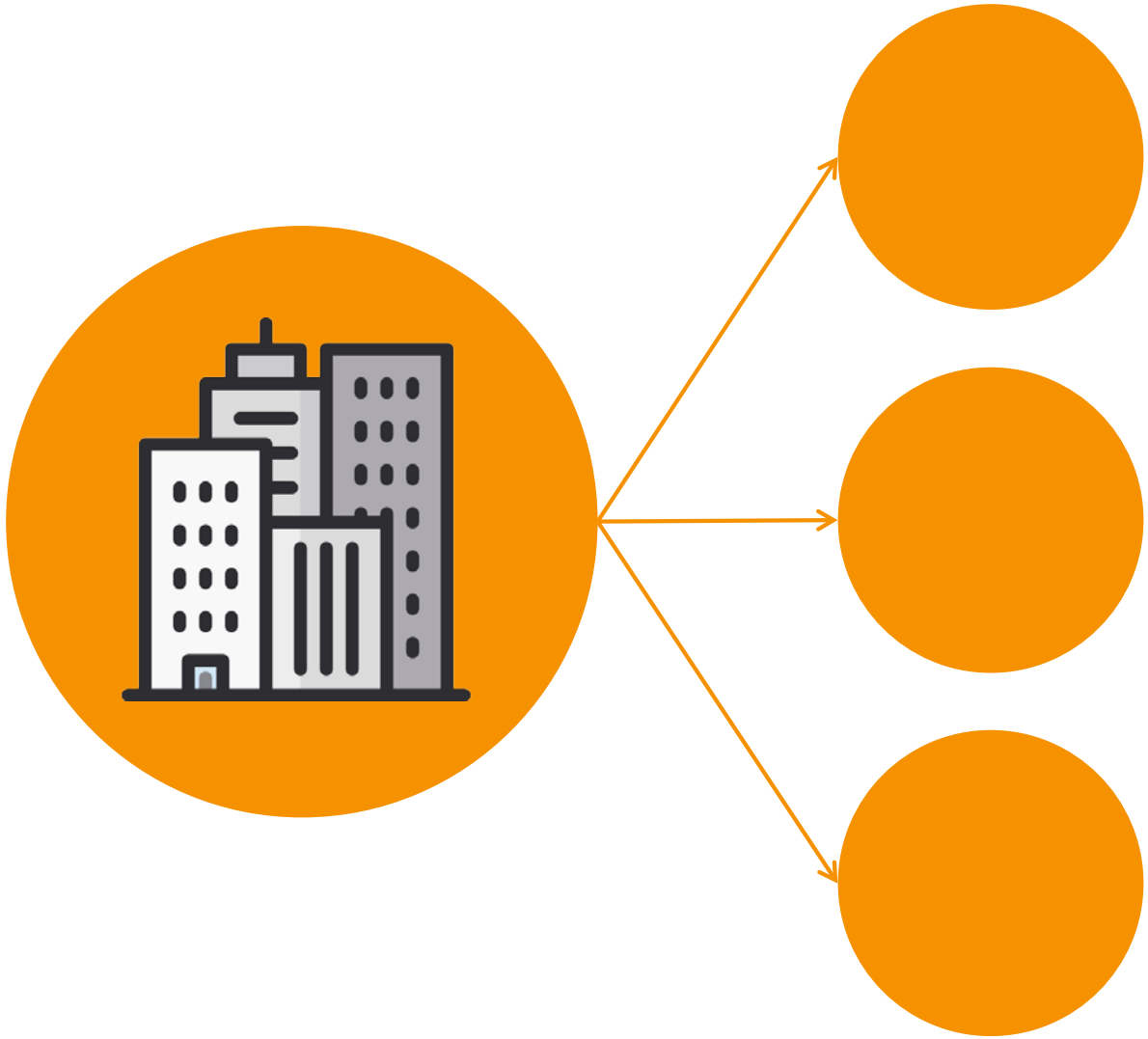
TÉCNICO LISBOA

ADAPTIVE FAÇADES

An Integrated Algorithmic Approach

MSc Thesis · Helena Freitas Martinho

PERFORMANCE CONSIDERATIONS



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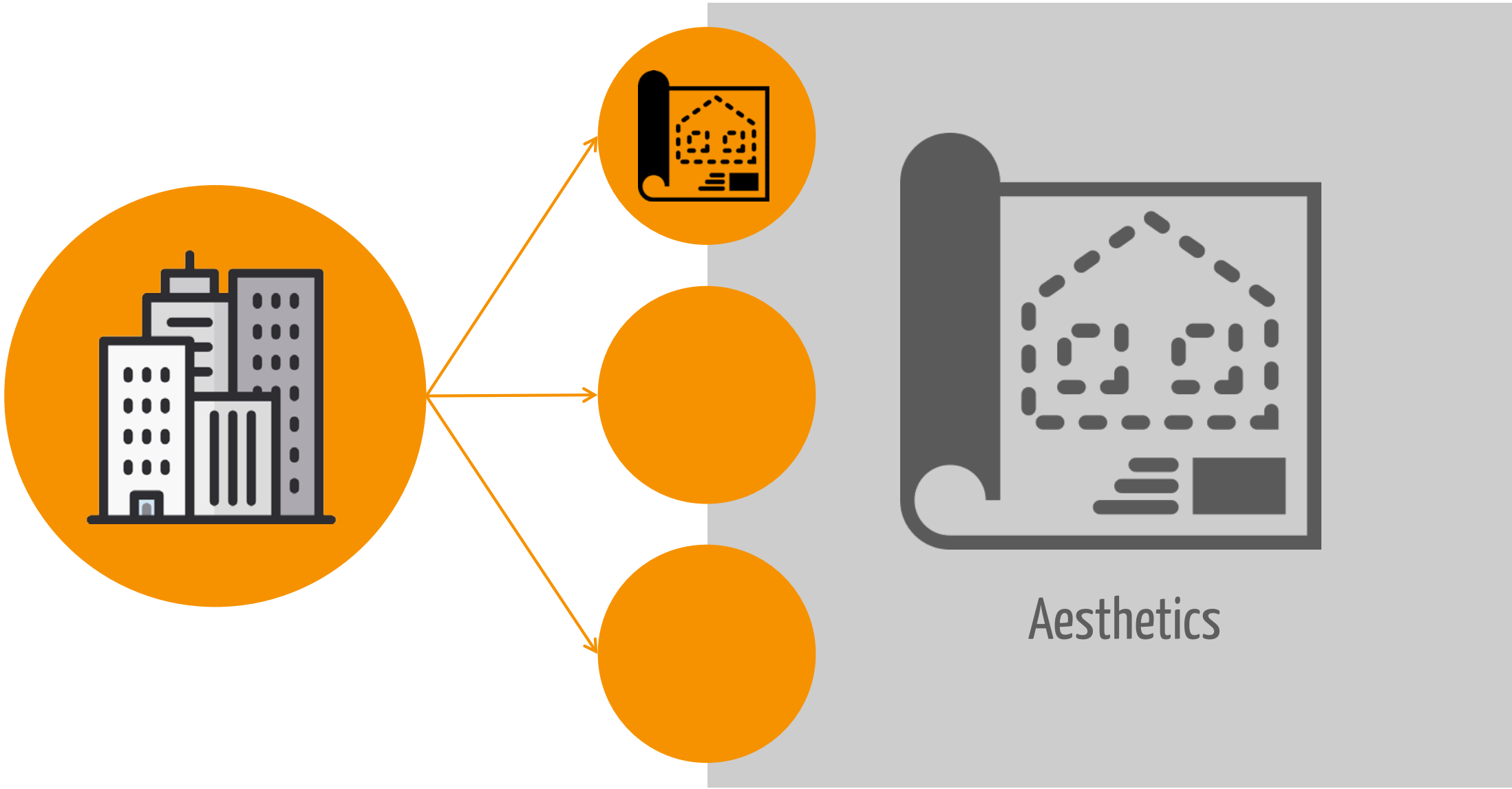

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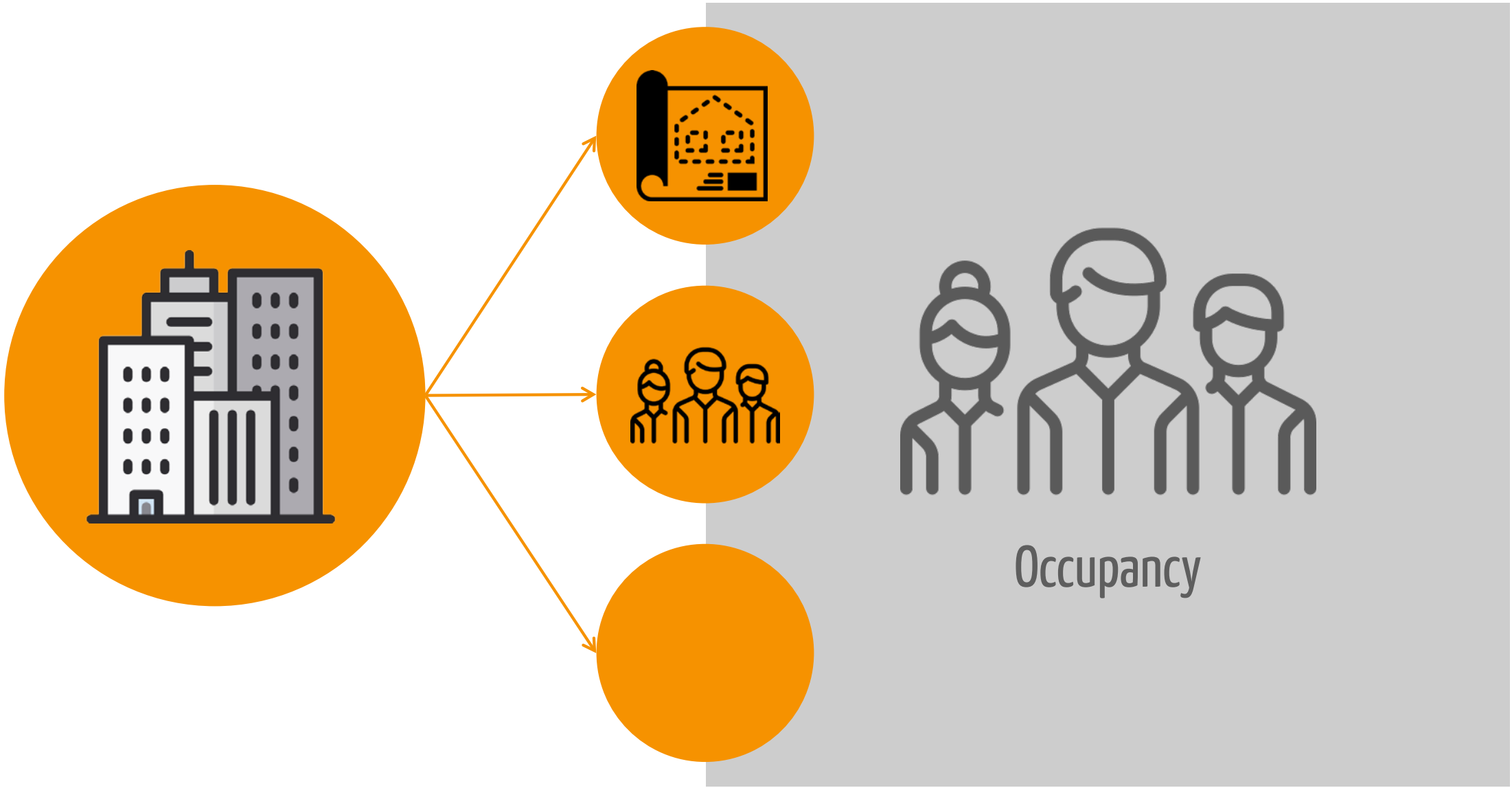

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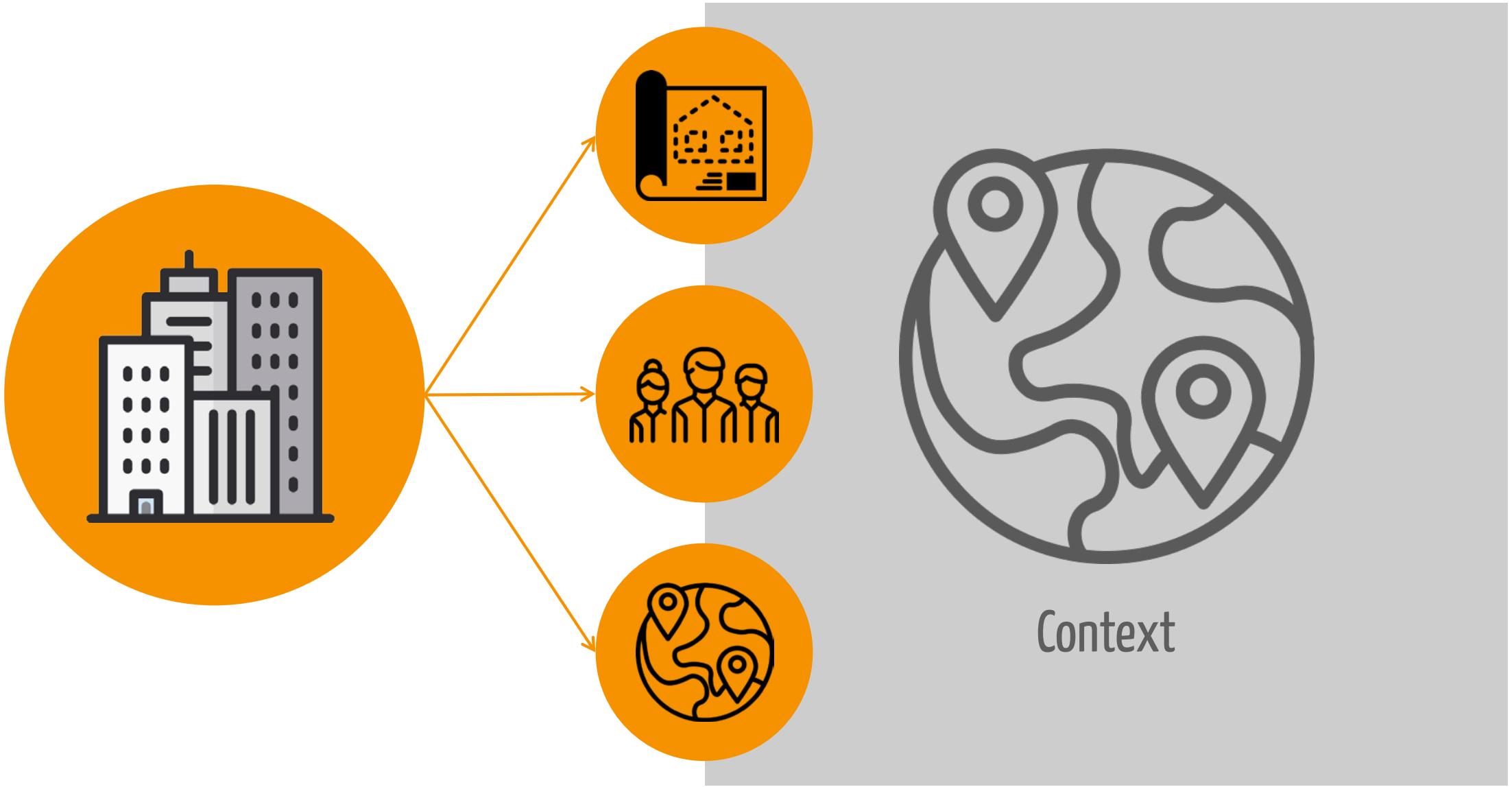
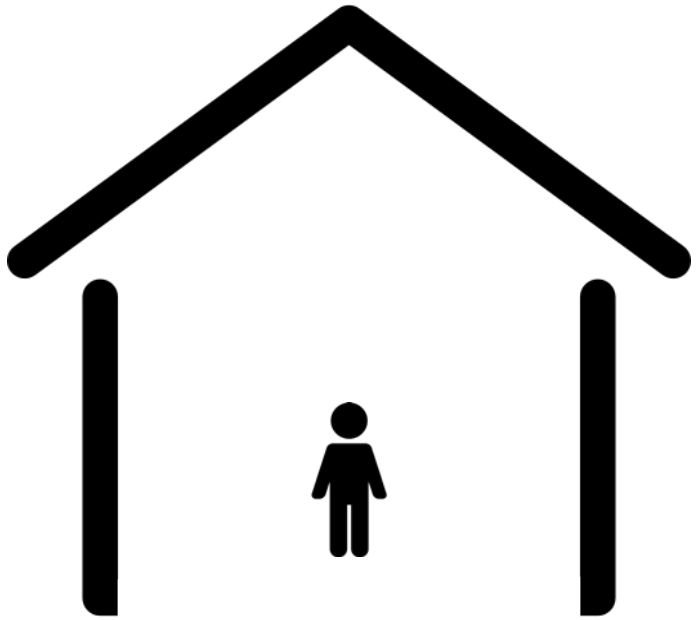
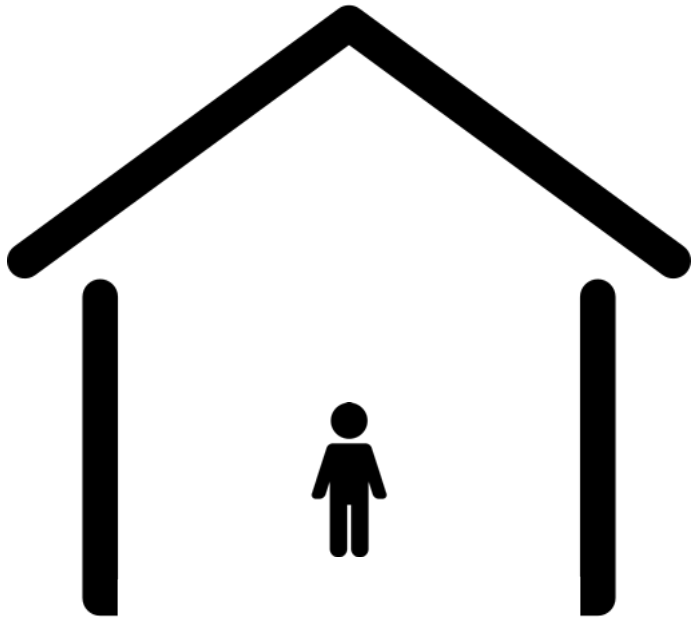


THE BUILDING ENVELOPE



THE BUILDING ENVELOPE

Structural



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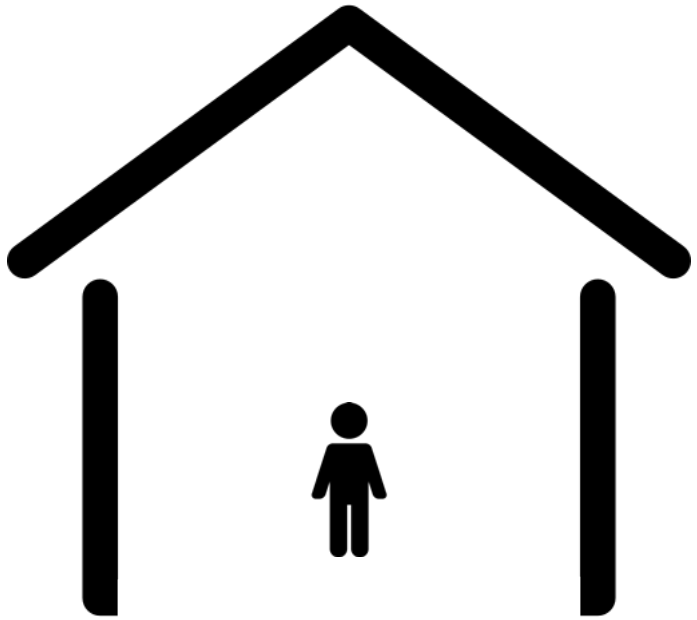
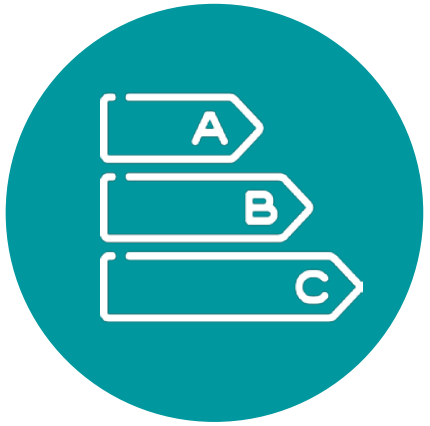
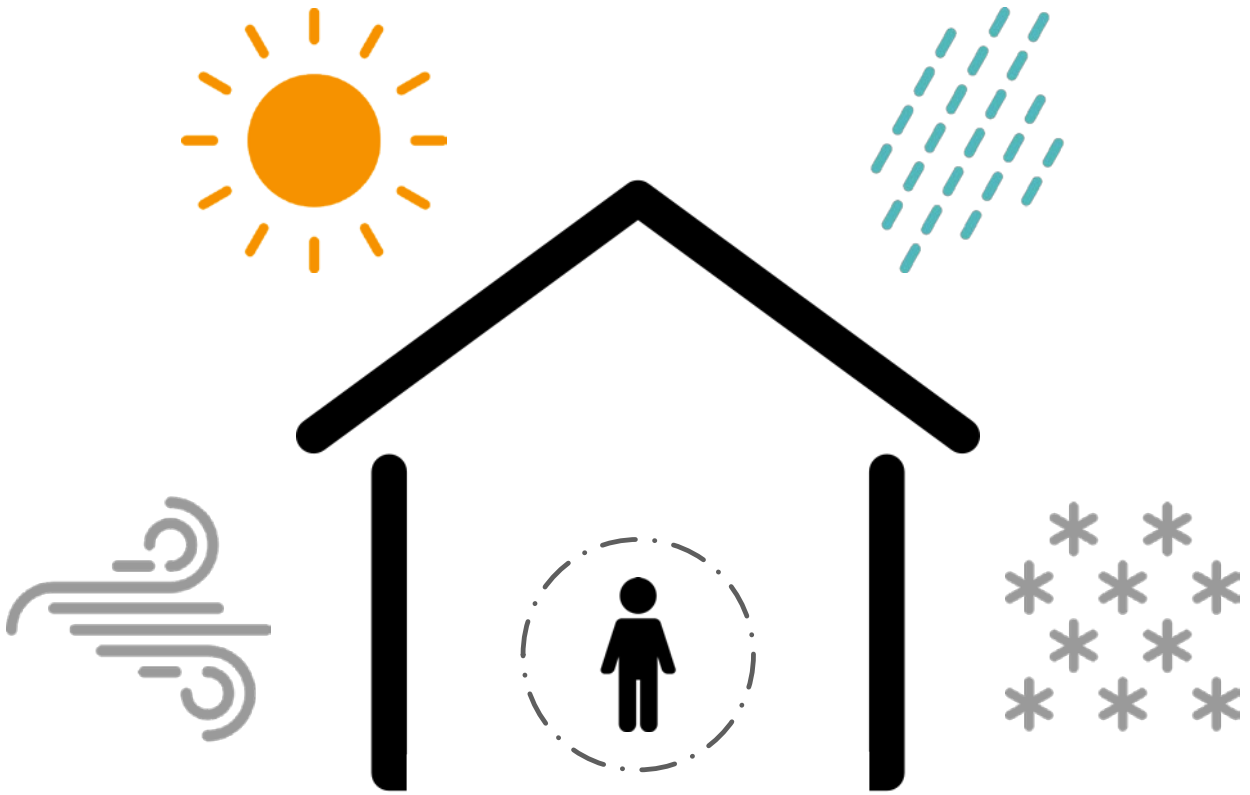




