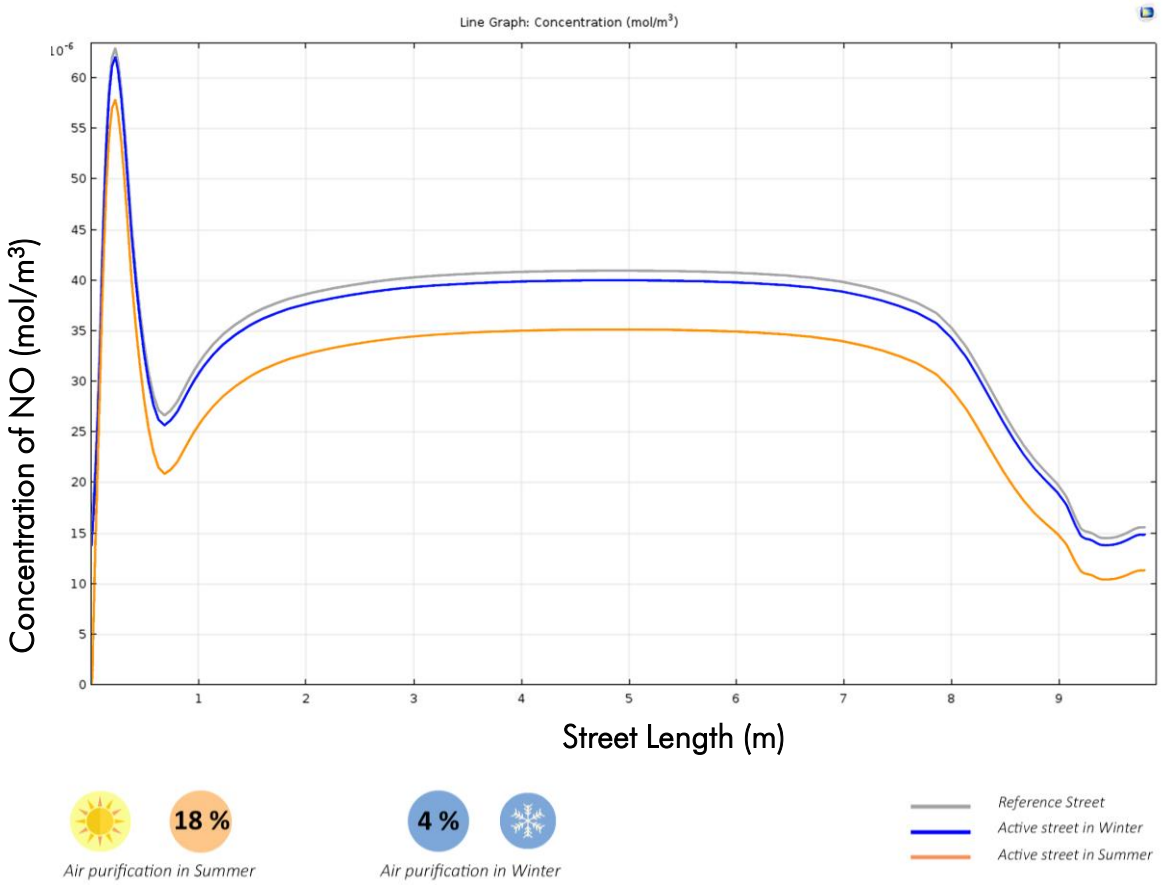
Designed façade with and without active surface

