Presentation P5

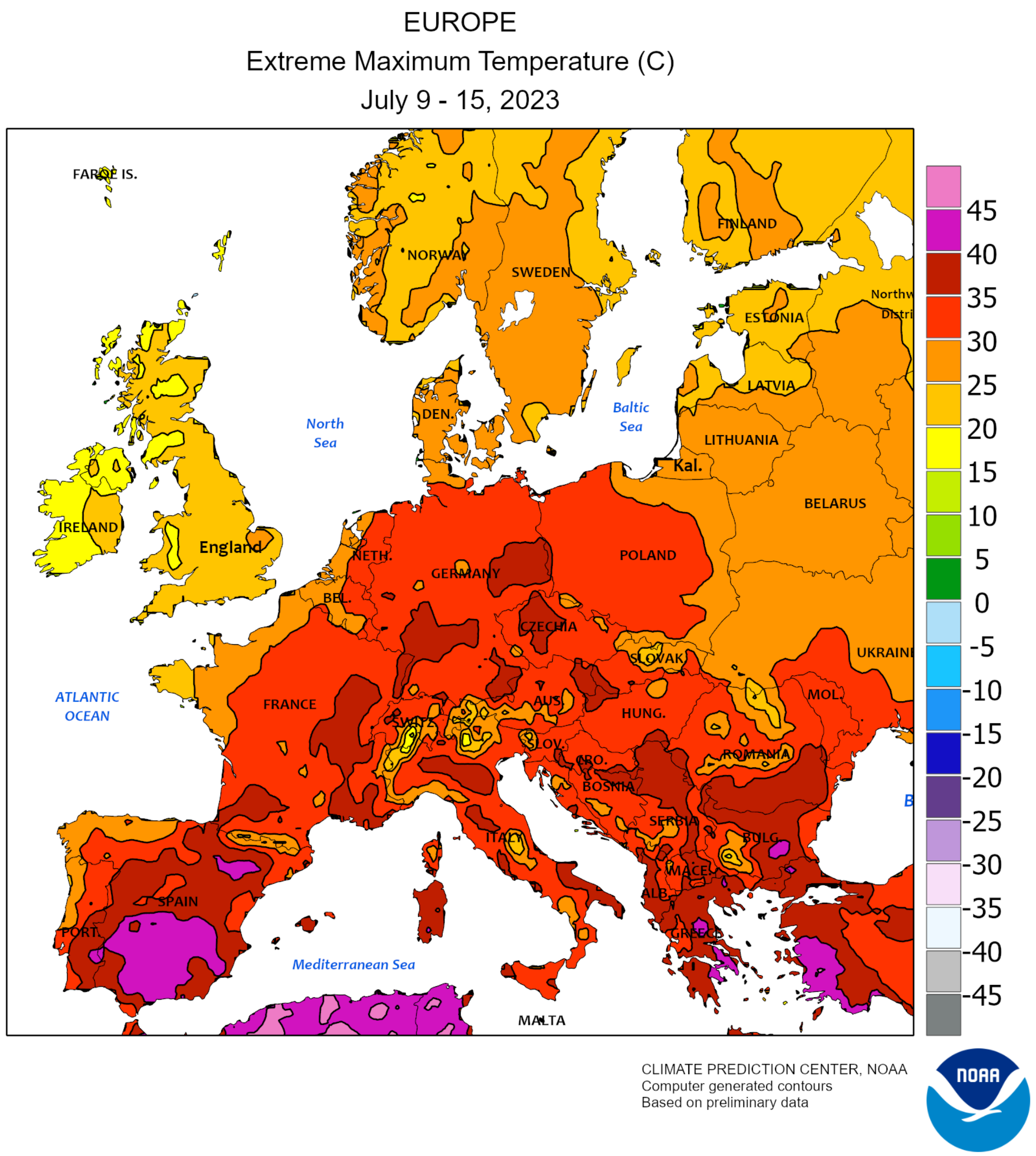
"How can a genetic algorithm based workflow be effectively employed in the multi-objective optimization of a shading system to improve the energy efficiency of an existing building envelope?"

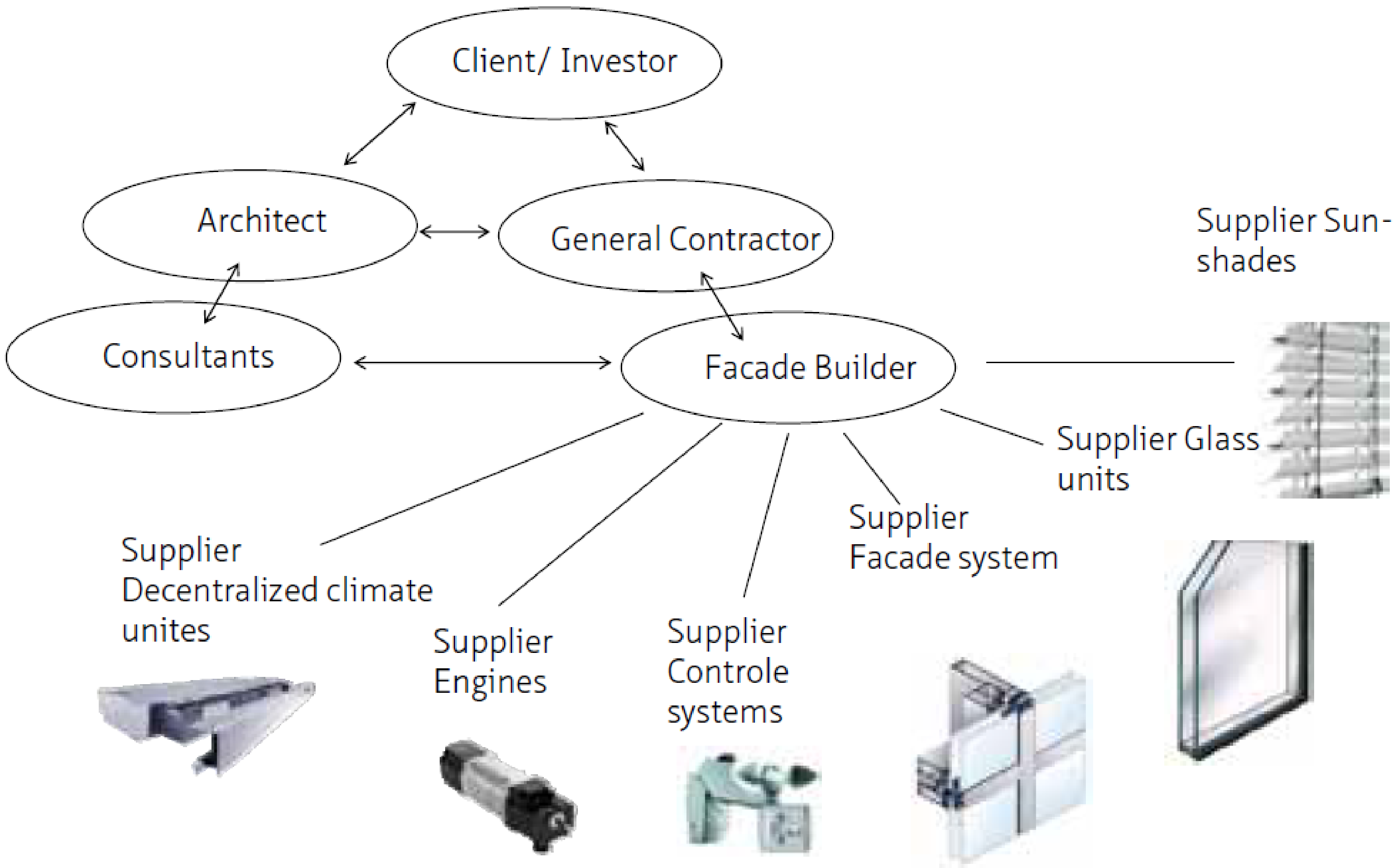
AR3B025 Building Technology Graduation Studio 2023-2024

21 June 2024

Mentors: Simona Bianchi, Charalambos Andriotis
Student: Alkiviadis Oikonomidis 5786746

Problem statement





https://commons.wikimedia.org/wiki/Category:Maximum_air_temperature_maps_of_Europe

Environment, T.Klein (2013). Integral Facade Construction: Towards a new product architecture for curtain walls. TU Delft.

Research question

“How can a **genetic algorithm based workflow** *be effectively employed in the* **multi-objective optimization** *of a* **shading system** *to improve the* **energy efficiency** *of an* **existing building envelope***?”*

Goals

- To be able to evaluate the energy performance of existing buildings.

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- To provide instant interdisciplinary feedback in a design team.

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- To be able to evaluate the energy performance of existing buildings.
- To provide instant interdisciplinary feedback in a design team.
- To improve an existing envelope's energy performance by reducing its cooling demands (with an optimized design).

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I. What are the primary typologies of facades and how can they be classified based on their materials, connection details and functions?

Research question

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I. What are the primary typologies of facades and how can they be classified based on their materials, connection details and functions?

II. What is resilience and how can it be quantified?

Research question

“How can a ***genetic algorithm based workflow*** *be effectively employed in the* ***multi-objective optimization*** *of a* ***shading system*** *to improve the* ***energy efficiency*** *of an* ***existing building envelope****?”*

I. What are the primary typologies of facades and how can they be classified based on their materials, connection details and functions?

II. What is resilience and how can it be quantified?

III. How to formulate a genetic algorithm-based multi-objective optimization workflow?

Research question

“How can a **genetic algorithm based workflow** *be effectively employed in the* **multi-objective optimization** *of a* **shading system** *to improve the* **energy efficiency** *of an* **existing building envelope***?”*

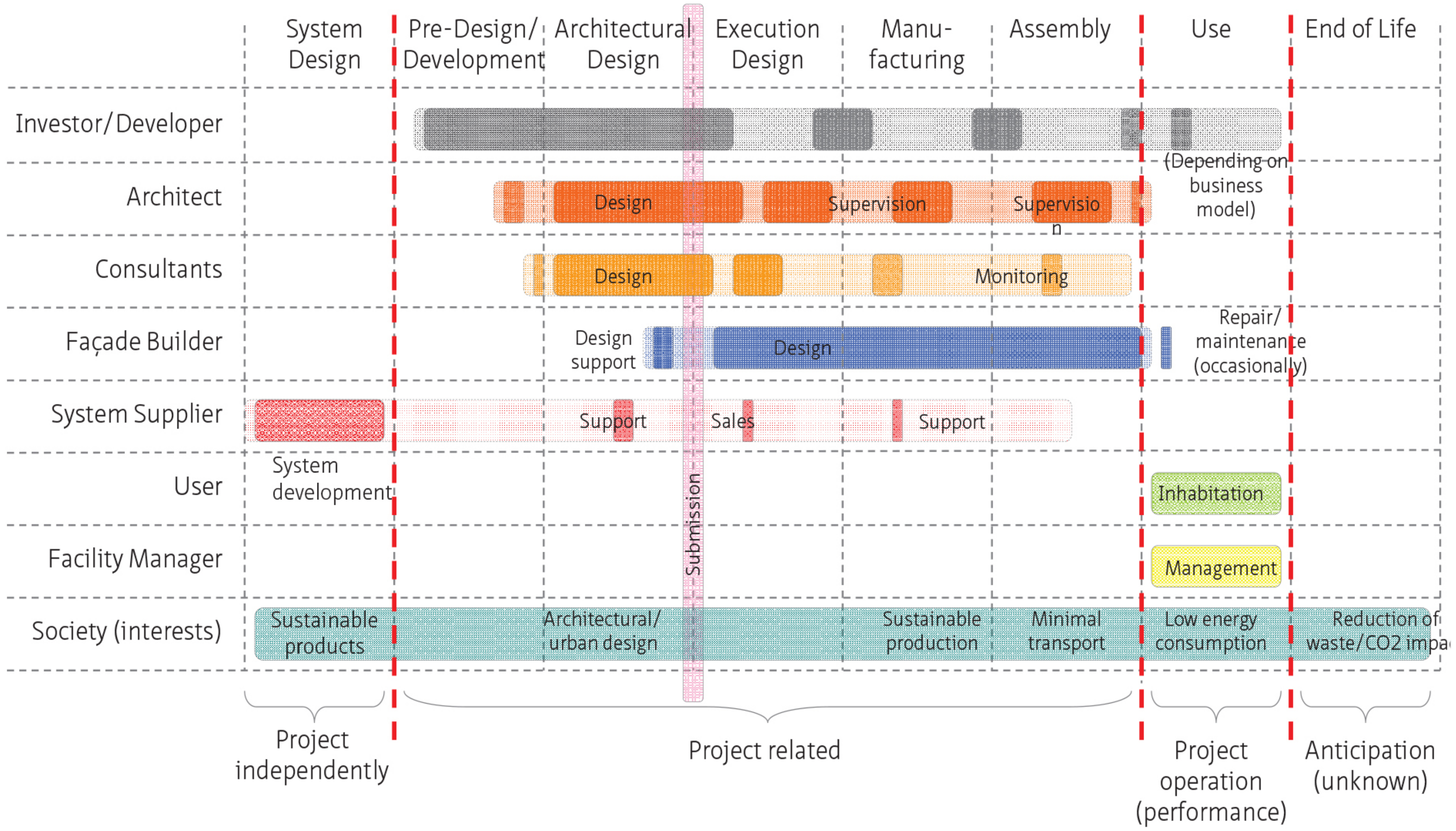
I. What are the primary typologies of facades and how can they be classified based on their materials, connection details and functions?

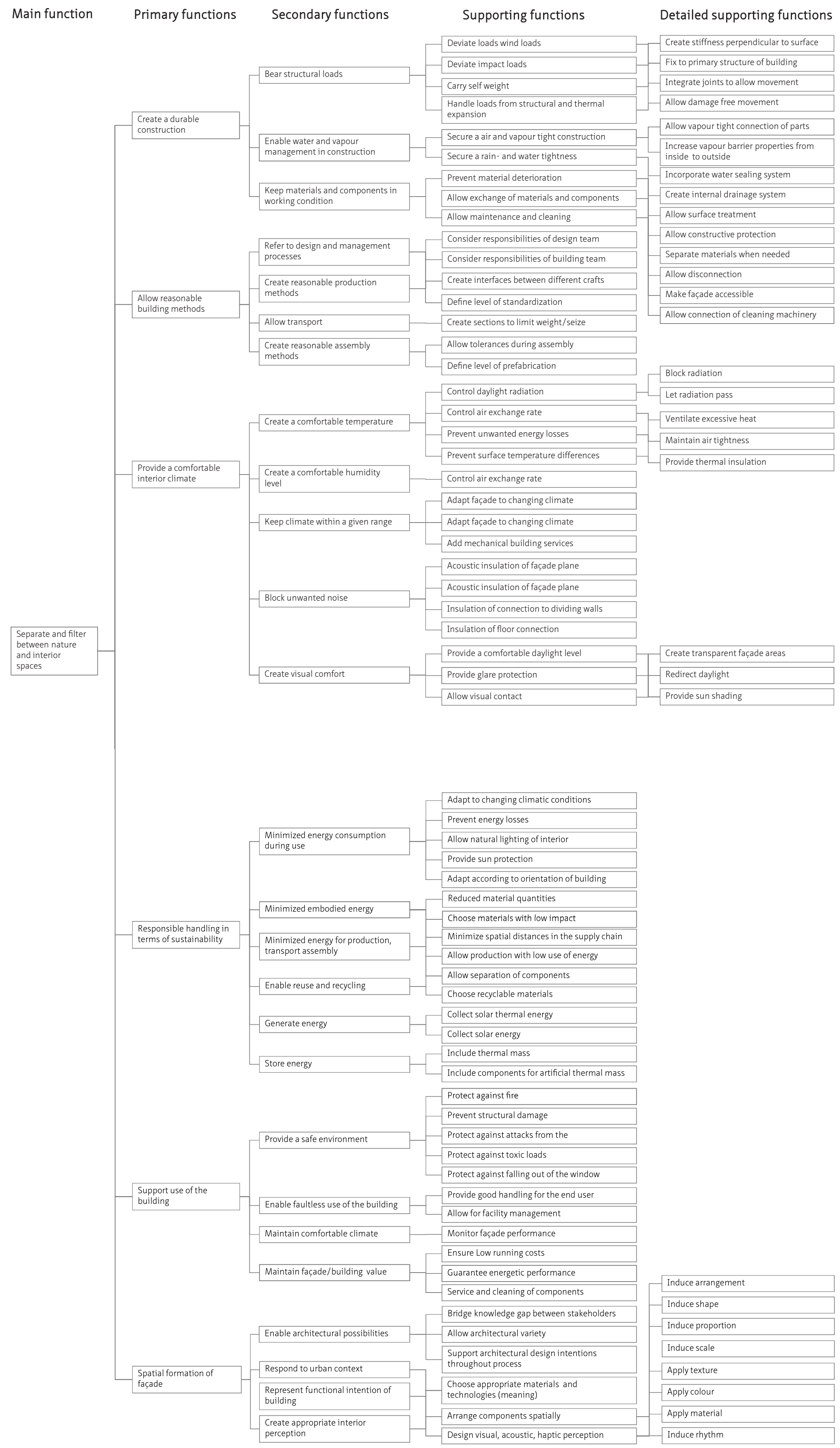
II. What is resilience and how can it be quantified?

III. How to formulate a genetic algorithm-based multi-objective optimization workflow?

IV. How can a digital design tool be implemented in a preliminary design phase of a shading system to enhance the thermal resilience of an existing curtain wall system and provide interdiciplinary feedback to a design team?