Energy efficiency

THE BUILDING ENVELOPE



Weathertightness

THE BUILDING ENVELOPE

STATIC

THE BUILDING ENVELOPE

STATIC

DYNAMIC

ADAPTIVE FAÇADES

ADAPTIVE FAÇADES

ADAPTIVE FAÇADES

ADAPT TO

Environmental changes

ADAPTIVE FAÇADES

ADAPT TO

Environmental changes

User needs

ADAPTIVE FAÇADES

ADAPT TO

Environmental changes

User needs

FOCUS

Increase efficiency

ADAPTIVE FAÇADES

ADAPT TO

Environmental changes

User needs

FOCUS

Increase efficiency

Reduce energy consumption

MOVEMENT

MOVEMENT

MECHANIC-BASED

MOVEMENT

MECHANIC-BASED

MATERIAL DEFORMATION

MOVEMENT

MECHANIC-BASED

Rotation

MATERIAL DEFORMATION

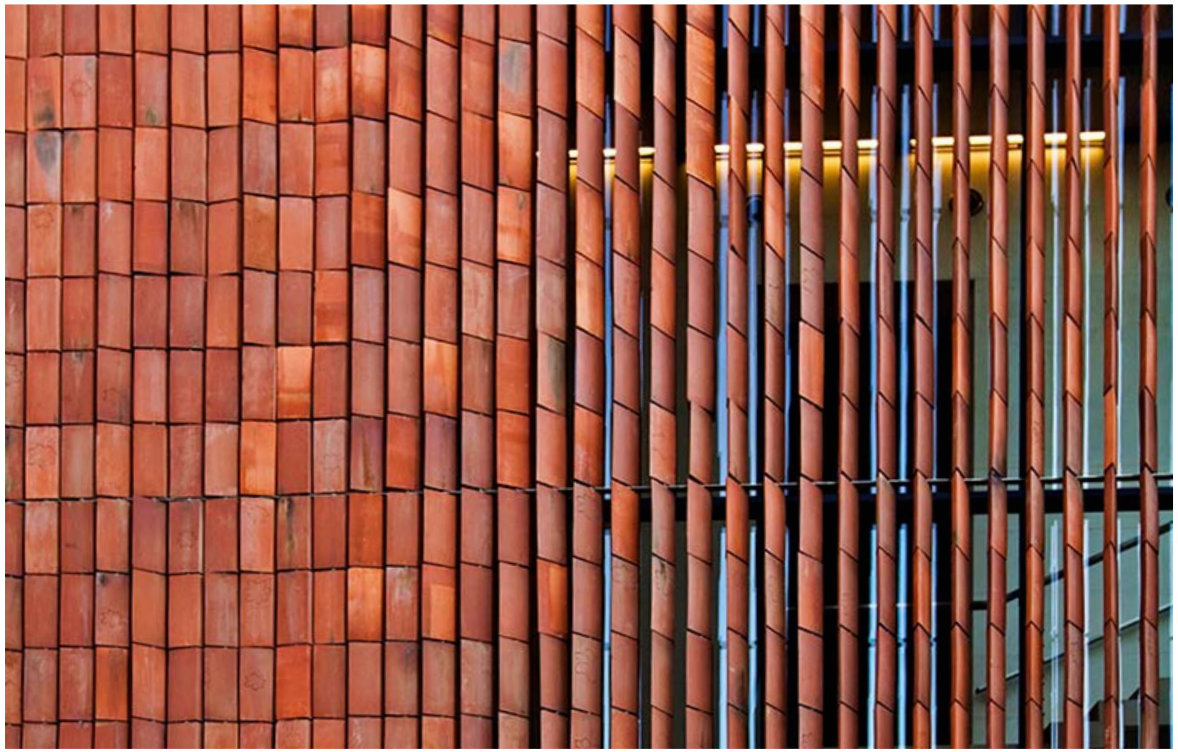
Wyspianski Pavilion, Krakow. Krzysztof Ingarden (2007)

MOVEMENT

MECHANIC-BASED

Rotation

MATERIAL DEFORMATION



Wyspianski Pavilion, Krakow. Krzysztof Ingarden (2007)

MOVEMENT

MECHANIC-BASED

Rotation

Translation

MATERIAL DEFORMATION

The Shed, New York. Diller Scofidio + Renfro (2019)

MOVEMENT

MECHANIC-BASED

Rotation

Translation

MATERIAL DEFORMATION

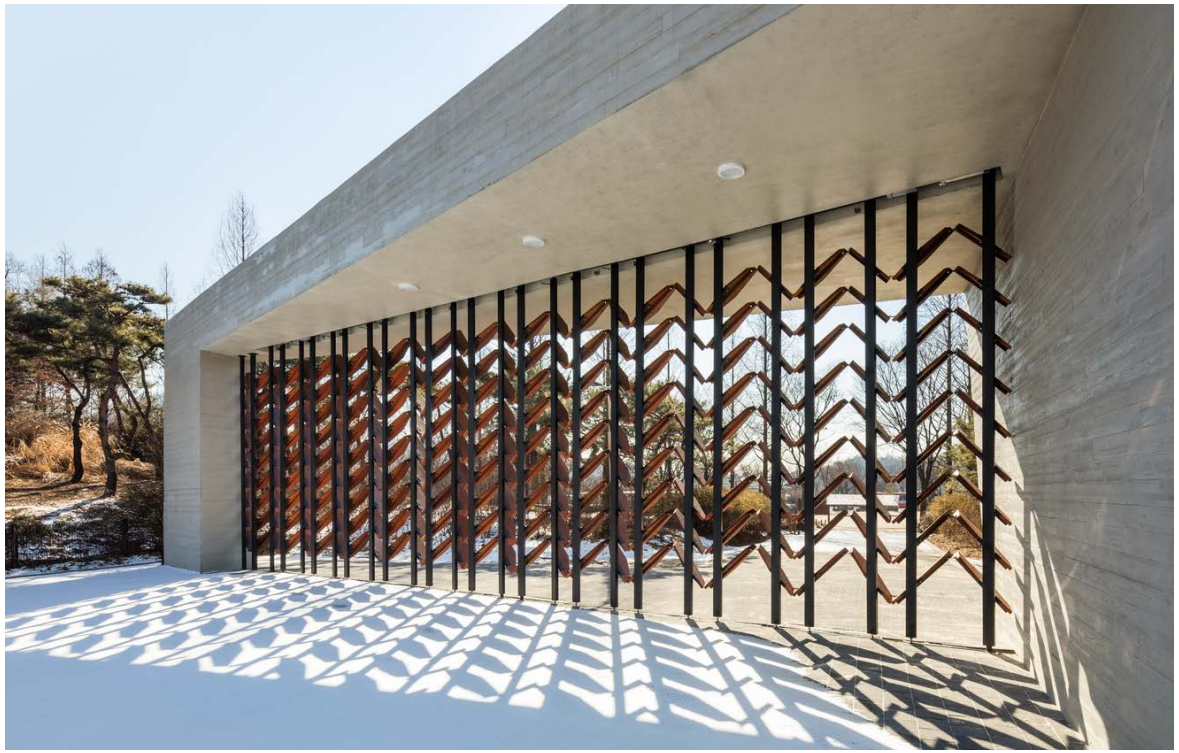
The Shed, New York. Diller Scofidio + Renfro (2019)

MOVEMENT

MECHANIC-BASED

- Rotation
- Translation
- Hybrid

MATERIAL DEFORMATION



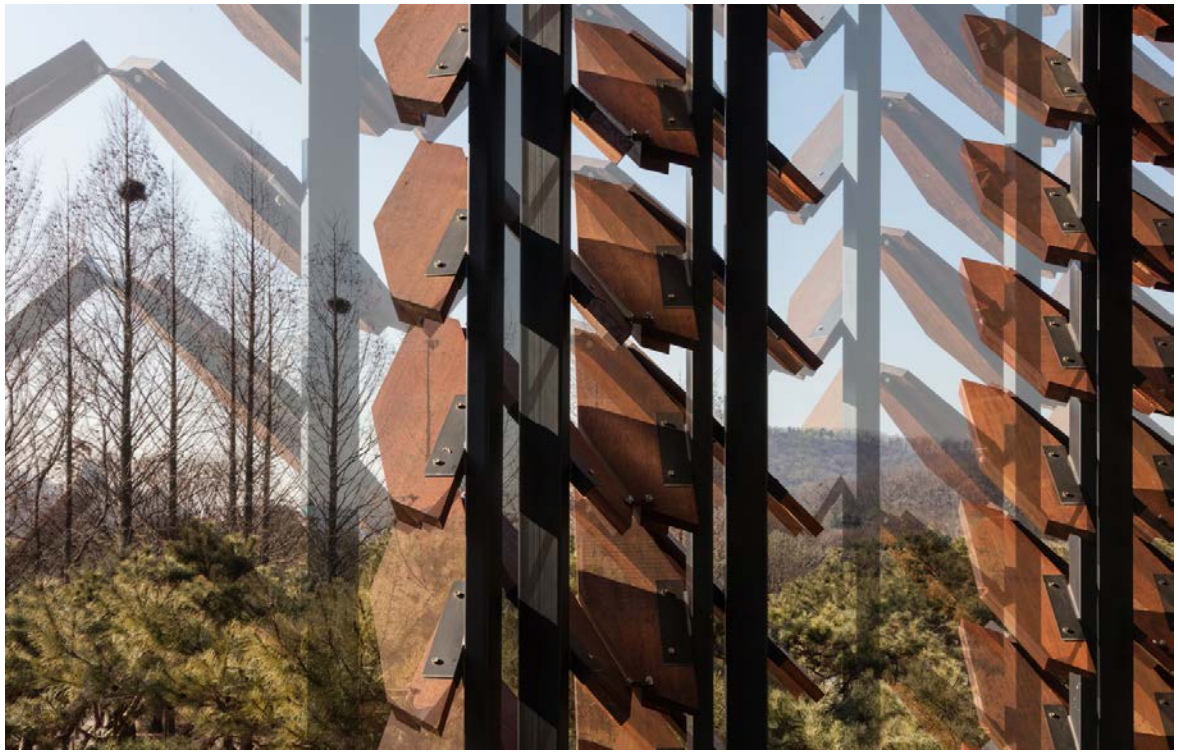
Mokyeonri, South Korea. softarchitecturelab (2017)

MOVEMENT

MECHANIC-BASED

- Rotation
- Translation
- Hybrid

MATERIAL DEFORMATION



Mokyeonri, South Korea. softarchitecturelab (2017)

MOVEMENT

MECHANIC-BASED

- Rotation
- Translation
- Hybrid

MATERIAL DEFORMATION

MOVEMENT

MECHANIC-BASED

- Rotation
- Translation
- Hybrid

MATERIAL DEFORMATION

- Self-change

Hygroskin Pavilion, France. David Correa et al. (2013)

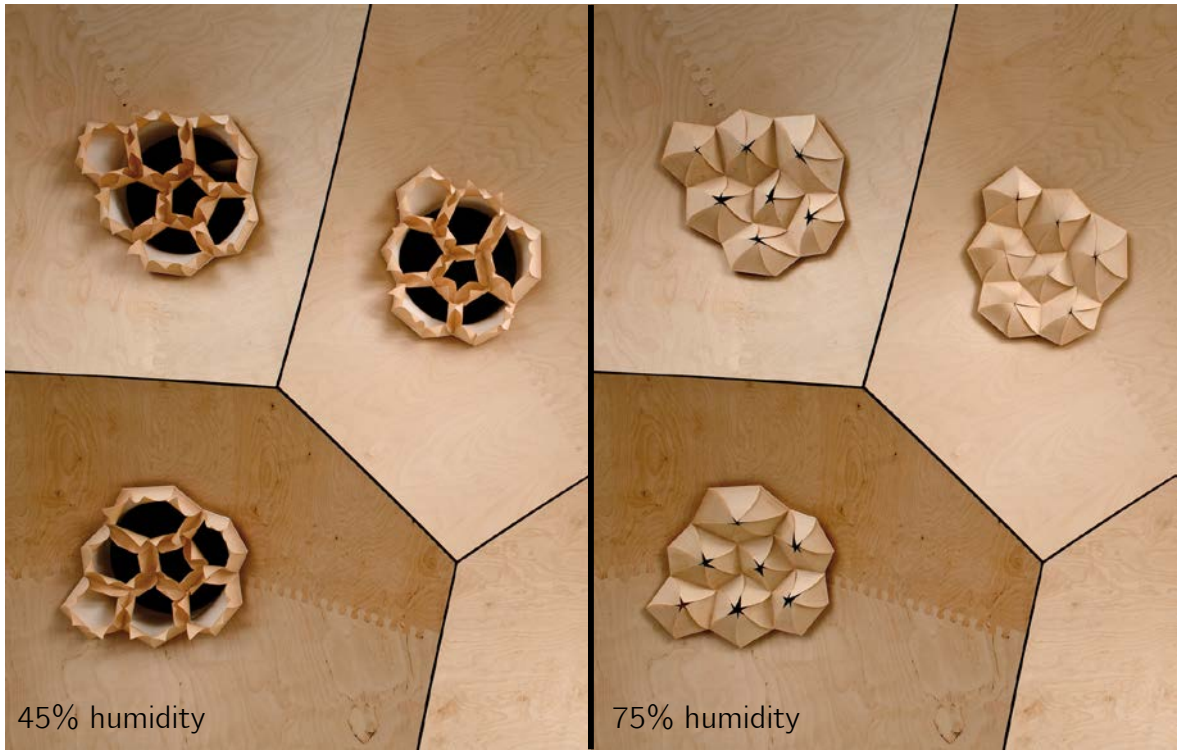
MOVEMENT

MECHANIC-BASED

- Rotation
- Translation
- Hybrid

MATERIAL DEFORMATION

- Self-change



Hygroskin Pavilion, France. David Correa et al. (2013)

MOVEMENT

MECHANIC-BASED

- Rotation
- Translation
- Hybrid

MATERIAL DEFORMATION

- Self-change
- External Input

ShapeShift prototype. EMPA (2010)

MOVEMENT

MECHANIC-BASED

- Rotation
- Translation
- Hybrid

MATERIAL DEFORMATION

- Self-change
- External Input

ShapeShift prototype. EMPA (2010)

CONTROL

CONTROL

CENTRAL

CONTROL

CENTRAL

LOCAL

CONTROL

CENTRAL

Direct

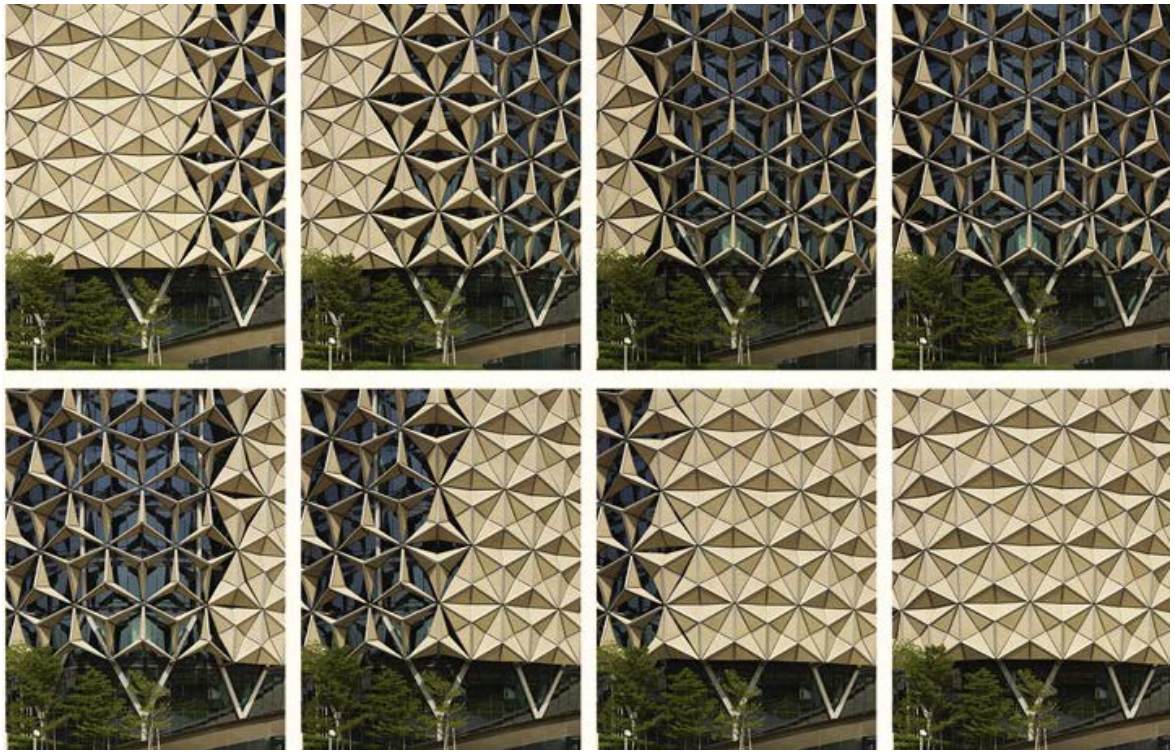
LOCAL

Al Bahr Towers, Abu Dhabi. Aedas (2013)

CONTROL

CENTRAL | Direct

LOCAL



Al Bahr Towers, Abu Dhabi. Aedas (2013)

CONTROL

CENTRAL

LOCAL

Direct

Reactive

Kolding Campus, Denmark. Henning Larsen (2014)

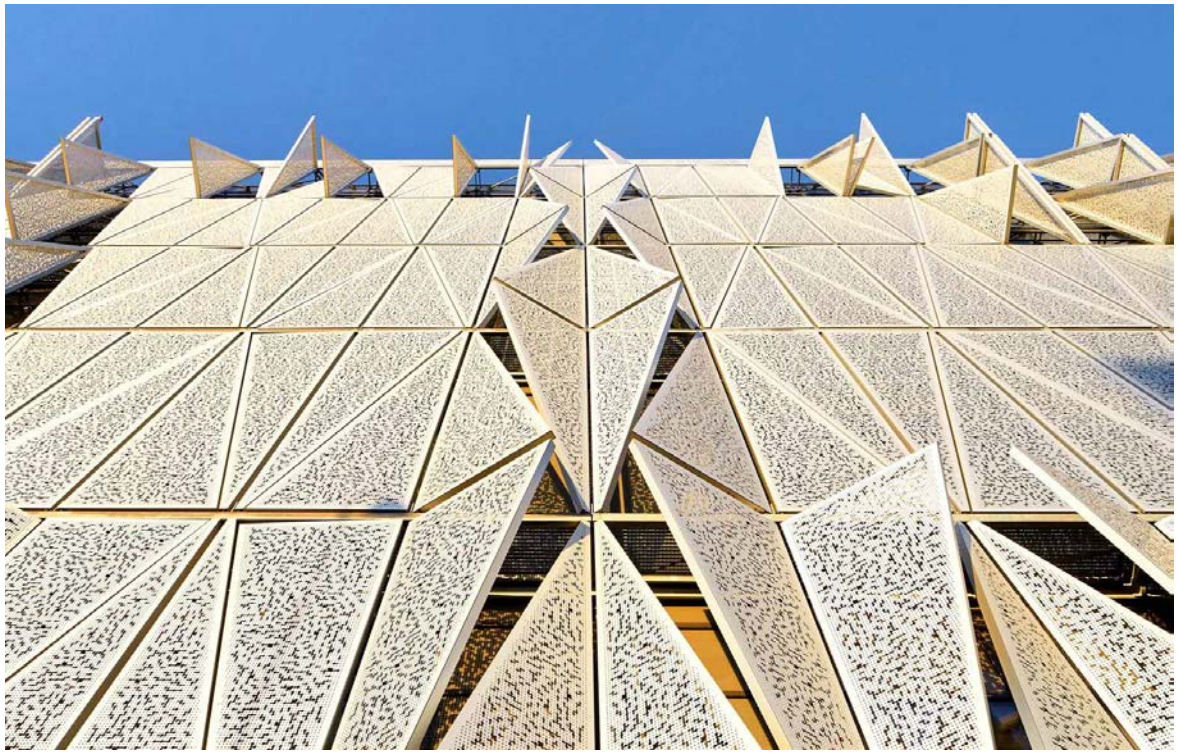
CONTROL

CENTRAL

Direct

Reactive

LOCAL



Kolding Campus, Denmark. Henning Larsen (2014)

CONTROL

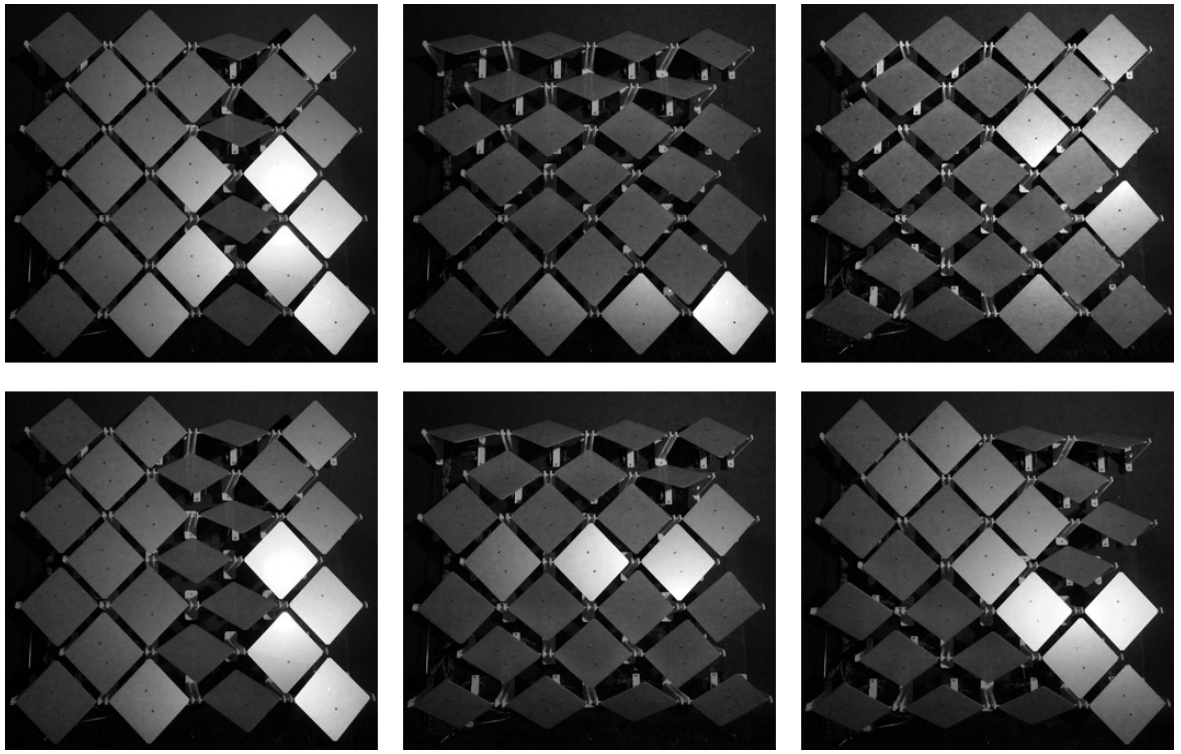
CENTRAL

Direct

Reactive

System-based

LOCAL



Adaptive fa[CA]de prototype. Maria Skavara (2009)

