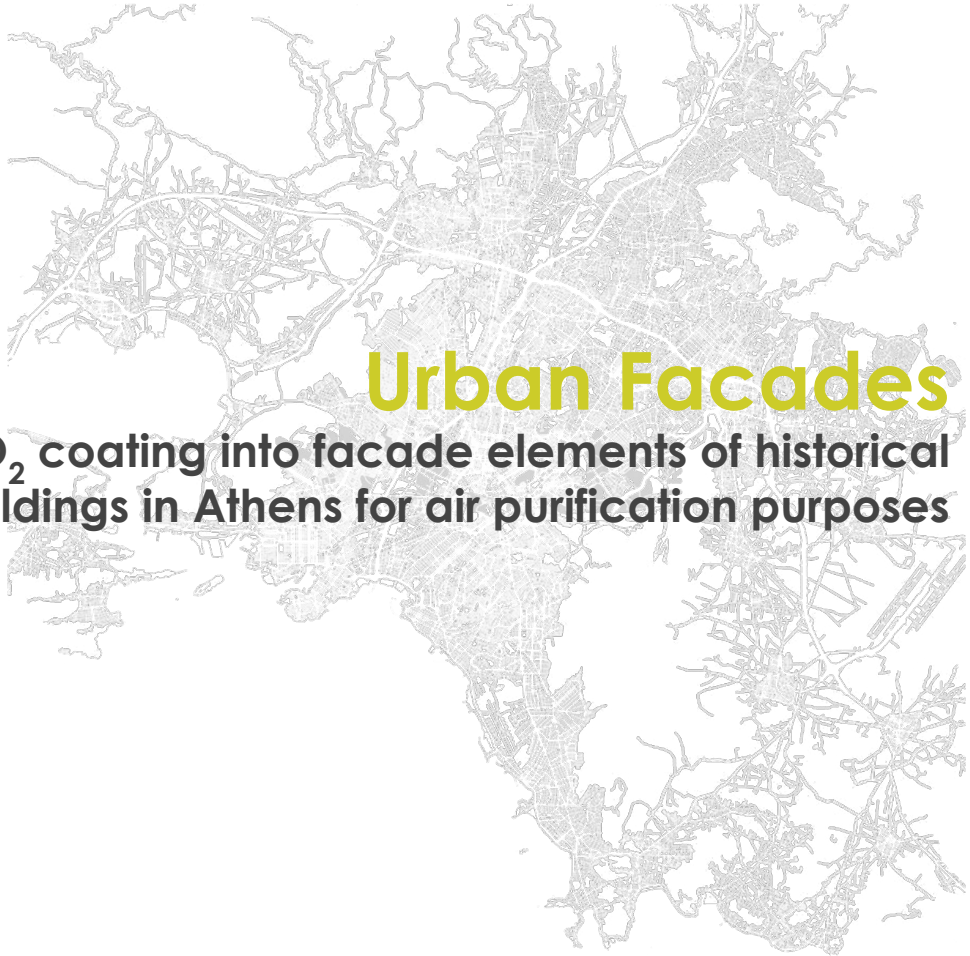


Urban Facades

Integration of TiO_2 coating into facade elements of historical buildings in Athens for air purification purposes

Olympia Apostolopoulou
5140242

INTRODUCTION

Problem: Air pollution and its negative effects

- Primary and secondary air **pollutants**
- Different **sources** and **types**
- Adverse effects on the Environment I Health I **Built Environment**
- Many **abatement strategies** for its reduction

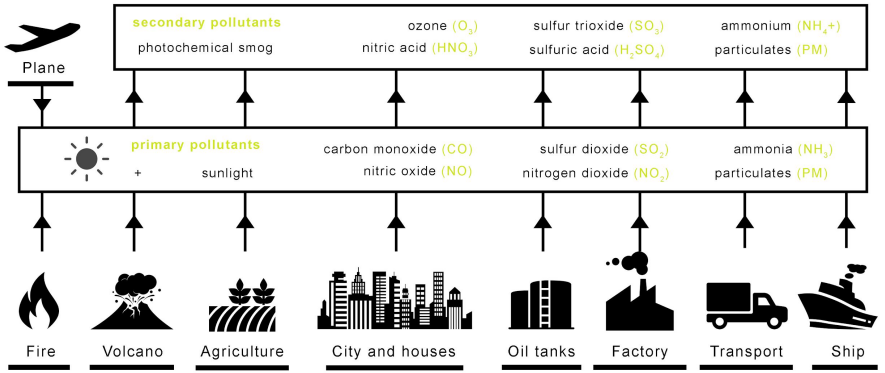
Need for:

➔ Selection of a specific **location**
➔ Focus on **building industry** and its reduction policies
➔ Focus on historical building stock
➔ Study of **TiO_2** as a promising air purification strategy

_Europe

_Greece

_Athens



_Type and sources of air pollutants

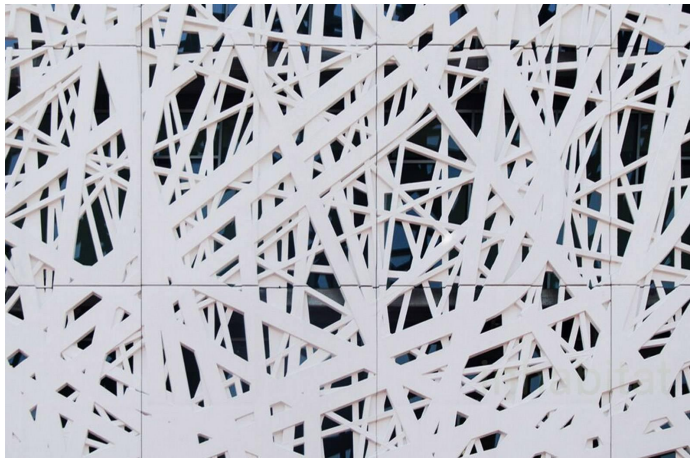
Problem statement

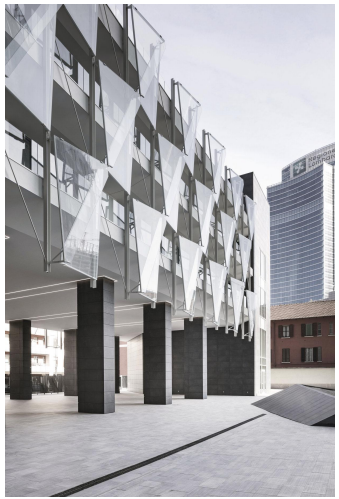
Problem statement: Why are TiO_2 coatings not widely used in the building industry?

- Lack of **prefabricated** units/products
- Lack of **technical knowledge**
- High **cost**
- Lots of **maintenance**
- Degradation of **durability** of coating
- Degradation of **photocatalytic activity** of coating
- Reduction of NOx abatement **removal** from facades

Need for:

➔ Enhancement of **durability** and **photocatalytic activity**
➔ Promotion of **widespread application**





WIDESPREAD APPLICATION

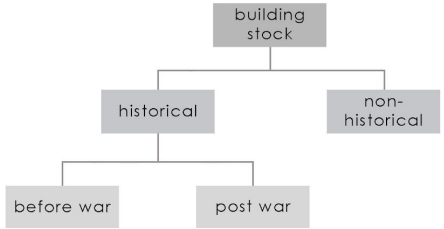
- **What is meant by "widespread application"?**
- **What would make this happen?**

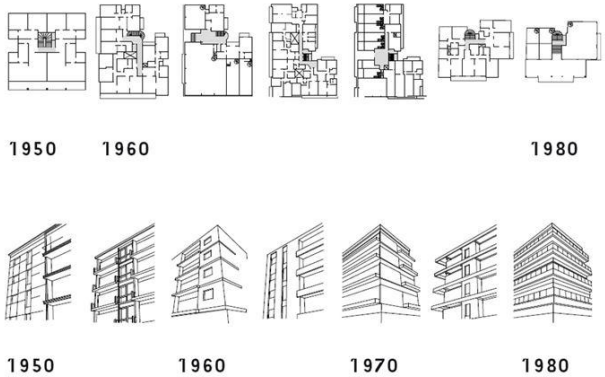
- TiO_2 can't be applied in the **same way** in all historical buildings
- Variety in **typologies**
- **Limitations** (administrative, aesthetical, financial, ownership)

➔ Prefabricated system doesn't work for all the cases
➔ Not feasible for all the historical stock

- **Need for a different approach regarding "widespread application"**

1. Creation of different **levels** of application
2. Division of facade into its **components** and
3. Decision on which level of **application** will be applied on each facade component (criterio needed)





Richard Woditsch, Plural. Public and Private Spaces of the Polykatoikia in Athens, Doctorate, TU Berlin 2009, pages. 74-75

Objective I research question

Main objective: to develop a **framework/roadmap** regarding the different ways a **TiO_2** coating can be applied on the various components of existing facades of **historical buildings** in Athens, in order to contribute to the **NOx** removal in the proximity of its application

How can a **TiO_2** coating be integrated differently on the various components of a facade, in order to find wider application on existing facades of **historical buildings** in Athens and to contribute to the **NOx** removal in the proximity of its application?