Facade types and goals





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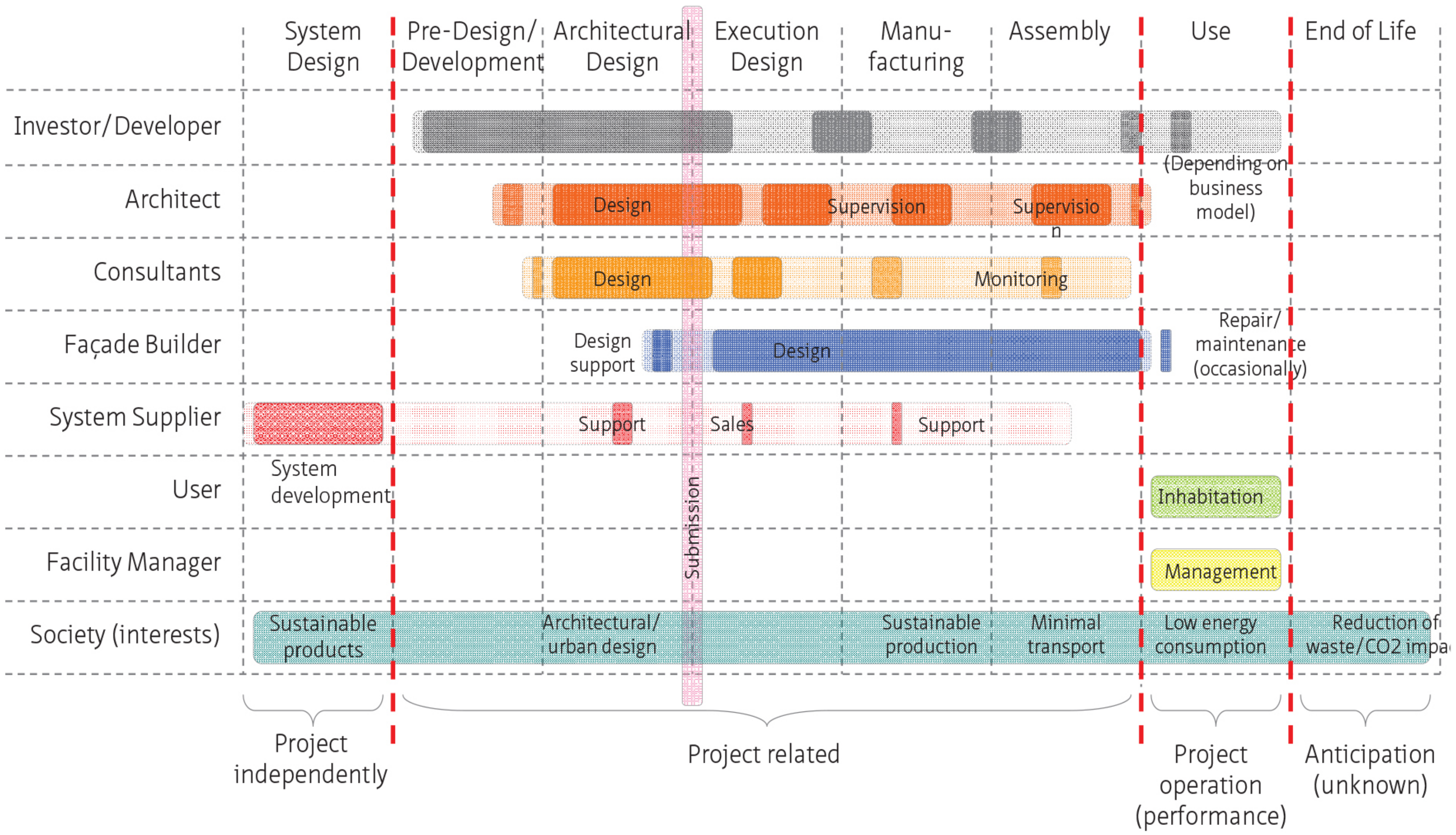

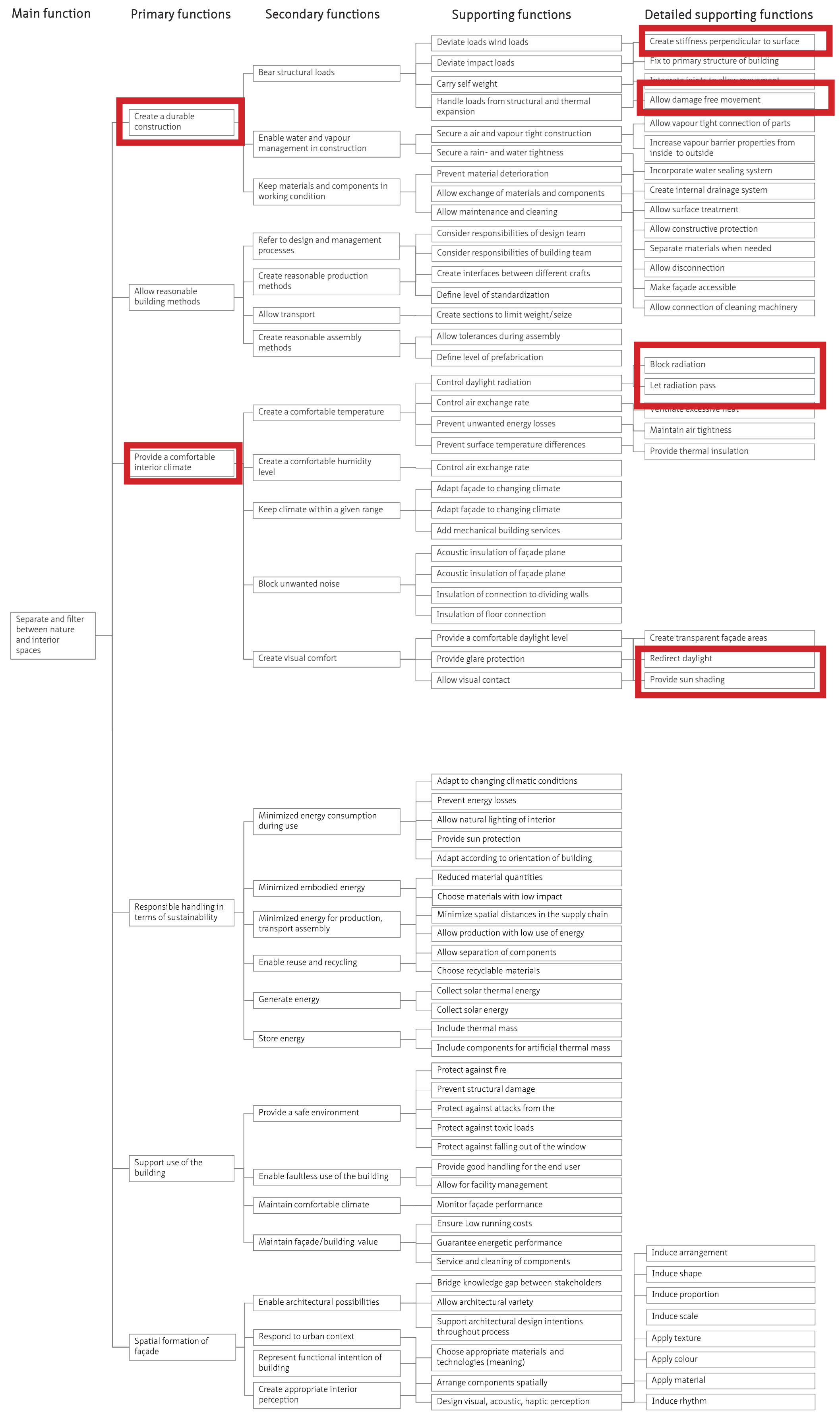

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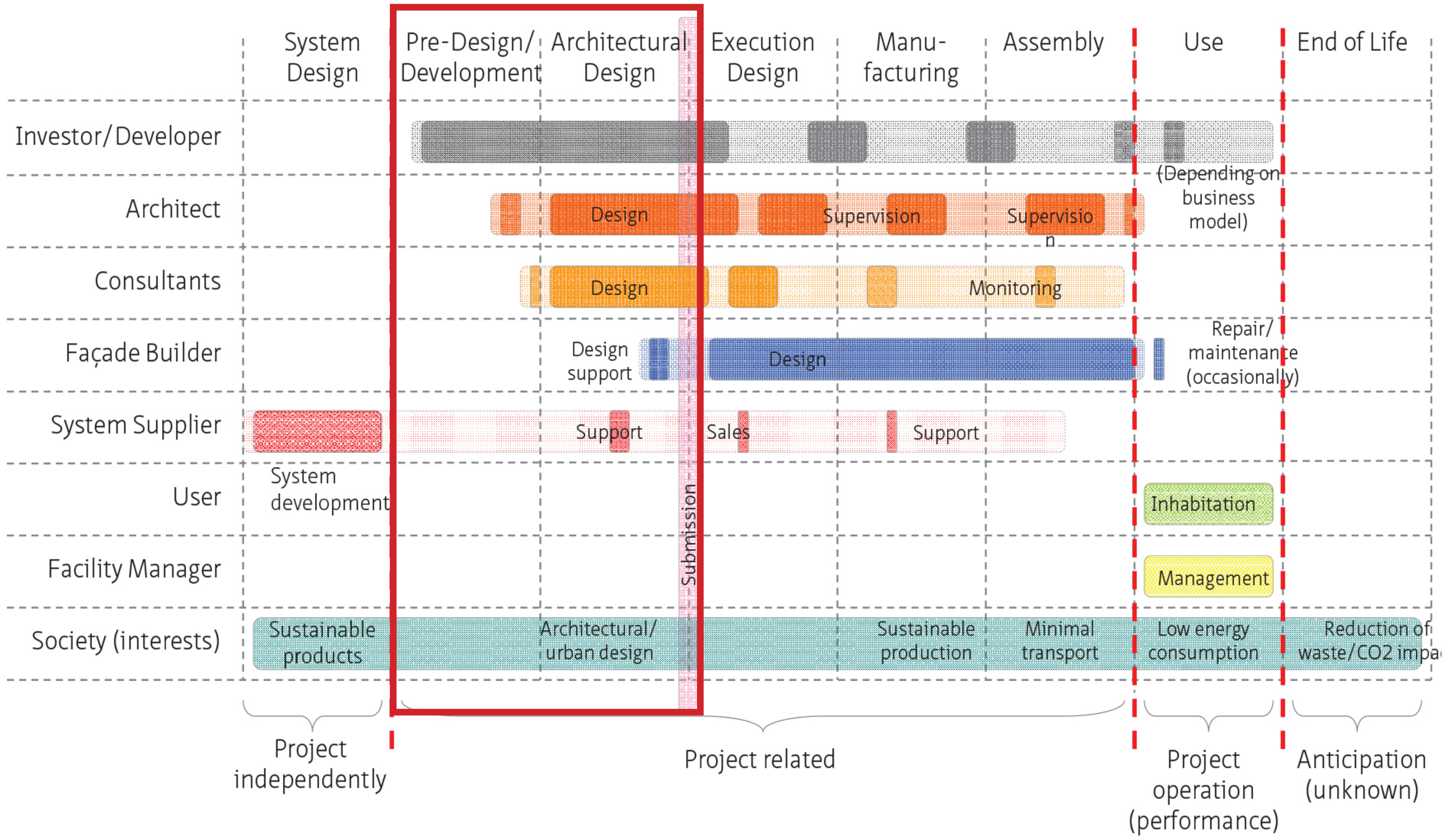

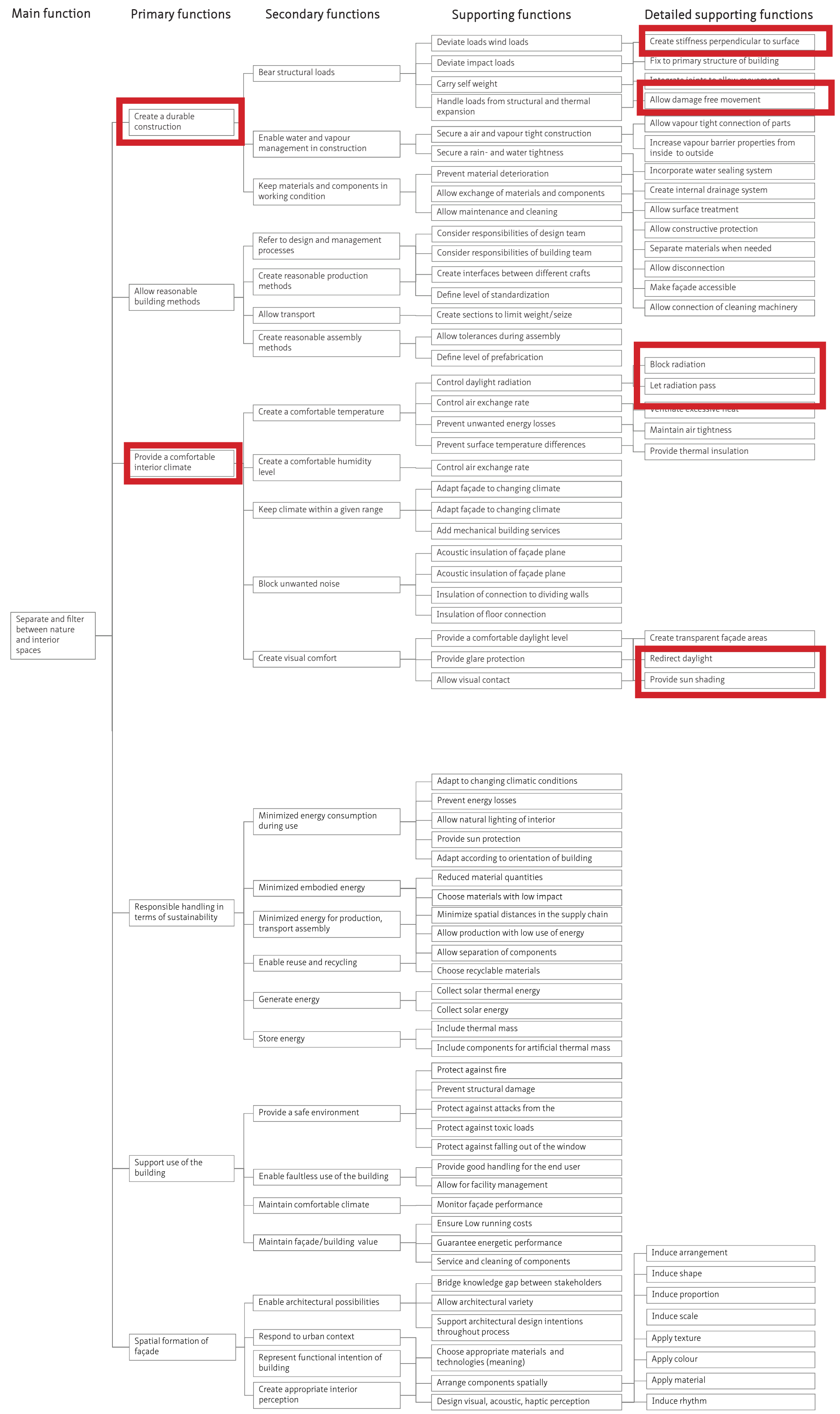

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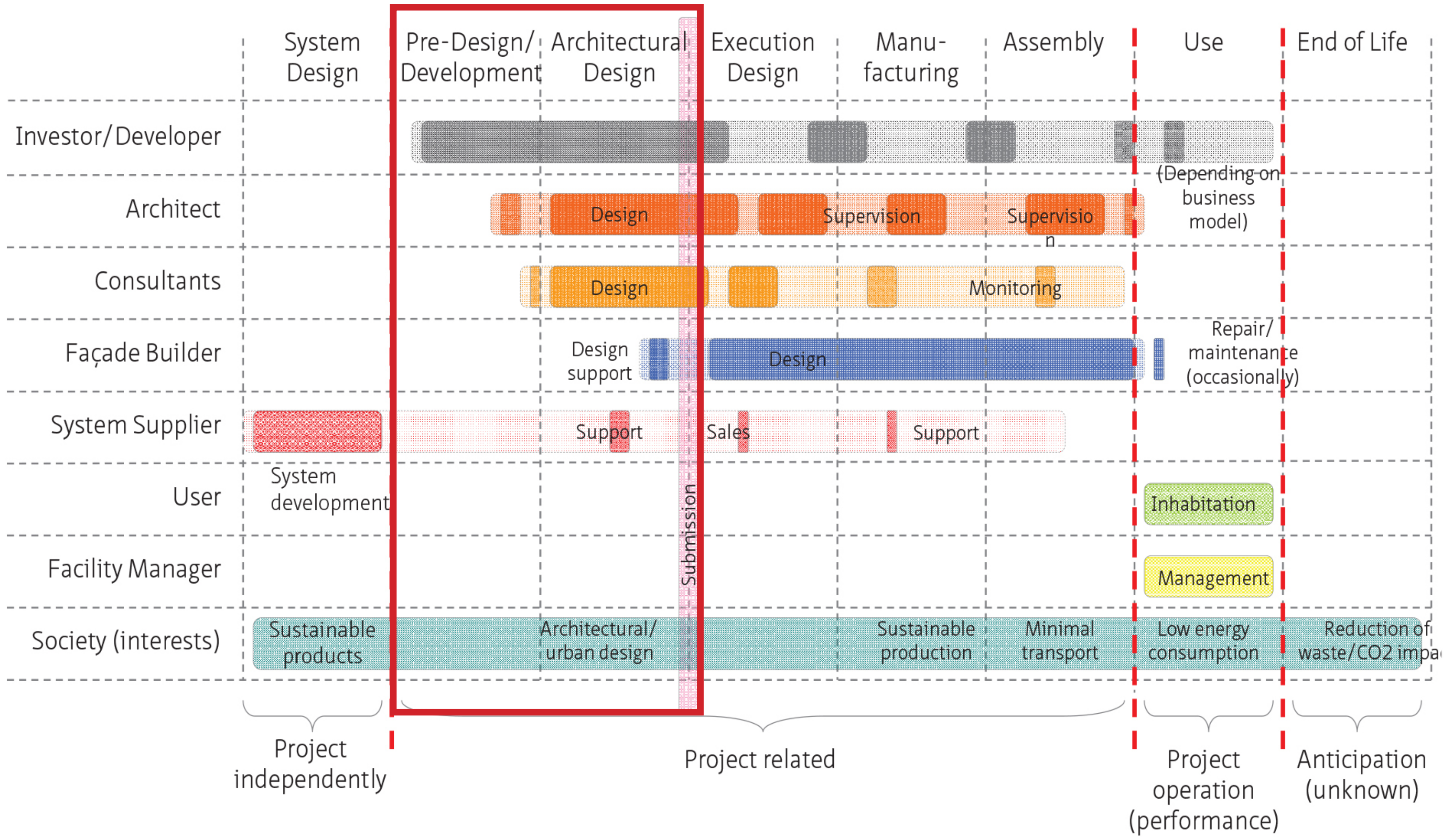