CONTROL

CENTRAL	Direct
	Reactive
	System-based
LOCAL	

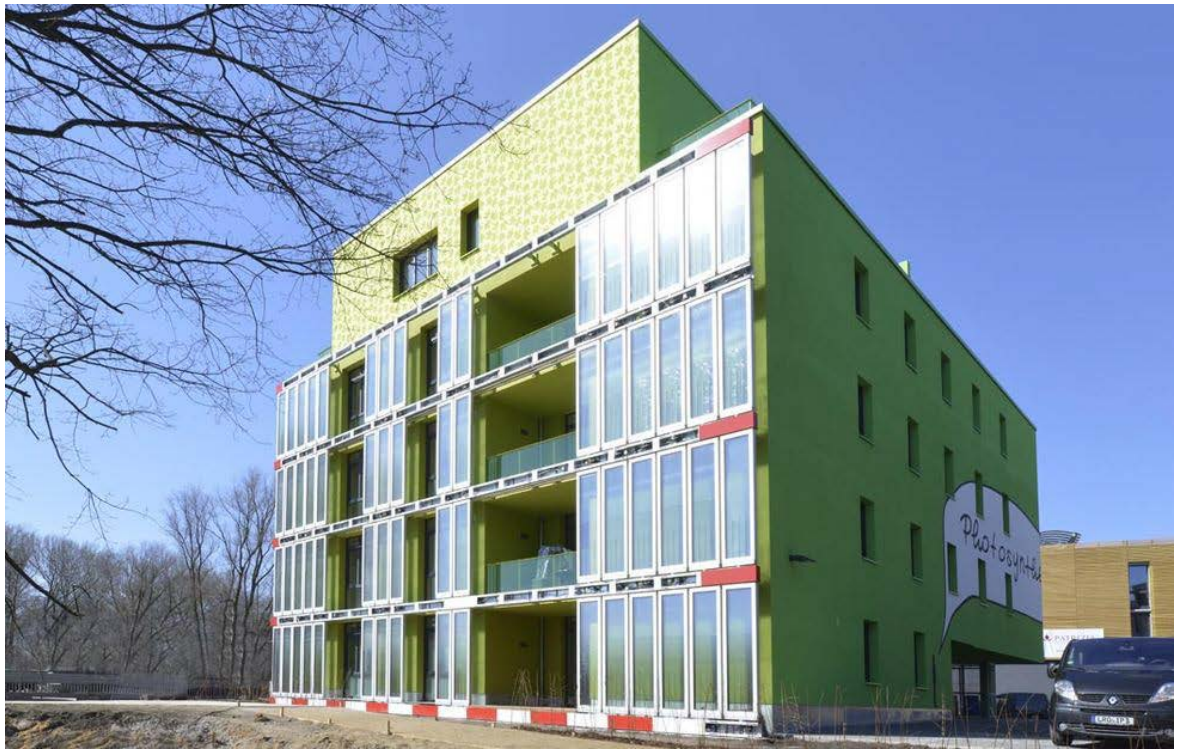
CONTROL

CENTRAL

- Direct
- Reactive
- System-based

LOCAL

- Material



BIQ House, Germany. Splitterwerk Architects (2013)

CONTROL

CENTRAL

- Direct
- Reactive
- System-based

LOCAL

- Material

BIQ House, Germany. Splitterwerk Architects (2013)

CONTROL

CENTRAL

- Direct
- Reactive
- System-based

LOCAL

- Material
- Sensor-based

The Arab World Institute, France. Jean Nouvel (1987)

CONTROL

CENTRAL

- Direct
- Reactive
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LOCAL

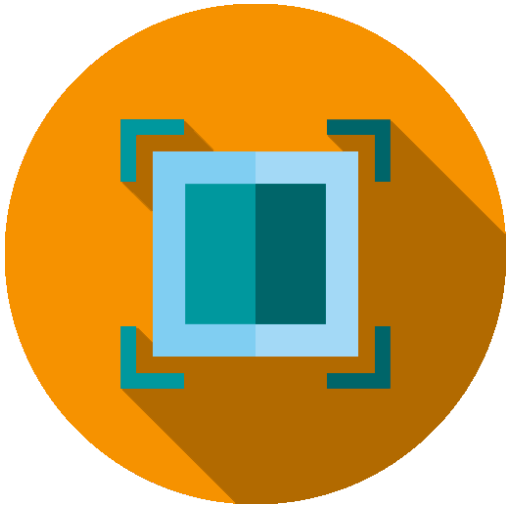
- Material
- Sensor-based

The Arab World Institute, France. Jean Nouvel (1987)

MOTIVATION

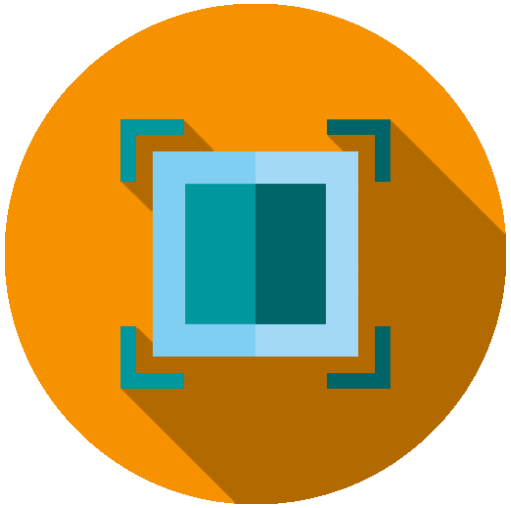
- Geometric Transformation

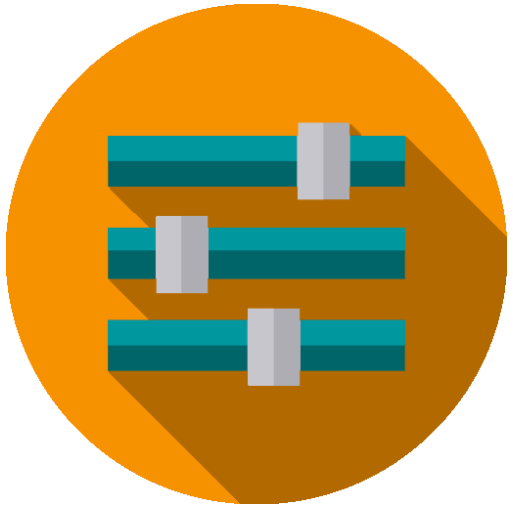
MOTIVATION



- Geometric Transformation → **Static façades** → **DESIGN METHOD**

MOTIVATION



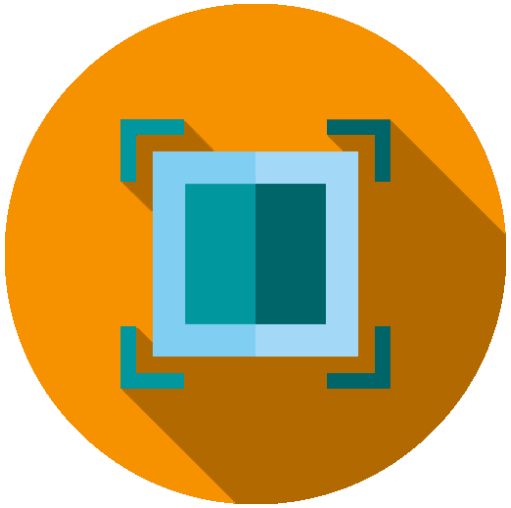


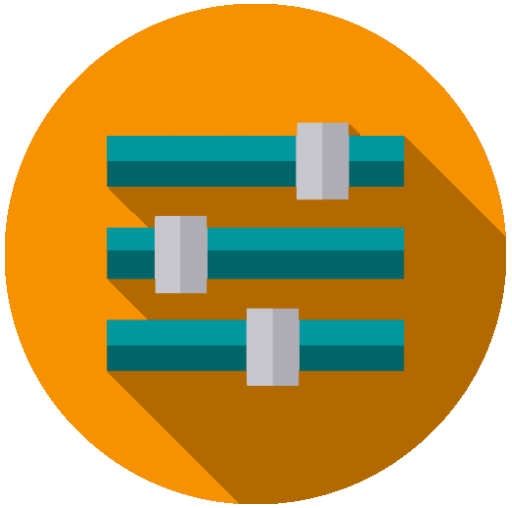
- Geometric Transformation

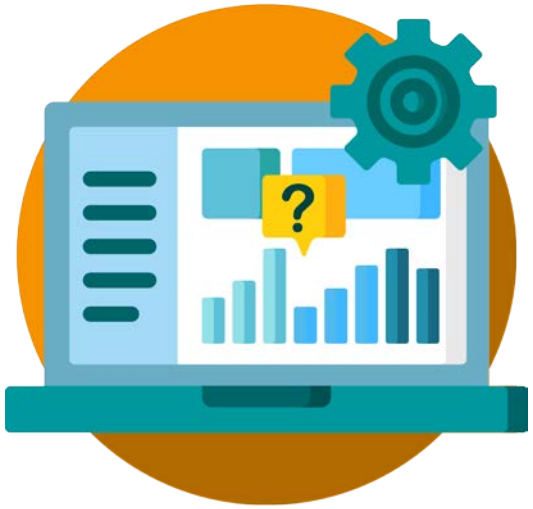
Static façades → DESIGN METHOD

Adaptive façades → DESIGN OUTCOME

MOTIVATION



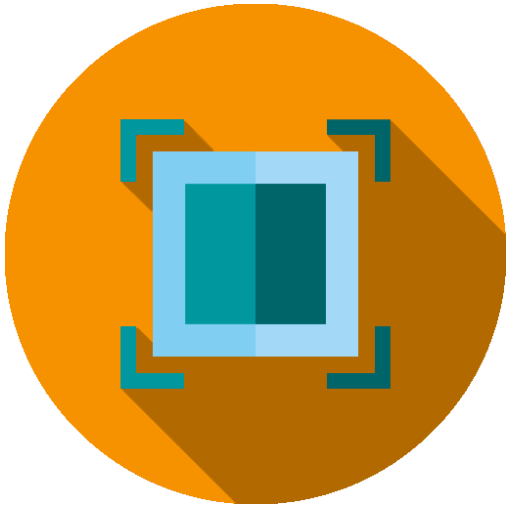


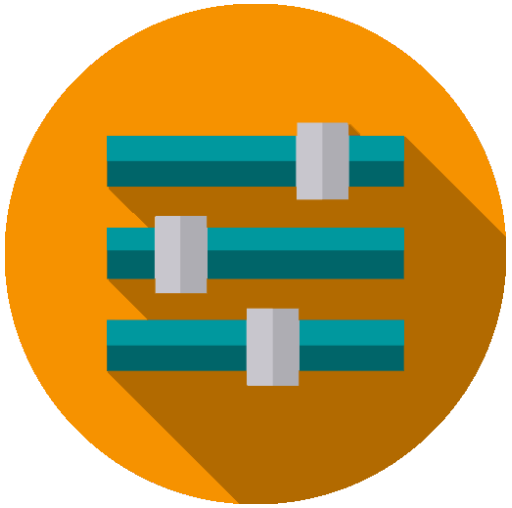


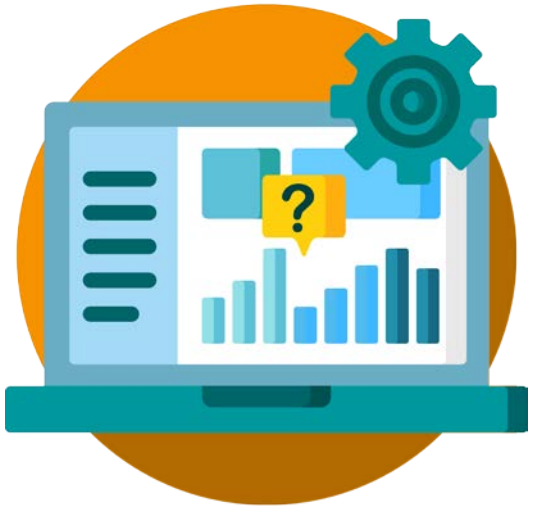
- Geometric Transformation
  - Static façades → DESIGN METHOD
  - Adaptive façades → DESIGN OUTCOME

- Analysis tools give limited guidance

MOTIVATION







- Geometric Transformation
  - Static façades → DESIGN METHOD
  - Adaptive façades → DESIGN OUTCOME
- Analysis tools give limited guidance
- Need to improve simulation-based design strategies

ALGORITHMIC DESIGN (AD)

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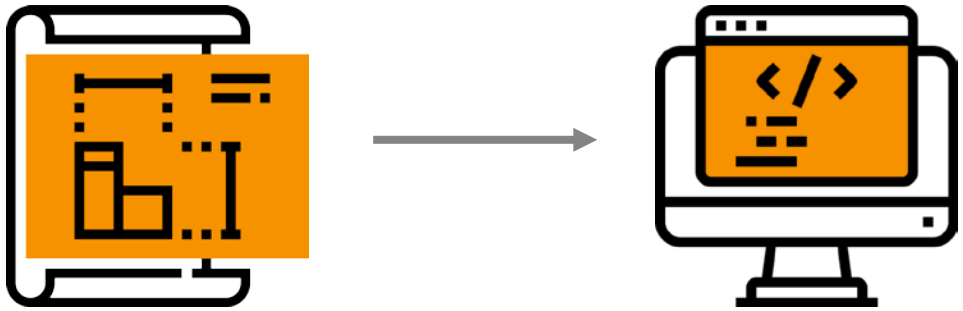


- description of an architectural design through algorithms

ALGORITHMIC DESIGN (AD)

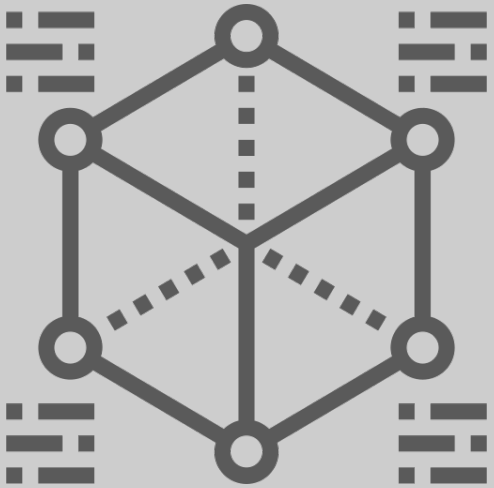
- description of an architectural design through algorithms
- parameters are translated into building geometries

ALGORITHMIC DESIGN (AD)

- description of an architectural design through algorithms
- parameters are translated into building geometries
- design variations can be quickly generated

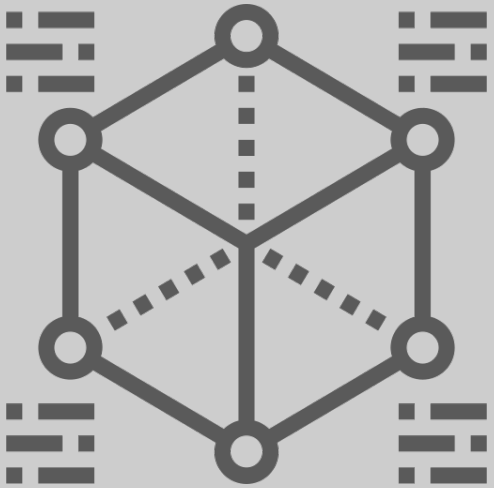
OBJECTIVES

OBJECTIVES



Generate model through AD tool

OBJECTIVES



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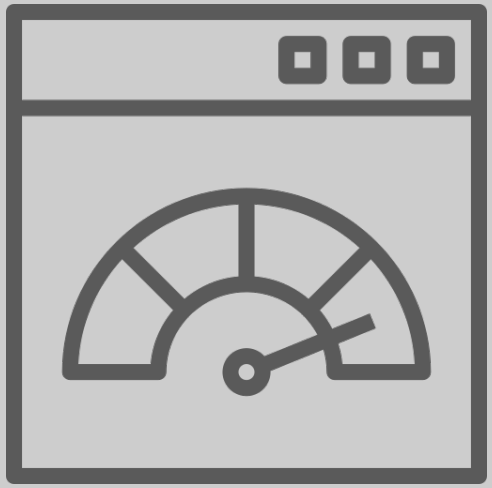
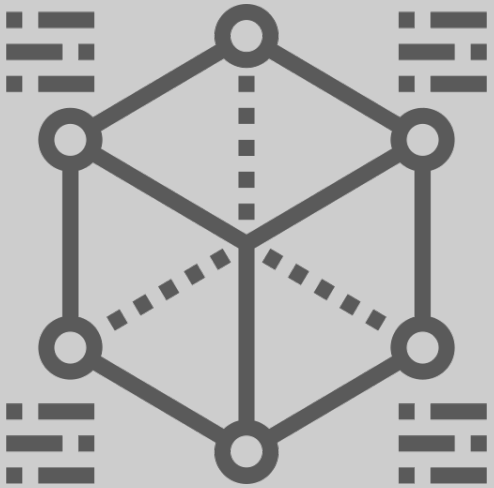


Evaluate impact on energy demands

OBJECTIVES



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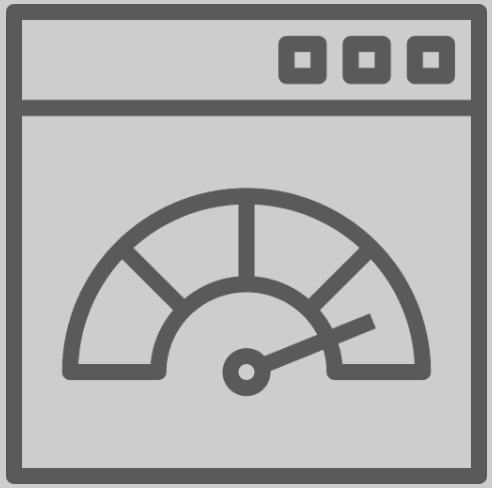
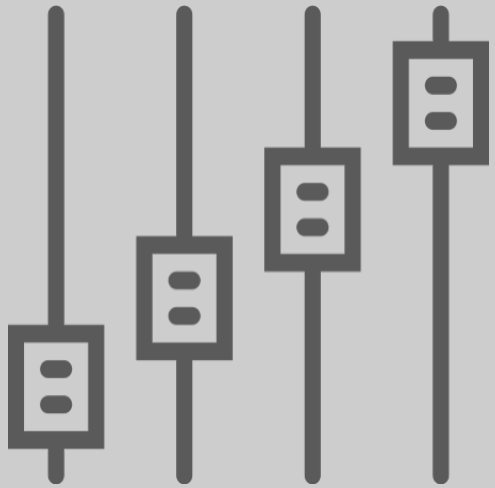
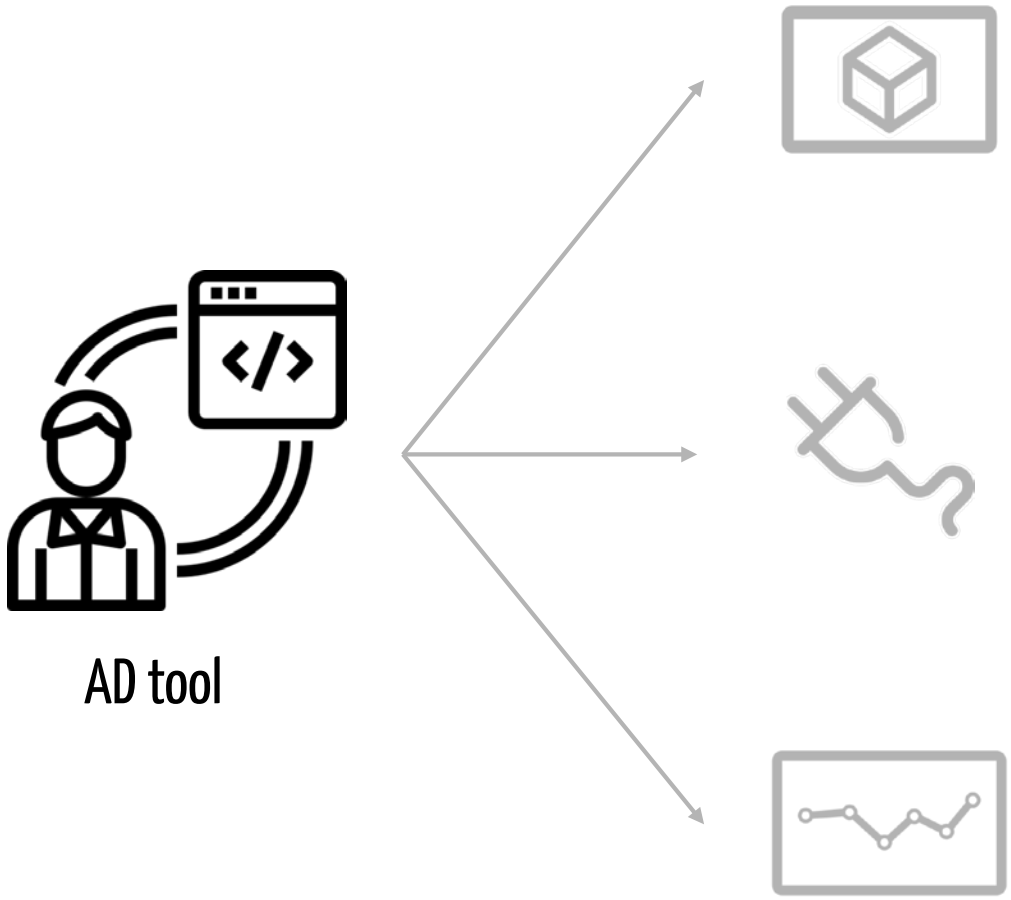