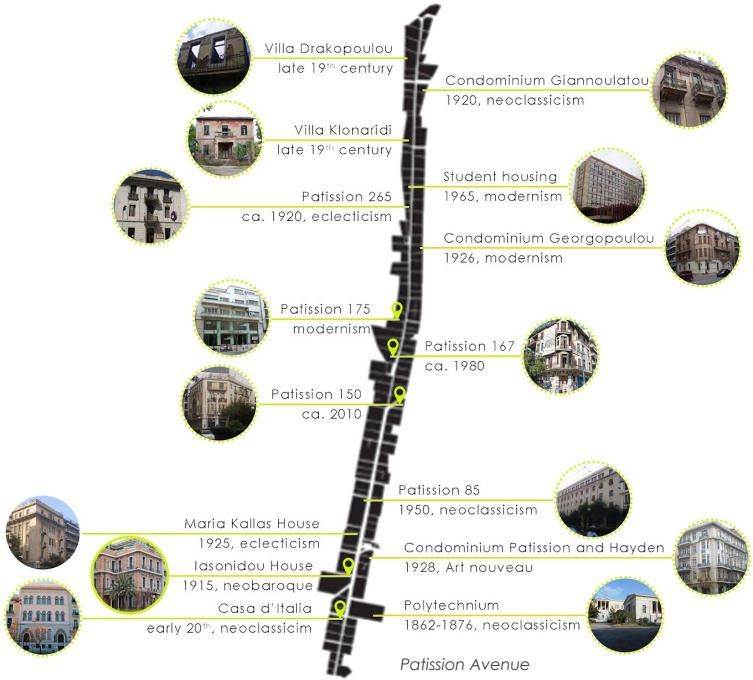
DESIGN GOAL		SUB-OBJECTIVES	RELEVANT QUESTION	METHOD	RESULT
How can a TiO_2 coating be integrated differently on the various components of a facade, in order to find wider application on facades of existing historical buildings in Athens and to contribute to the NOx removal in the proximity of its application?	MATERIAL	To determine the factors that influence the photocatalytic activity of the TiO_2 coatings, in terms of environment and materials and to define the aspects that can lead to an enhancement of photocatalysis over time	How do the environment and the substrate influence the successful photocatalytic performance of TiO_2 façade coatings over time?	RESEARCH	Overview and assessment of the factors that influence the photocatalytic activity of the TiO_2 coatings, in terms of environment and materials via case studies, research and comparative evaluation of their effect on its improvement
		To specify the parameters that hinder a widespread application of TiO_2 coatings on façade products and to define possible factors or scenarios that can facilitate a more extensive use of them	What are the parameters that hinder a widespread application of photocatalytic coatings on façade products and which are the factors able to facilitate a more extensive use of them in the façade industry by creating different levels of TiO_2 application?	RESEARCH + EVALUATION	Overview of parameters that both hinder and facilitate the application of TiO_2 coatings via case studies and research, evaluation of possible factors (related with cost, maintenance, durability) that can promote a more extensive use of them and creation of different TiO_2 application levels
		To determine the NOx removal efficiency of various photocatalytic products used on different substrates and environmental conditions and to define their effectiveness in a potential application on different facade elements	What is the NOx removal efficiency of certain photocatalytic products and what is their potential effectiveness, when used as a reference for a certain level (1st) of TiO_2 application on different facade components?	RESEARCH + EVALUATION	Overview of the NOx removal efficiency of certain photocatalytic products used on different substrates via case studies and experimental data and calculation of NOx reduction of a chosen case study by their theoretical application
	B.STOCK	To define the aspects that facilitate or hinder a direct or/and indirect application of surface treatments on the facades of existing buildings with historical value in Athens	How can the values embedded in a historic building be taken into account when deciding for an intervention using TiO_2?	RESEARCH + EVALUATION	Overview of the different values used in heritage to assess the importance of a facade component, creation of a matrix for a chosen case study to show how this system works and classification of the components based on their value
	FACADE	To come up with different geometries of a chosen facade element that facilitate the photocatalytic performance of TiO_2 coatings and to test their efficiency, considering the given design criteria	How to design a façade element capable of enhancing the photocatalytic activity of TiO_2 coatings by considering the given design criteria and respecting the historical value/image of a building at the same time?	DESIGN + SIMULATIONS + (EXPERIMENTS)	Different proposals/designs of a specific facade element and comparative evaluation of their efficiency considering the specific design criteria (surface roughness, surface enlargement, wind flow, solar irradiation)
	CLIMATE	To simulate the performance of the final TiO_2-coated façade product regarding NOx abatement in the vicinity of the building and to compare the results with the situation prior to the intervention (without TiO_2 and only by applying TiO_2 at the 1st level)	What is the impact of the final TiO_2-coated façade on the NOx levels in the vicinity of the building, onto which is applied and what are the results yielded by the comparison with the pollution levels prior to the intervention (without TiO_2 and only by applying TiO_2 at the 1st level)?	RESEARCH + CALCULATIONS + SIMULATIONS	Calculation of NOx emissions in the vicinity of the building (urban street canyon) before (without TiO_2 and 1st level) and after the design of the final façade product (2nd level) with the help of tested models and softwares as well as comparative assessment of the product's efficiency in regard to NOx pollution levels

Theoretical work

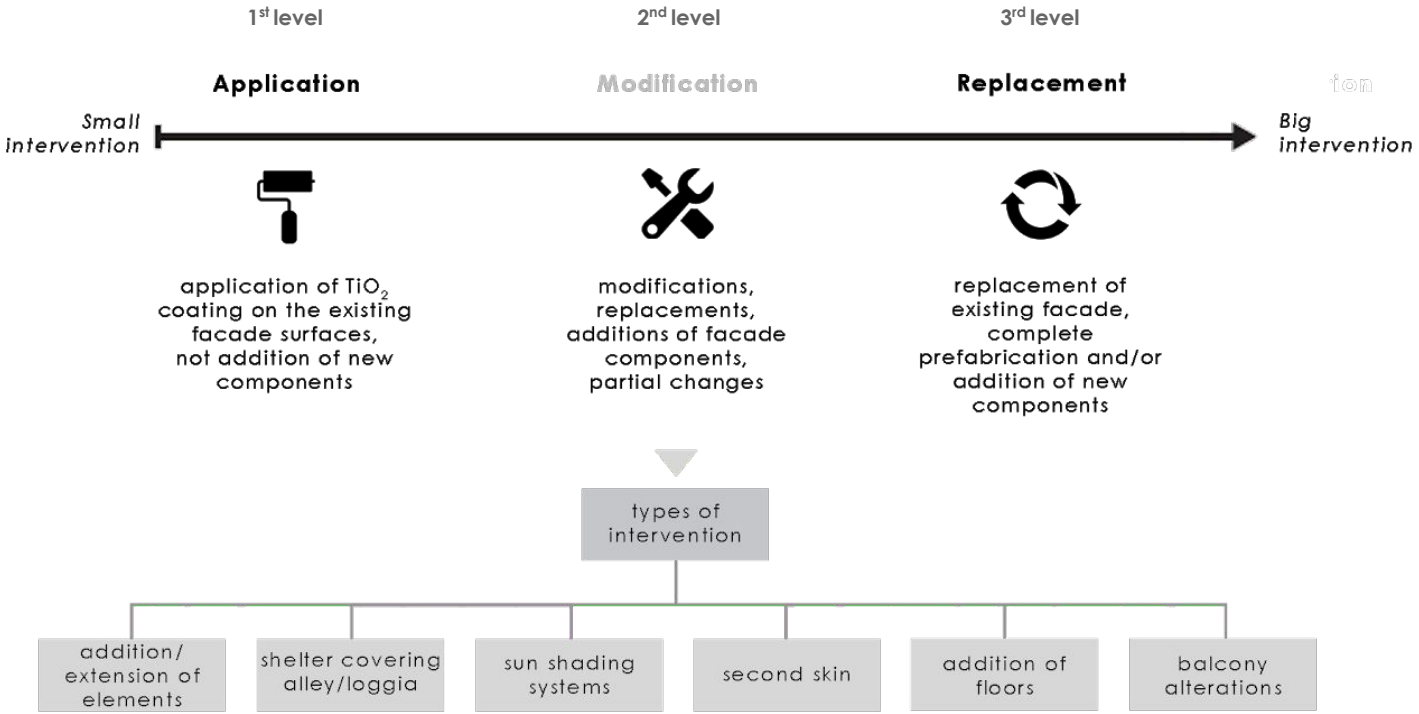
- **Research regarding:**
- **TiO_2** types and properties
- Photocatalysis and **environmental** conditions
  - UV-A radiation
    (10 W/m^2 as min_{allow})
  - Southern orientation
    (direct solar irradiation)
  - Certain RH levels (10%-50%)
  - Low flow rates for increased wind residence time
- Influence of **substrate** material
  - Cementitious
  - Non-cementitious
- Case studies results for **cementitious** mixtures
  - Material's high porosity I Large surface area
  - Type, ratio, particle size of aggregates
  - TiO_2 content
- Pros and Cons of **TiO_2 coating** application
- Considerable **design** aspects
  - Technical I Design I Economic I Environmental I Social I Legal

Theoretical work

- **Focusing on Athens:**
- Air pollution I Air pollutants I Negative effects
- **Climatological** factors
- **Morphological** factors
- Types of urban street canyons and **wind flows**
- Selection of a specific **urban street canyon**
- Air pollution levels and trends in **Patission Avenue**
  - NO I NO_2 I O_3
- **Design context**
  - Buildings typologies
  - Storeys I Style I Materials I Ownership I Function



3 Levels of intervention

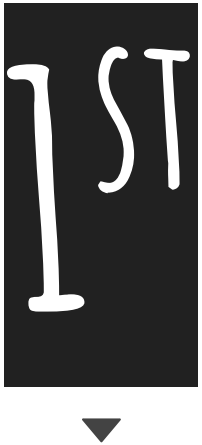


2ND LEVEL

Why focusing on the 2nd level of intervention?

- Apply I **Modify** I Replace
- More **options** than Apply
- Apply and Replace offer **'easiest'** solutions
- Modify:certain **limitations** (real life scenario)
- More **representative**: some parts can be replaced and some other they can't
- More interesting and **feasible**: I don't have to change more things than I need to change
- Conservation: **minimal interventions**, try to keep what's there and if I can't, then I replace it

OBJECTIVE



Assumption

Link to theoretical work

Test

Comparative Evaluation

FACADE

facade components

glazing

frame

door

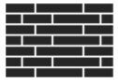
cornice

blinds

sun shading

balcony

structure



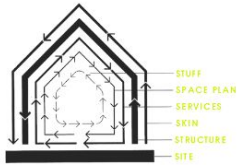
filling

WHICH IS THE CRITERION TO DETERMINE THE TiO_2 APPLICATION LEVEL?