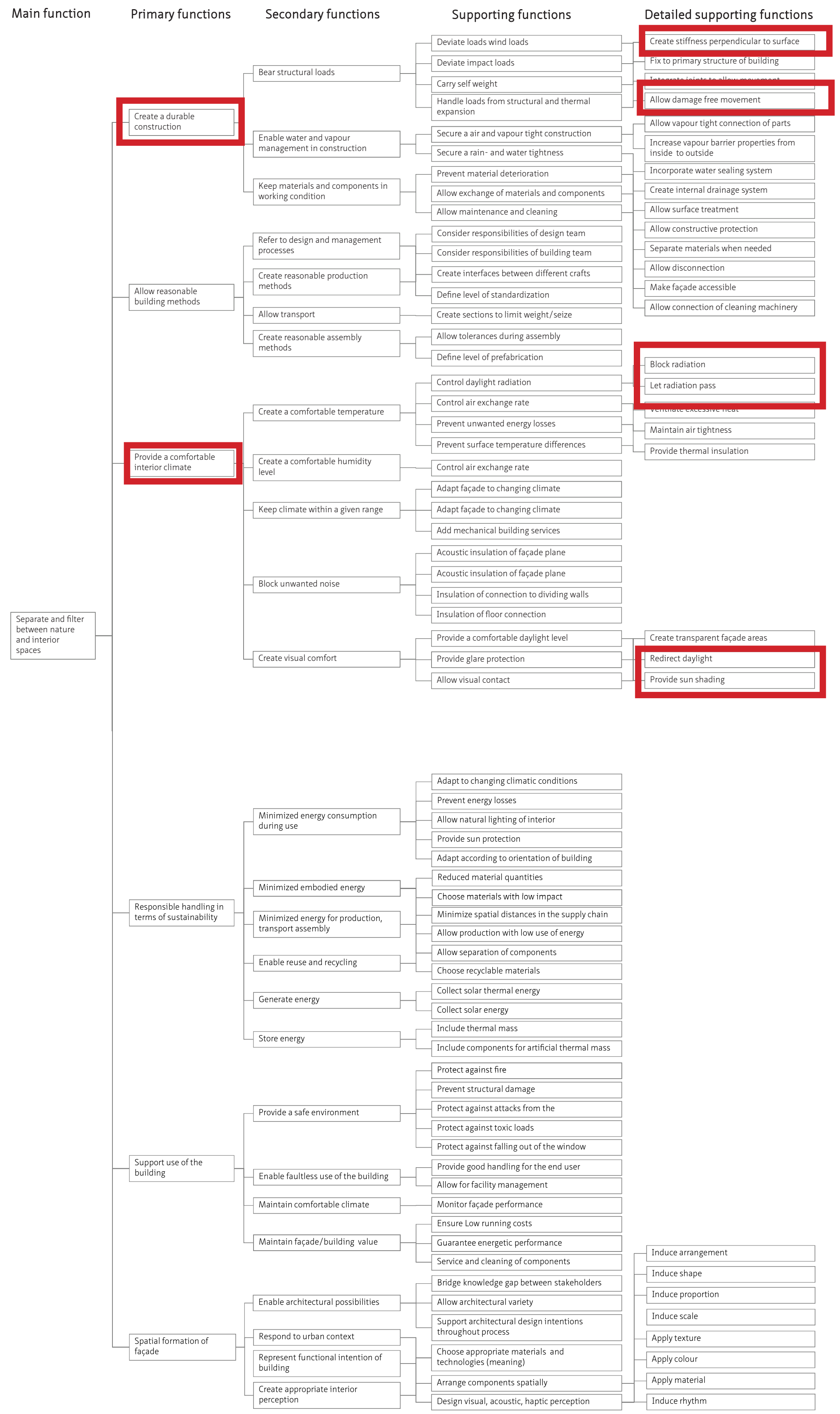

A shading system preliminary design

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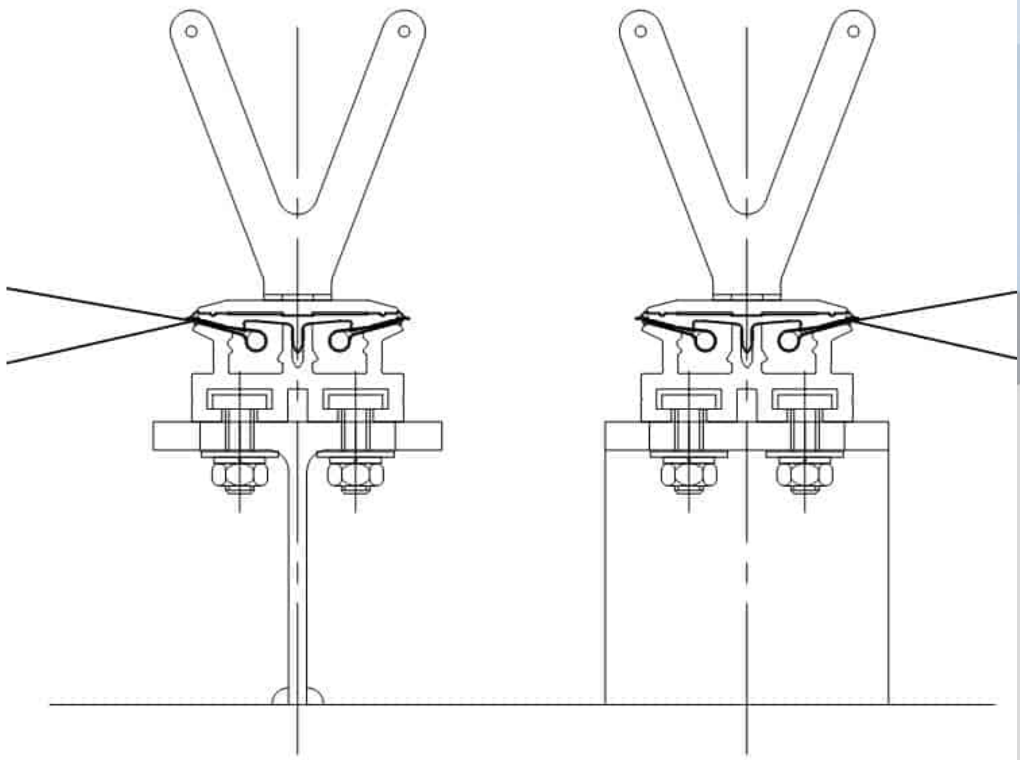
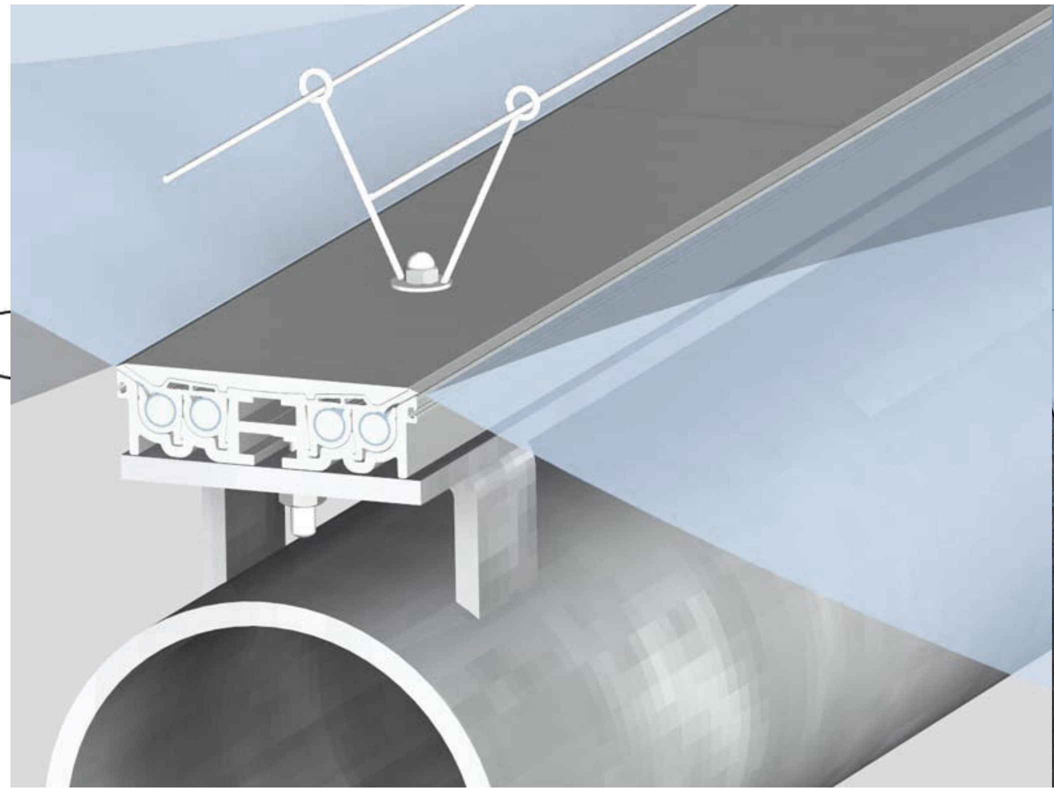
Literature review

+	-
• Lightweight	• 100% manmade
• Durable	• toxic ingredients
• 100% Recyclable	• need of constant inflation

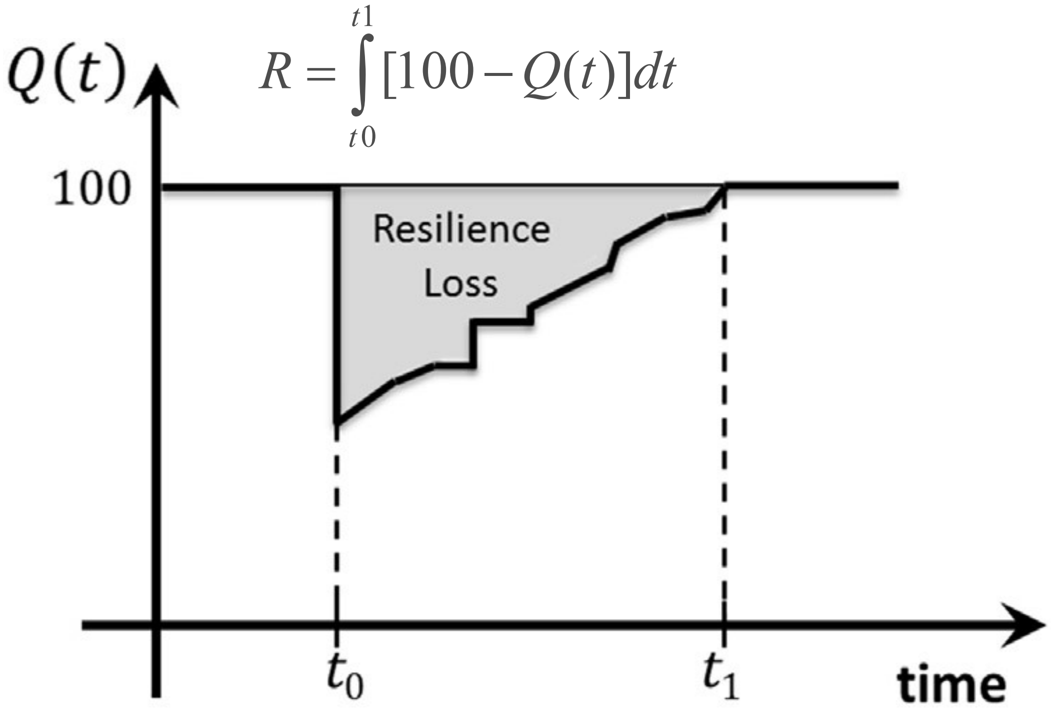


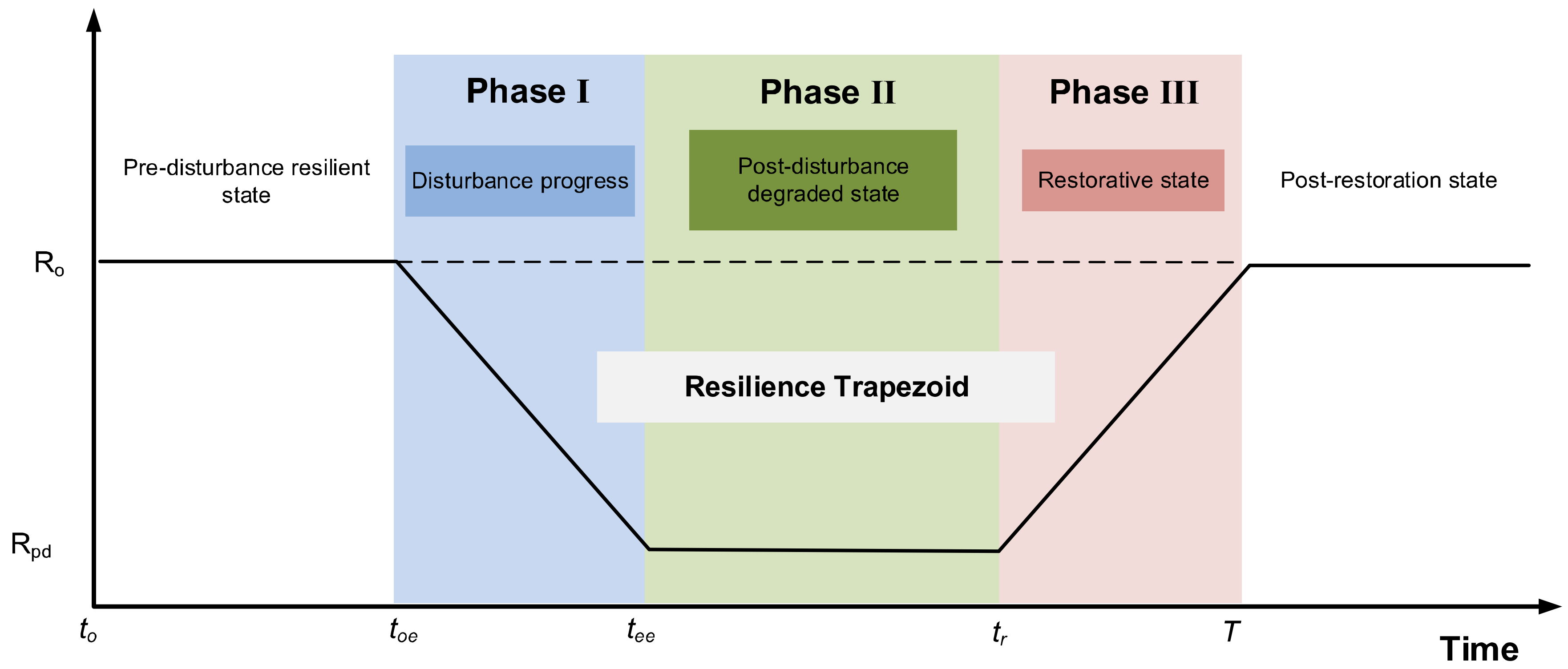


Literature review

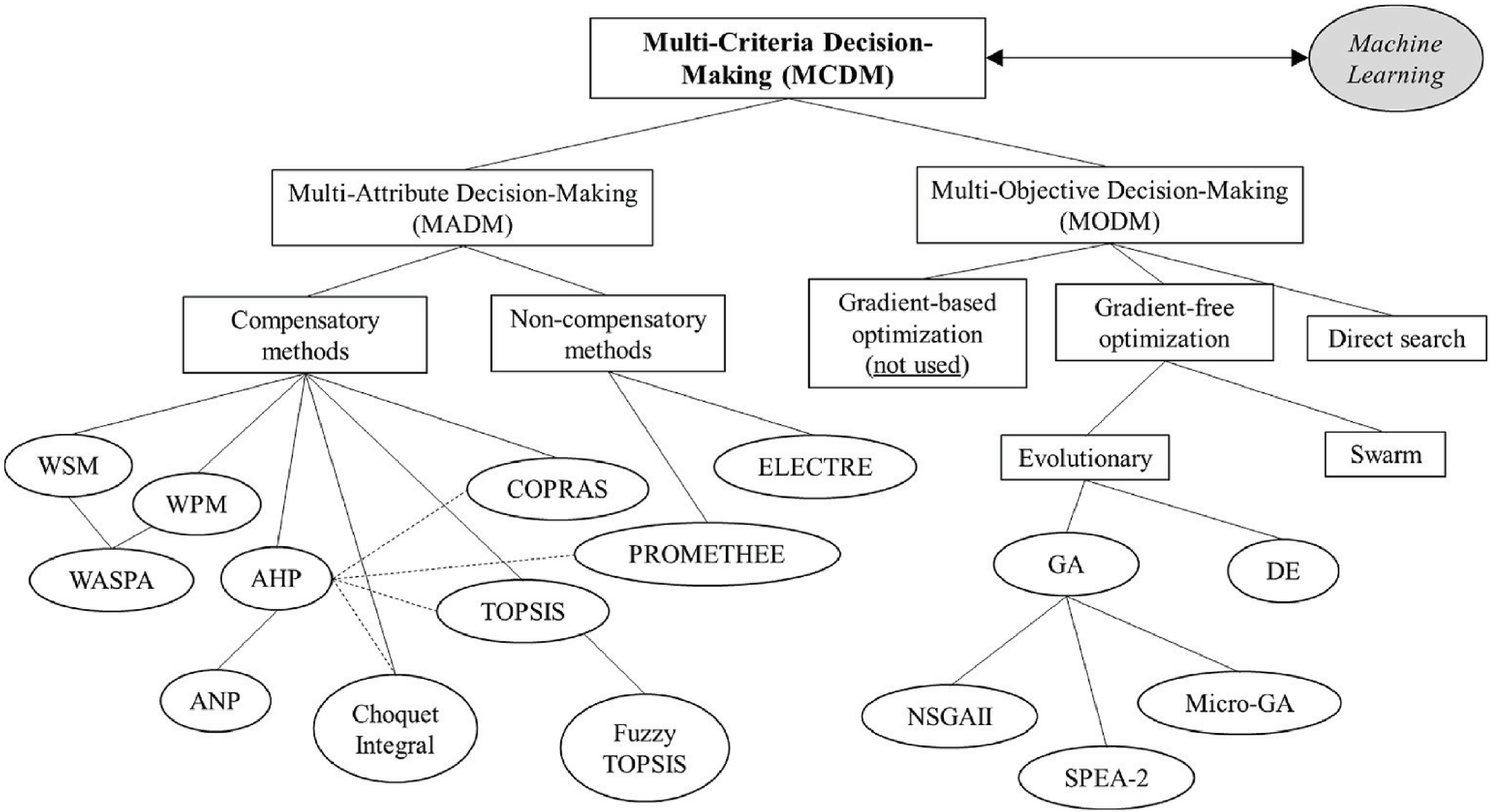
Resilience is a time dependent measurable assessment of a system against a balance disturbance.

Thermal resilience is the ability of the building to maintain its indoor thermal comfort in case of extreme hot weather conditions.





Literature review



Literature review

Multi-Attribute decision making (MADM)

- closer to data-driven models
- creation of hierarchies of façade design alternatives either by reducing the complexity of a problem or with the comparison of solution ratings.

Multi-Objective decision making (MODM)

- closer to forward models
- based on optimization algorithms
- numerical simulations for the defintion of a larger amount of design options and their evaluation

Literature review

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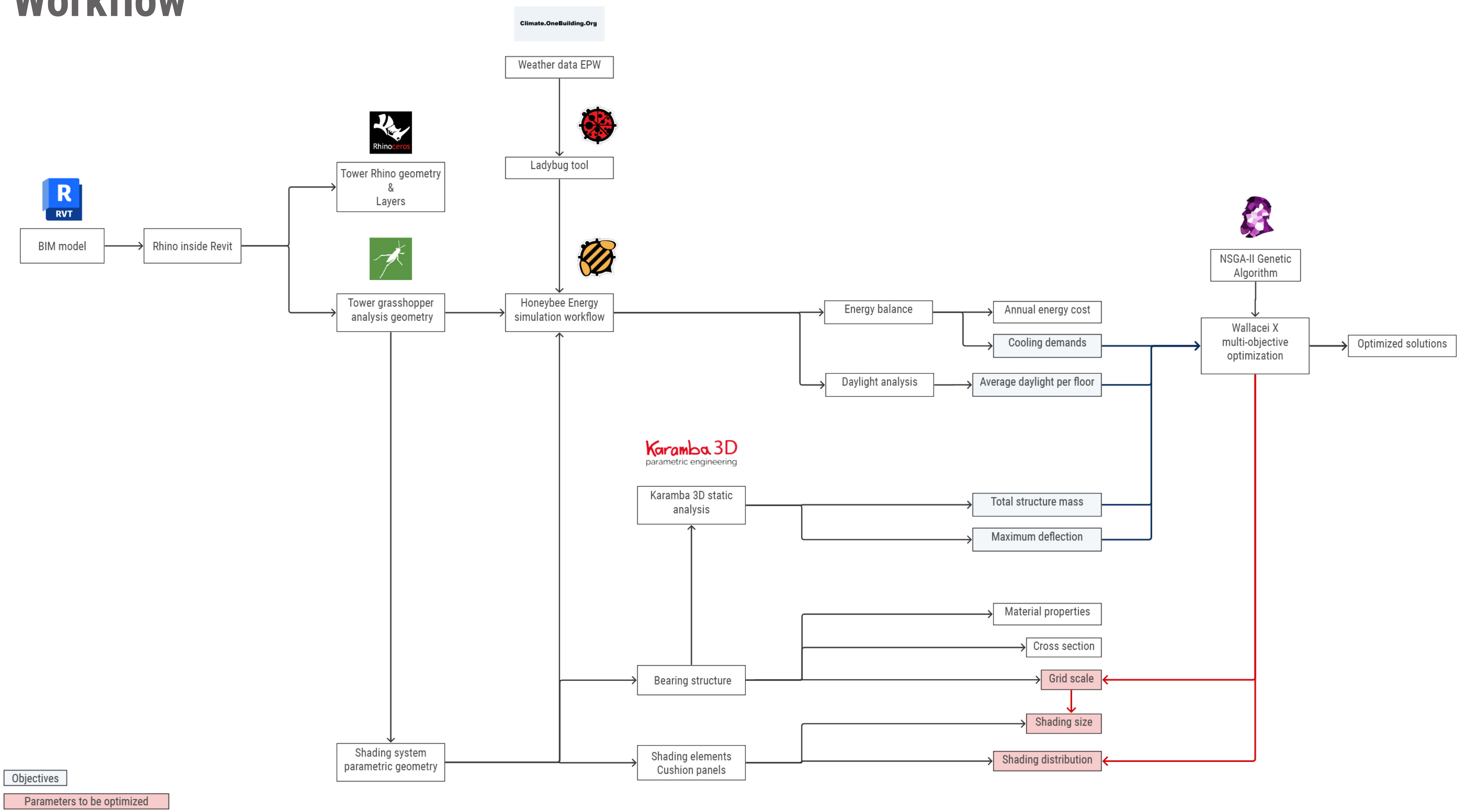
NSGA II algorithm - niching approach