Evaluate impact on energy demands

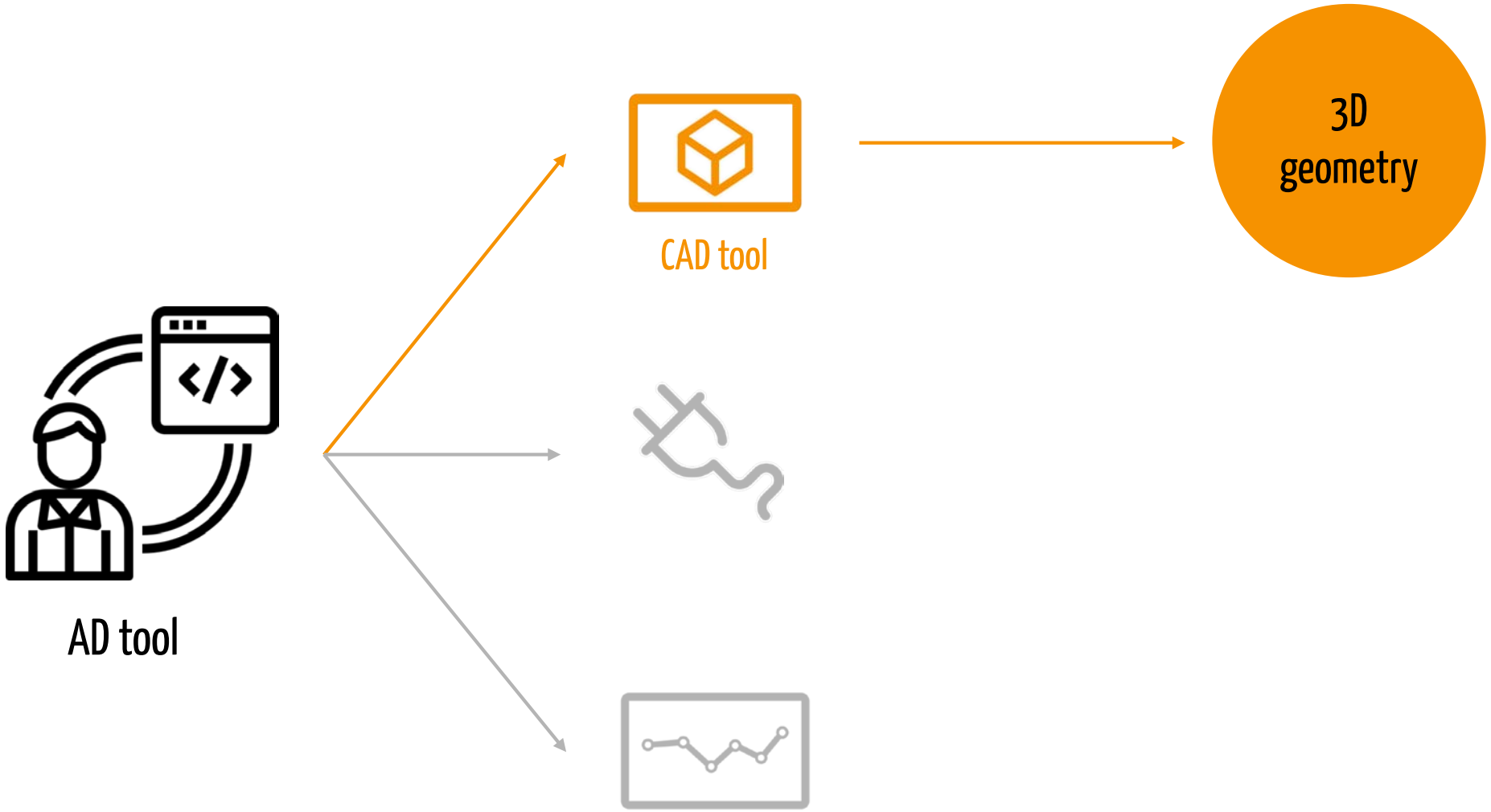


Define optimal control system

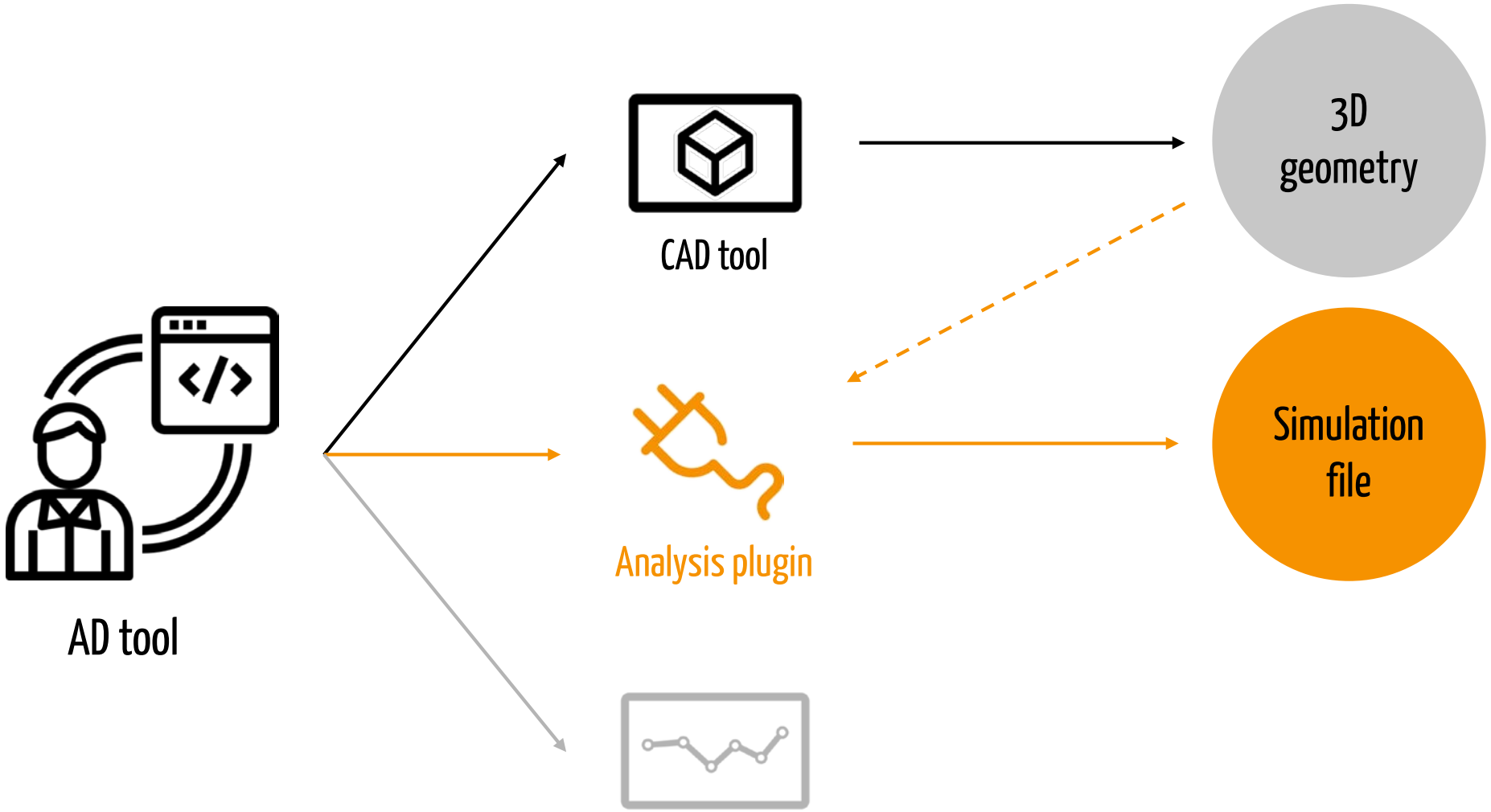
WORKFLOW



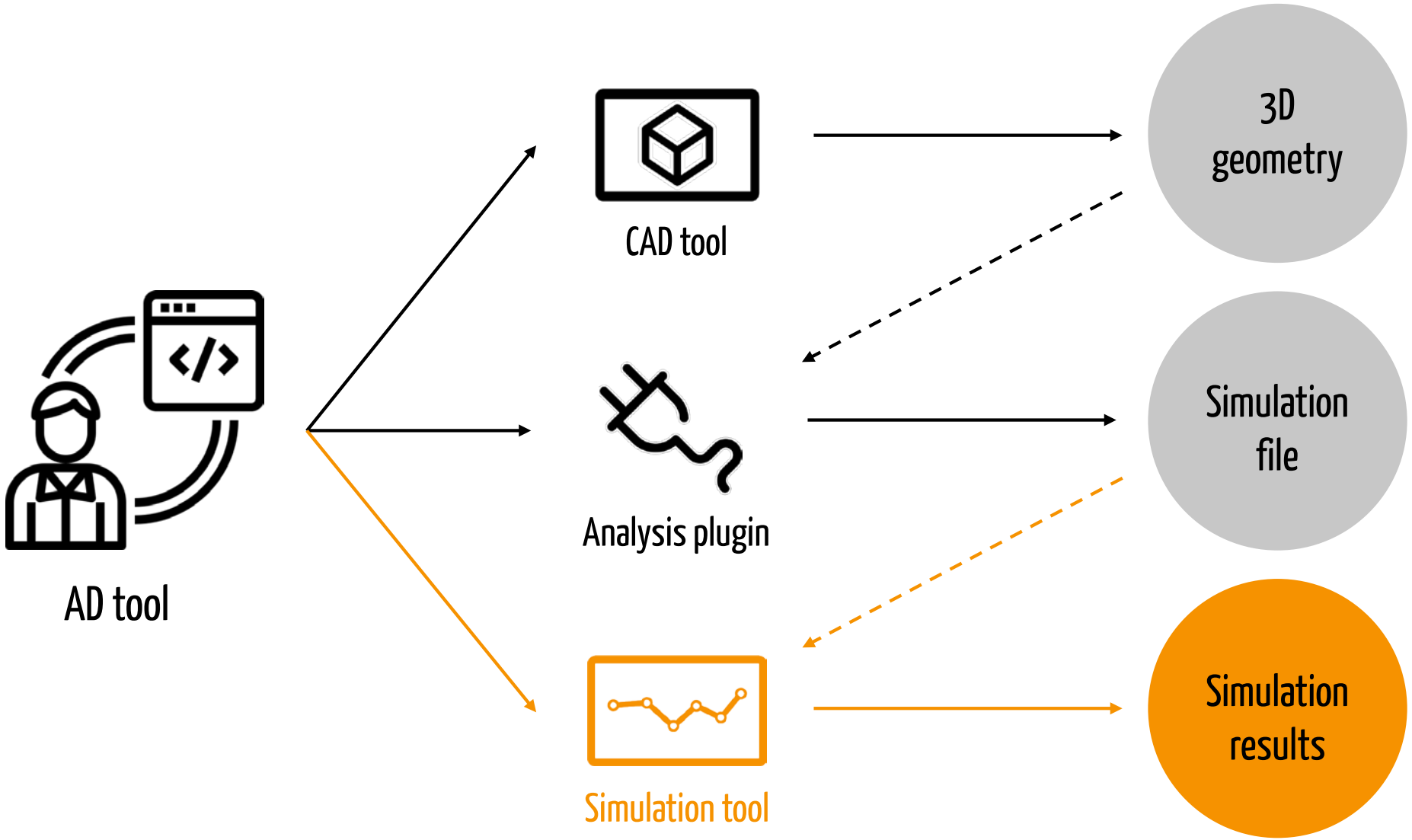
WORKFLOW



WORKFLOW


3D
geometry
CAD tool
Simulation
file
Analysis plugin
AD tool

WORKFLOW


AD tool
CAD tool
Analysis plugin
Simulation tool
3D geometry
Simulation file
Simulation results

VALIDATION

INTER-MODEL COMPARATIVE TESTING

VALIDATION

INTER-MODEL COMPARATIVE TESTING

- helps identify external errors

VALIDATION

INTER-MODEL COMPARATIVE TESTING

- helps identify external errors
- does not require data from real buildings

VALIDATION

INTER-MODEL COMPARATIVE TESTING

- helps identify external errors
- does not require data from real buildings
- allows the comparison of any cases that two or more tools can model

BUILDING ENERGY SIMULATION TEST (BESTEST)

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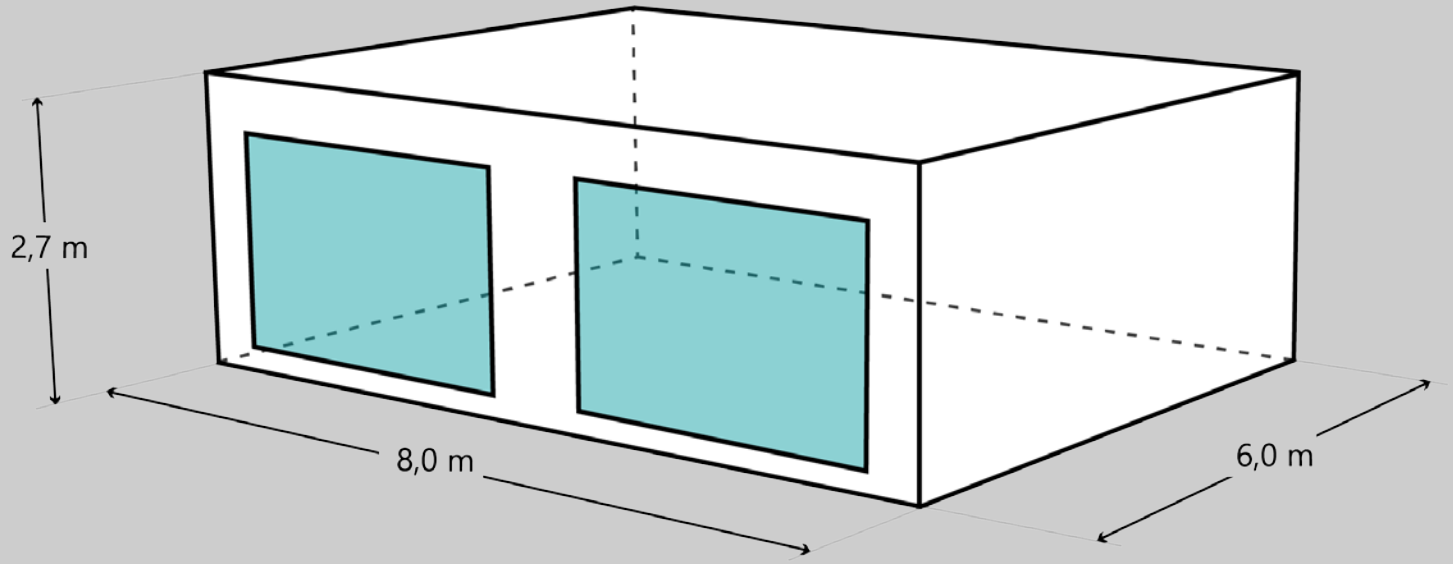
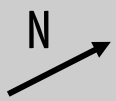
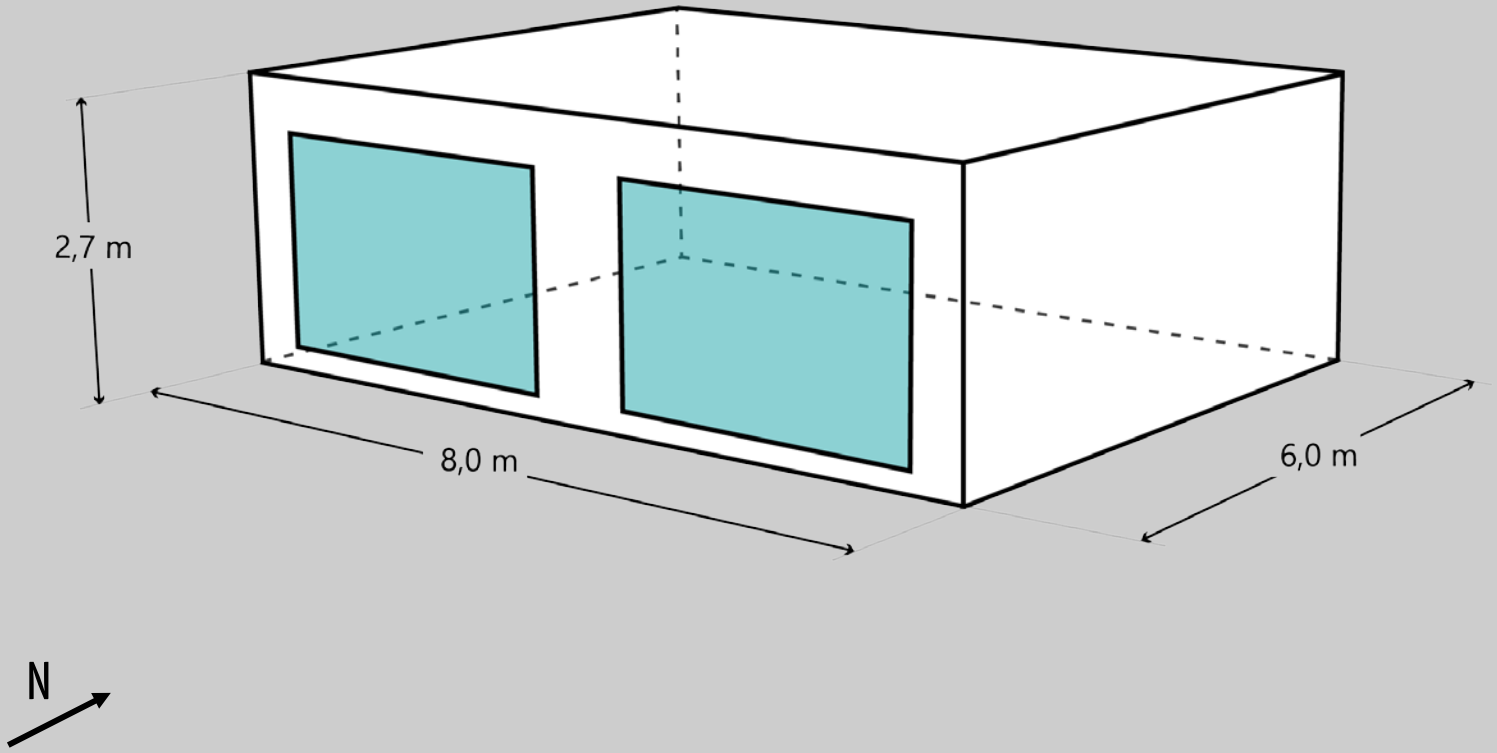




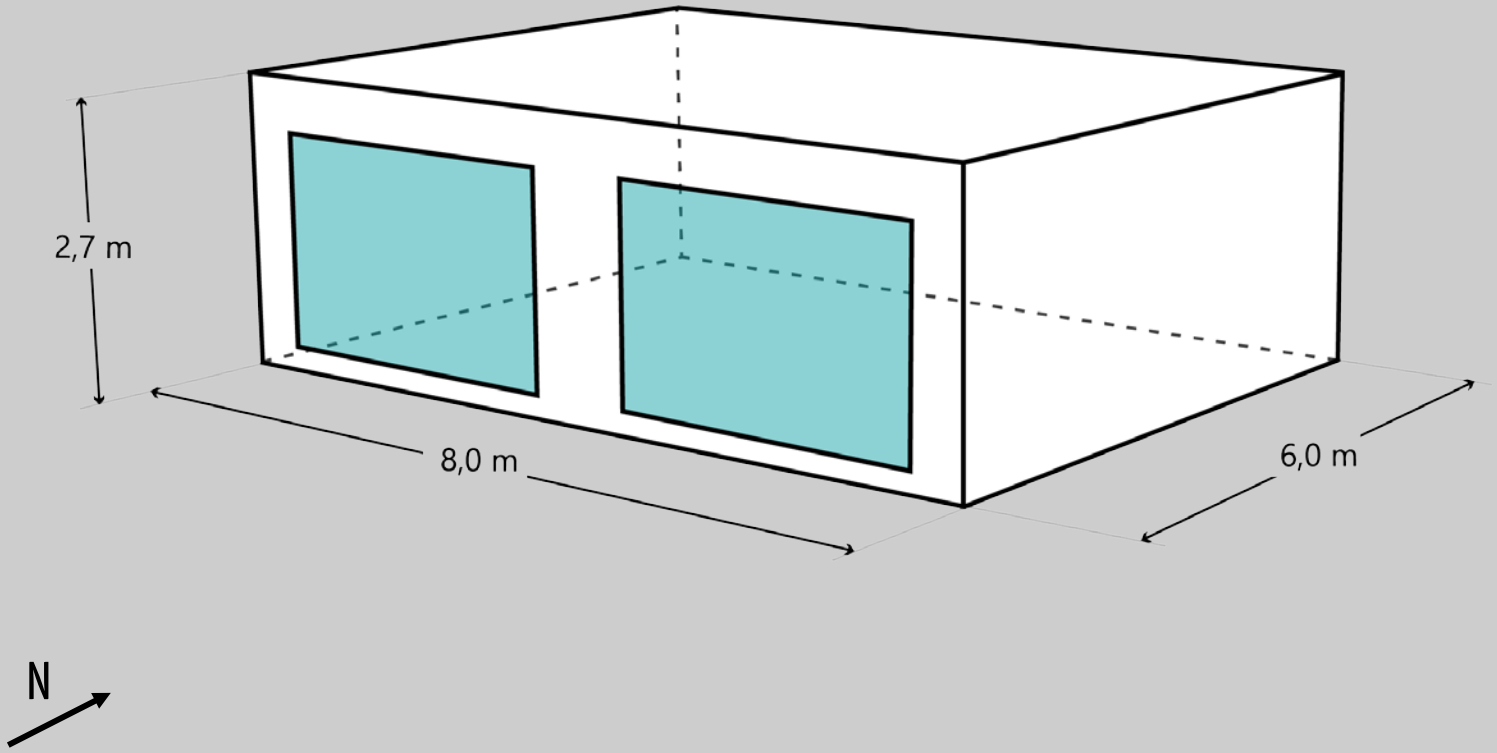
BUILDING ENERGY SIMULATION TEST (BESTEST)



INTERNAL GAINS

Occupancy	-
Lighting Load	-
Equipment Load	200 W
Heating Setpoint	20 ºC
Cooling Setpoint	27 ºC
Infiltration	0.5 ACH

BUILDING ENERGY SIMULATION TEST (BESTEST)



SIMULATION PARAMETERS

Analysis Period

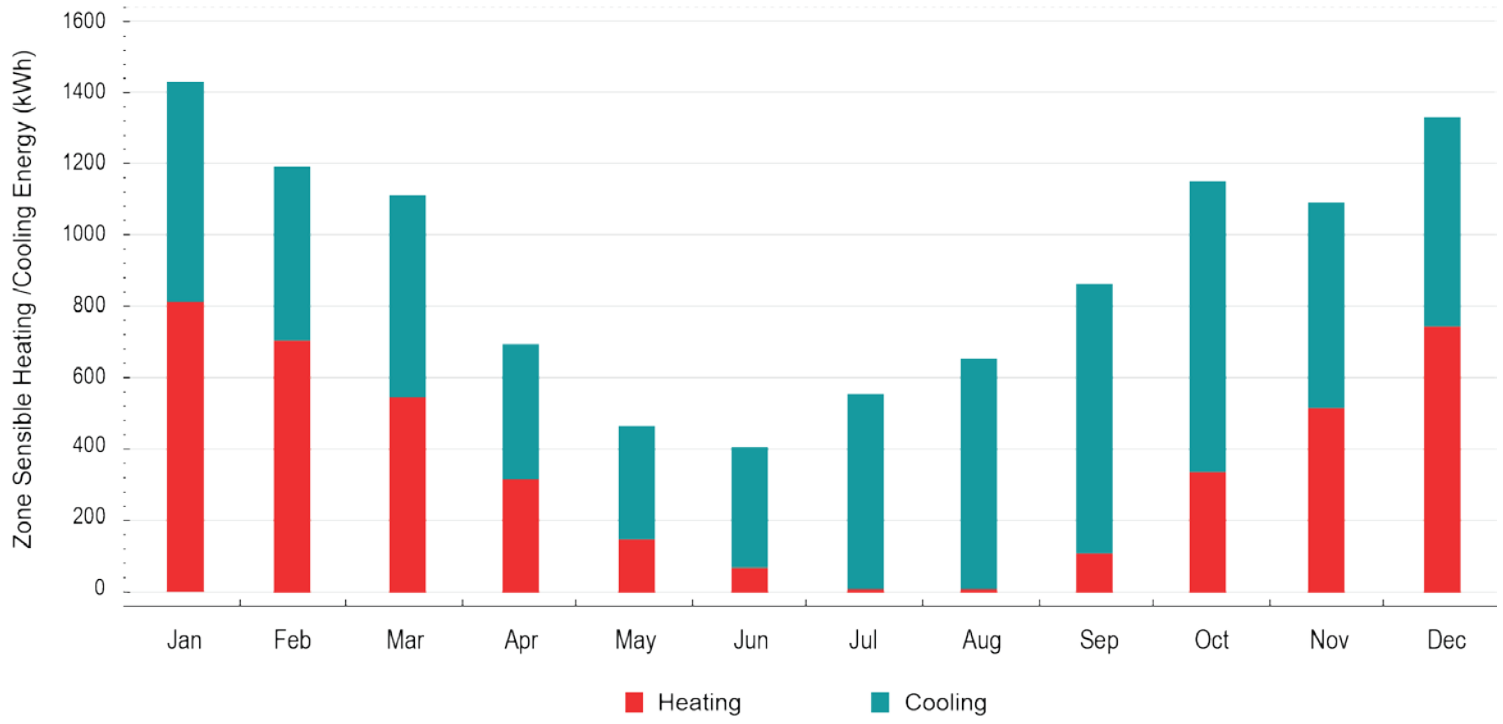
12 months

Requested Output

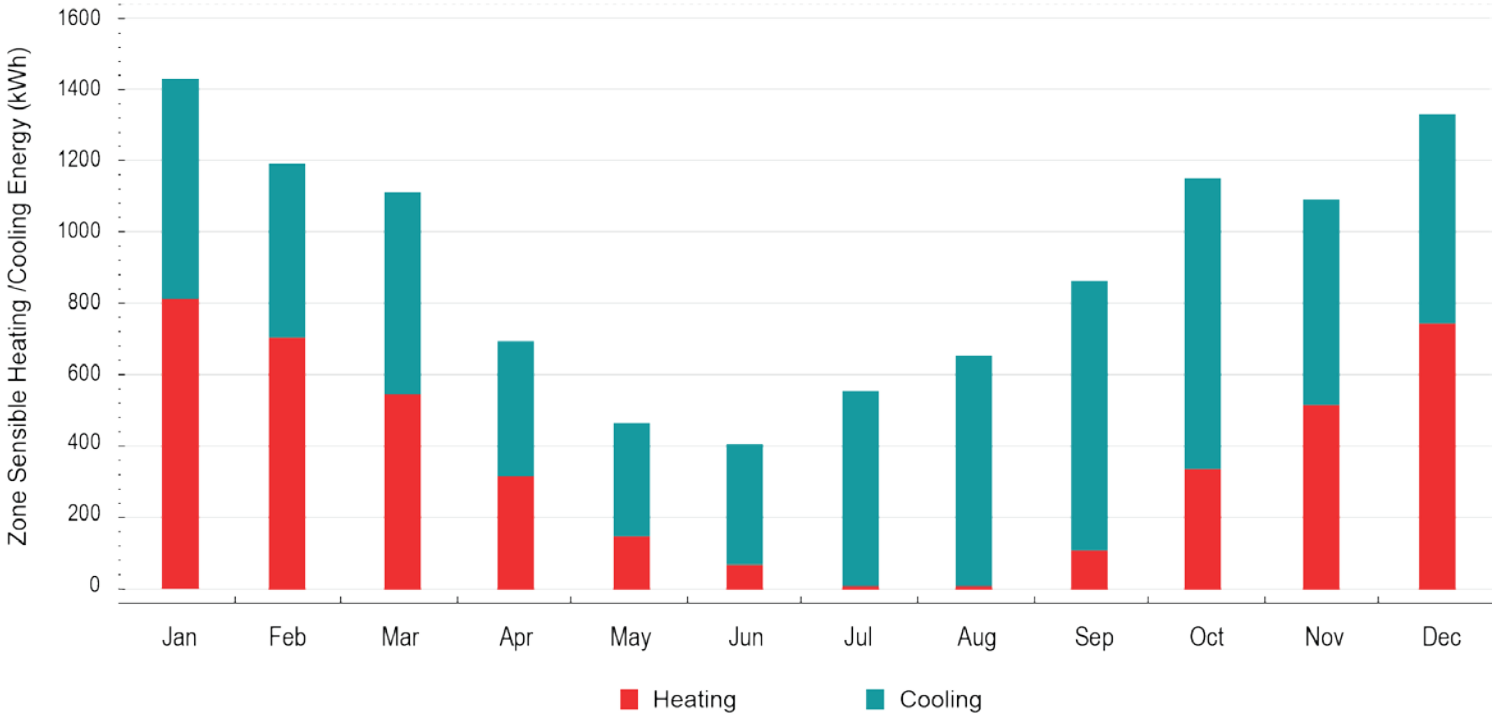
Heating demand [kWh]
Cooling demand [kWh]