WHICH IS THE CRITERION TO DETERMINE THE TiO_2 APPLICATION LEVEL?

Aspect of Value

ASPECT OF VALUE



aspect of value

site

skin

structure

space

services

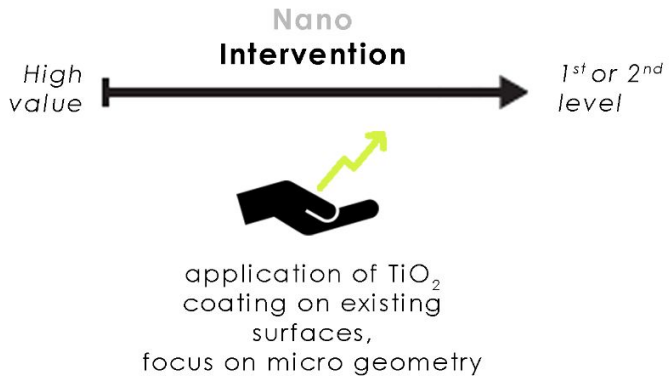
stuff

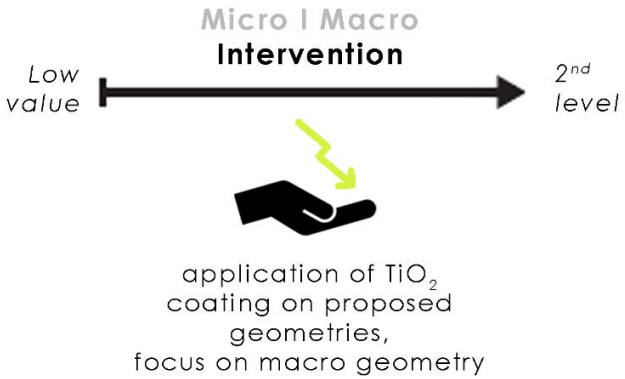
spirit of place

society

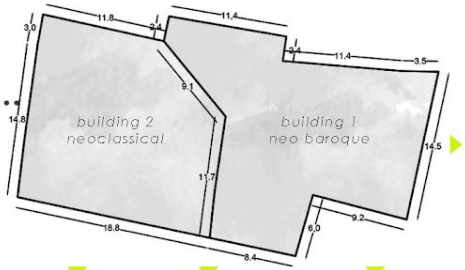
further division of
the exterior skin

Aspect of value





Case study: validation

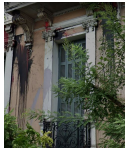


East facade

South

South

Southeast facade



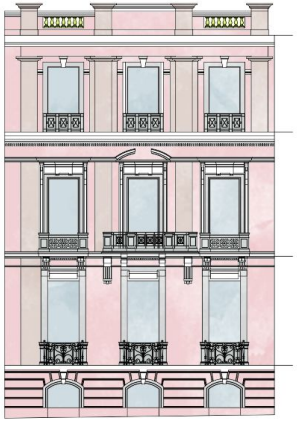
- 2 main facades with different orientation
- Corner building with Southern facade in a pedestrian street
- Eastern facade facing main avenue

Building	
	
Location	Patission 69 & Enianos, Athens
Date of construction	1910-1915
Number of storeys	4
Architectural style	French neobaroque Neoclassicism
Owner	General Confederation of Greek Workers
Orientation	East facade South facade
Initial use	Residency Hotel I Hospital
Current use	Offices
Renovation potential	Already renovated once
Structure	In situ construction No prefabrication
Load bearing walls	Concrete in situ
External walls (non-load bearing)	Brick walls
Windows	Single glazing Wooden frames Wooden blinds
Balcony	Marble Metal
External stairs	Marble
Cornice	Stone Marble

DECISION MAKING

Why focusing on that building?

- It represents the **majority of the existing building stock**
- It is representative in terms of **style** (repetitive rhythm of windows, decorative elements, color palette)
- It is an apt example of the most common used **materials** (concrete, bricks + mortar, wood, plaster)
- It also has extra **unique elements** (outdoor staircases, ornate decor)
- It is more likely for a **residential building** to turn into offices and not the other way around
- It is already **renovated once** (approved alterations)
- No need for **radical** renovation works (preserved)
- It is a **feasible** choice, given the fact that the building is **currently in use**
- It is a **corner building** with both East and South facades



_East facade 1

_East facade 2

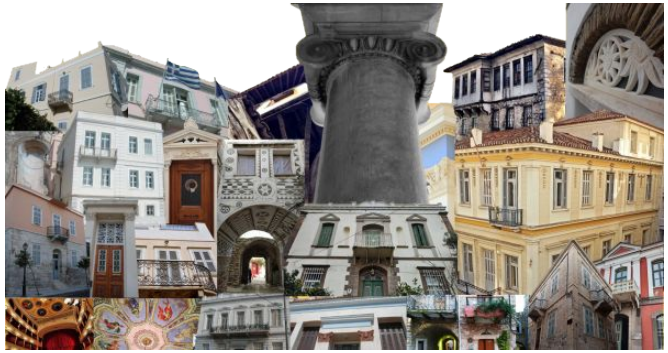
_South facade 1

_South facade 2

DECISION MAKING

Why changing something in the building?

- **Government's target:** energy upgrade of 12%-15% of national building stock until 2030 (600.000 buildings)
- **Legislation** that financially supports complete restoration, facade preservation or cleaning in the framework of 'Preserve' programme
- **Climate** faces radical changes in recent years → unpleasant urban and working environments
- Increase in **air pollution levels**, especially in main avenues with direct exposure to pollutants
- **Renovation** took place over 40 years ago → certain parts may need restoration or enhancement.
- Some elements constitute a large **percentage** of the total facade surface (21%) →
  possible enhancement with TiO_2 coating may upgrade its performance significantly



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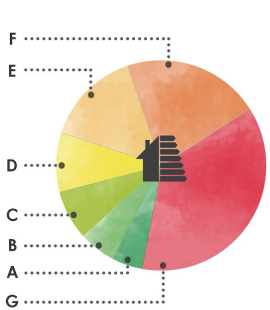


CHOSEN FACADE

FLOOR 4	glazing - frames -	structure 4.8 m² filling 7.51 m²	lesene 6.48 m² columns -	railing - blinds -	balconies - balustrade 1.56 m²	door - stairs -	cornice 6.53 m²
FLOOR 3	glazing 17.1 m² frames 7.2 m²	structure 18.8 m² filling 18.73 m²	lesene 19.6 m² columns -	railing - blinds 54.61 m²	balconies - balustrade 6.6 m²	door - stairs -	cornice 16.36 m²
FLOOR 2	glazing 18 m² frames 14.22 m²	structure 24 m² filling 16.8 m²	lesene 12.8 m² columns -	railing - blinds 80.35 m²	balconies 12.08 m² balustrade -	door - stairs -	cornice 21.32 m²
FLOOR 1	glazing 23.32 m² frames 11.19 m²	structure 21.2 m² filling 14.84 m²	lesene 14.34 m² columns -	railing - blinds 54.61 m²	balconies 7.8 m² balustrade -	door - stairs -	cornice 13.35 m²
GROUND FLOOR	glazing 6 m² frames 3 m²	structure 10.4 m² filling 14.84 m²	lesene - columns -	railing 2.7 m² blinds 9 m²	balconies - balustrade -	door - stairs -	cornice 5.31 m²
TOTAL m²	glazing 64.32 m² frames 36.31 m²	structure 79.2 m² filling 76.73 m²	lesene 99.39 m² columns -	railing 2.7 m² blinds 160.35 m²	balconies 30.22 m² balustrade -	door - stairs -	cornice 62.46 m²

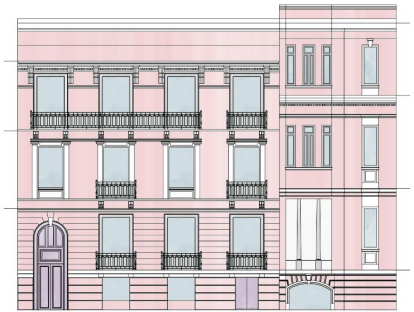
_East facade 1

FLOOR 4	glazing - frames -	structure 1.69 m² filling 6.2 m²	lesene - columns -	railing - blinds -	balconies - balustrade -	door - stairs -	cornice 3.6 m²
FLOOR 3	glazing 7.37 m² frames 3.24 m²	structure 6.3 m² filling 24.9 m²	lesene 1.22 m² columns -	railing - blinds 8.2 m²	balconies 3.3 m² balustrade -	door - stairs -	cornice 14.67 m²
FLOOR 2	glazing 5.86 m² frames 6.24 m²	structure 8.15 m² filling 31.85 m²	lesene - columns -	railing - blinds 10.84 m²	balconies - balustrade -	door - stairs -	cornice 7.54 m²
FLOOR 1	glazing 3.84 m² frames 1.86 m²	structure 6.3 m² filling 44.08 m²	lesene 1.82 m² columns 2 m²	railing - blinds 5.7 m²	balconies - balustrade -	door 7.86 m² stairs 8 m²	cornice 6.49 m²
TOTAL m²	glazing 30.87 m² frames 11.34 m²	structure 34.55 m² filling 107.05 m²	lesene 3.02 m² columns 2 m²	railing - blinds 24.74 m²	balconies 9.84 m² balustrade -	door 7.86 m² stairs 8 m²	cornice 22.3 m²