70%

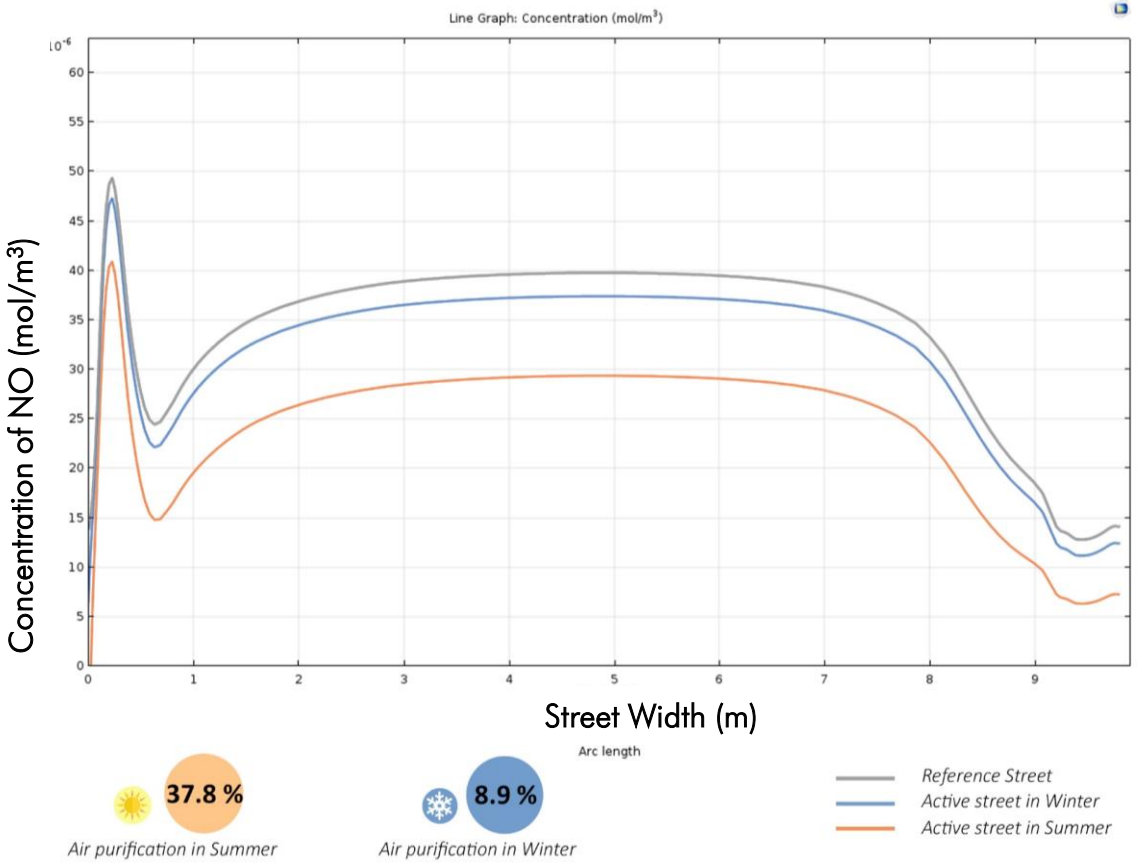
2 m/s → 34 W/m²

4 m/s → 1.5 W/m²

Comparison of a flat and designed panel

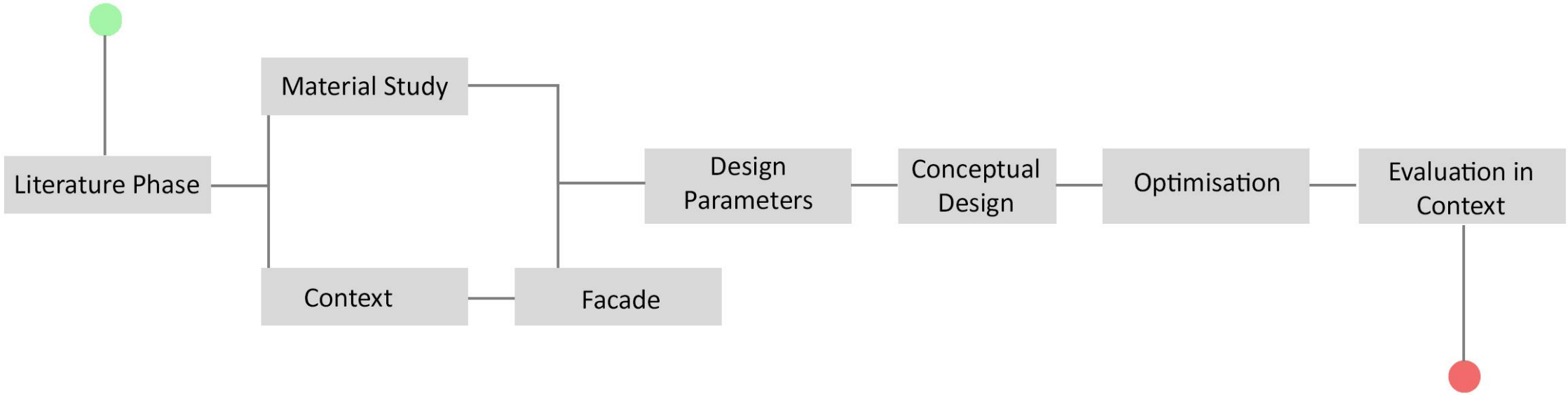


NOx abatement results for the designed panel (2 m/s)



NOx abatement results for the designed panel (3 m/s)