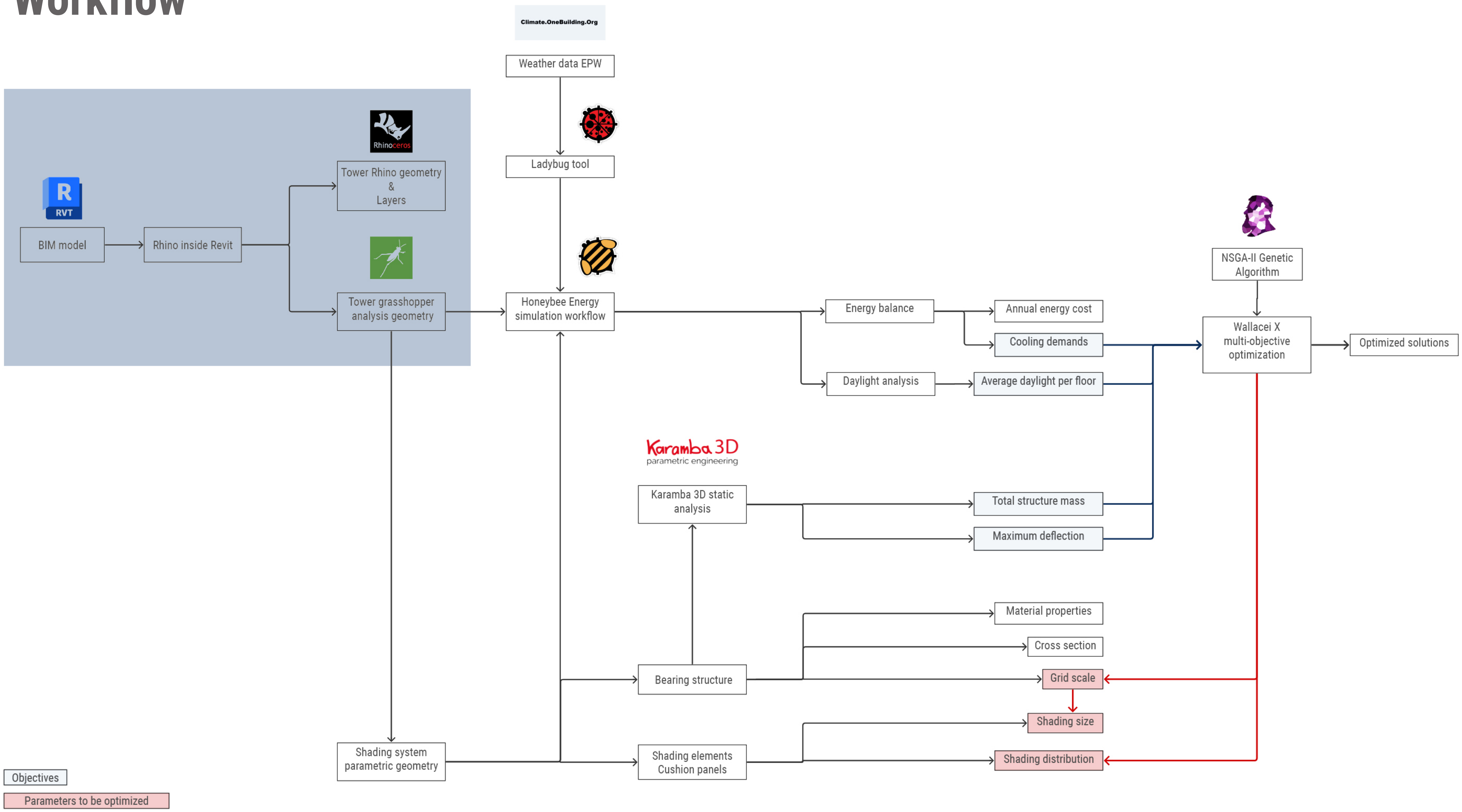
Walacei

Workflow



Revit-Grasshopper integration Energy simulation workflow Shading system definition Static analysis Multi-objective optimization

Workflow



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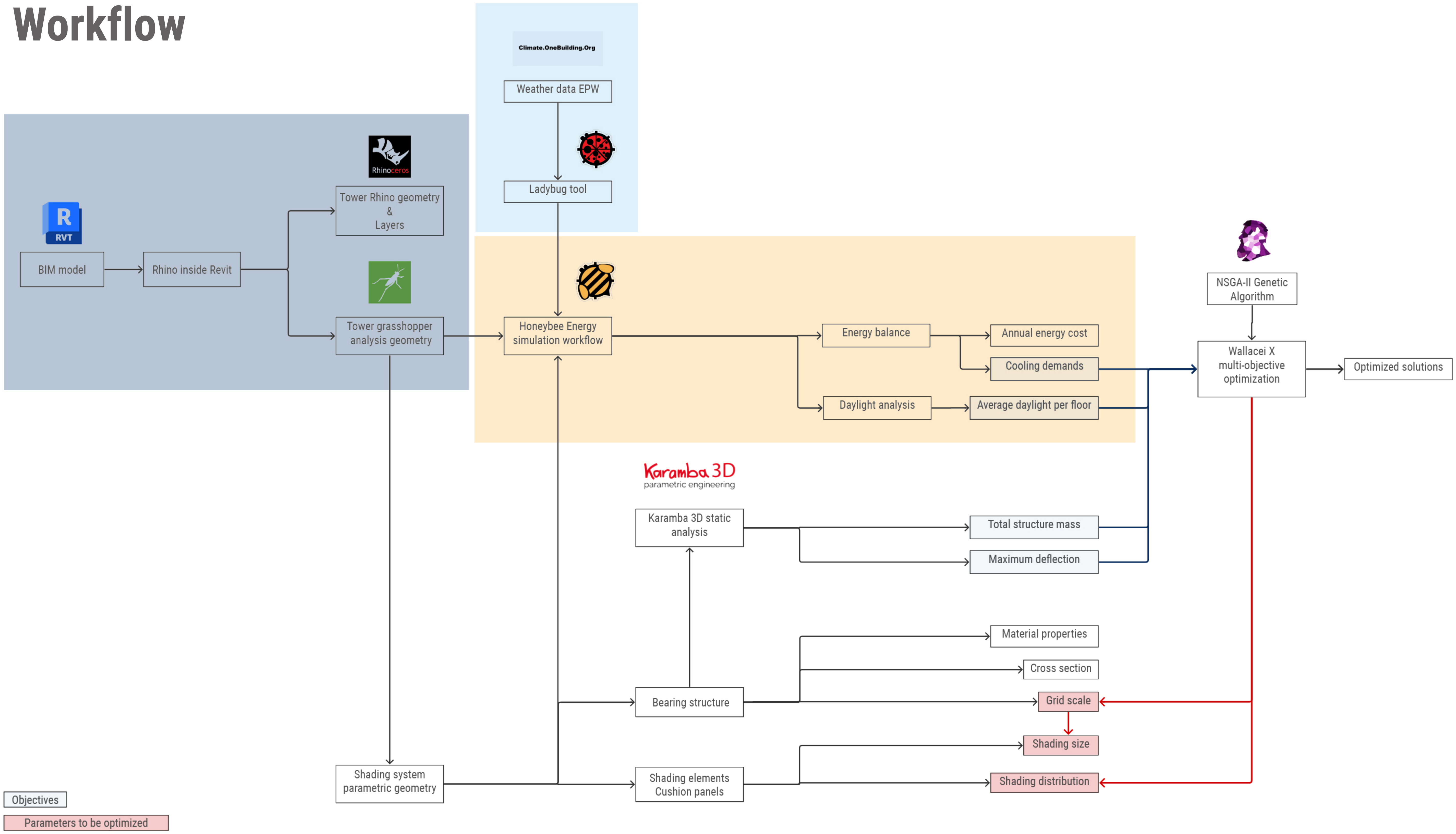

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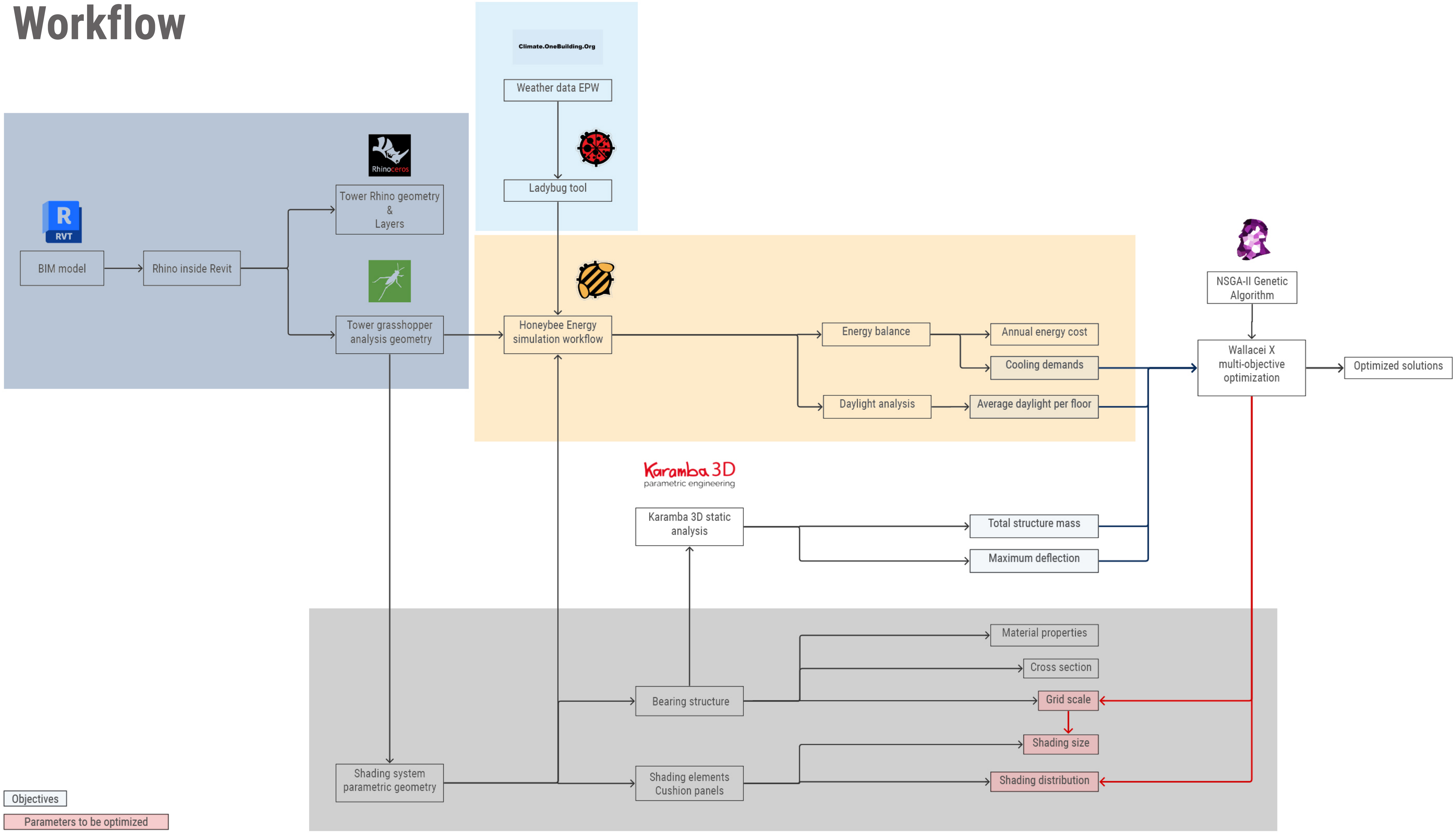
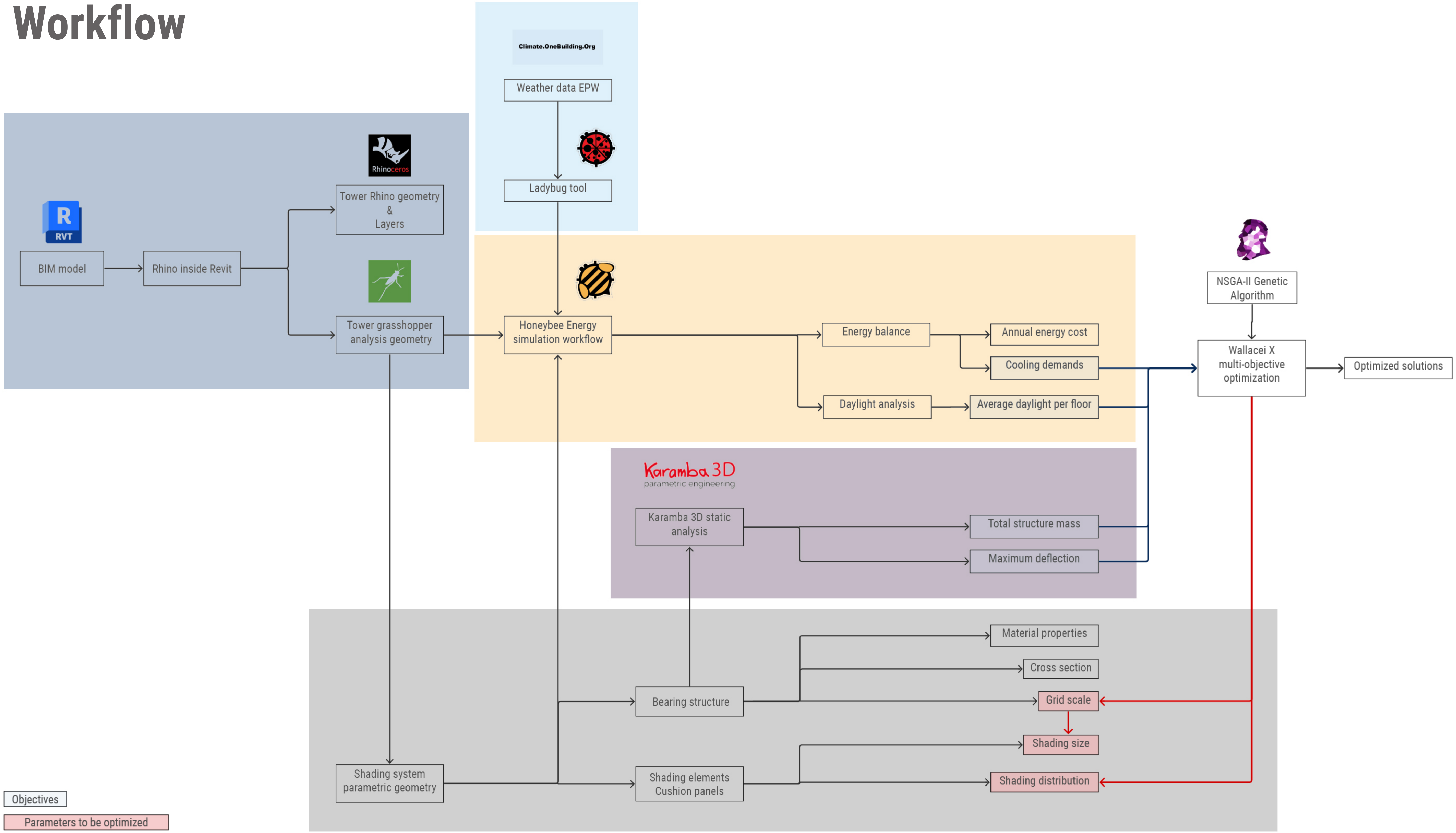


Revit-Grasshopper integration · Energy simulation workflow · Shading system definition · Static analysis · Multi-objective optimization

Workflow



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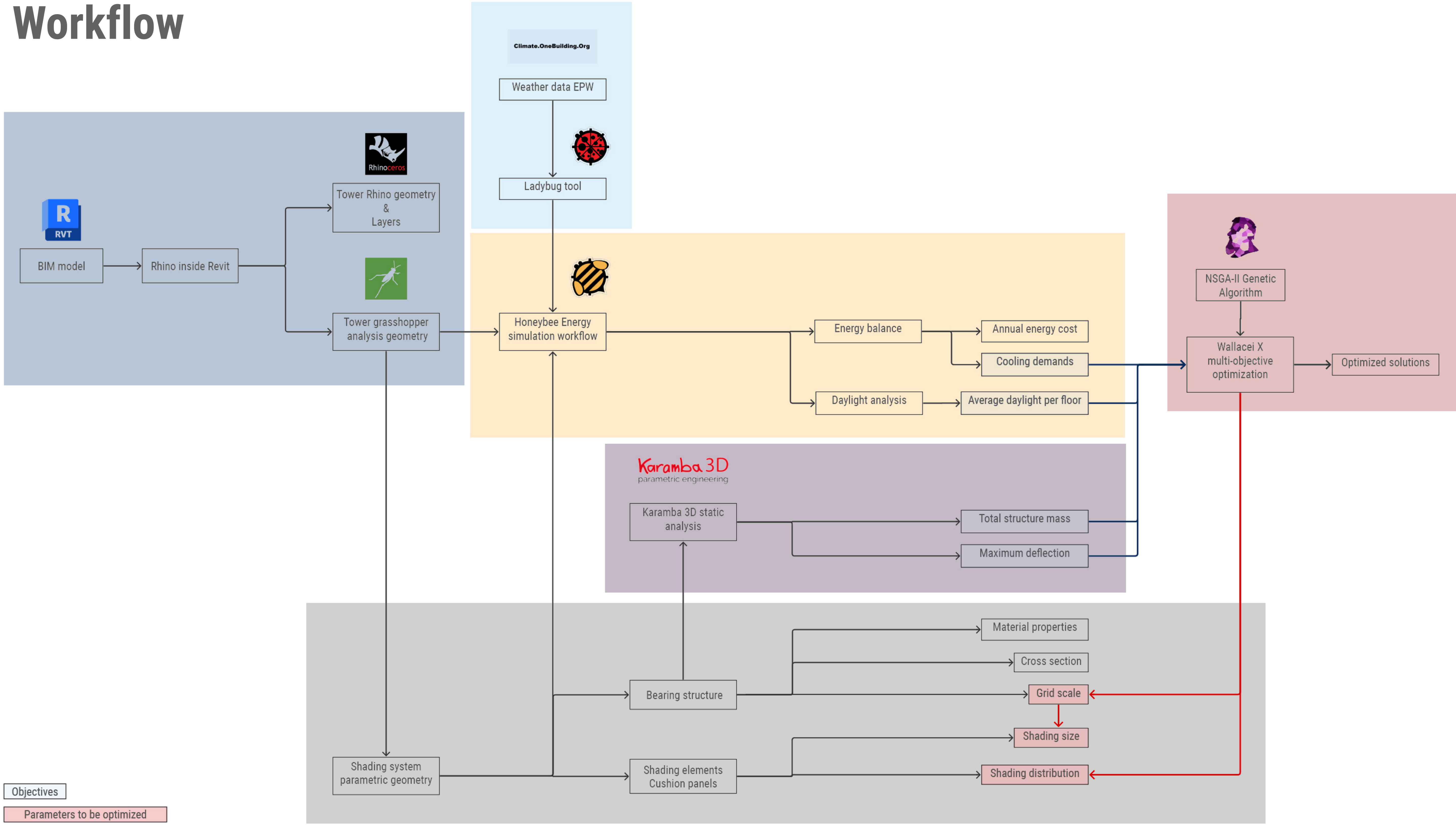
Workflow