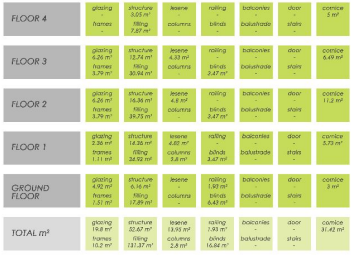
_East facade 2

FLOOR 4	glazing - frames -	structure 5.4 m² filling 5.28 m²	lesene 9.24 m² columns -	railing - blinds -	balconies - balustrade 1.44 m²	door - stairs -	cornice 3.2 m²
FLOOR 3	glazing 11.4 m² frames 5 m²	structure 9.2 m² filling 6.84 m²	lesene 11.12 m² columns -	railing - blinds 16.4 m²	balconies 4.4 m² balustrade -	door - stairs -	cornice 11 m²
FLOOR 2	glazing 12 m² frames 9.85 m²	structure 12 m² filling 8.5 m²	lesene 9.32 m² columns -	railing - blinds 21.68 m²	balconies 6.26 m² balustrade -	door - stairs -	cornice 13.02 m²
FLOOR 1	glazing 6.66 m² frames 4.65 m²	structure 10.6 m² filling 11.56 m²	lesene - columns 3 m²	railing - blinds 11.31 m²	balconies - balustrade -	door 11.9 m² stairs 0.18 m²	cornice 4.6 m²
GROUND FLOOR	glazing 3 m² frames 1.5 m²	structure 6 m² filling 8.71 m²	lesene - columns -	railing 1.95 m² blinds 6.5 m²	balconies - balustrade -	door - stairs -	cornice 2.83 m²
TOTAL m²	glazing 35.56 m² frames 20.73 m²	structure 40.2 m² filling 40.99 m²	lesene 23.68 m² columns 3 m²	railing 1.95 m² blinds 51.79 m²	balconies 10.66 m² balustrade 1.44 m²	door 11.9 m² stairs 0.18 m²	cornice 33.63 m²

_South facade 1



FLOOR 3	glazing - frames -	structure 15 m² filling 42.3 m²	lesene - columns -	railing - blinds -	balconies - balustrade -	door - stairs -	cornice 16.95 m²
FLOOR 2	glazing 29.2 m² frames 11.12 m²	structure 25 m² filling 29.22 m²	lesene - columns -	railing - blinds 40.32 m²	balconies 16.96 m² balustrade -	door - stairs -	cornice 21.64 m²
FLOOR 1	glazing 23.42 m² frames 3.96 m²	structure 30 m² filling 36.76 m²	lesene 11.84 m² columns -	railing - blinds 26.38 m²	balconies 9 m² balustrade -	door - stairs -	cornice 13.31 m²
GROUND FLOOR	glazing 28.3 m² frames 8.4 m²	structure 86.35 m² filling 42.82 m²	lesene - columns -	railing 1.92 m² blinds 36.7 m²	balconies 9.78 m² balustrade -	door 19.05 m² stairs -	cornice 9.75 m²
TOTAL m²	glazing 80.92 m² frames 37.48 m²	structure 196.35 m² filling 150.5 m²	lesene 11.84 m² columns -	railing 1.92 m² blinds 102.4 m²	balconies 35.74 m² balustrade -	door 19.05 m² stairs -	cornice 61.65 m²



FLOOR 4	glazing - frames -	structure 5.05 m² filling 7.87 m²	lesene - columns -	railing - blinds -	balconies - balustrade -	door - stairs -	cornice 5 m²
FLOOR 3	glazing 6.26 m² frames 3.79 m²	structure 12.74 m² filling 30.94 m²	lesene 4.33 m² columns -	railing - blinds 3.47 m²	balconies - balustrade -	door - stairs -	cornice 6.49 m²
FLOOR 2	glazing 6.26 m² frames 3.79 m²	structure 14.36 m² filling 39.73 m²	lesene 4.8 m² columns -	railing - blinds 3.47 m²	balconies - balustrade -	door - stairs -	cornice 11.2 m²
FLOOR 1	glazing 2.36 m² frames 1.11 m²	structure 14.36 m² filling 34.92 m²	lesene 4.82 m² columns 3.6 m²	railing - blinds 3.47 m²	balconies - balustrade -	door - stairs -	cornice 5.73 m²
GROUND FLOOR	glazing 4.92 m² frames 1.51 m²	structure 6.16 m² filling 17.89 m²	lesene - columns -	railing 1.93 m² blinds 6.43 m²	balconies - balustrade -	door - stairs -	cornice 3 m²
TOTAL m²	glazing 19.8 m² frames 10.2 m²	structure 52.67 m² filling 131.37 m²	lesene 13.95 m² columns 2.8 m²	railing 1.93 m² blinds 16.82 m²	balconies - balustrade -	door - stairs -	cornice 31.42 m²

_South facade 2

Qualitative Division of chosen facade

facade components

glazing

frame

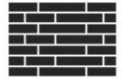
door

cornice

blinds

balcony

structure



filling

Quantitative Division of chosen facade

	Eastern facade 1							
	material	ground floor	floor 1	floor 2	floor 3	floor 4 (higher)	total m2	total %
glazing(dim*n)	glass	6	23.22	18	17.1		64.32	20.09
window frame	wood	3	11.19	14.52	7.5		36.21	11.31
railing (glazing)	metal	2.7					2.7	0.84
blinds	wood	9	34.41	32.52	24.6		100.53	31.40
balconies	-						30.22	9.44
metal	metal		7.8		6.6		15.72	4.91
stone	stone			12.08			14.50	4.53
balustrade	stone					1.26	1.26	0.39
lesene	concrete + plaster		4.54	12.8	19.8	6.48	99.59	31.10
doors	wood						-	-
stairs	stone						-	-
structure	concrete	10.4	21.2	24	18.8	4.8	79.2	24.74
filling	bricks + mortar	14.84	18.85	16.8	18.73	7.51	76.73	23.97
cornice	concrete + plaster	5.51	12.33	21.32	16.758	6.53	62.45	19.50
columns	stone						-	-
total facade (m2)		39.75	86.79	94.64	78.89	20.1	320.17	

Division of East facade into its components: material I m^2 I position I %

_East facade facing the main street canyon

- **%** → indicative factor for future steps
- **Material** → influencing choice of TiO_2 product
- **Division**→ important for upcoming heritage matrix

Different values

Facade components of chosen facade

	Age value	Historical	Non intended commemorative value	Use value	New-ness value	(relative) Art value	Technical value
Glazing	No obvious distortions, discolorations, changes in glass thickness	-	Typical single glazing of that era, not something unique or no longer found/produced	In good condition (no cracks or breaks)	Probably cleaned, repaired, insulated or replaced during the first renovation (no data)	-	Non load bearing single glazing No data about the type of used glass (float, coated toughened, laminated) Identical module repeated in S and E facades, both horizontally and vertically
Window frame	Wooden frames with no decayed or damaged parts and discolorations	Not a representative example of a specific architectural style or technique	Wooden frame found in many other buildings of the era	Probably insulated during the first renovation (not validated) but definitely not initially	Probably cleaned, repaired, insulated or replaced during the first renovation (no data)	-	Wooden frames, not custom-made No data about the type of used wood Identical module repeated in S and E facades, both horizontally and vertically
Structure	Load bearing concrete columns with no obvious structural damage	Not a representative example of a specific construction technique of a certain era	Not a construction technique that is no longer found (unique), but rather typical	In good condition, maybe a future assessment for potential repairs or enhancements	-	-	Concrete columns along its heights, with no combination of different materials No data about the type of used concrete or whether was reinforced Traditional in situ construction method with no unitised parts
Filling	Bricks and mortar, with no sign of damp, greenery, cracks etc, but stained with paints	Not a representative example of a specific construction technique of a certain era	Not a construction technique or type of materials no longer found (unique, extinct)	Probably insulated during the first renovation (not validated) but definitely not initially	-	-	Bricks and mortar filling, repeated on the facades with no prefabricated units No data about the used materials Non load bearing elements, placed traditionally in situ
Blinds	Wooden blinds with no signs of decay, damage or discolorations	Typical green wooden blinds found in many buildings in Athens that were built in the late 20th century	Geometry, design widely found in many buildings (not unique)	Adequate functionality for sun protection In good condition (no cracks, broken, missing, decayed parts)	Cleaned, repaired and repainted	Original	Wooden green blinds, mass-produced No data about the used wood Modules repeated in almost all the windows Two pieces of blinds, opening to the outside (vertical axis)
Balcony	Metal and marble balconies with no signs of decay, but stained with paint or/and gas emissions	Representative example of neo baroque architecture (not many examples in Athens)	Unique decorative elements, different patterns even in the same facade	In good condition (no cracks or missing parts), but not properly insulated	Cleaned, repaired and repainted (metal ones)	Original	Metal and stone balconies of different depths and patterns along the facade No data about the used materials In situ construction, no prefabrication Non load bearing elements
Door	Wooden doors, properly maintained with no signs of decay	-	Unique decorative elements and patterns	In good condition (no cracks, broken, missing, decayed parts, discolorations), but probably not insulated	Cleaned and repaired during the first renovation	Original	Wooden doors of different patterns, geometries and sizes Probably custom made production, made by hand in an old, traditional way No data about the used wood
Cornice	Stains and discolorations along the facade height (exposure to main street)	Many cosmetic element of neo baroque (front) and neoclassicism (back)	Unique decorative elements, probably no longer found	In good condition (possibly a few cracks, missing parts, discolorations)	Cleaned and repaired during the first renovation	Original	Decorative elements made of plaster found in all the facades (above windows, under deep balconies, horizontal division of facade's levels) No data about the used materials

Heritage matrix for Eastern_Facade_1

Age value: building as an organic object

Historical value: building as representation of a precise moment in history

Not intended comm. value: no aim for a person's memory embodiment

Use value: linked to functionality and everyday use

New-ness value: evidence of human intervention over nature's forces

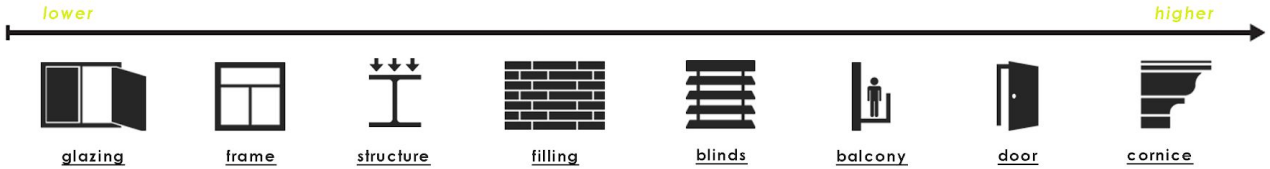
Technical value: linked to used materials and construction techniques