VALIDATION

HEATING AND COOLING DEMAND



HEATING AND COOLING DEMAND

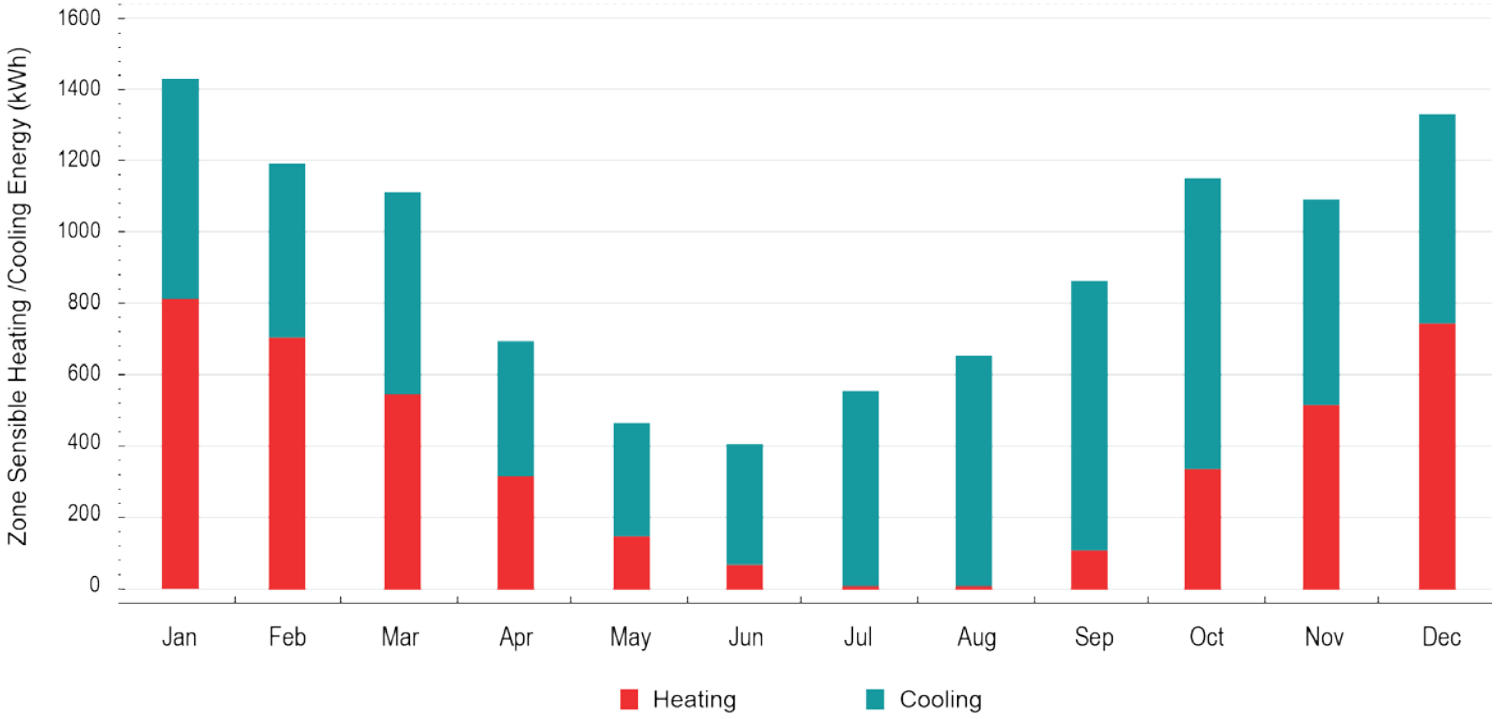


Annual heating (MWh)

6,597

6,137 7,964

HEATING AND COOLING DEMAND



Annual heating (MWh)

6,597

6,137 — 7,964

Annual cooling (MWh)