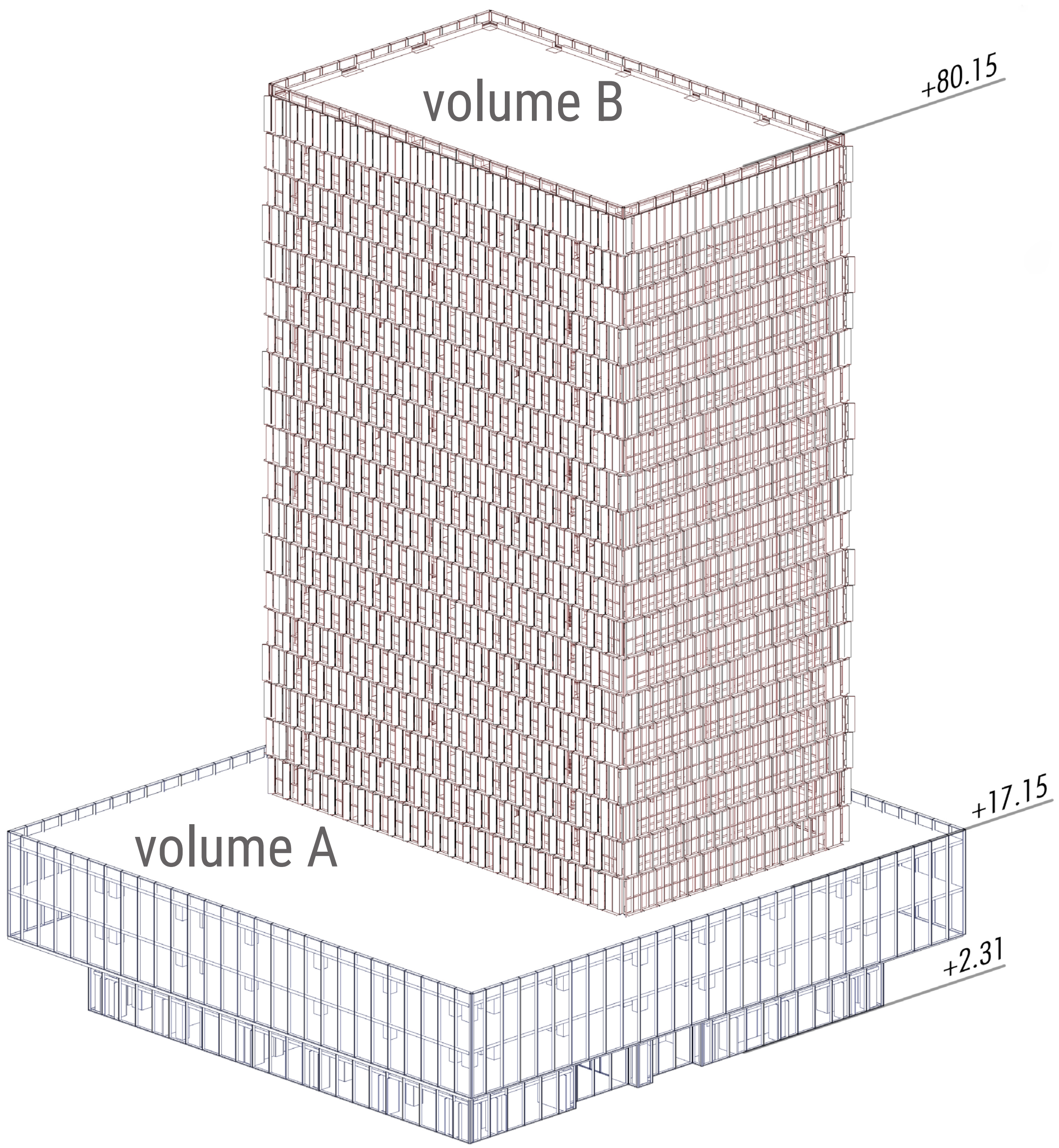


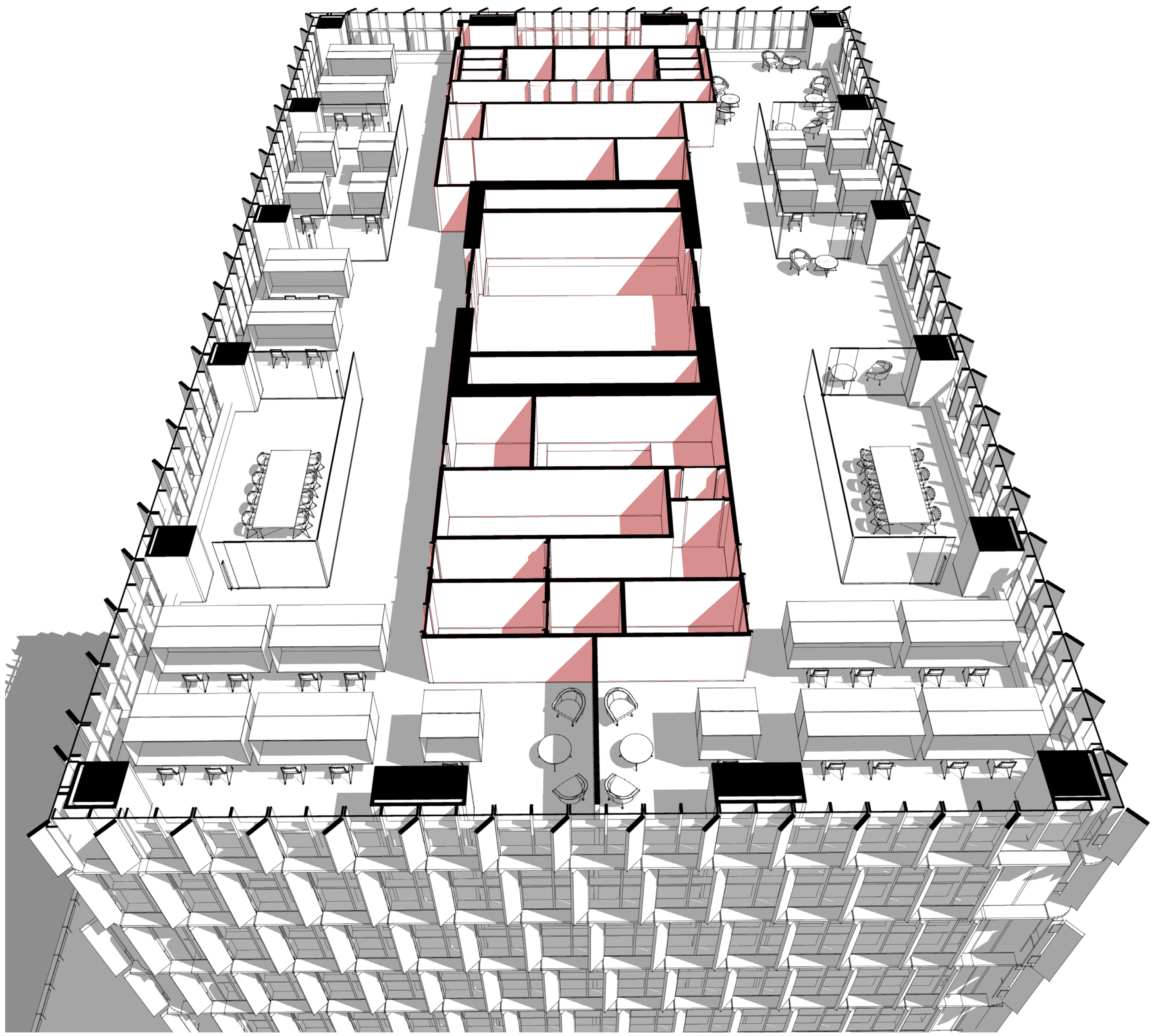
Revit-Grasshopper integration · Energy simulation workflow · Shading system definition · Static analysis · Multi-objective optimization

Actual Workflow

Revit-Grasshopper integration *Energy simulation workflow* *Shading system definition* *Static analysis* *Multi-objective optimization*