Low value

Medium value

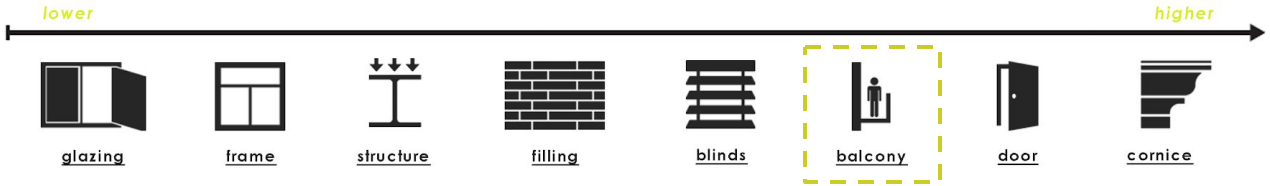
High value

VALUE SCALE



Subjective and not 100% objective
Relies upon designer's judgement
Unique for every different case study

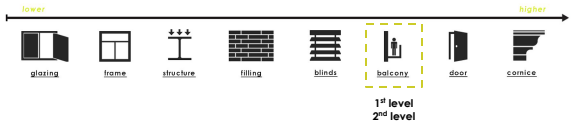
Chosen facade component

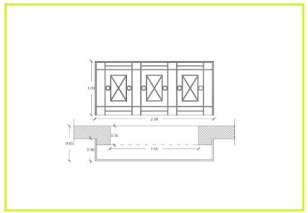


CHOSEN FACADE COMPONENT

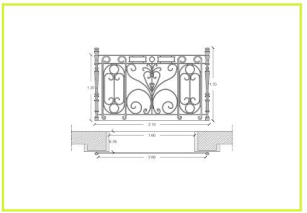
Why focusing on the balconies?

- Different potential **design scenarios** ⟶ enhancement of coating's photocatalytic activity
- **Direct exposure** to main street
- **Extruded** towards the main street ⟶ more chances to trap and neutralize pollutants
- Ease of **modifications**: external elements
- Ease of **redesign**
- **Materials**: stone + metal
- gap/solid **ratio**: 7:3 I 1:10 I 1:4 I 7:3 I 6:4
- **10 %** of overall facade surface

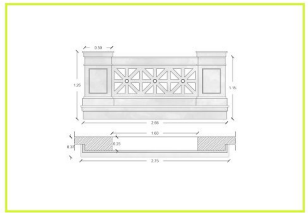




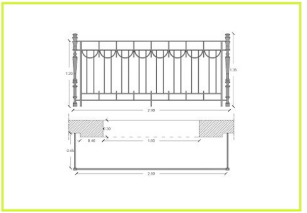
Facade : East_1 I East_2 I South_1
Level : 3rd I 1st 2nd I 3rd
Number : 3*2.20 m I 1*7.44 m + 1*2.20 m
Material : metal railing painted with dark green paint



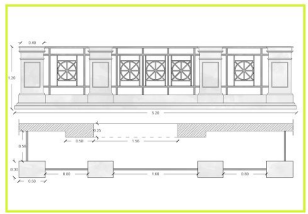
Facade : East_1
Level : 1st
Number : 3*2.60 m
Material : metal railing painted with dark green paint



Facade : East_1 I South_1
Level : 2nd I 2nd
Number : 2*3.13 m I 2*3.13 m
Material : stone, probably marble in white, light grey colour



Facade : South_2 (big)
Level : 0 I 1st I 2nd
Number : 3*3.26 m I 2*3.26 m I 1*3.26 m + 1*13.7 m
m² : metal railing painted with dark green paint



Facade : East_1
Level : 2nd
Number : 1*5.82 m
Material : stone, probably marble in white, light grey colour + dark green painted metal railing

1ST LEVEL OF APPLICATION: ASSUMPTION

	Glazing	Window frame	Blinds	Door	Railing (glazing)	Balcony (metal)	Balcony (marble)	Stairs	Columns	Structure	Filling	Cornice	Balustrade
Surface Area m^2	64.32	36.21	100.53	-	2.70	15.72	14.50	-	-	79.20	76.73	62.45	1.26
Material	**Glass**	**Wood**			**Metal**		**Marble**			**Concrete**			Mixed or applied on top
Product 1	Mineral silicate paint treated with 10% TiO_2	StoPhotosan NOx white					Water based TiO_2 sol 3.6 ± 0.19 mg/cm^2			Anatase (5% TiO_2)			On top
Nox removal	74% NO 27% NO_2	75% NOx					16% photodegradation efficiency, after a year			20% NOx			
Product 2	Water-based styrene acrylic paint treated with 10% TiO_2	9 wt. % TiO_2 + 9 wt. % P25					Water-based TiO_2 suspension (1 wt %)			40 kg/m^3 of TiO_2 on top layer			On top
NOx removal	91% NO 71% NO_2	30%-60% NOx					10% photodegradation efficiency, after 1 hour			78% NO			
Product 3	Aerodisp® W740X, anatase-TiO_2, about 40 g/m^2 - determined by weighing	9 wt. % P25					Alcohol-based TiO_2 suspension (2 wt %)			Aerodisp® W740X, anatase-TiO_2, about 40 g/m^2 - determined by weighing			Mixed
Nox removal	15%-45% NOx	50%-90% NOx					35% photodegradation efficiency, after 1 hour			35%-45% NOx			
Product 4	Thin TiO_2 coating 15 nm	9 wt. % TiO_2 + 9 wt. % PC500					Single-layer treatment of 0.20 g/m^2 TiO_2			P25, Degussa 2% by cementitious materials weight			Mixed
NOx removal	57%-71% NO_2	30%-60% NOx					40% NO			17% NOx			
Product 5	**Average : 82.5% NO 54% NO_2 30% NO_x**	9 wt. % PC500 anatase					Three-layer treatment of 0.60 g/m^2 TiO_2			P25, Degussa 5% by cementitious materials weight			Mixed
Nox removal		70%-90% NOx					50% NO			25% NOx			
Product 6		Evonik P25, StoColor Climasan					**Average NOx : 45% NO**			P25, Evonik (2% TiO_2)			On top
NOx removal		3.5% NOx								60% NOx			
Product 7		**Average NOx : 53% NO_x**								P25, Evonik (5% TiO_2)			On top
Nox removal										30% NOx			
Product 8										P25 spray coating (60 g/m^2)			On top
NOx removal										60% NOx			
Product 9										P25 (1% TiO_2)			On top
Nox removal										25% NOx			
Product 10										P25 spray coating			On top
NOx removal										45% NOx			
										Average NOx : 78% NO 35.78% NO_x			

Key points

Glass substrate

- **10% TiO_2 content** in the paint → high NOx removal levels
- **Anatase** form of TiO_2 → less effective compared to the combination of both anatase and rutile (Degussa P25)
- **Coatings** → high NOx removal levels → direct contact with the air pollutants

Wood and metal substrate

- Paints that contain P25 and in most cases 9 wt.% **P25** → better performance

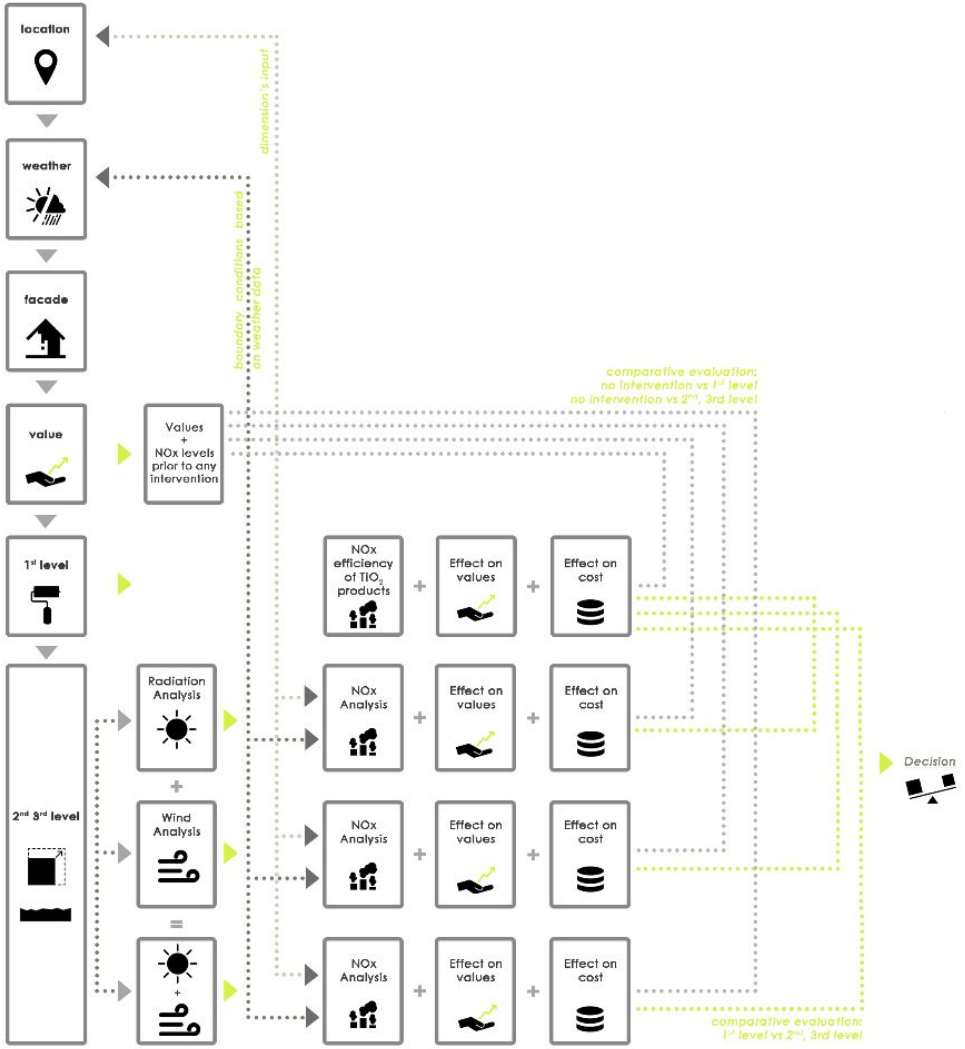
Stone substrate

- **Alcohol based** TiO_2 treatments > water based
- **Three layer treatments** > one layer by 10% However, the difference is not that big and after a **certain point**, the % doesn't vary much