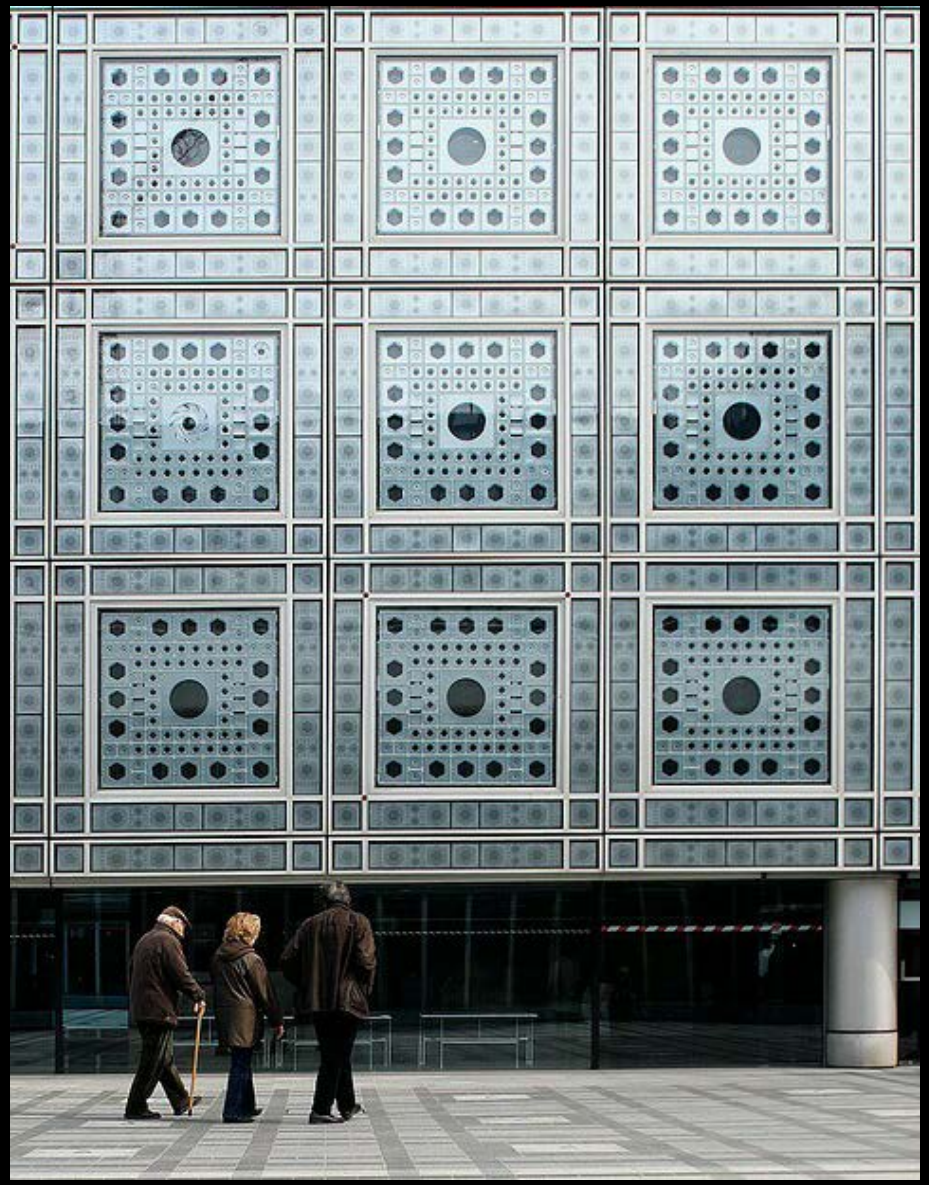
4,345

4,296 — 5,709

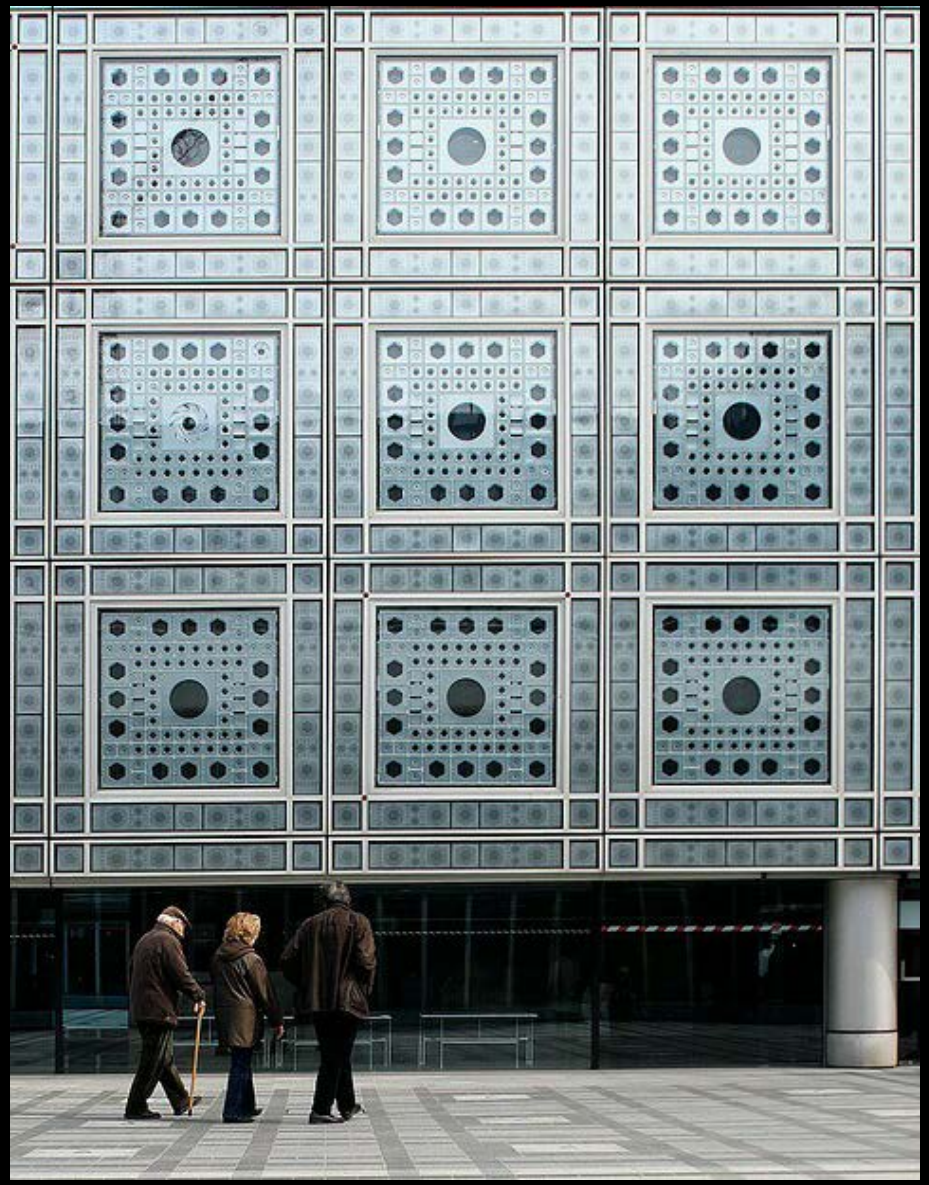
THE ARAB WORLD INSTITUTE

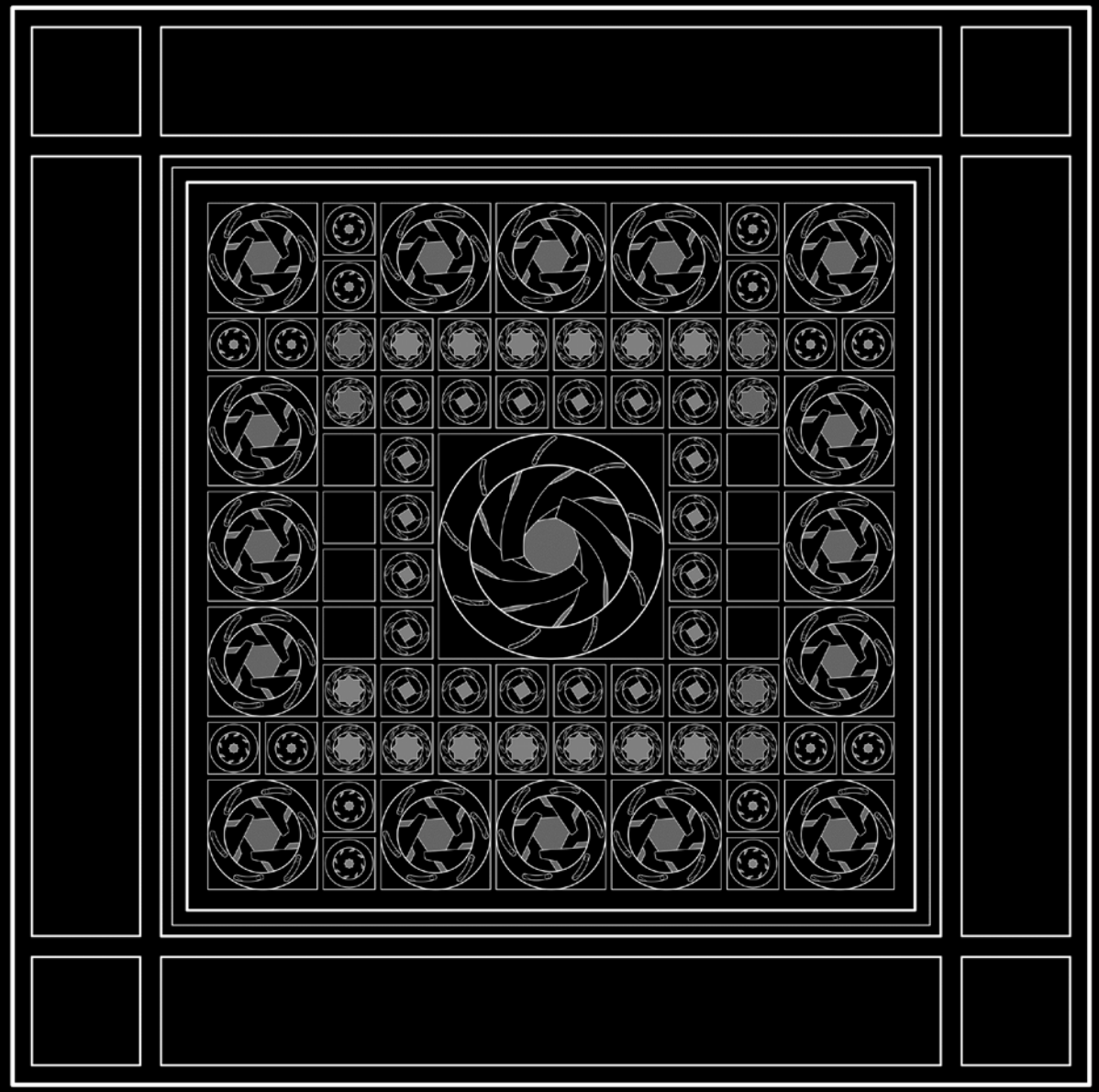
A CASE STUDY

FAÇADE SYSTEM



FAÇADE SYSTEM





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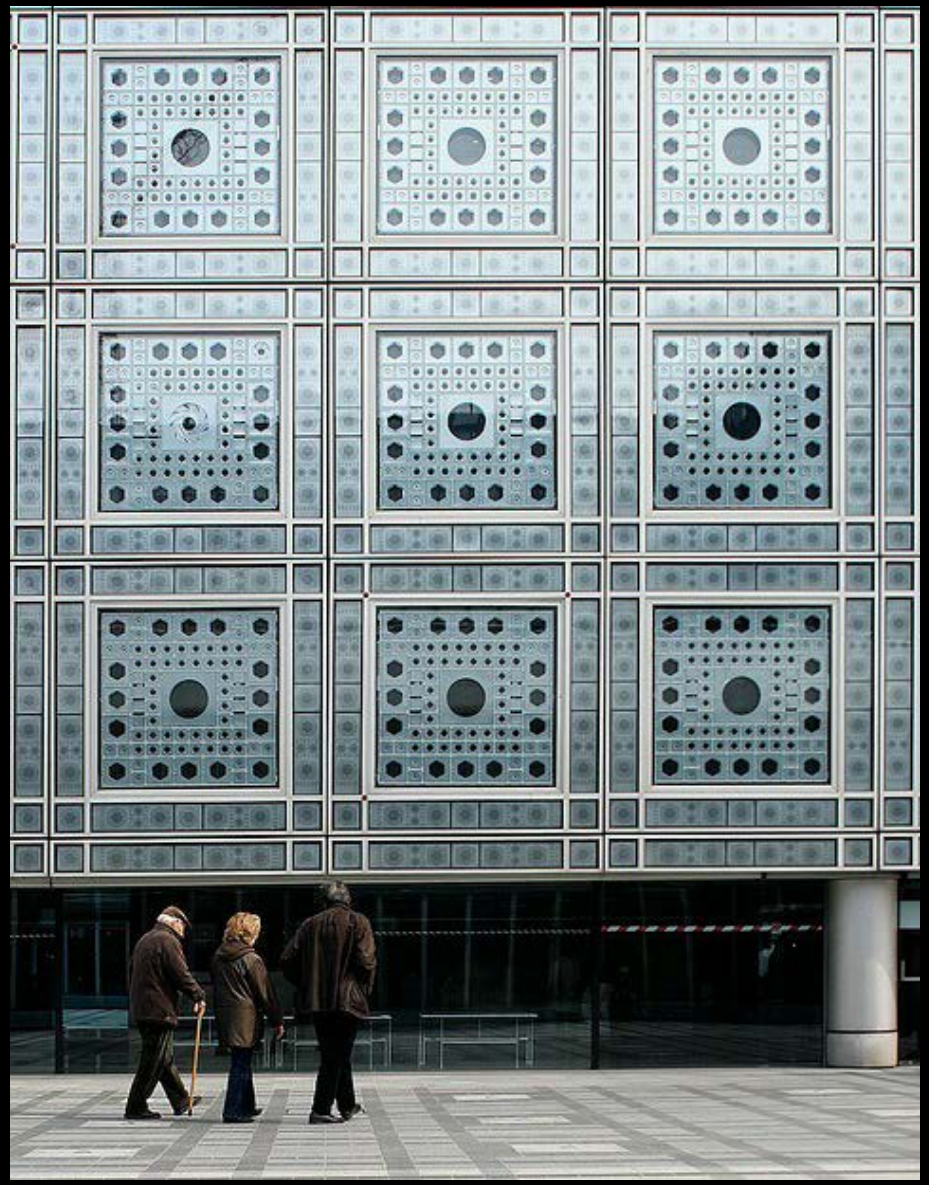
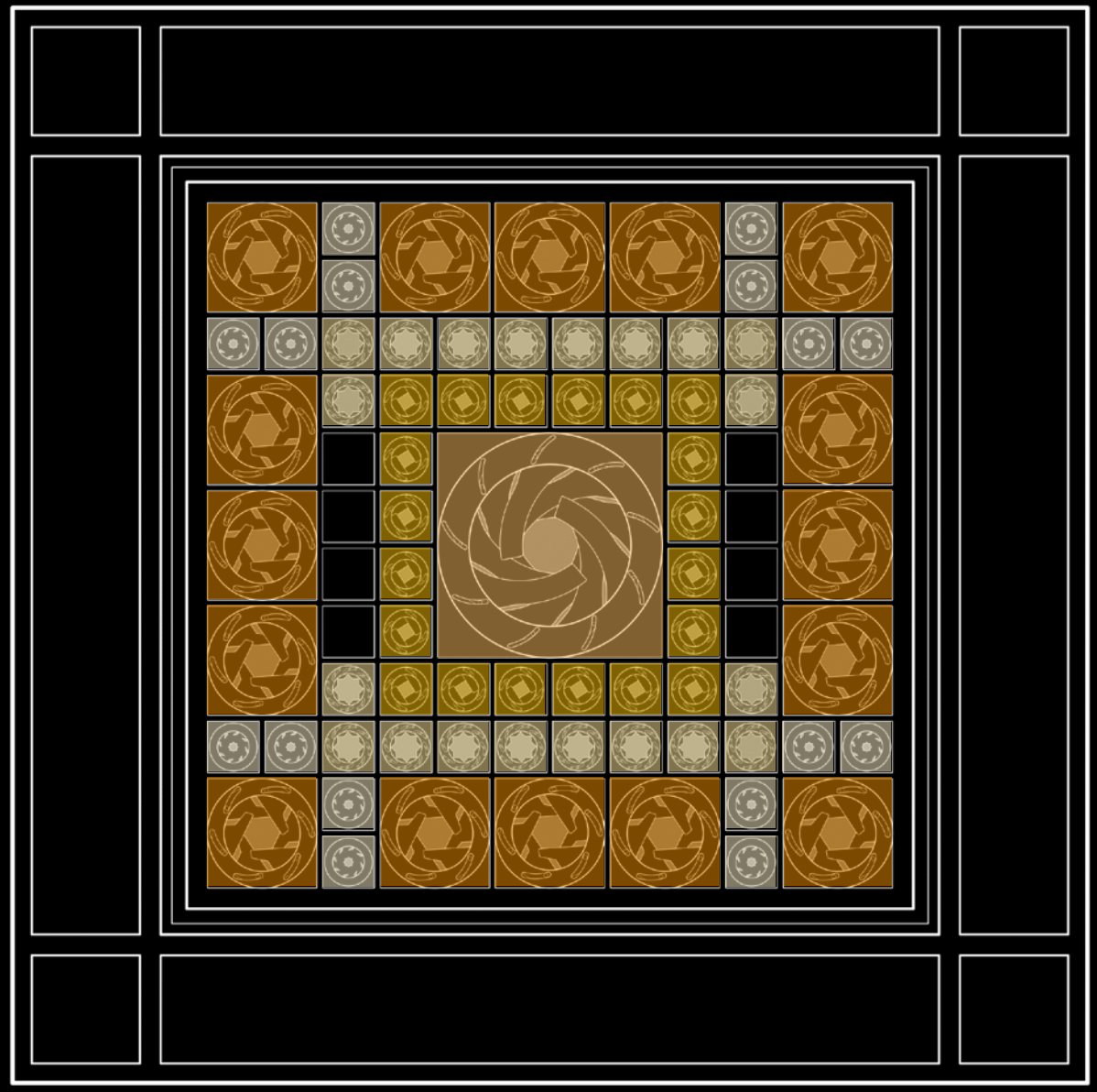
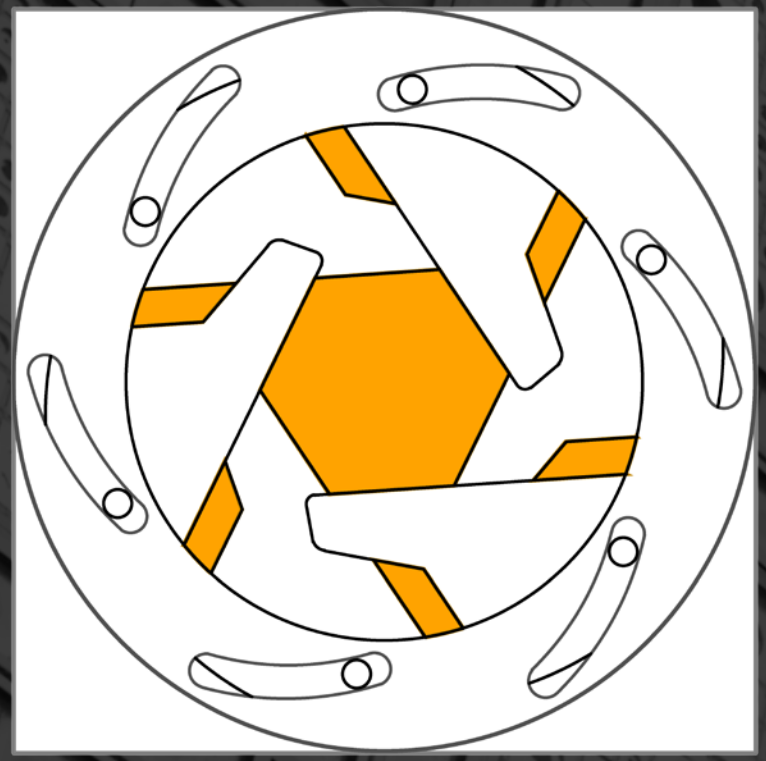
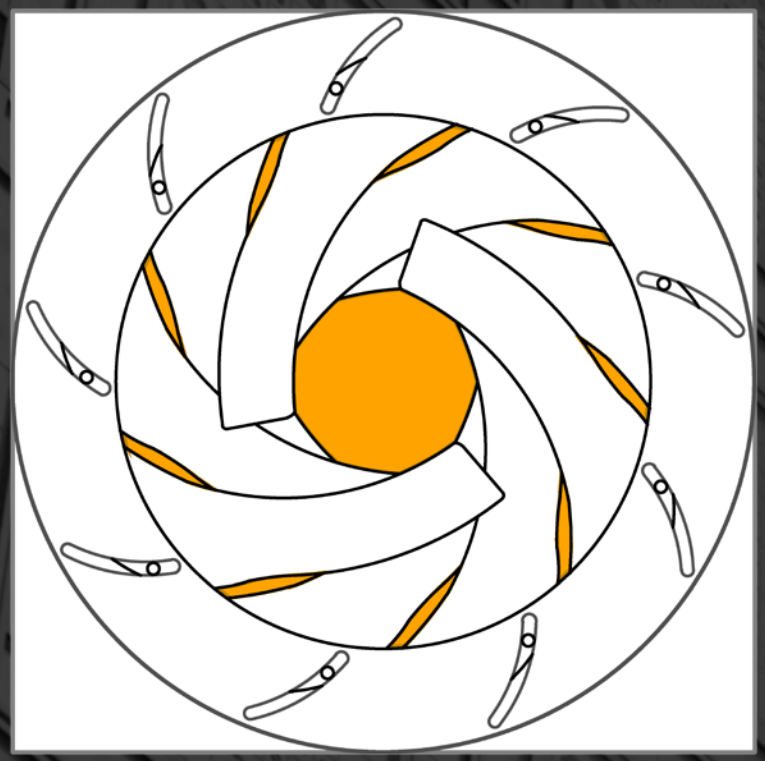




GEOMETRIC SIMPLIFICATION





GEOMETRIC SIMPLIFICATION

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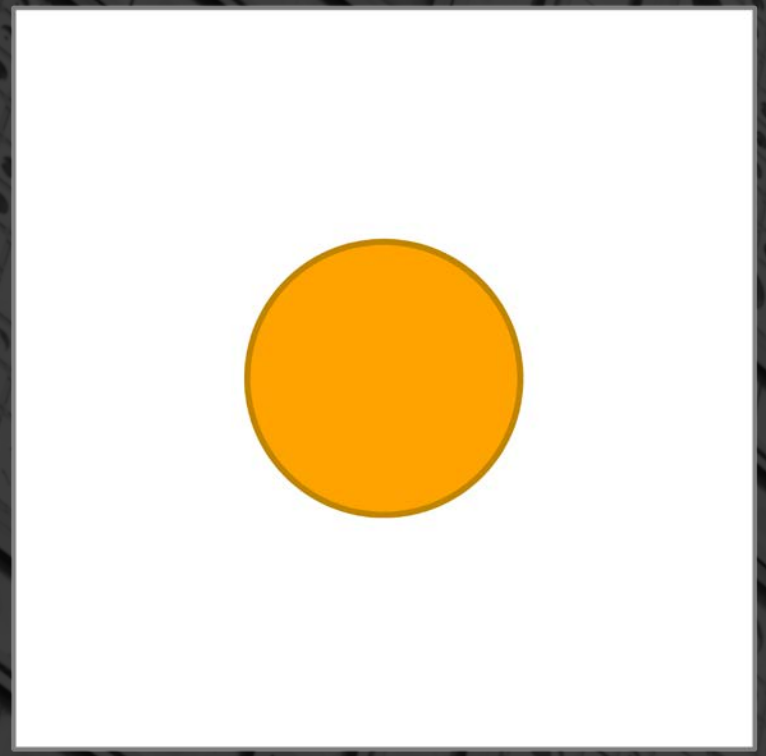
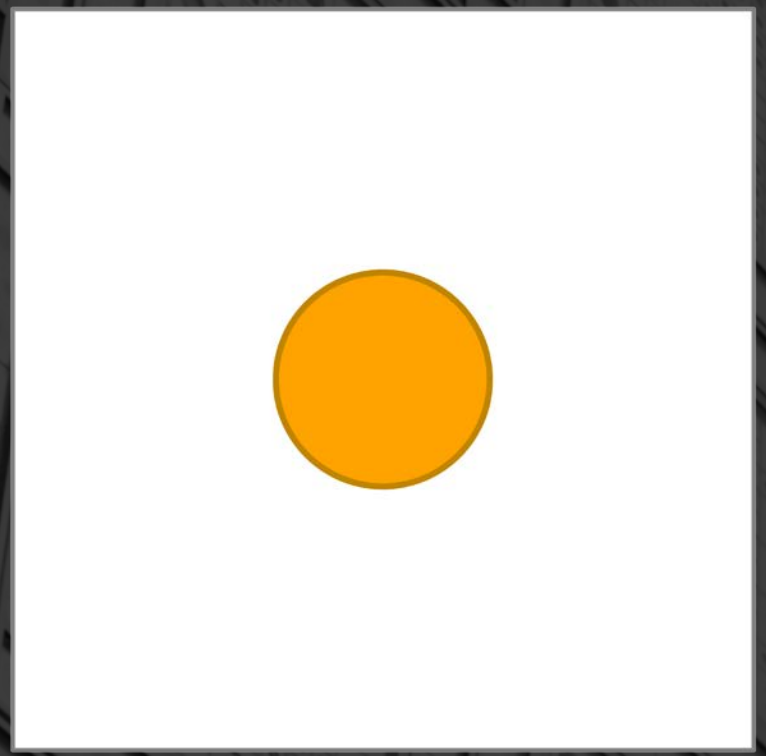
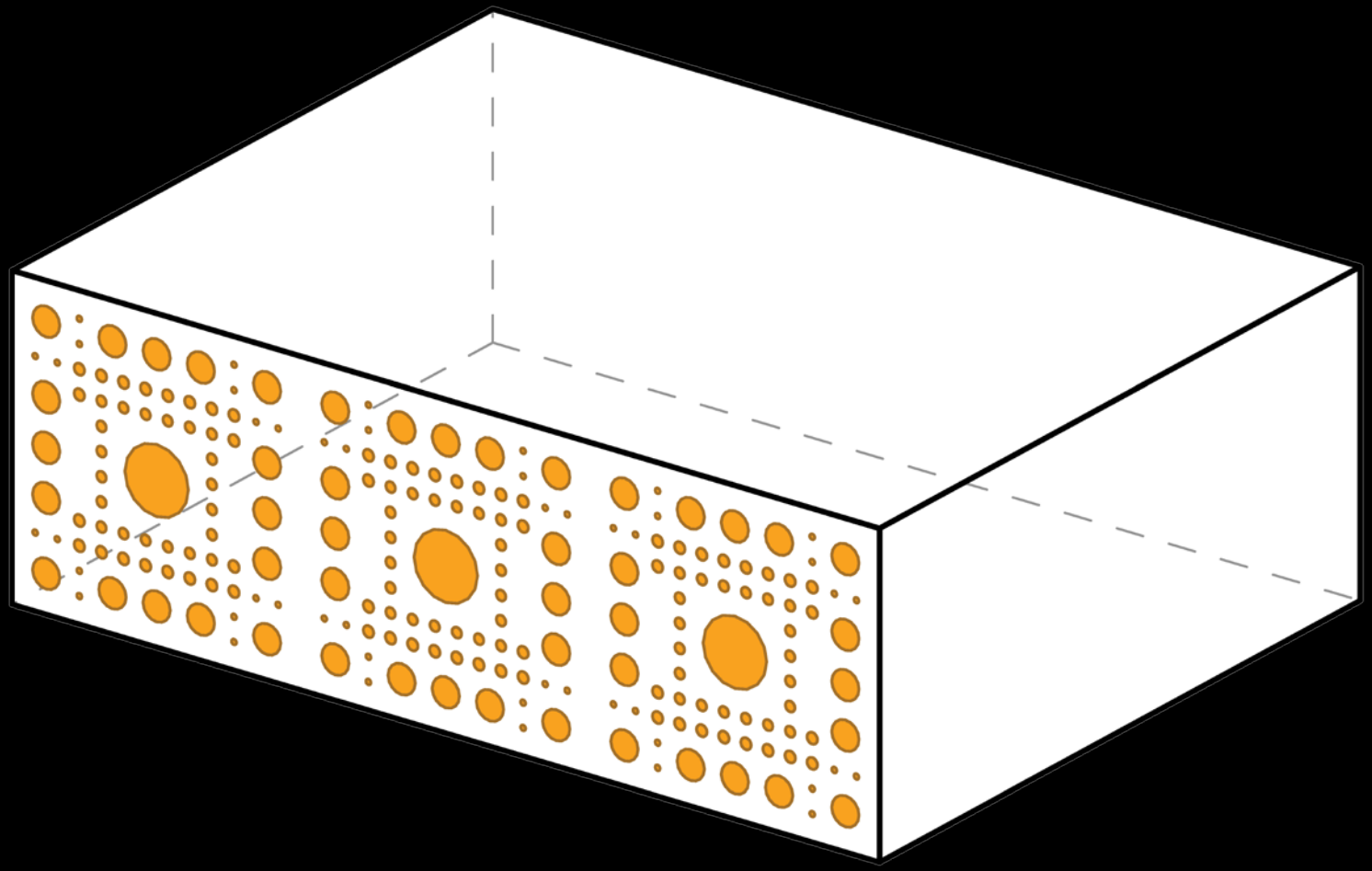




MODEL



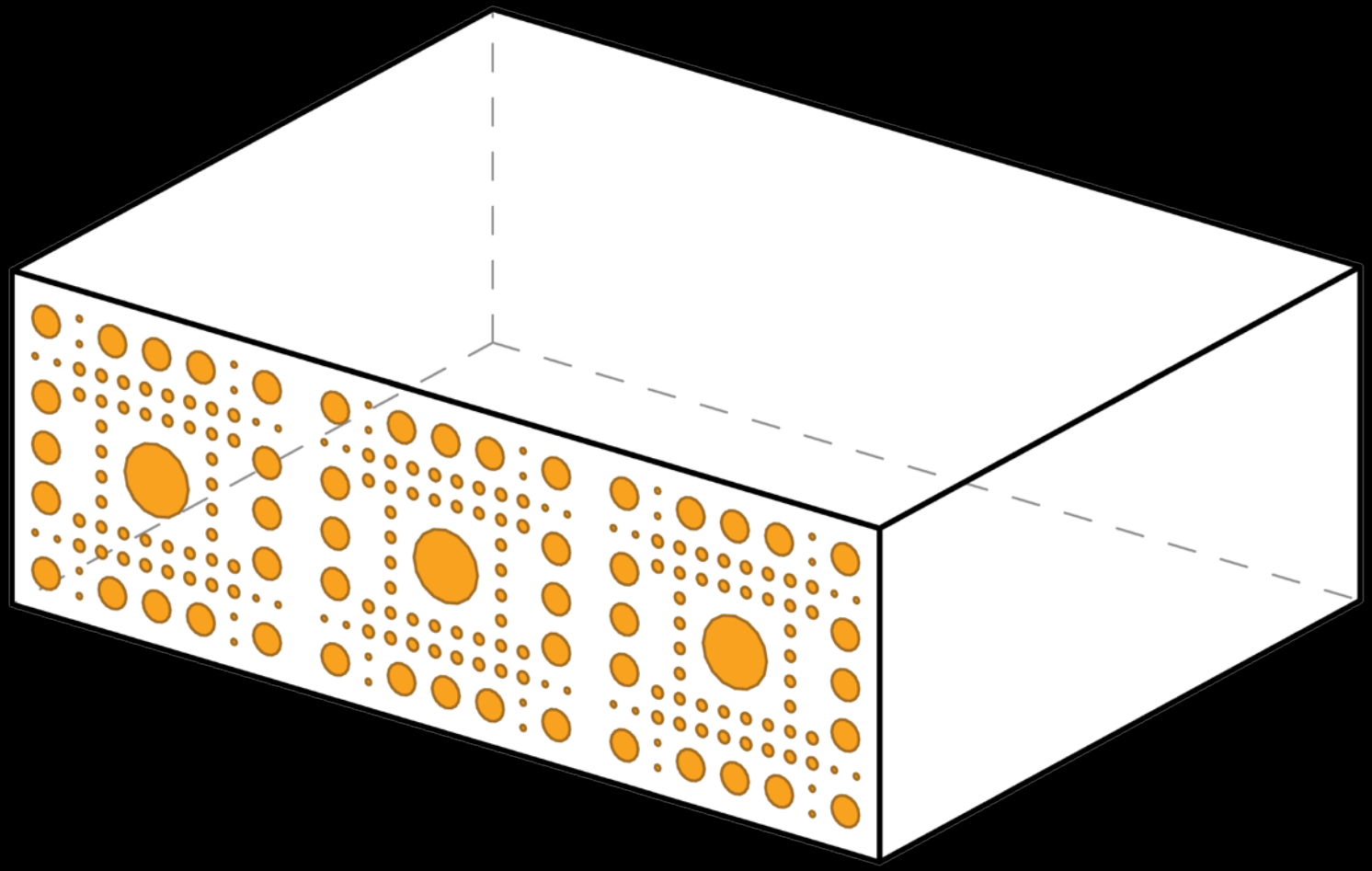
SIMULATION PERIOD

12 months

REQUESTED OUTPUT

Heating demand [GJ]
Cooling demand [GJ]

MODEL



SIMULATION PERIOD

12 months

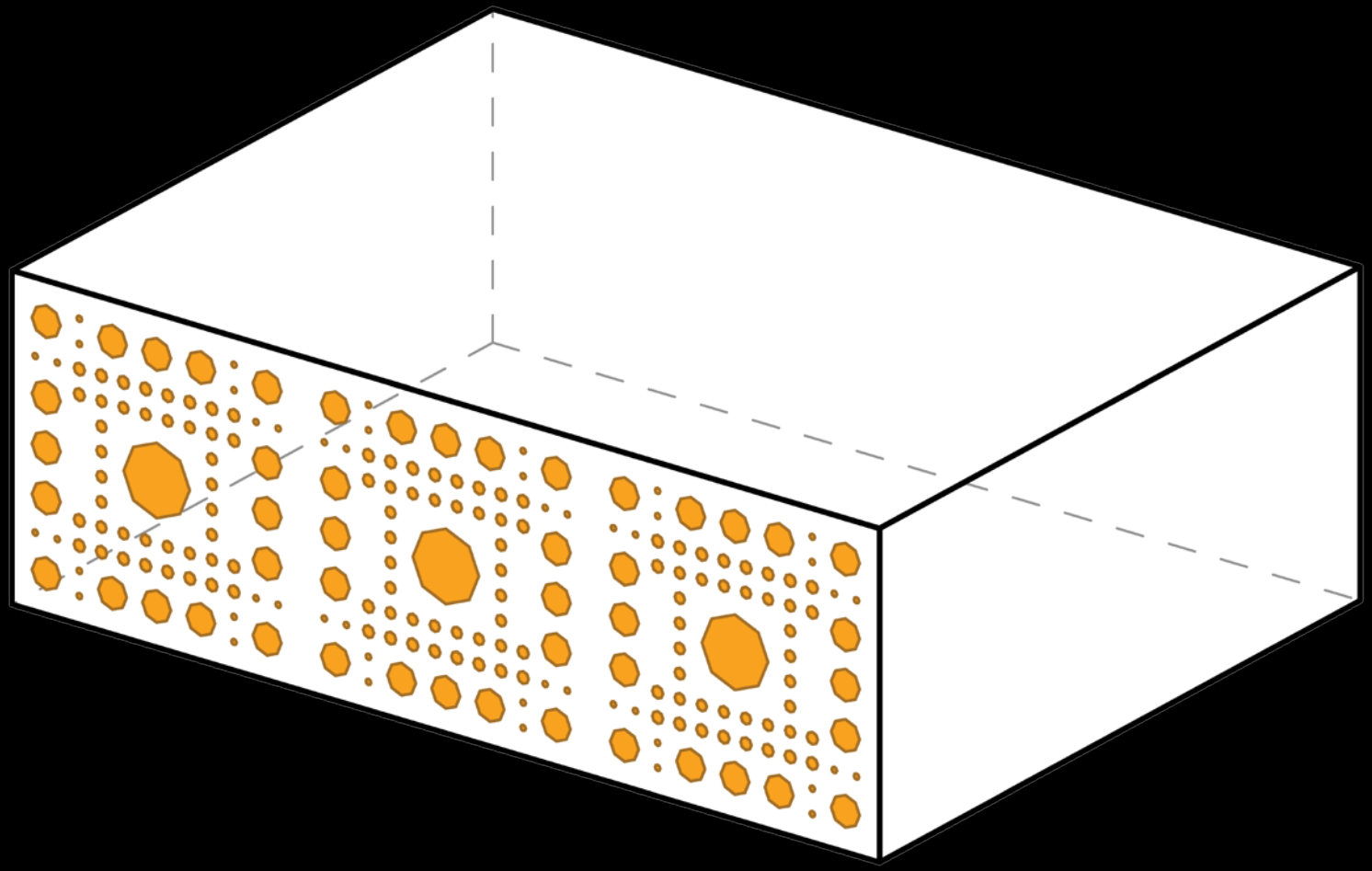
REQUESTED OUTPUT

Heating demand [GJ]
Cooling demand [GJ]

16

6h 30min

MODEL



SIMULATION PERIOD

12 months

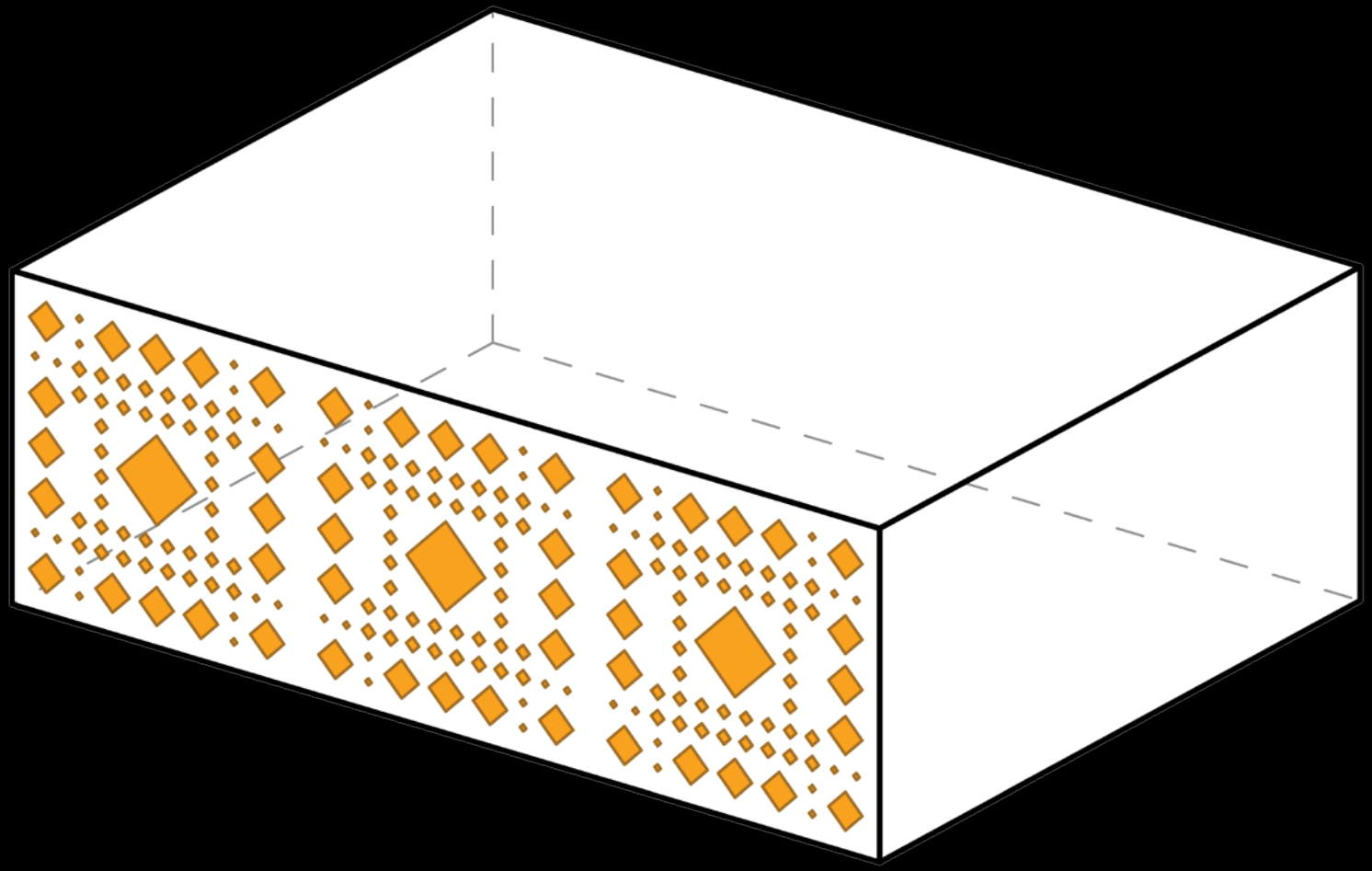
REQUESTED OUTPUT

Heating demand [GJ]
Cooling demand [GJ]