Conclusion



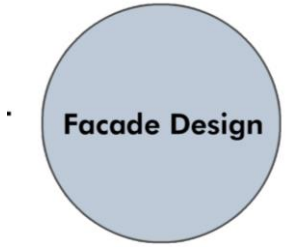
Air Purification

3 – 18 % at low wind velocity (at 2 m/s)

8 – 37.8 % at low wind velocity (at 3 m/s)

Recommendations

- Life cycle assessment
- Environmental impact of nanoparticles



Optimizing for various orientations

Simulations

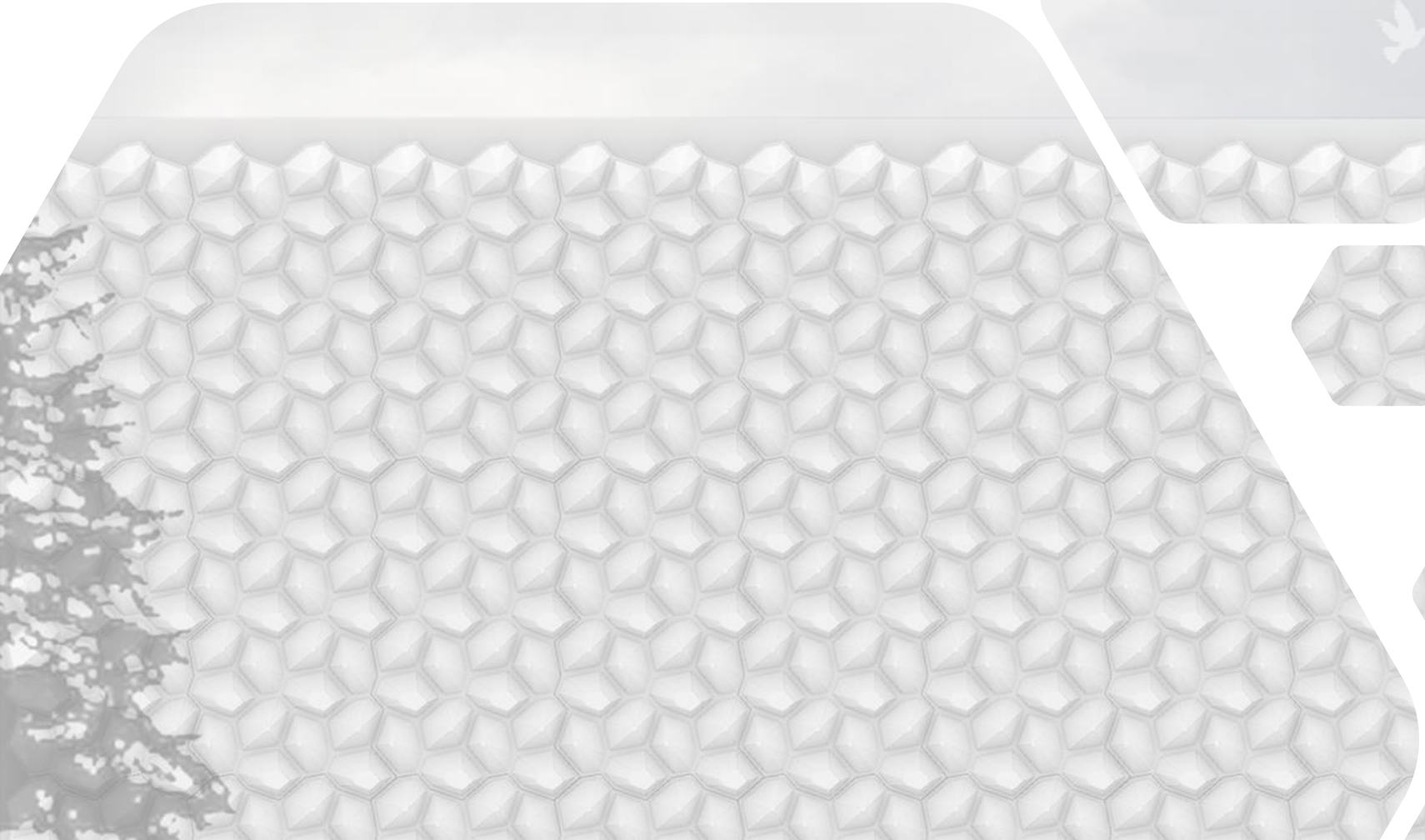
Including a time dependent model

Physical tests

- Fabricating the façade geometry and iterations
- Field tests to test air purifying effect

Questions?

Thank You!



Additional Slide: Wind Velocity Field