Concrete substrate

- Coating, on **top of the substrate** > mixed in
- **P25** > products that contain other forms of TiO_2

ROADMAP


location
weather
facade
value
1st level
2nd 3rd level
dimension's input
boundary conditions based on weather data
Values + NOx levels prior to any intervention
Radiation Analysis
Wind Analysis
NOx efficiency of TiO2 products
NOx Analysis
NOx Analysis
NOx Analysis
Effect on values
Effect on values
Effect on values
Effect on values
Effect on cost
Effect on cost
Effect on cost
Effect on cost
comparative evaluation: no intervention vs 1st level
no intervention vs 2nd, 3rd level
comparative evaluation: 1st level vs 2nd, 3rd level
Decision

Assessment of proposal

NOx Efficiency

+

Value

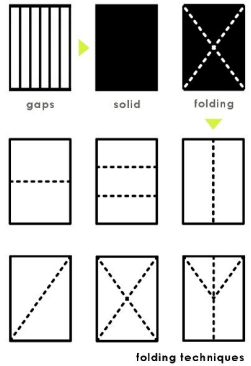
+

Cost

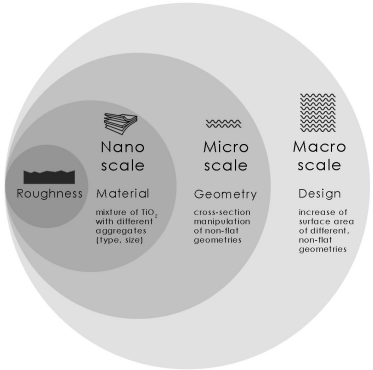
Design guidelines for 2nd and 3rd level

Arrangement and manipulation of surface geometry

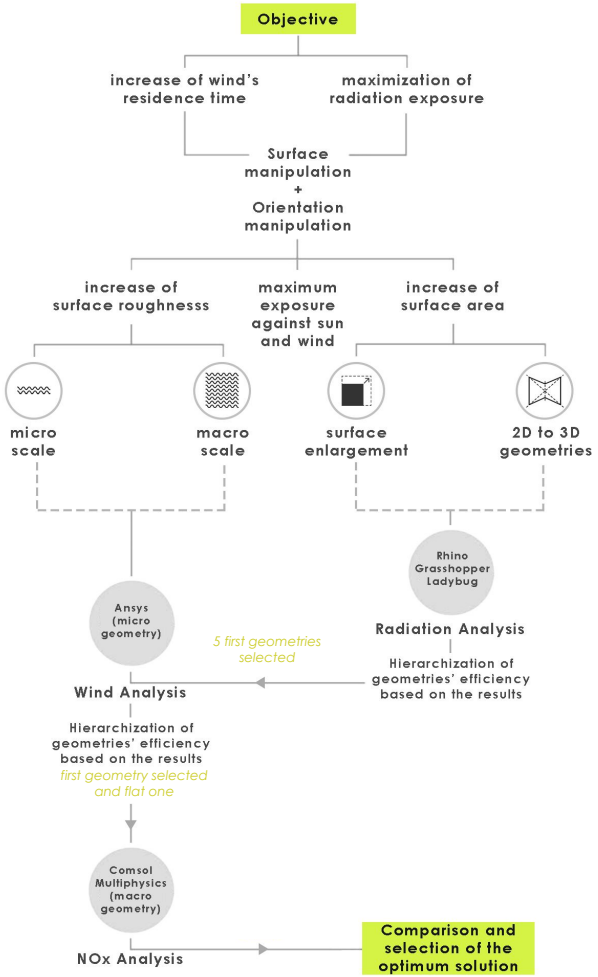
- **Surface Area**
  - Increase → more sides I m^2
  - Geometry → against wind flow + sun
  - Higher amount of irradiation throughout day + year



- **Surface Roughness**
  - Nano level → material (experiments, experts)
  - Micro level → micro geometry (cross section)
  - Macro level → macro geometry (design oriented)



PLAN FOR THE BALCONIES



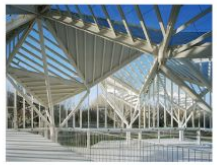
Design inspiration

Design inspired by

- Art of **origami**
- **Folded** structures
- 2D → **3D** geometries
- Minimal geometries **blended** with original building
- Inspired + based on **design guidelines**

Medallion : Extension of Banco de España
Retrieved from URL: https://gr.pinterest.com/pin/557390891363231793/

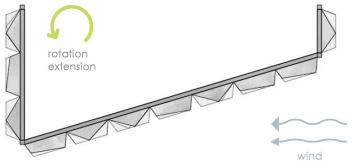
Tel Aviv Museum of Art
Retrieved from URL: https://www.archilovers.com/projects/151942/gallery?1266778



Glass Pavilion, Cuenca, Spain
Retrieved from URL: https://aasarchitecture.com/2013/01/glass-pavilion-by-moneo-brock-studio.html/

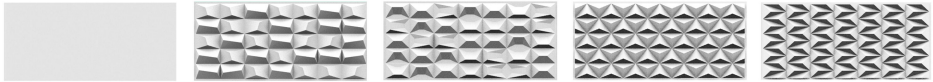
Rock Climbing Hall proposal
Retrieved from URL: https://www.archdaily.com/470579/new-wave-architecture-designs-rock-gym-for-polur?ad_medium=gallery