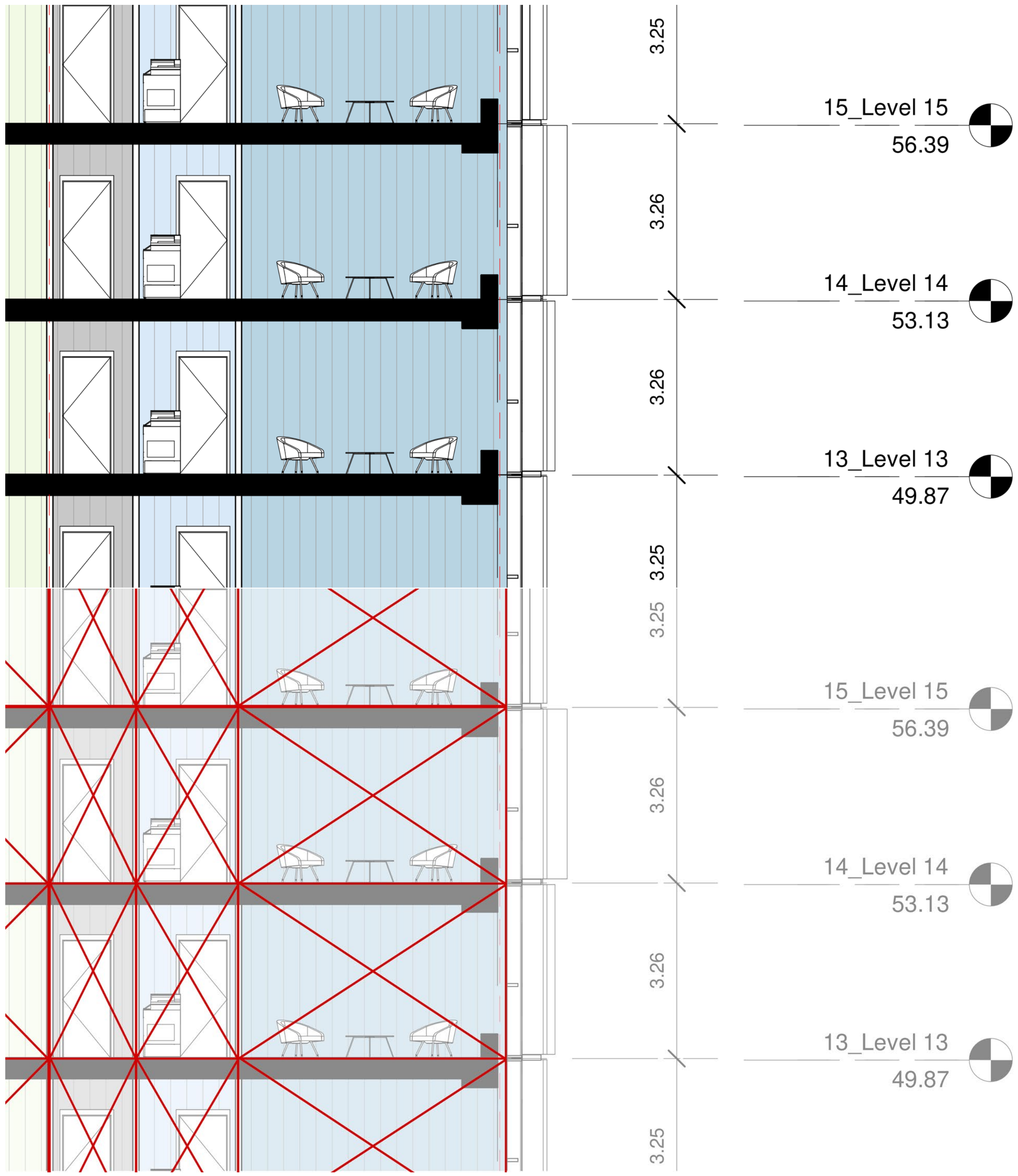
BIM model - Piraeus Tower





Revit-Grasshopper integration

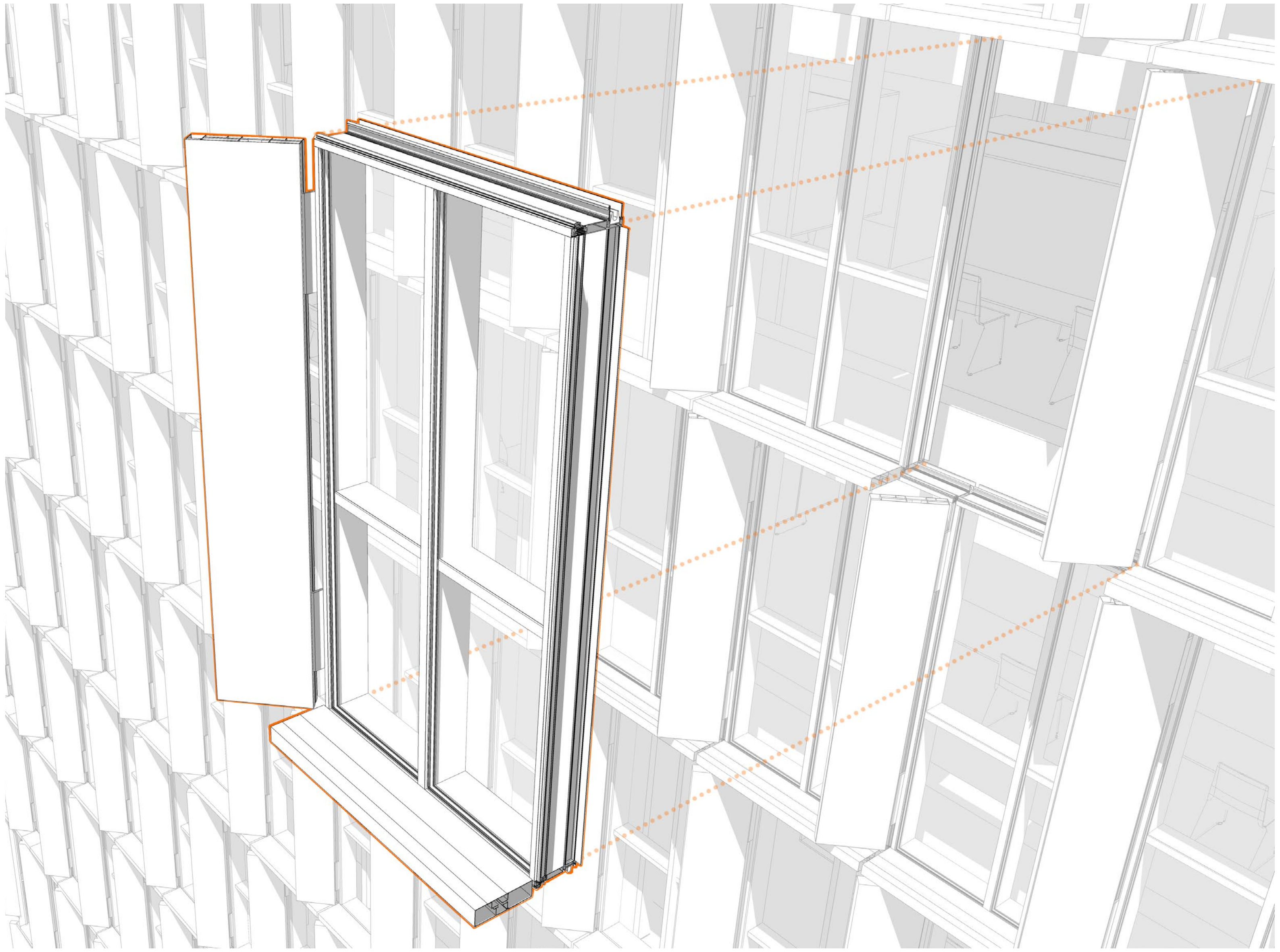
BIM model - Rooms definition

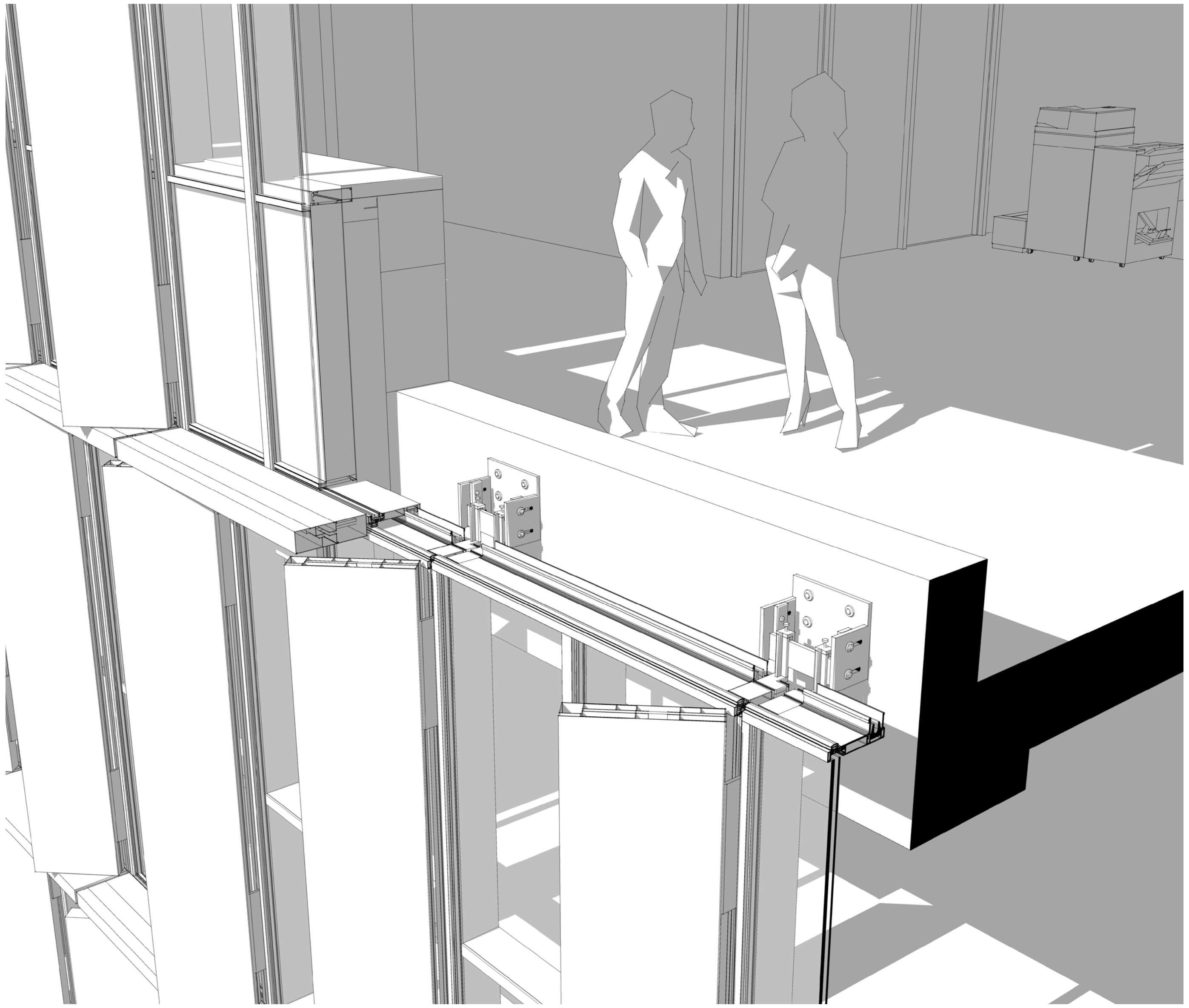


Revit-Grasshopper integration

BIM model - Bearing structure

Exsiting facade system





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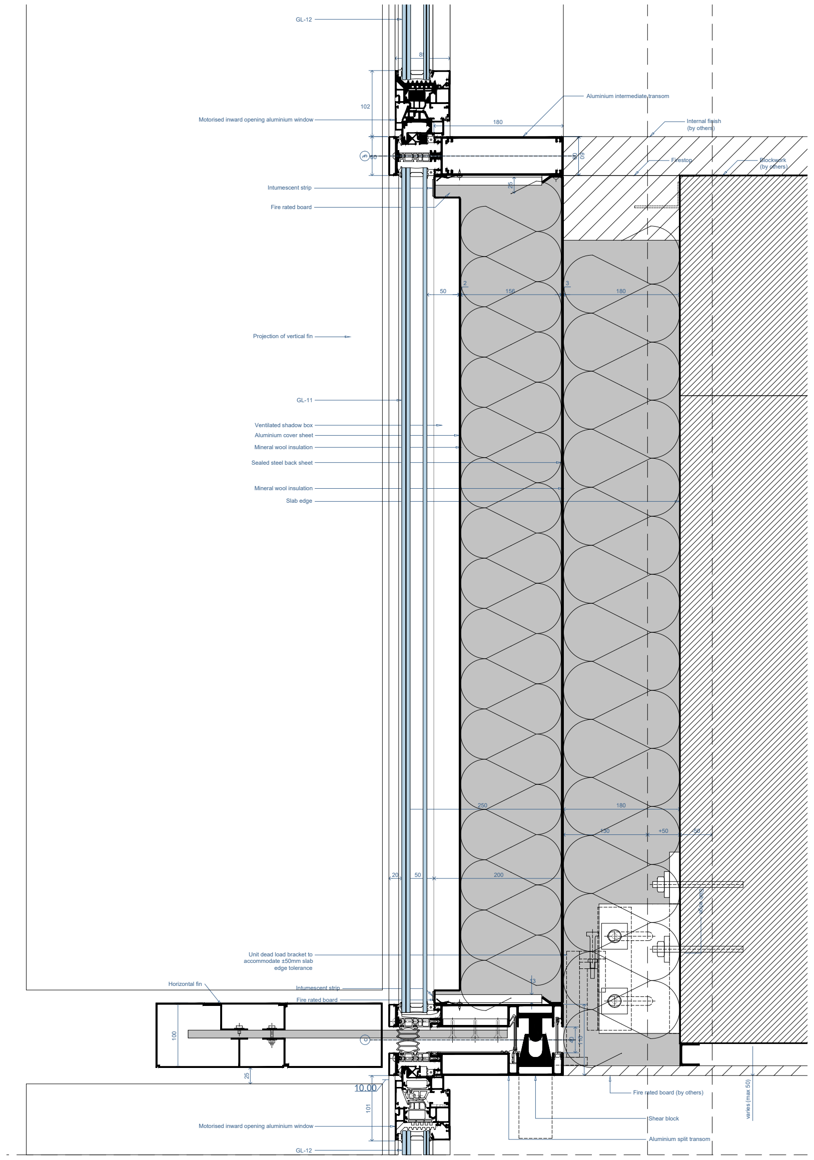
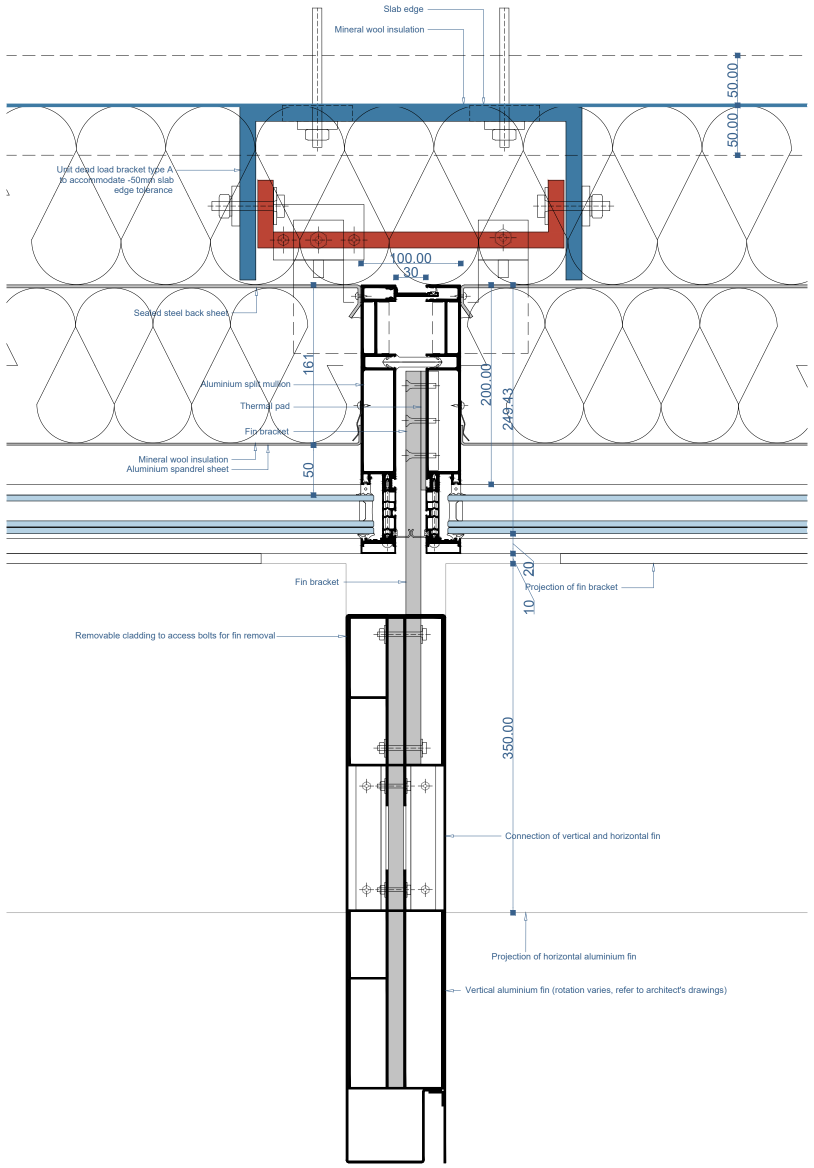
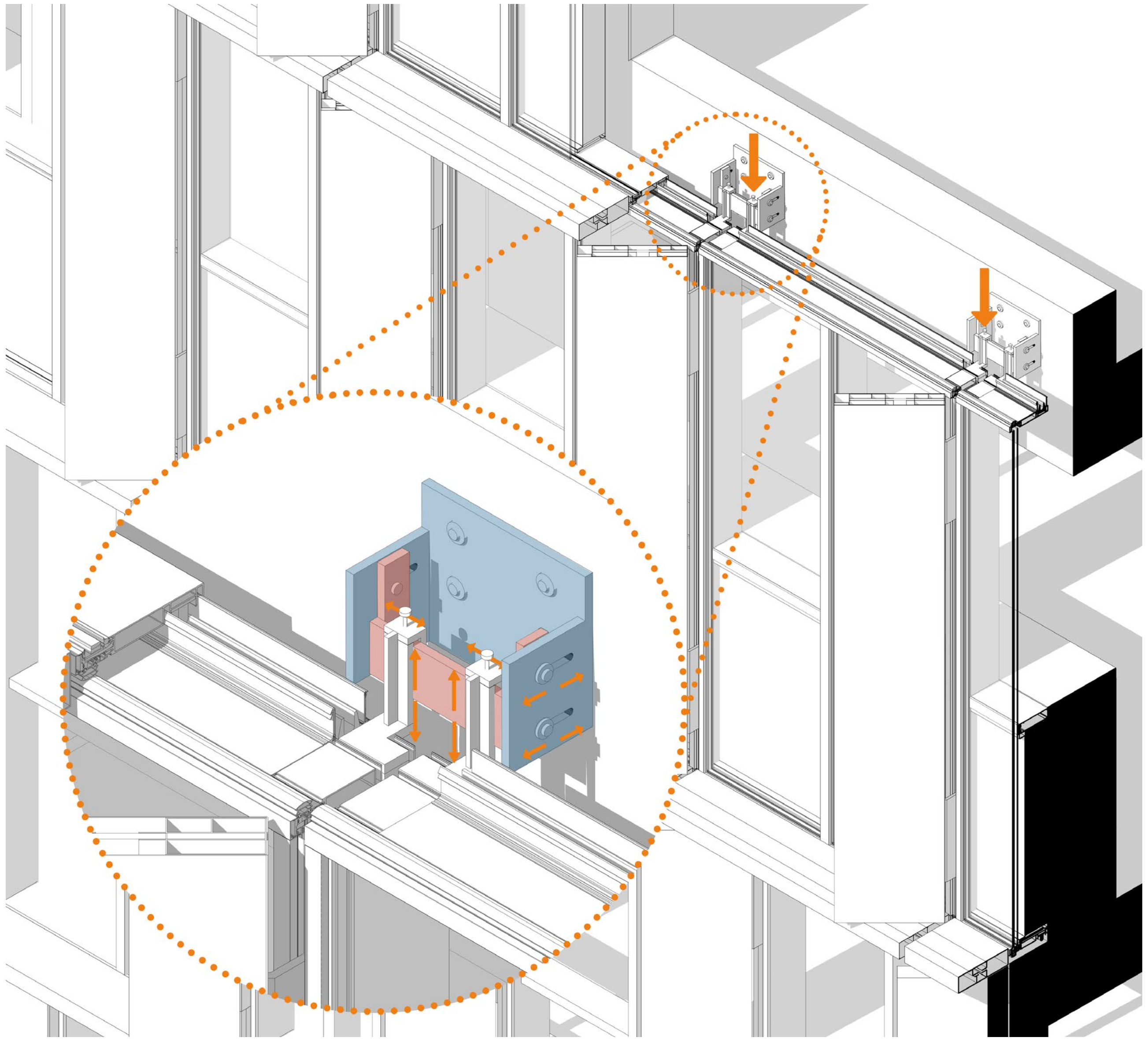
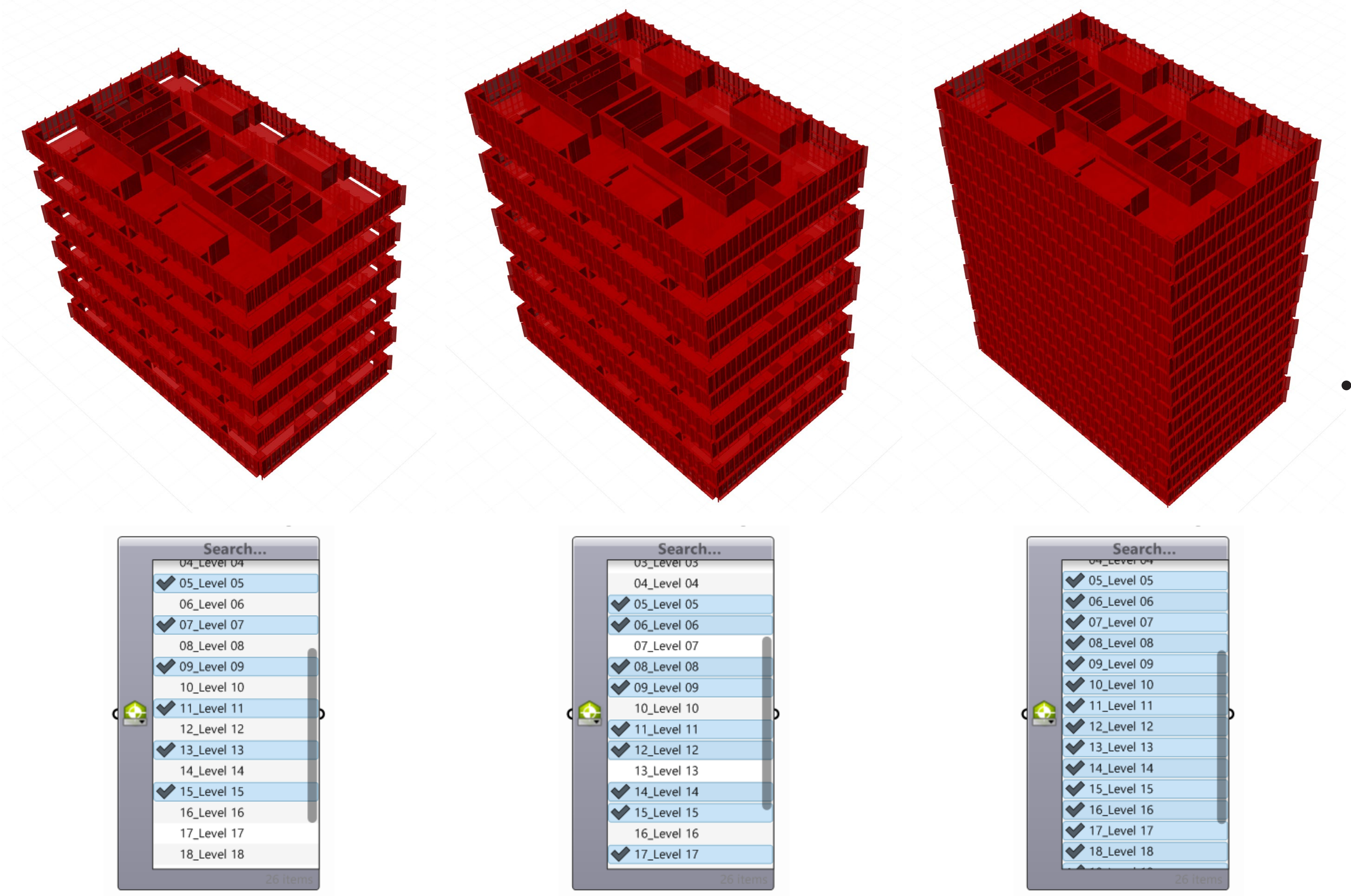
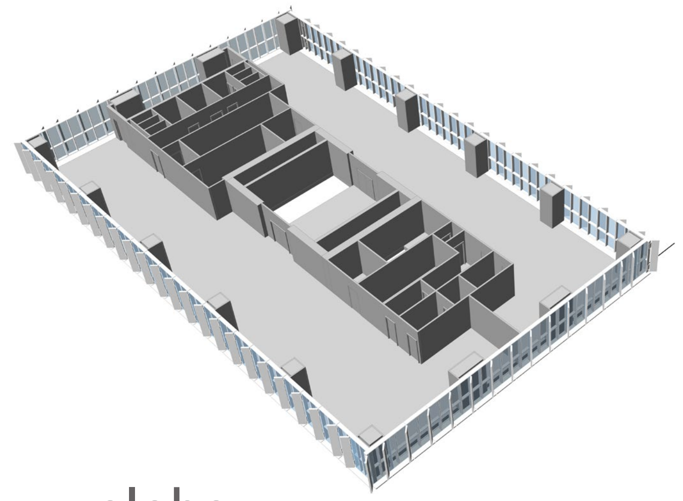