16 6h 30min

8 34min 30sec

MODEL



SIMULATION PERIOD

12 months

REQUESTED OUTPUT

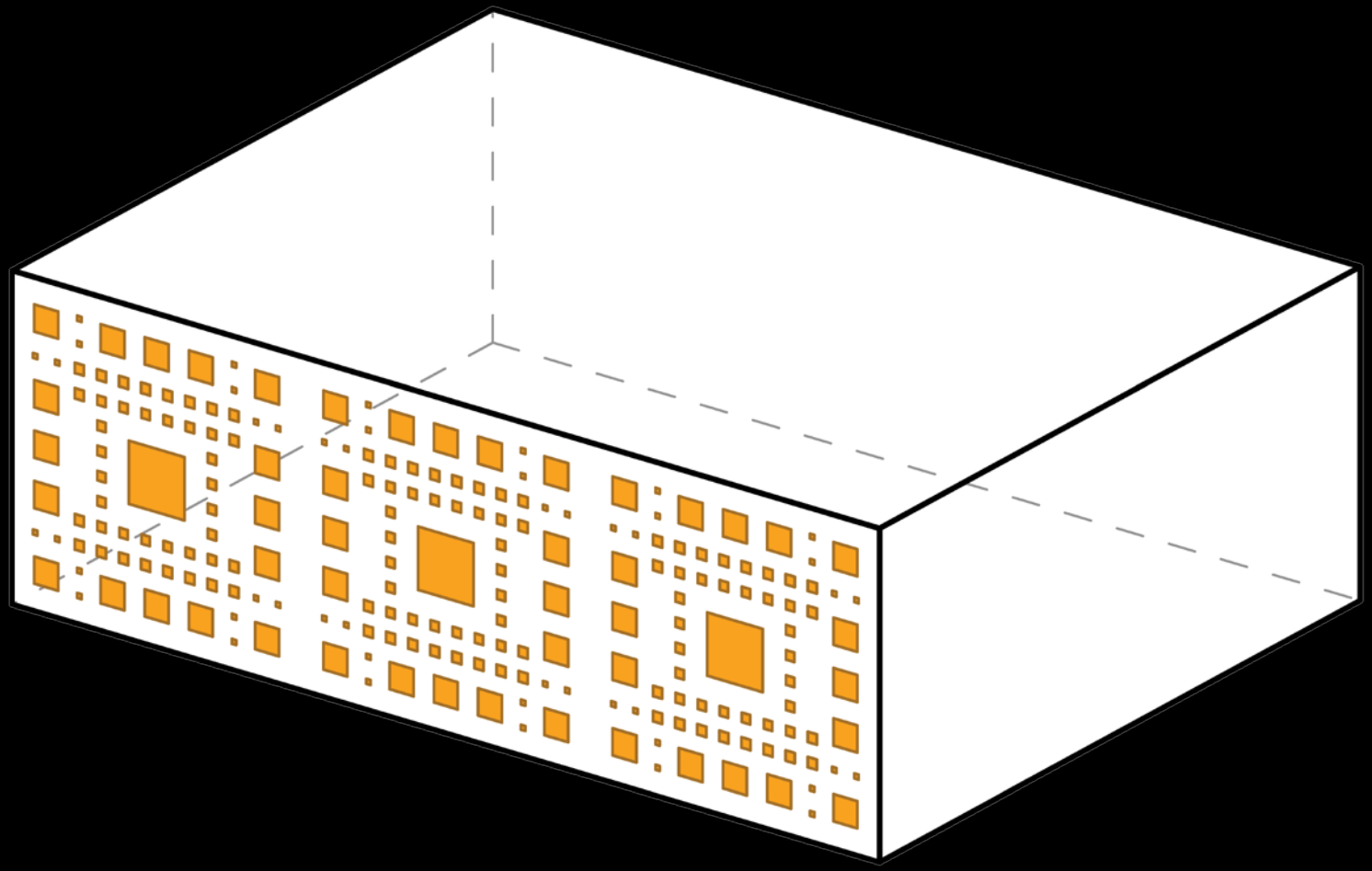
Heating demand [GJ]
Cooling demand [GJ]

16 6h 30min

8 34min 30sec

4 6min 50sec

MODEL



SIMULATION PERIOD

12 months

REQUESTED OUTPUT

Heating demand [GJ]

Cooling demand [GJ]

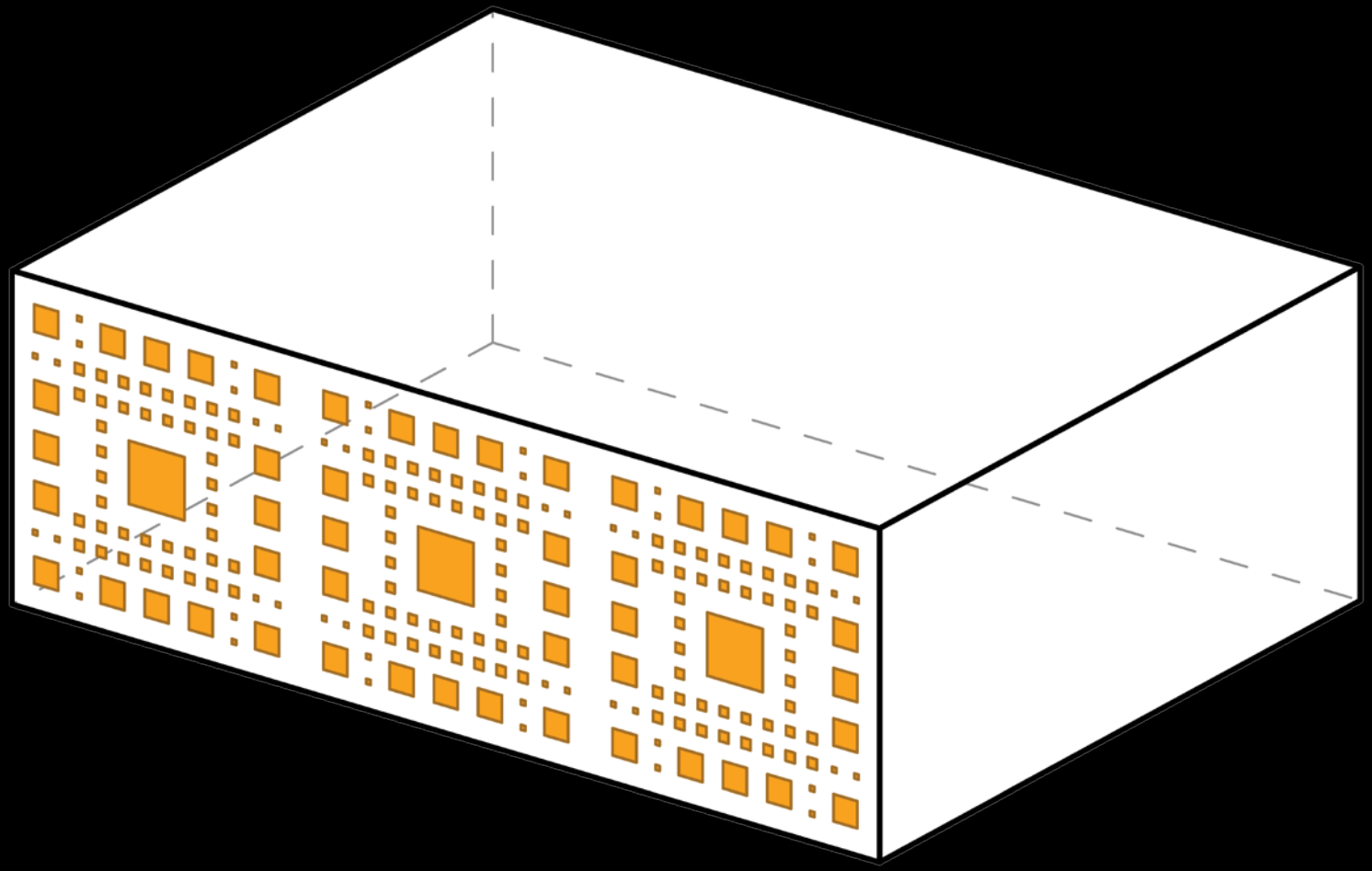
16 — 6h 30min

8 — 34min 30sec

4 — 6min 50sec

4 — 1min 30sec

MODEL



SIMULATION PERIOD

12 months

REQUESTED OUTPUT

Heating demand [GJ]
Cooling demand [GJ]

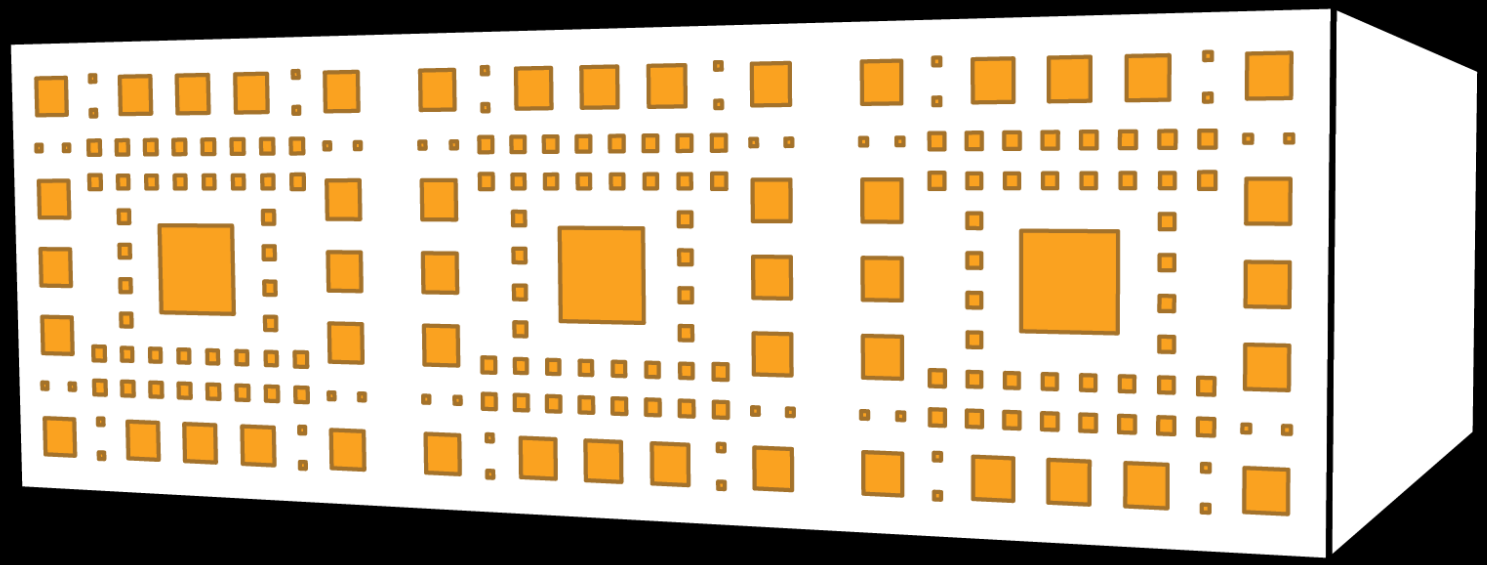
16 — 6h 30min — 15.162 5.896

8 — 34min 30sec — 15.134 5.901

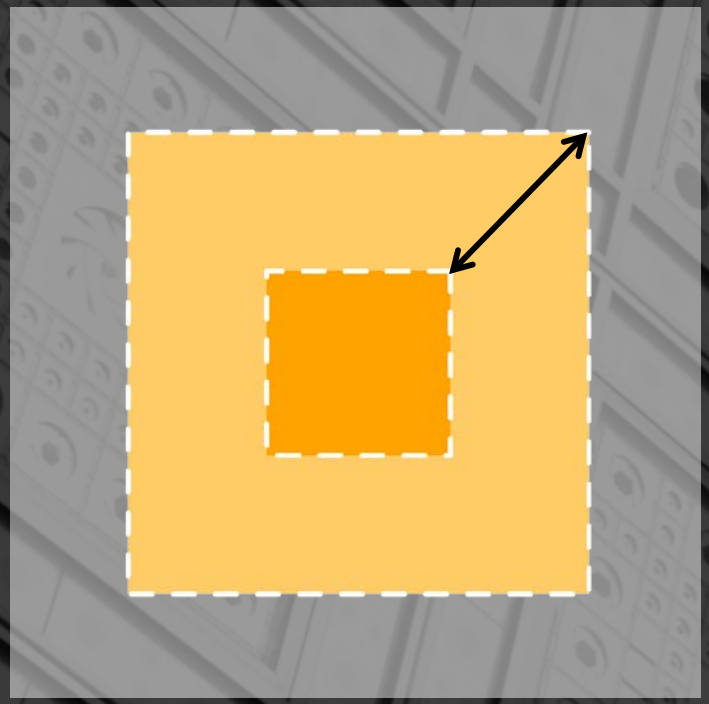
4 — 6min 50sec — 15.114 5.903

4 — 1min 30sec — 15.096 5.905

MODEL

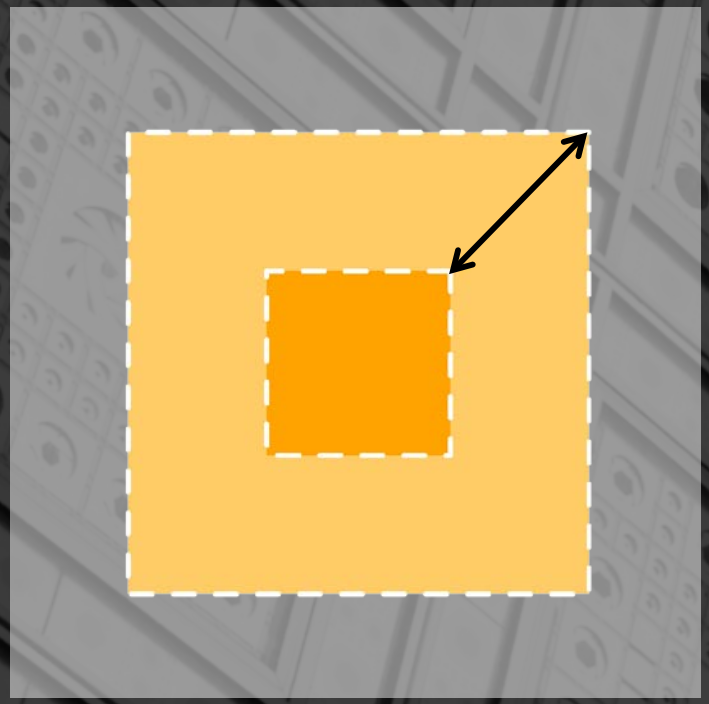


ANALYSIS

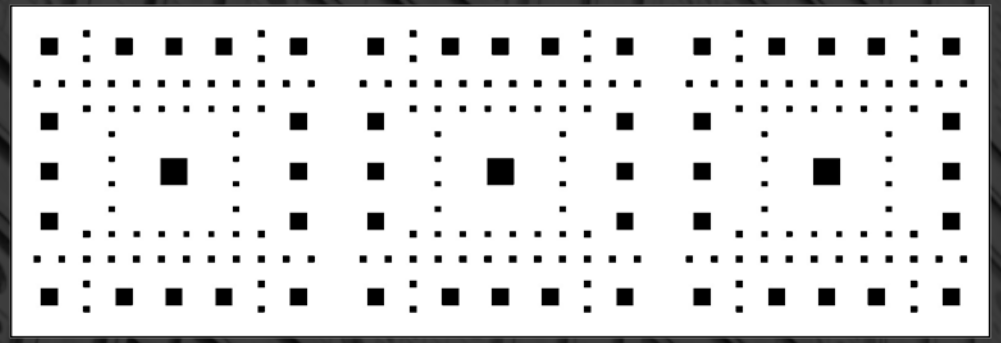


Diaphragm opening factor *(f)*

ANALYSIS



Diaphragm opening factor *(f)*



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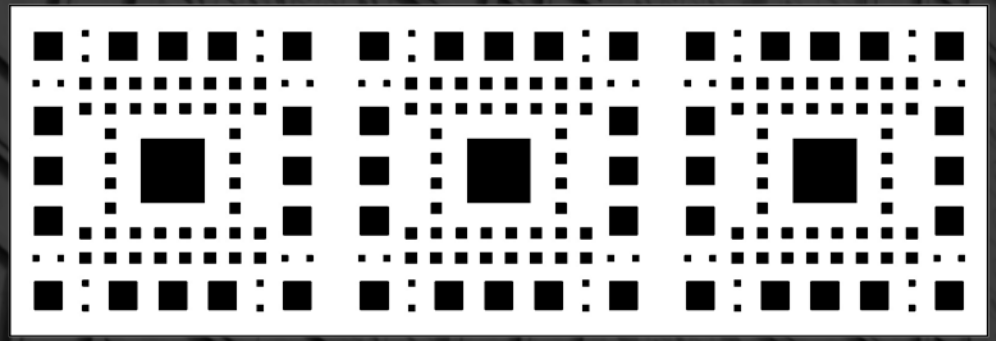