Creation of depth

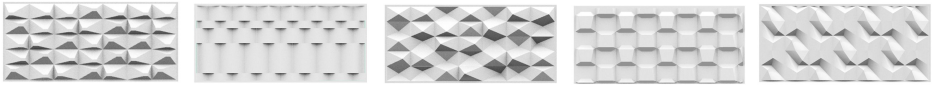


Depth expansion

Rotation towards the wind

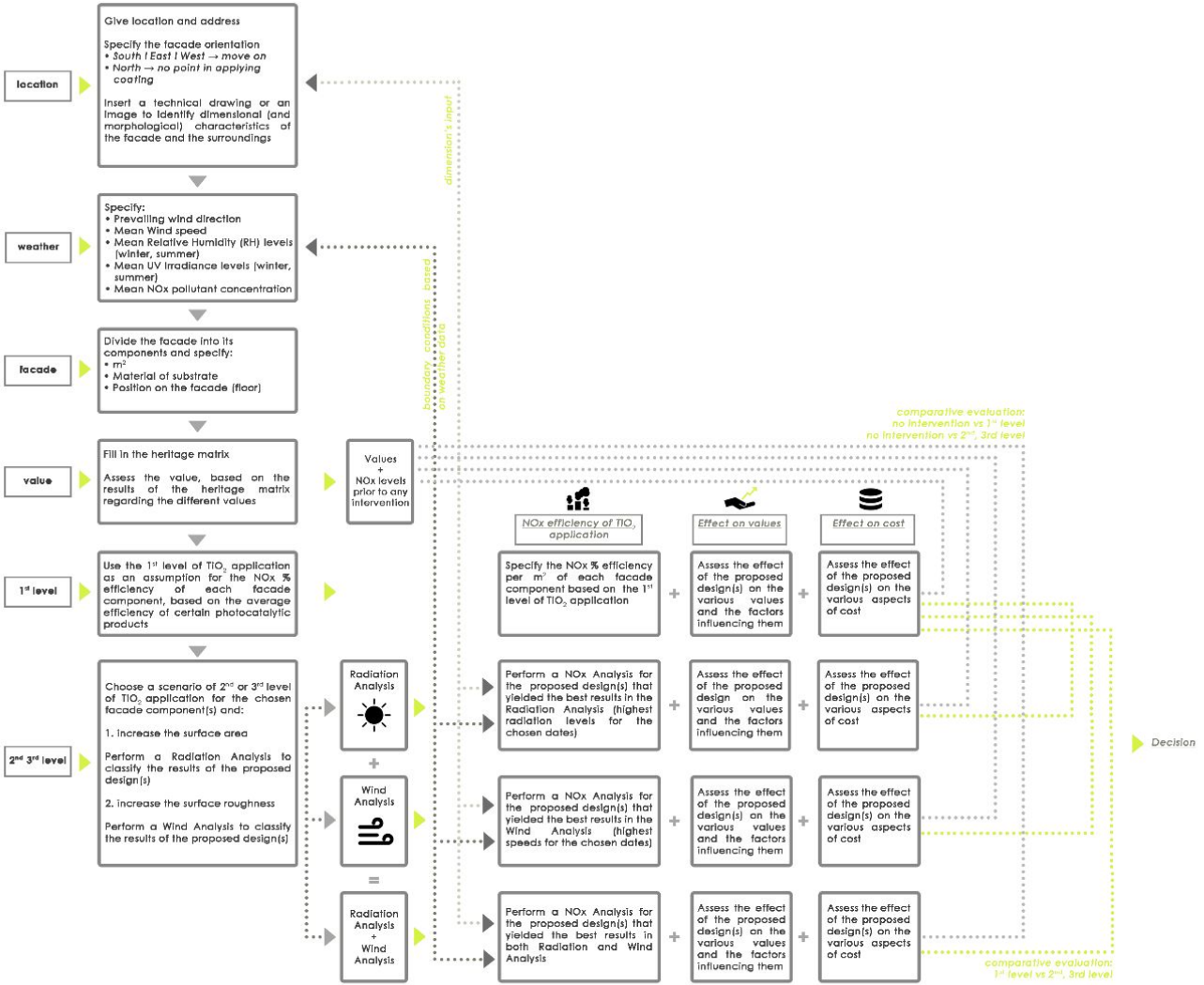


Panel 0 | Panel 1 | Panel 2 I 2a | Panel 3 I 3a | Panel 3b I 3c



Panel 4 I 4a | Panel 5 | Panel 6 I 6a | Panel 7 | Panel 8

ROADMAP


location
Give location and address
Specify the facade orientation
• South / East / West → move on
• North → no point in applying coating
Insert a technical drawing or an image to identify dimensional (and morphological) characteristics of the facade and the surroundings
weather
Specify:
• Prevailing wind direction
• Mean Wind speed
• Mean Relative Humidity (RH) levels (winter, summer)
• Mean UV irradiance levels (winter, summer)
• Mean NOx pollutant concentration
facade
Divide the facade into its components and specify:
• m²
• Material of substrate
• Position on the facade (floor)
value
Fill in the heritage matrix
Assess the value, based on the results of the heritage matrix regarding the different values
Values + NOx levels prior to any intervention
1st level
Use the 1st level of TiO2 application as an assumption for the NOx % efficiency of each facade component, based on the average efficiency of certain photocatalytic products
2nd 3rd level
Choose a scenario of 2nd or 3rd level of TiO2 application for the chosen facade component(s) and:
1. Increase the surface area
Perform a Radiation Analysis to classify the results of the proposed design(s)
2. Increase the surface roughness
Perform a Wind Analysis to classify the results of the proposed design(s)
Radiation Analysis
+
Wind Analysis
=
Radiation Analysis + Wind Analysis
dimension's input
location - condition - based on weather data
comparative evaluation: no intervention vs 1st level
no intervention vs 2nd, 3rd level
NOx efficiency of TiO2 application
Effect on values
Effect on cost
Specify the NOx % efficiency per m² of each facade component based on the 1st level of TiO2 application
Assess the effect of the proposed design(s) on the various values and the factors influencing them
Assess the effect of the proposed design(s) on the various aspects of cost
Perform a NOx Analysis for the proposed design(s) that yielded the best results in the Radiation Analysis (highest radiation levels for the chosen dates)
Perform a NOx Analysis for the proposed design(s) that yielded the best results in the Wind Analysis (highest speeds for the chosen dates)
Perform a NOx Analysis for the proposed design(s) that yielded the best results in both Radiation and Wind Analysis
Decision
comparative evaluation: 1st level vs 2nd, 3rd level

STEP 1 I RADIATION ANALYSIS

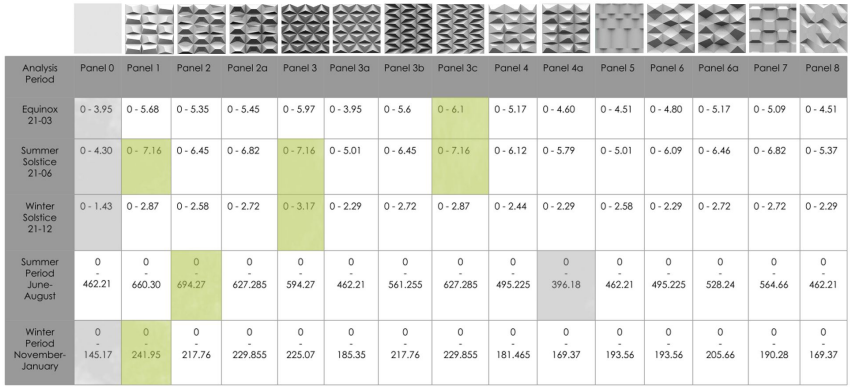
Goal: To find the configuration, which receives the highest amount of solar irradiation throughout the year

- **Analysis period:** Equinox (21-03)
  Summer Solstice (21-06)
  Winter Solstice (21-12)
  Summer period (June - August)
  Winter period (November - January)

- **Desirable result:** High levels of UV radiation in all 5 analysis periods

- **Best performed panel** → Panel 1

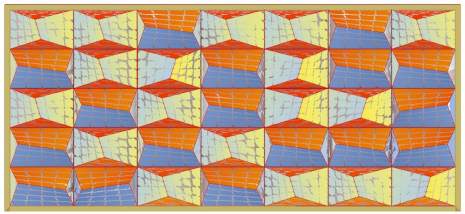
- **Panels that move on to next level** → Panel 1
  Panel 3
  Panel 3c
  Panel 2a
  Panel 2



Analysis Period	Panel 0	Panel 1	Panel 2	Panel 2a	Panel 3	Panel 3a	Panel 3b	Panel 3c	Panel 4	Panel 4a	Panel 5	Panel 6	Panel 6a	Panel 7	Panel 8
Equinox 21-03	0 - 3.95	0 - 5.68	0 - 5.35	0 - 5.45	0 - 5.97	0 - 3.95	0 - 5.6	0 - 6.1	0 - 5.17	0 - 4.60	0 - 4.51	0 - 4.80	0 - 5.17	0 - 5.09	0 - 4.51
Summer Solstice 21-06	0 - 4.30	0 - 7.16	0 - 6.45	0 - 6.82	0 - 7.16	0 - 5.01	0 - 6.45	0 - 7.16	0 - 6.12	0 - 5.79	0 - 5.01	0 - 6.09	0 - 6.46	0 - 6.82	0 - 5.37
Winter Solstice 21-12	0 - 1.43	0 - 2.87	0 - 2.58	0 - 2.72	0 - 3.17	0 - 2.29	0 - 2.72	0 - 2.87	0 - 2.44	0 - 2.29	0 - 2.58	0 - 2.29	0 - 2.72	0 - 2.72	0 - 2.29
Summer Period June-August	0 - 462.21	0 - 660.30	0 - 694.27	0 - 627.285	0 - 594.27	0 - 462.21	0 - 561.255	0 - 627.285	0 - 495.225	0 - 396.18	0 - 462.21	0 - 495.225	0 - 528.24	0 - 564.66	0 - 462.21
Winter Period November-January	0 - 145.17	0 - 241.95	0 - 217.76	0 - 229.855	0 - 225.07	0 - 185.35	0 - 217.76	0 - 229.855	0 - 181.465	0 - 169.37	0 - 193.56	0 - 193.56	0 - 205.66	0 - 190.28	0 - 169.37

min value
max value

Radiation values (kWh/m^2) for all the panels for each analysis period



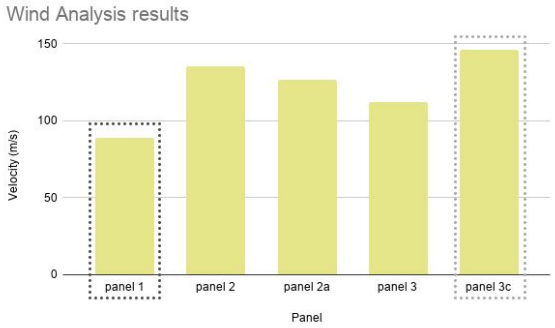
Panel 1 for Summer Solstice (21-06)

STEP 2 I WIND ANALYSIS

Goal: To find the configuration, which results to the lowest wind speed values

- **Boundary conditions:** Inlet Velocity = 20 m/s
  (average wind speed in Athens)
  3° North orientation

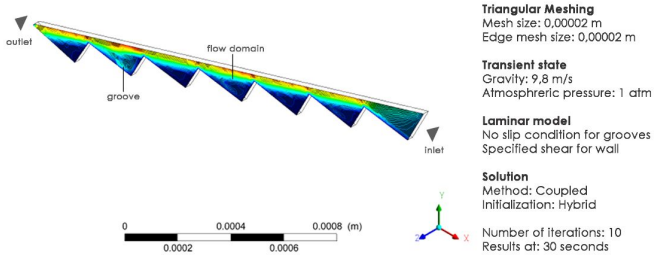
Final score	Velocity m/s	
Panel 1	0 - 88.88	
Panel 3	0 - 112	
Panel 2a	0 - 126.7	
Panel 2	0 - 135.7	
Panel 3c	0 - 145.9	



- **Desirable result:** Low wind speed values →
  Increased wind residence time on the panel →
  Captivation and neutralization of pollutants

- **Best performed panel** → Panel 1

- **Panels that move on to next level** → Panel 1
  Panel 0 (flat panel)



CFD model and set up parameters

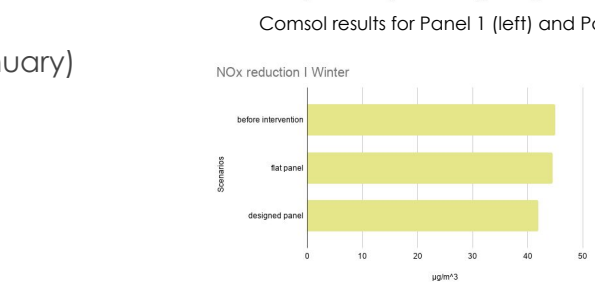
STEP 3 I NO_x ANALYSIS

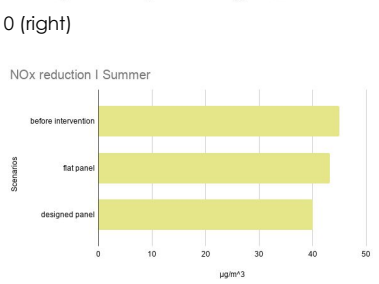
Goal: To find out whether Panel 1 (designed) performs better than Panel 0 (flat panel) in terms of NOx removal efficiency