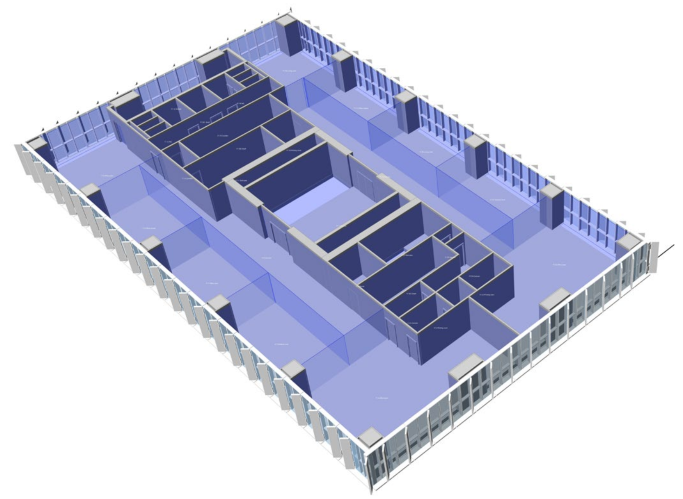


Energy model geometry





- slabs
- columns
- beams
- walls
- curtain wall

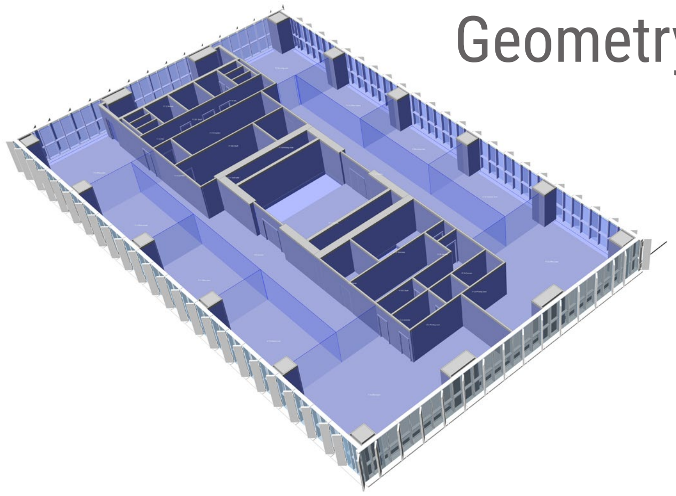


- rooms geometry

Revit-Grasshopper integration

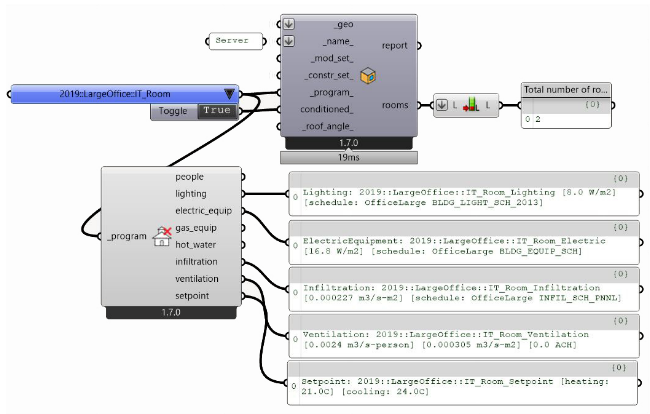
Energy model assembly

Geometry

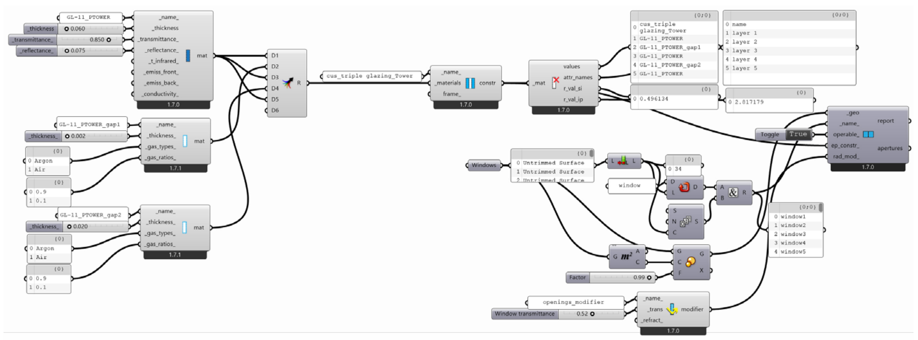


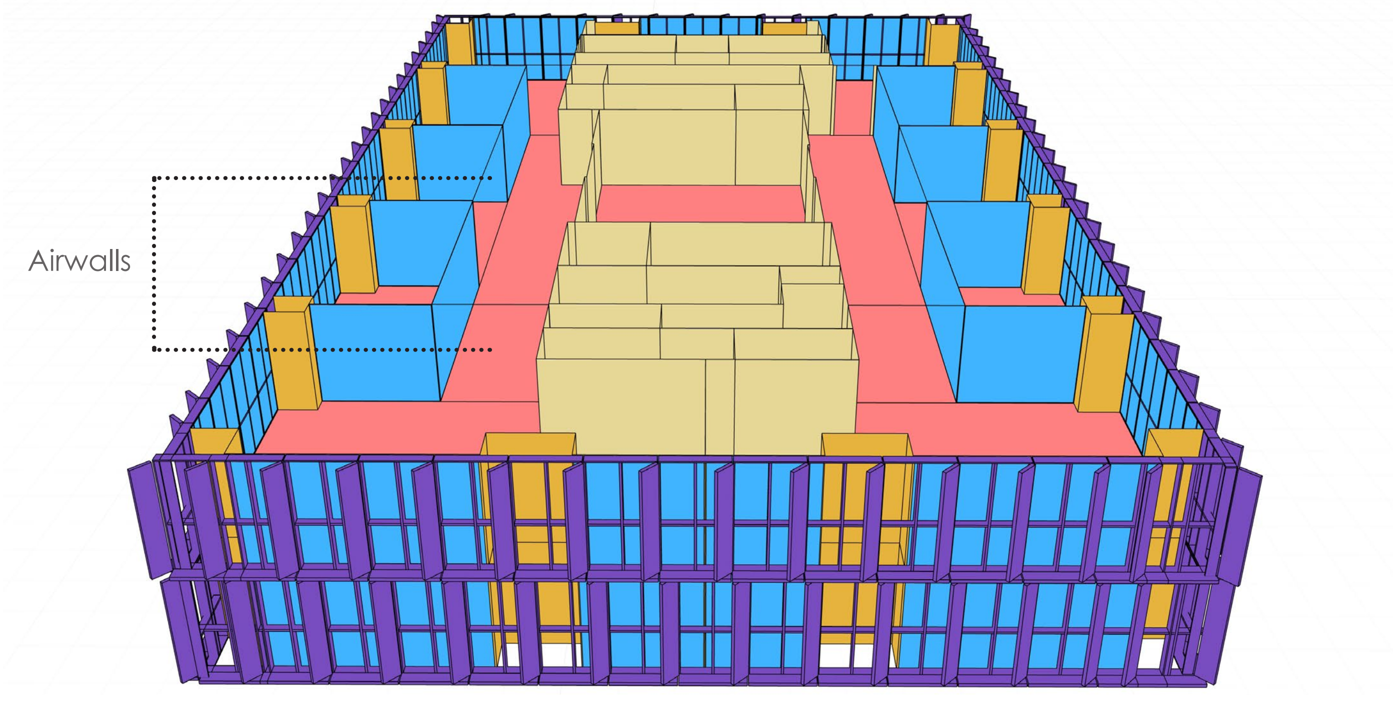
Weather data

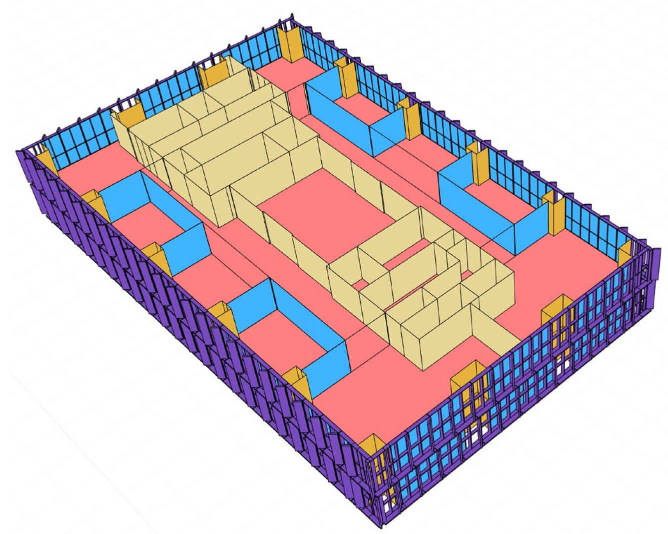
Program



Materiality

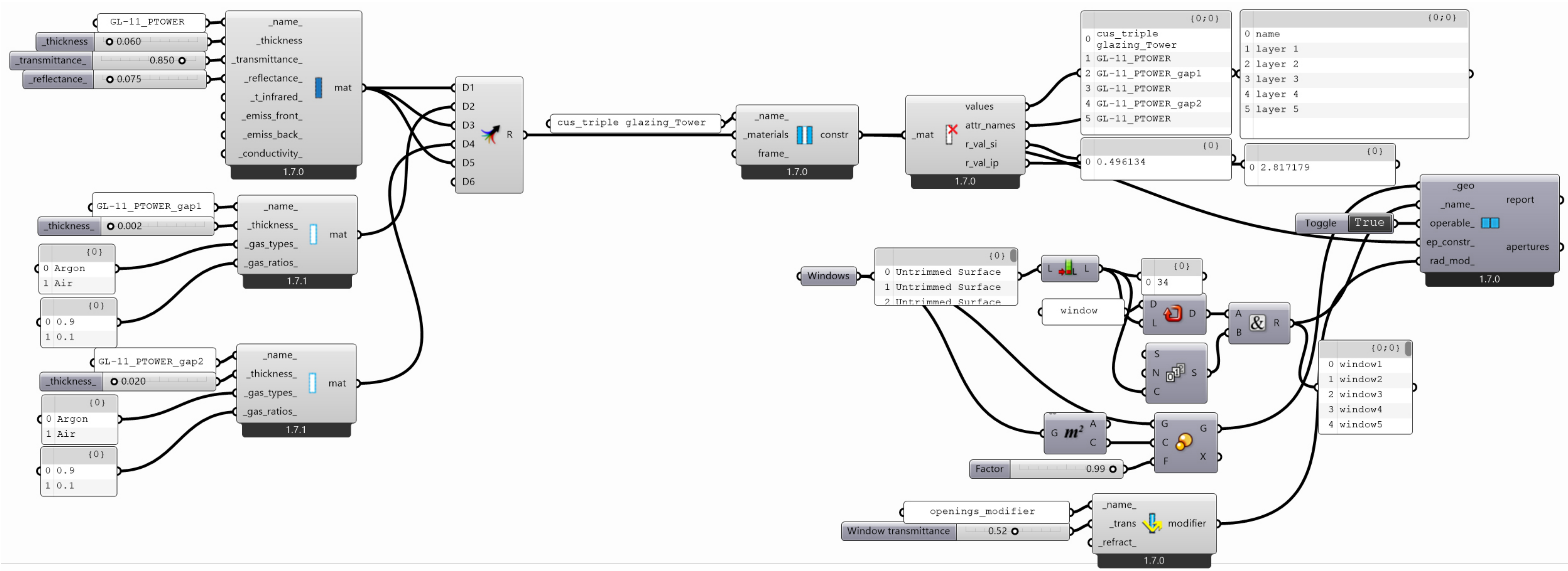




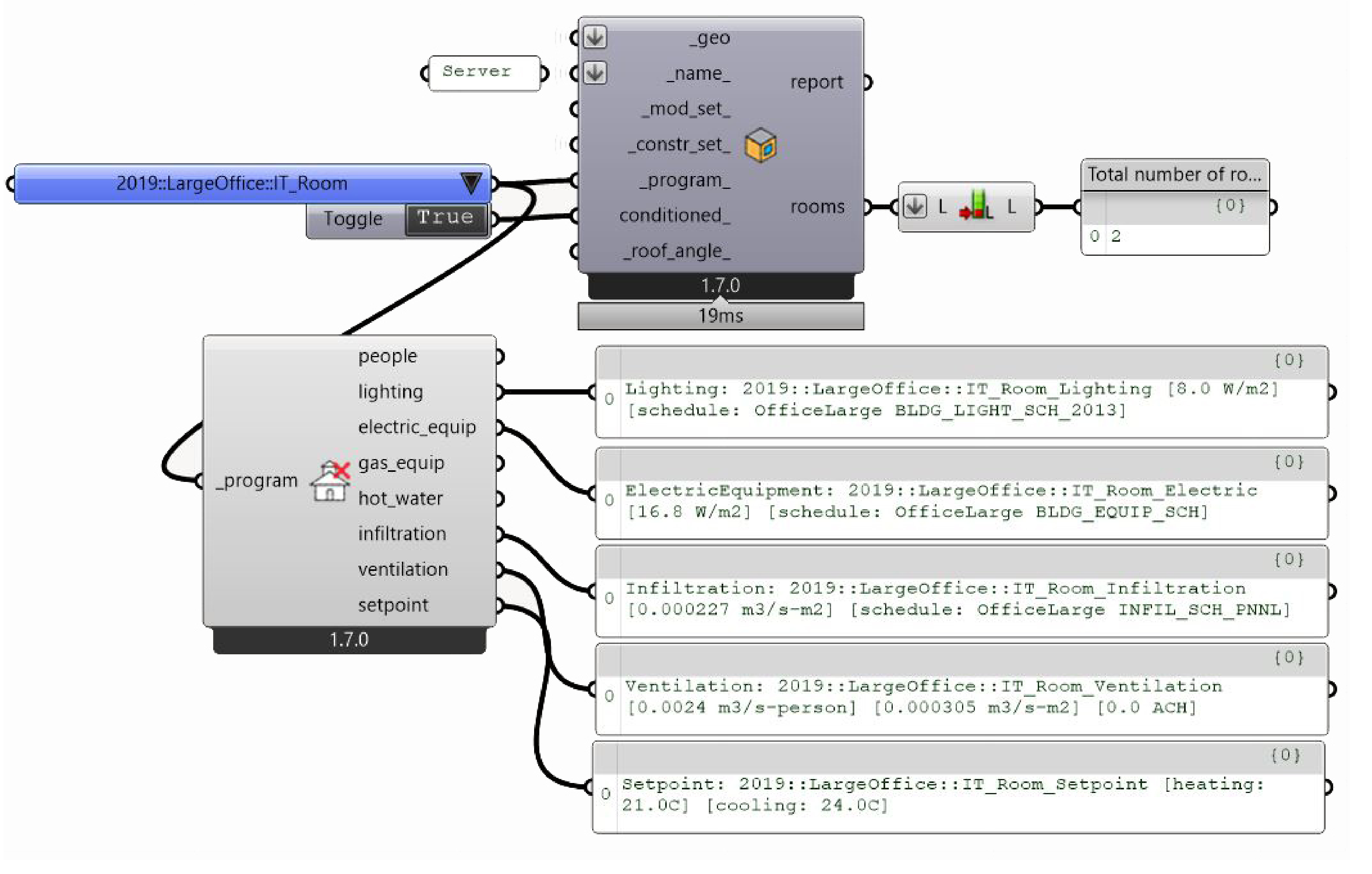


Energy model

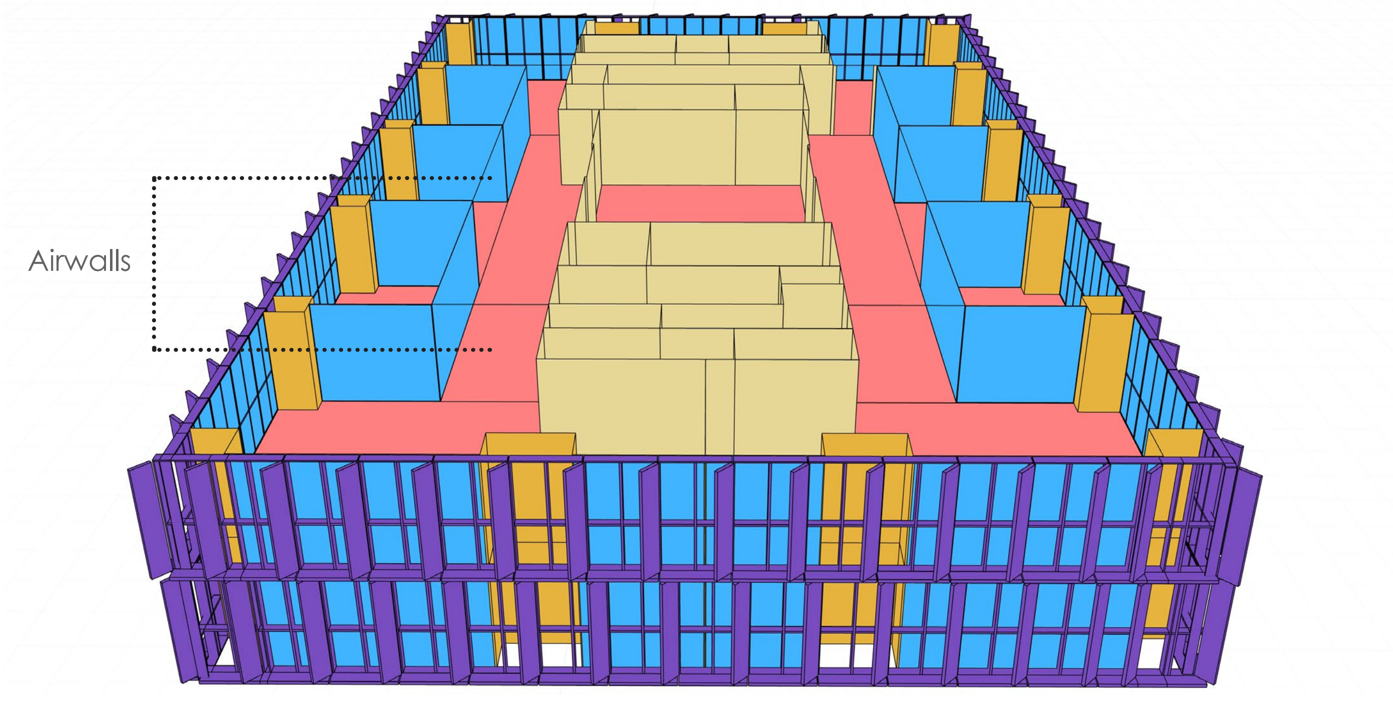
Energy model materiality

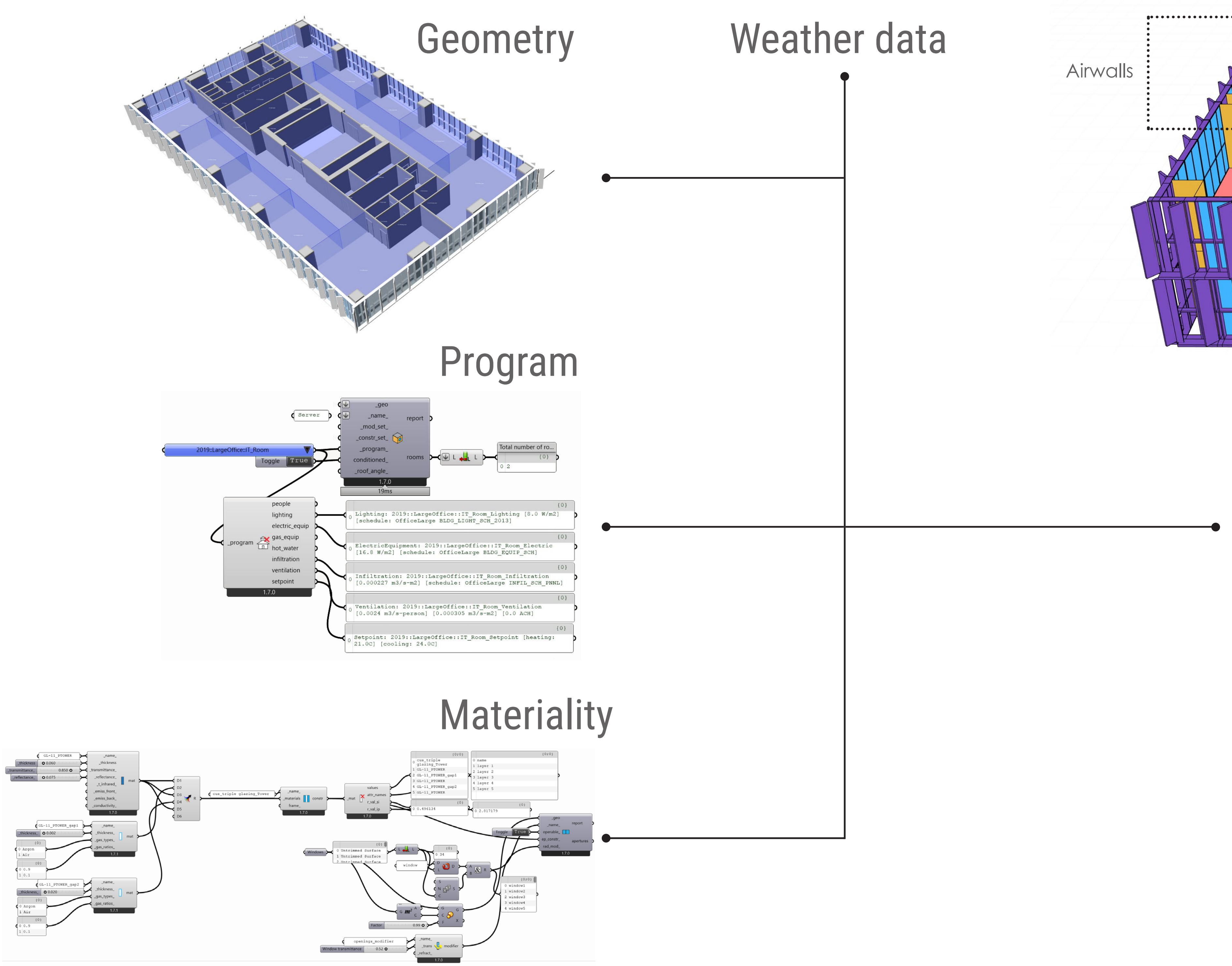


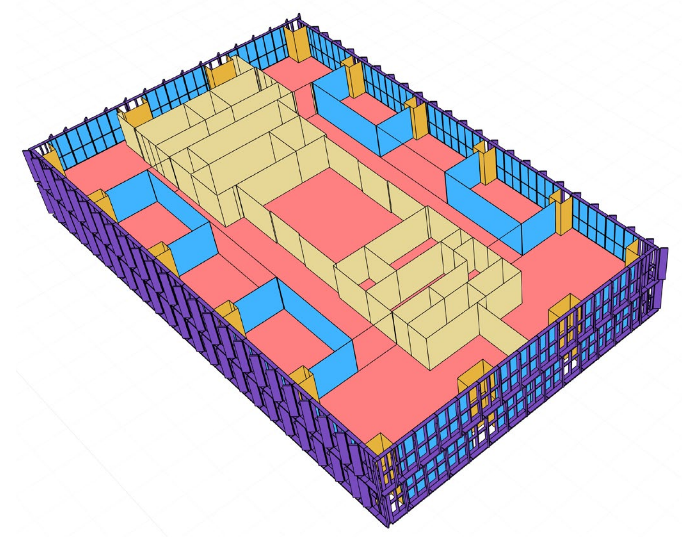
Energy model program