f = 1

ANALYSIS

Simulation Period

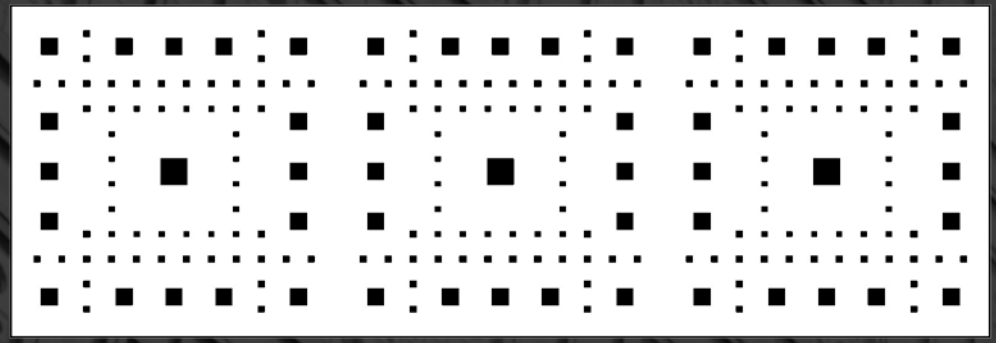
12 months

Requested Output

Heating demand
Cooling demand
Lighting demand

Sensor Variables

Incident solar radiation
Outdoor temperature



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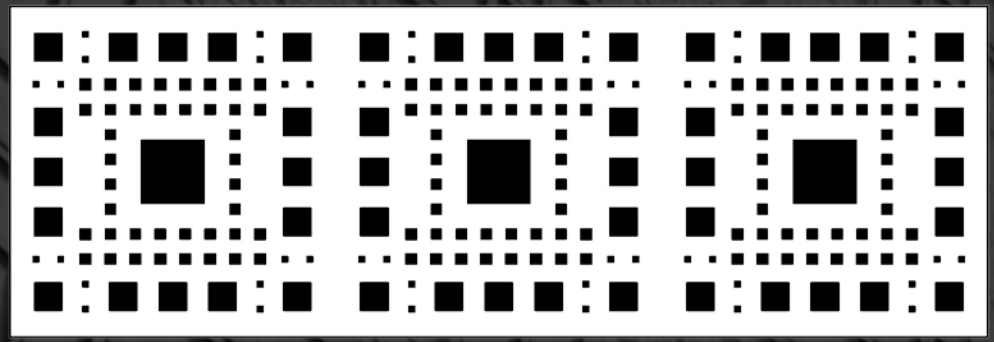
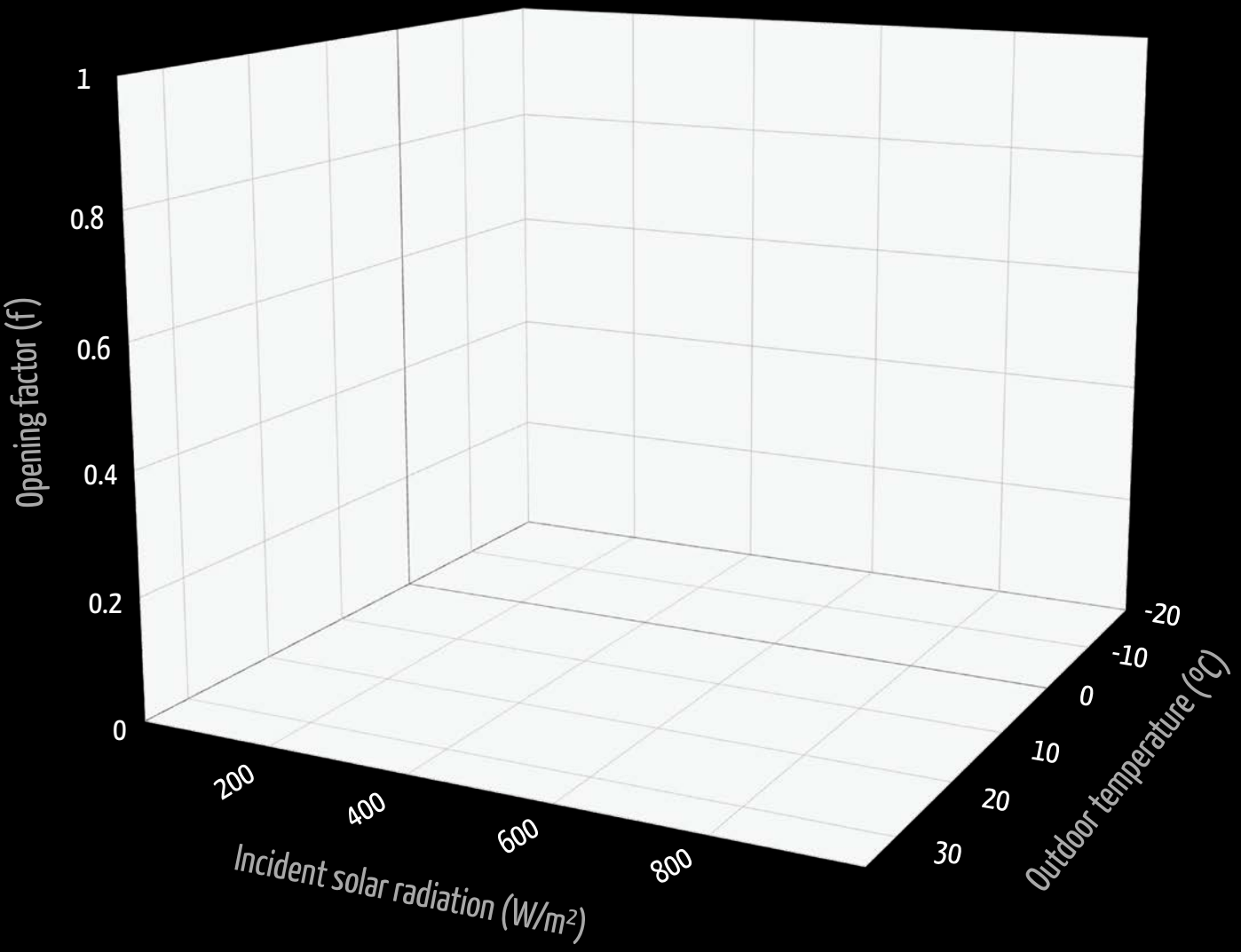
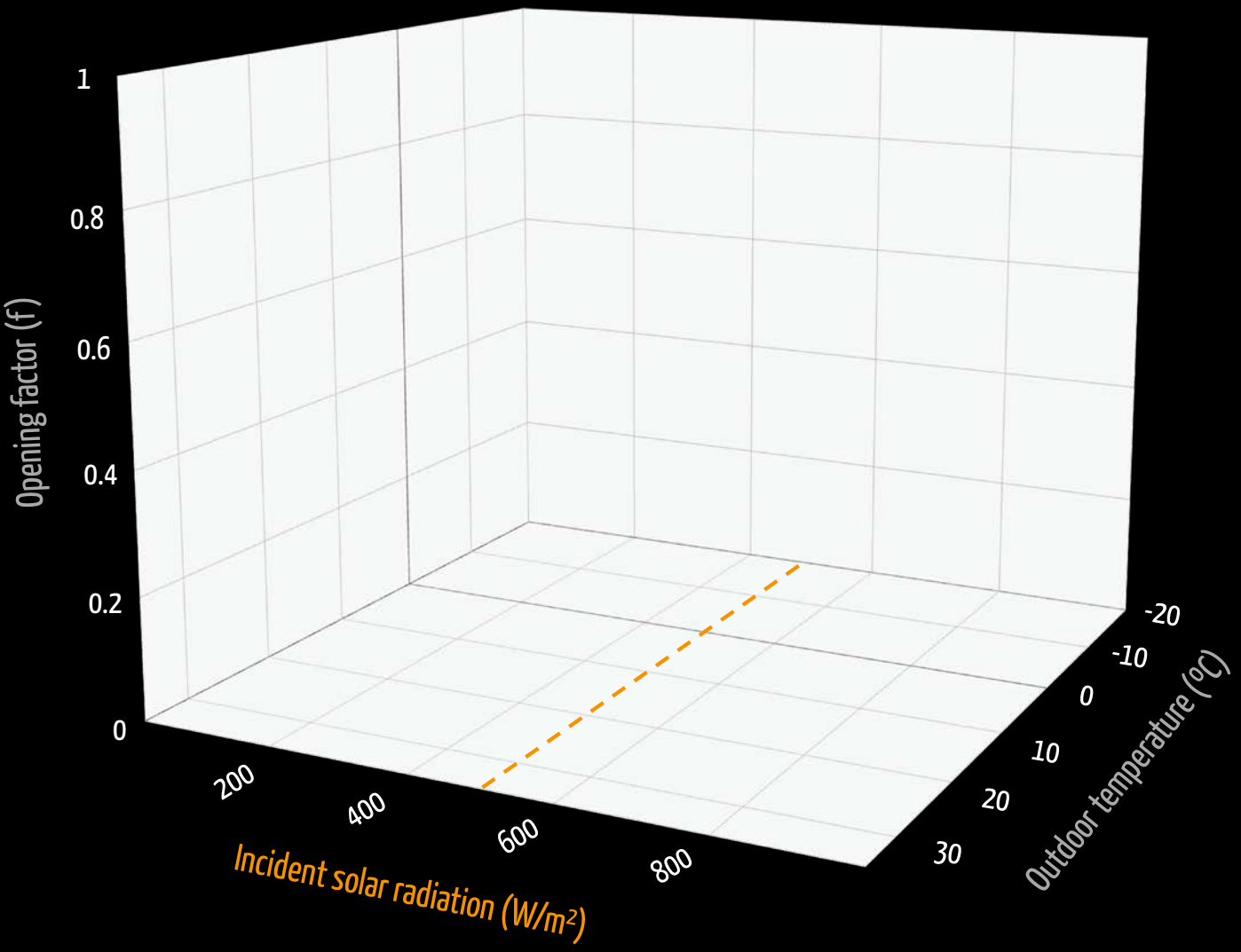


f = 1

OPTIMIZATION



OPTIMIZATION



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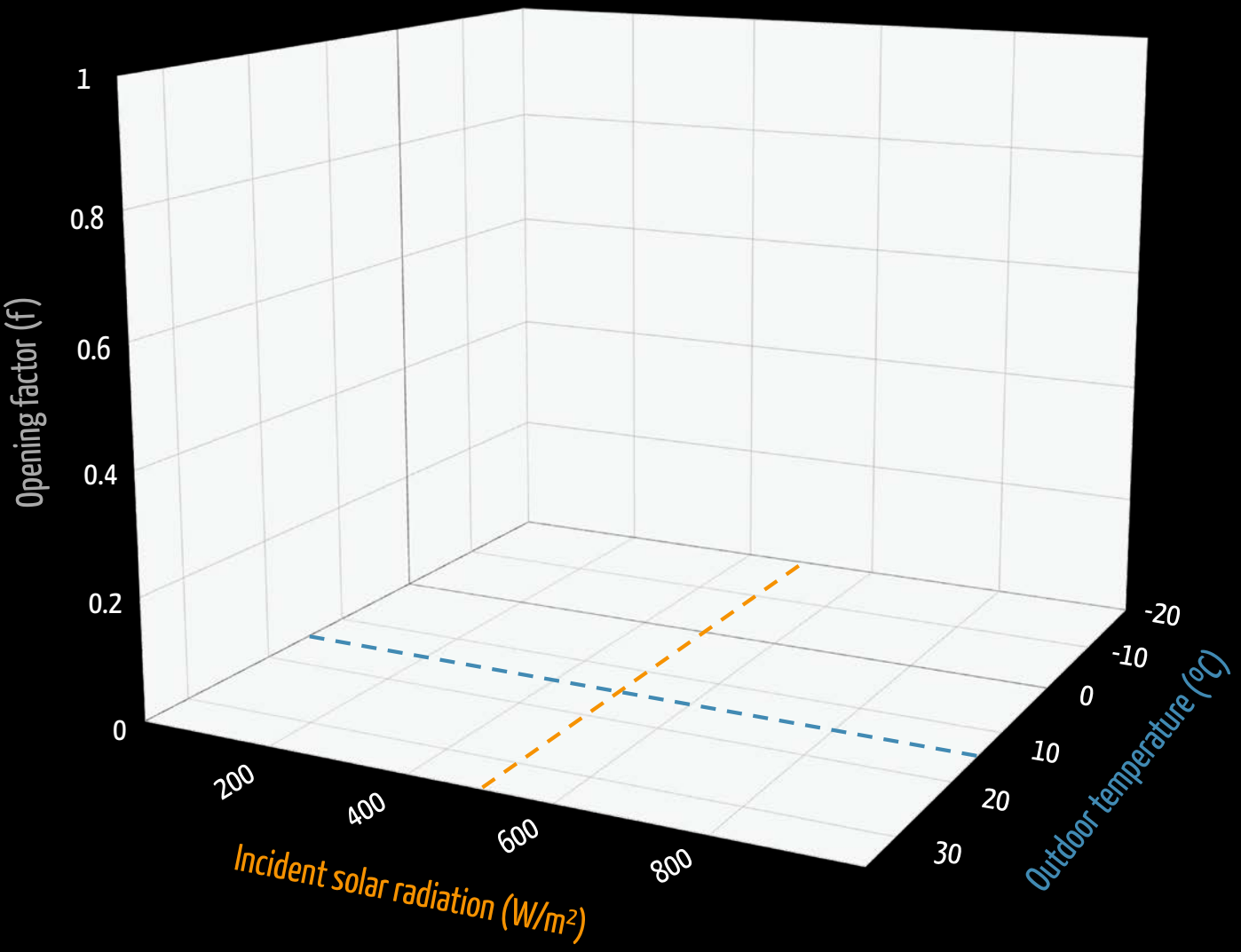

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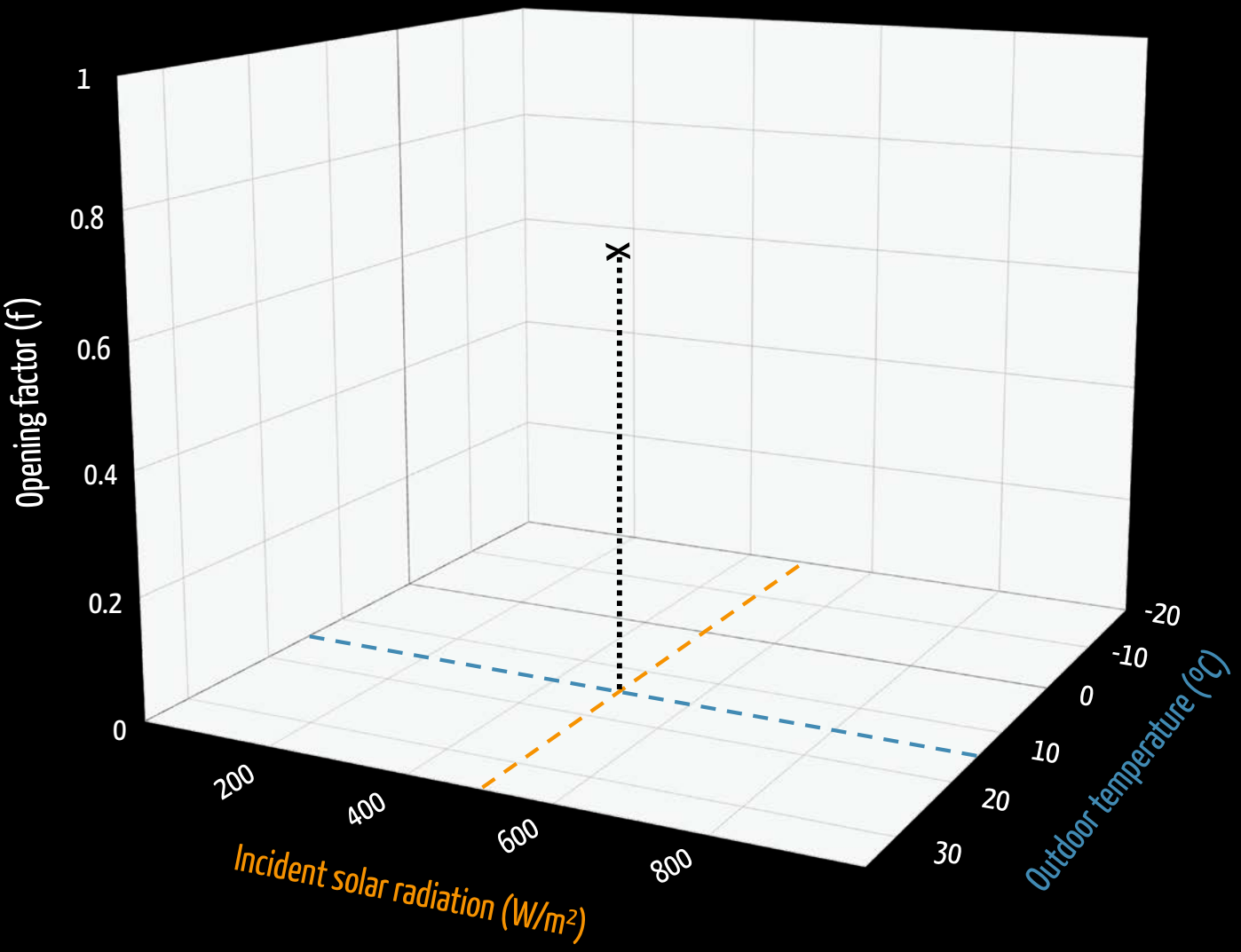

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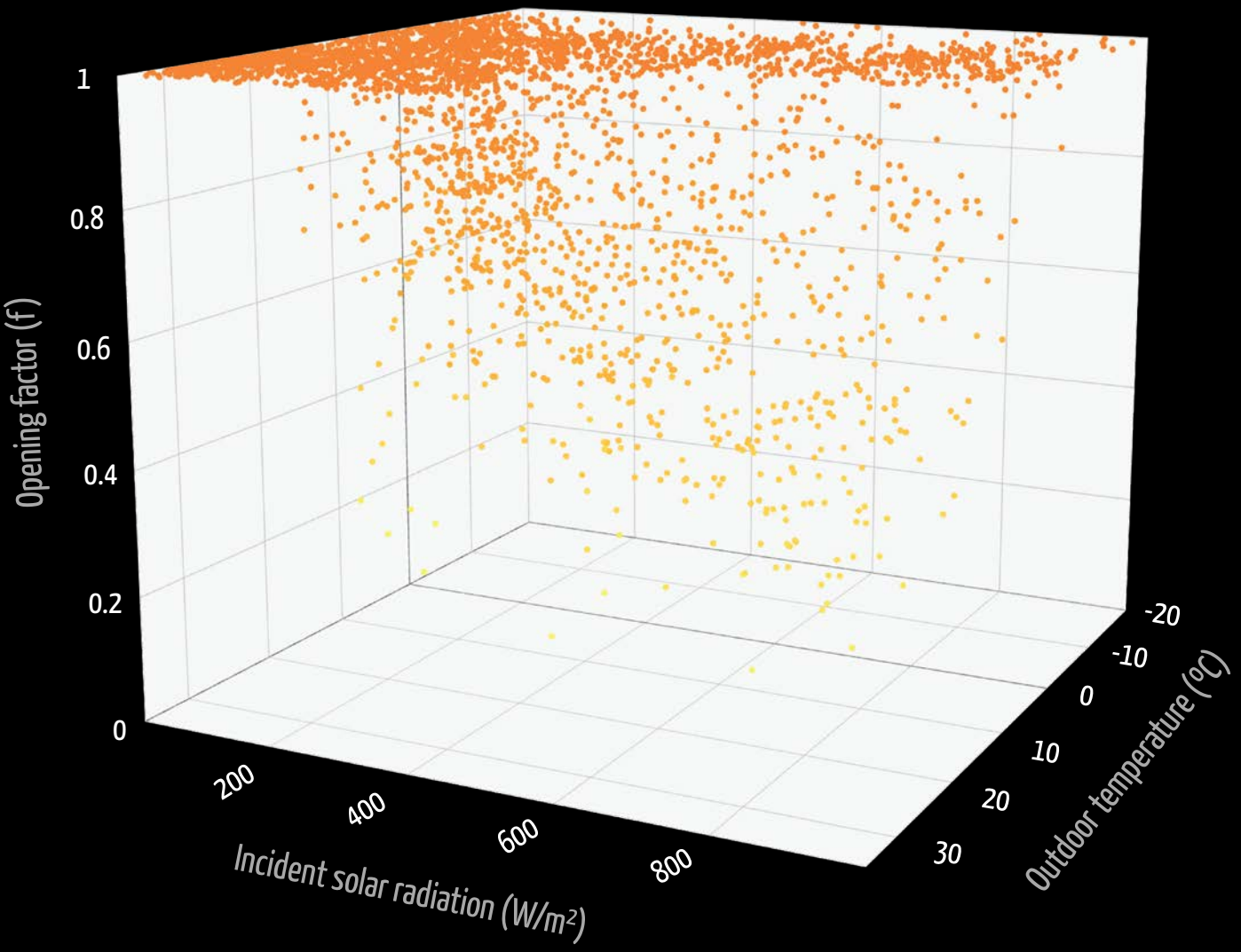

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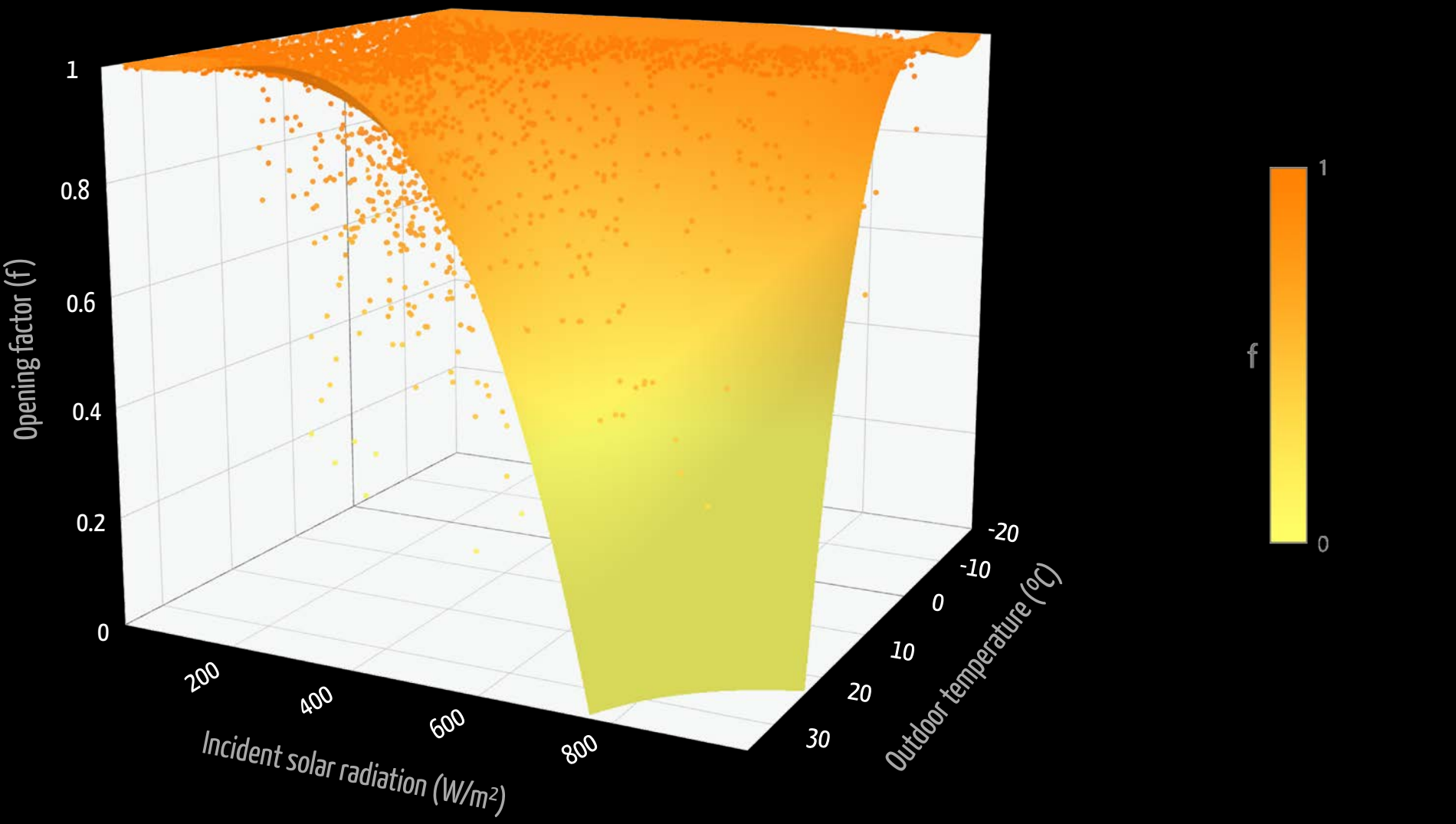

CONCLUSIONS

Unified approach

CONCLUSIONS

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Validated workflow

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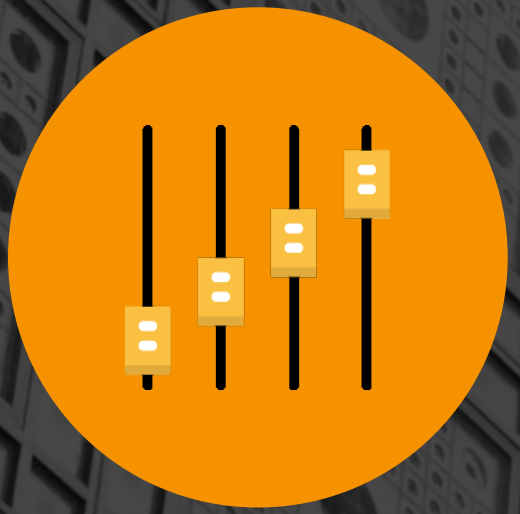
Unified approach

Validated workflow

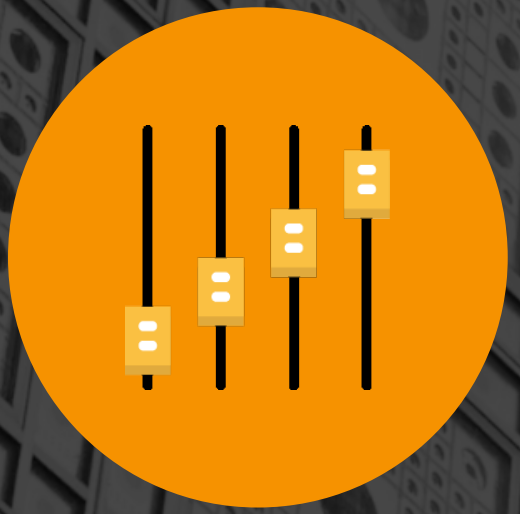


Results define control

CONCLUSIONS

Unified approach

Validated workflow



Results define control

Architectural applicability

FUTURE WORK

Model flexibility

FUTURE WORK

Model flexibility

Iteration

FUTURE WORK

Model flexibility

Iteration

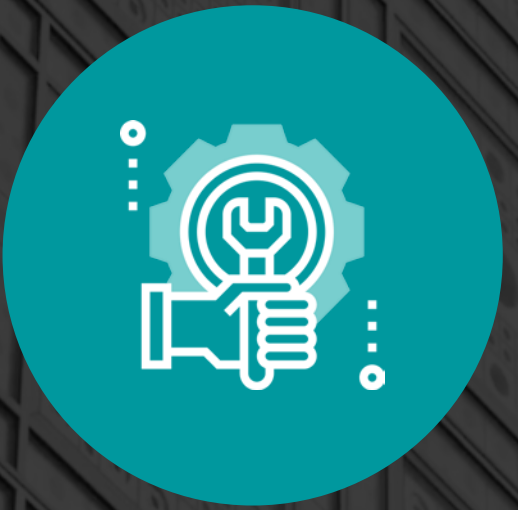
Time-delayed feedback

FUTURE WORK

Model flexibility

Iteration

Time-delayed feedback



Maintenance

CONTRIBUTIONS

Martinho, H., Leitão, A., Belém, C., Loonen, R., and Gomes, M. (2019)

ALGORITHMIC DESIGN AND PERFORMANCE ANALYSIS OF ADAPTIVE FAÇADES

Proceedings of the 24th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) - Volume 1, Victoria University of Wellington, New Zealand, 685-694.

THANK YOU

Questions?