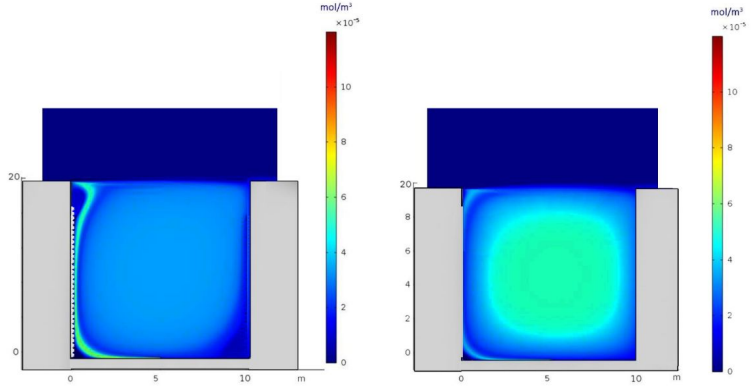
- **Analysis period:** Summer period (June - August)
  Winter period (November - January)

- **Boundary conditions :** Turbulent flow
  RH= 30% (summer)
  60% (winter)
  Wind speed= 2 m/s
  UV irradiance= 40 W/m^2 (summer)
  5 W/m^2 (winter)
  NO pollutant= 45 $\mu g/m^3$

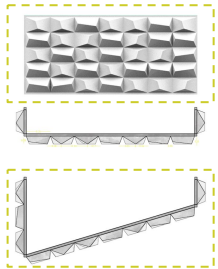
- **Best performed panel** → Panel 1, although slight reduction
  7% in winter
  11% in summer







Comsol results for Panel 1 (left) and Panel 0 (right)



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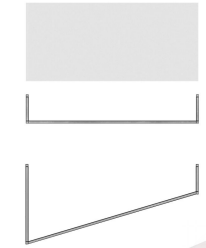
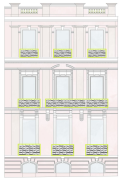
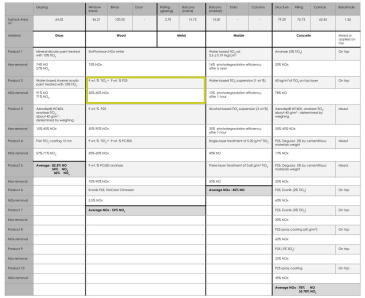




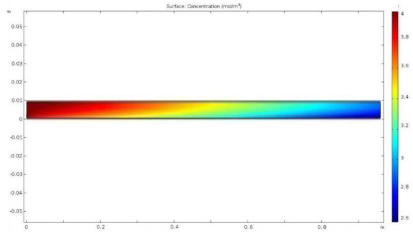
STEP 4 I COMPARISON WITH 1ST LEVEL

Goal: To find out whether Panel 1 (designed) yields better NOx % results than a flat surface coated with photocatalytic paint, achieving 45% NOx reduction

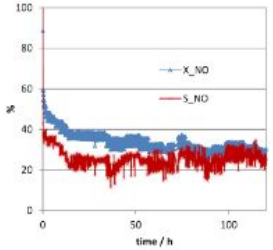
- **Analysis period:** 100 hours
- **Boundary conditions :** Laminar flow
  RH= 50%
  NO feed rate= 0.7 L/min at 1 ppmv
  =0.0084 kg/s
  UV irradiance= 10 W/m^2
  1 ppm=1.23 mg/m^3=4.10e-5 mol/m^3



Selected photocatalytic paint



Laminar flow between parallel plates for designed panel I Comsol setup



Results from paper for photocatalytic paint

- **Best performed panel** → Panel 1 → 53 % NOx reduction
  4.10e-5 mol/m^3 → 2.20e-5 mol/m^3

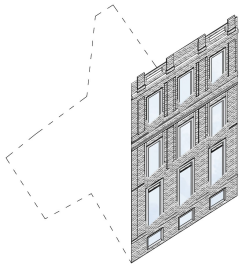
Conclusion for NOx efficiency

Combination of 1st and 2nd level

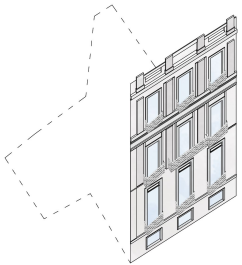
Goal: To find out which scenario yields better results in terms of NOx efficiency

- **Best performed scenario 1** → 1st level (glazing)
  +
  2nd level (rest)

- **Best performed scenario 2** → 2nd level (designed balconies)
  +
  1st level (rest)



Scenario 1



Scenario 2

Scenario	Level of TiO_2 application	Facade part	% on Facade Surface	Type of substrate	Orientation	Extension	Increase of surface area	Increase of surface roughness	NOx Concentration (µg/m3)
	- (situation prior to intervention)	Entire facade	100	Concrete Metal Stone Glass	East (original)	X	X	X	45
	1	Glazing	20	Glass	East (original)	X	X	X	41.4
	1	Entire facade	100	Concrete Metal Stone Glass	East (original)	X	X	X	35.3
	2	Balconies Flat panels	15	Concrete	NE	✓	✓	X	43.2
	2	Balconies Designed panels	17	Concrete	NE	✓	✓	✓	41.85
	1 (glazing) 2 (flat panels)	Glazing + Balconies	35	Glass + Concrete	East + NE	✓	✓	✓	39.6
	1 (glazing) 2 (designed panels)	Glazing + Balconies	37	Glass + Concrete	East + NE	✓	✓	✓	38.3
	1 (entire facade) 2 (flat panels)	Entire facade	100	Concrete Metal Stone Glass	East + NE	✓	✓	✓	37.1
	1 (entire facade) 2 (designed panels)	Entire facade	100	Concrete Metal Stone Glass	East + NE	✓	✓	✓	33
	1 (glazing) 2 (rest)	Entire facade	100	Concrete Metal Stone Glass	East + NE	✓	✓	✓	30.35

Combinations of 1st and 2nd level

Value and cost assessment of combined scenarios

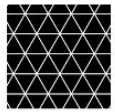
colour

gloss

reflection

texture

material compatibility

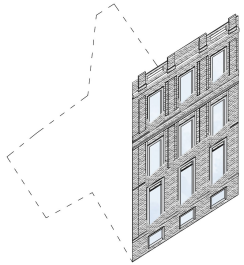


pattern compatibility

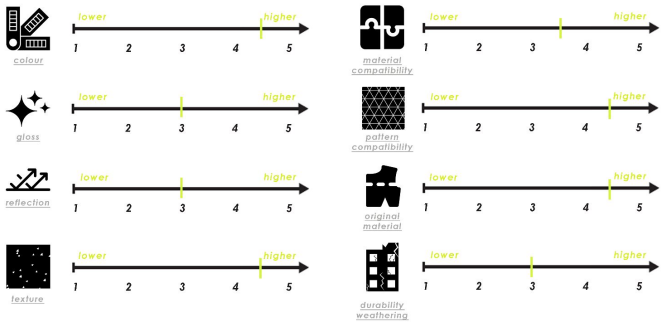
original material

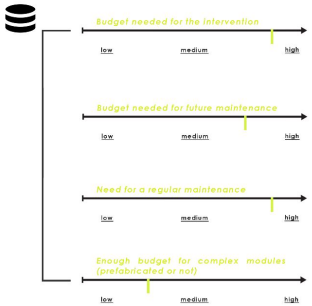
durability weathering

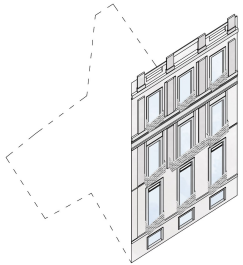
Value and cost assessment of combined scenarios



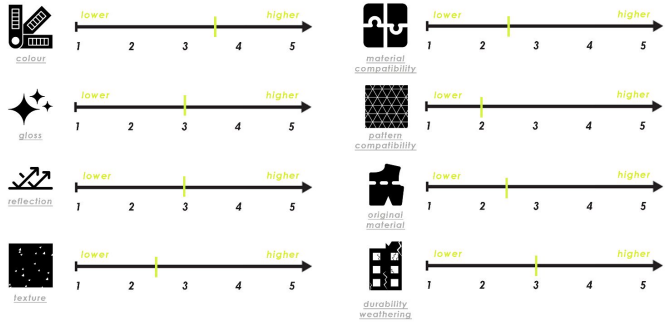
Scenario 1

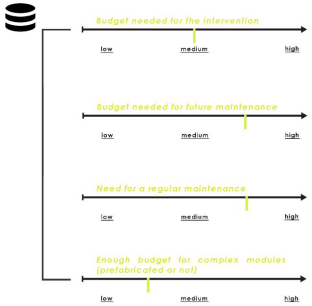




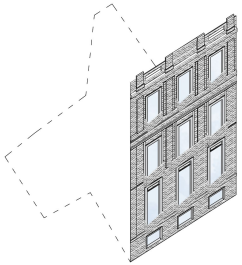


Scenario 2





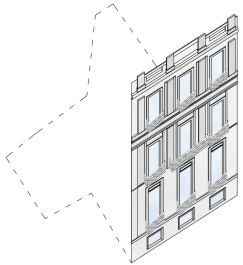
Overall assessment



Scenario 1

NOx Efficiency + **Value** + **Cost**

✔



Scenario 2

✔ ✔

Scenario 2

Assessment of proposal

NOx Efficiency

+

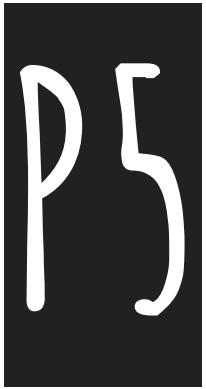
Value

+

Cost

Balance between the 3 factors

Combination of levels to achieve higher NOx efficiency while respecting the building's historical significance



Thank you for your attention