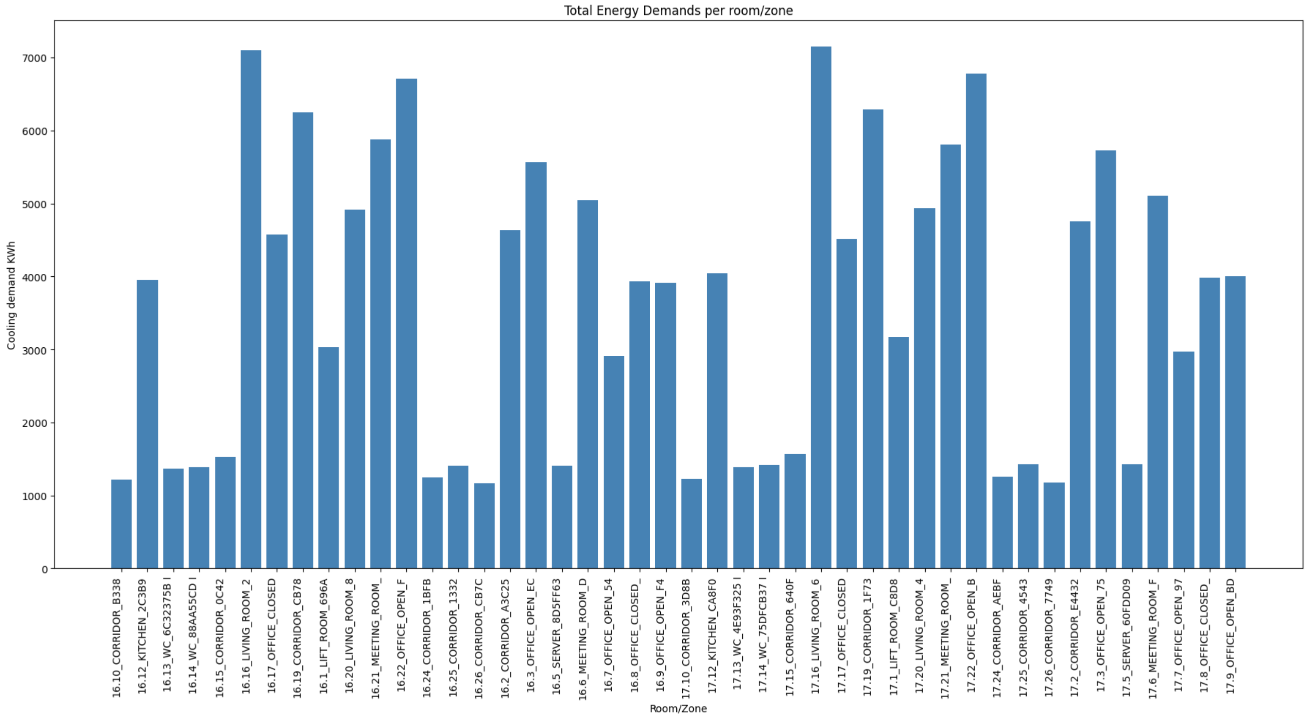
Energy model assembly

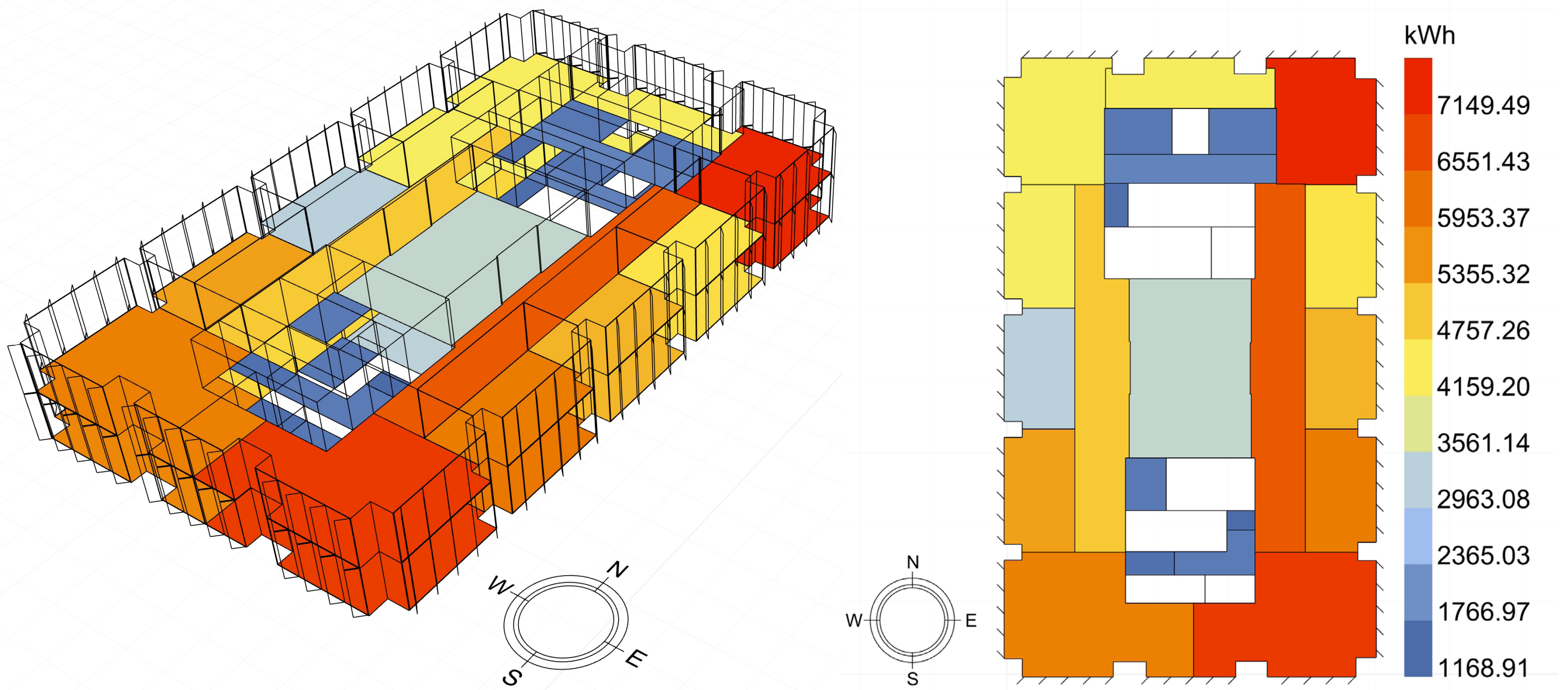


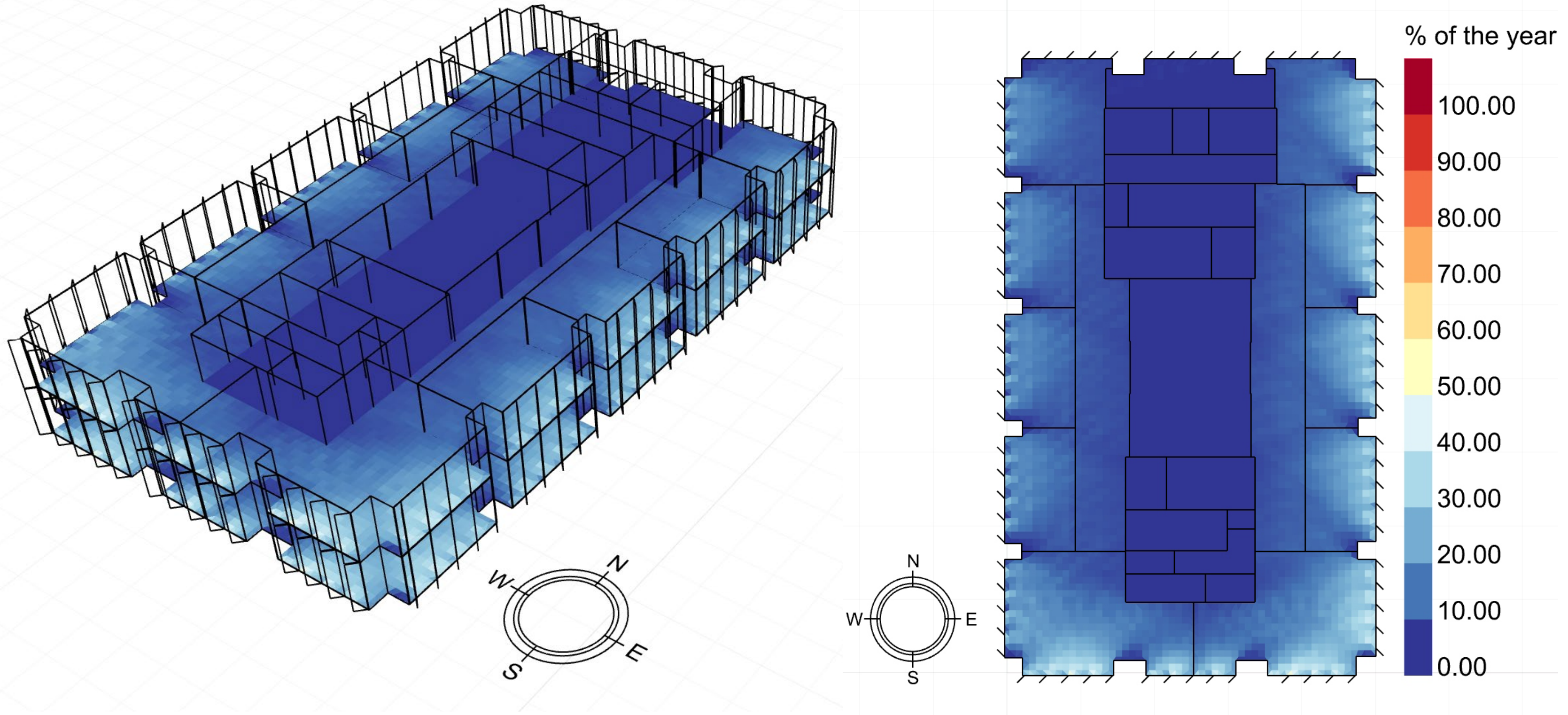




Simulation results - Annual analysis period





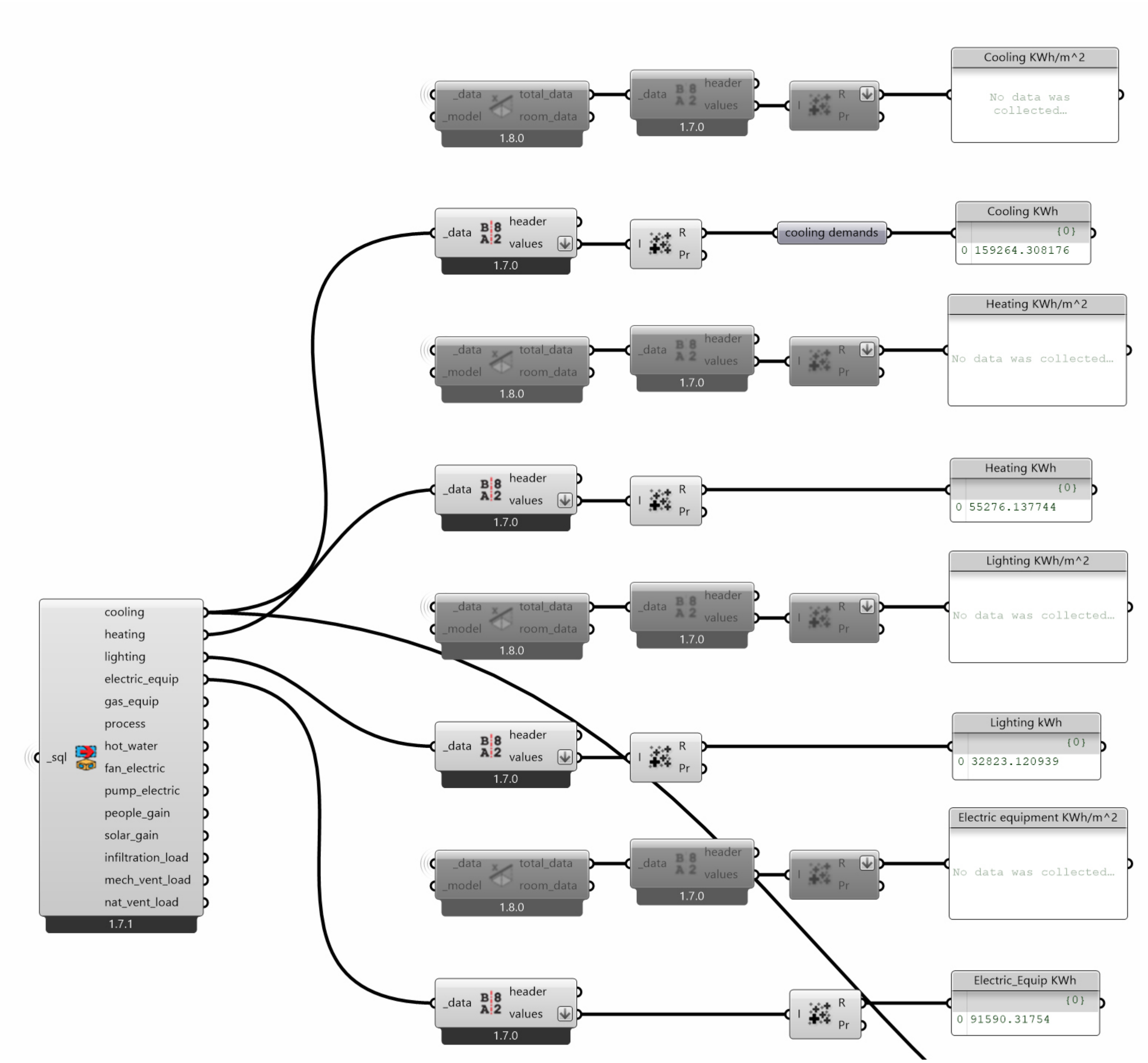


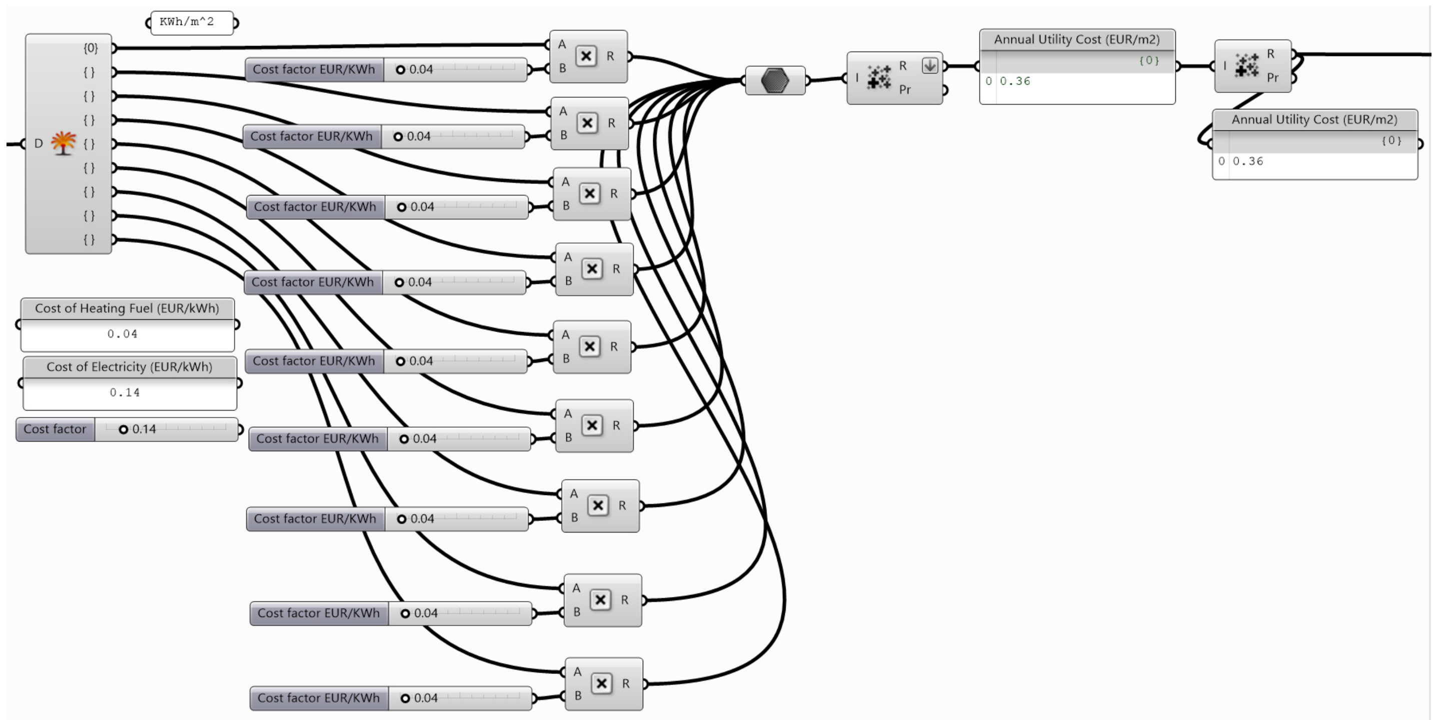
For the typical levels under investigation:

Total cooling demands: 159264 KWh/y

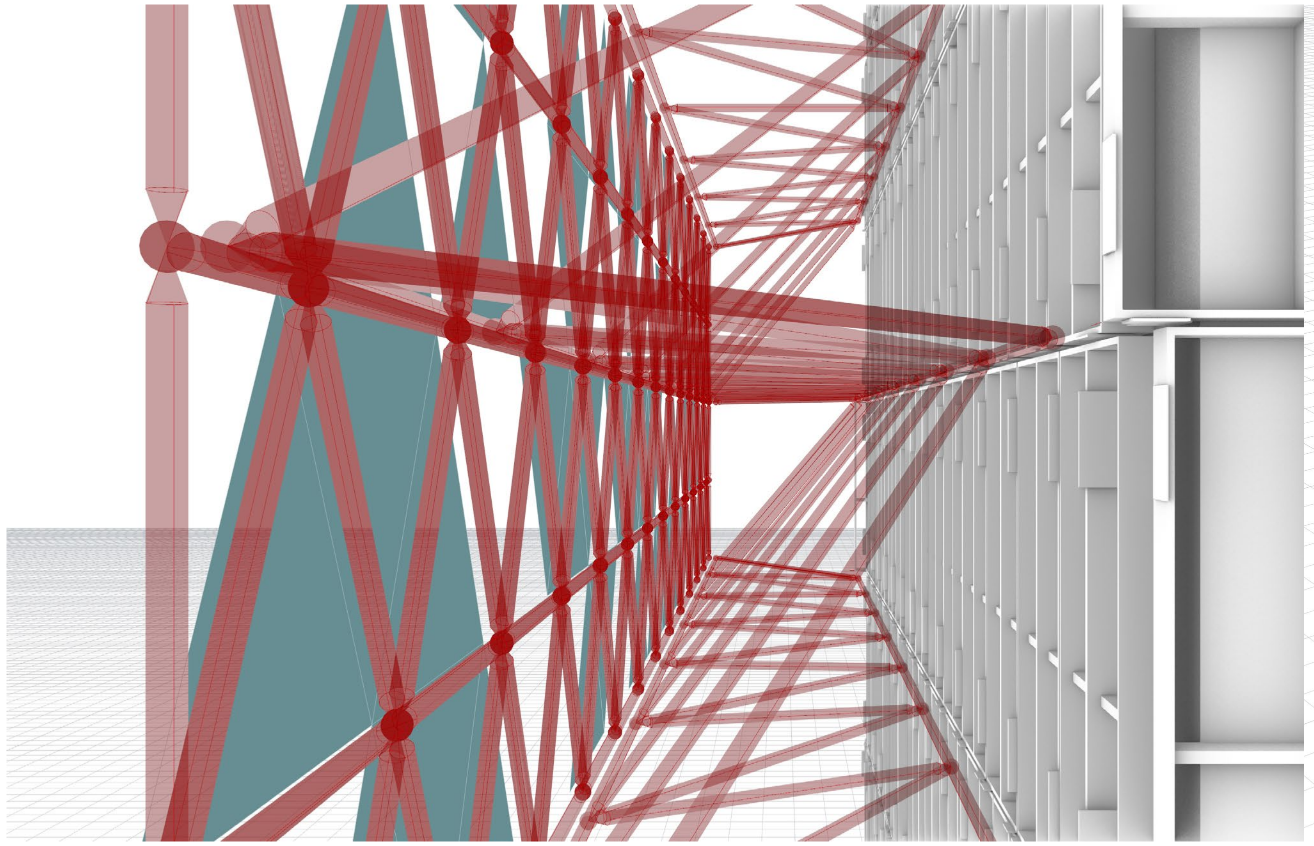
Average Daylight autonomy for all spaces: 4.1%/y

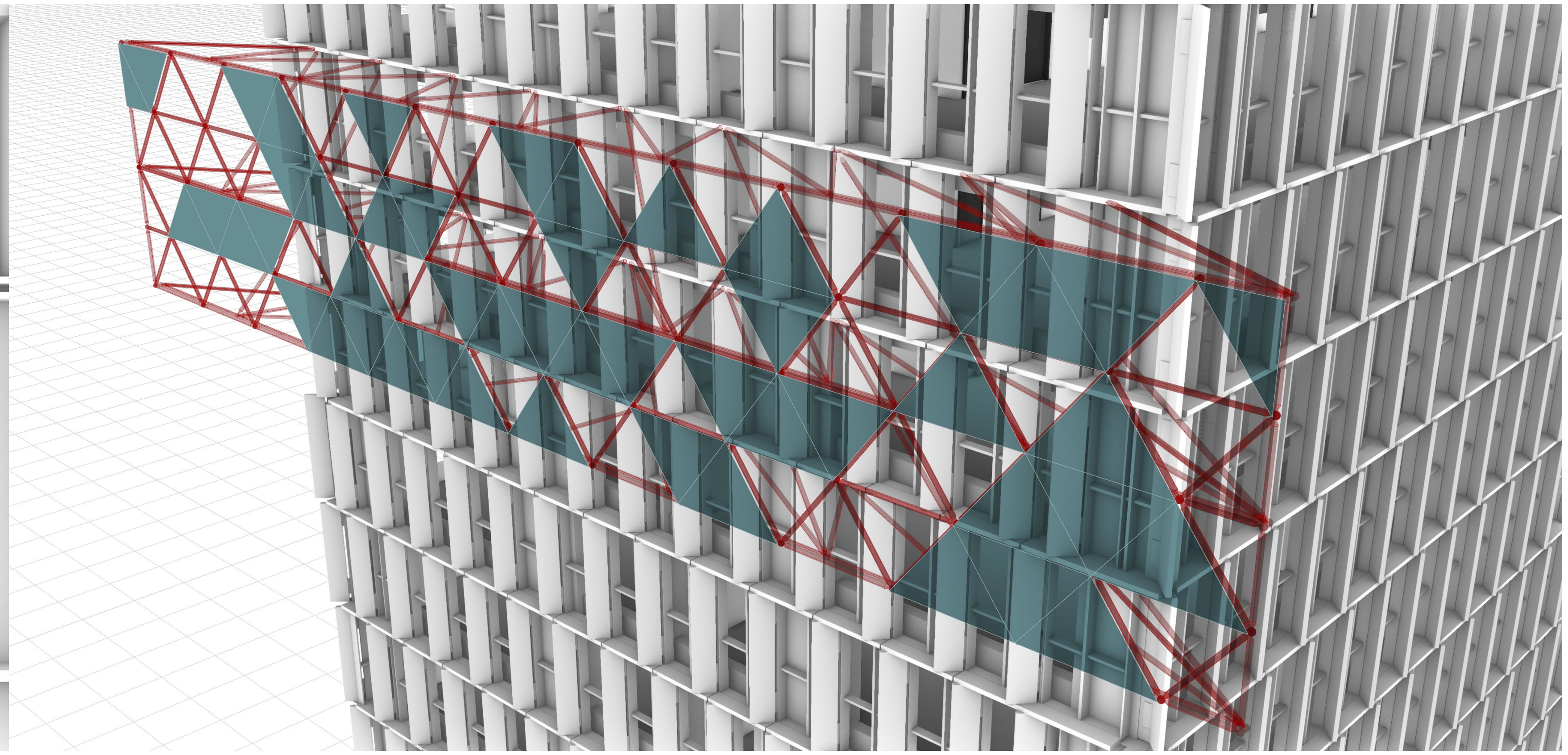
Simulation results - Annual Utility cost estimation



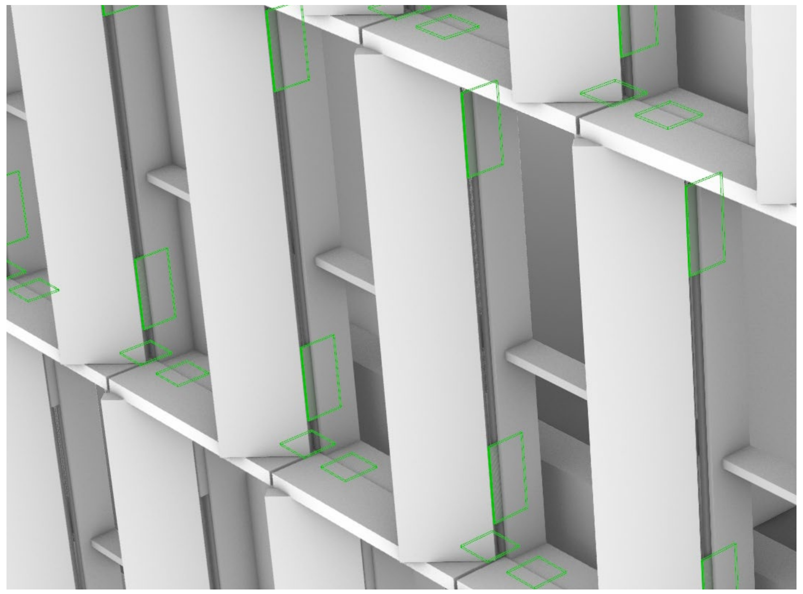


Shading system design





First attempt of connecting diagrid with vertical and horizontal brackets.



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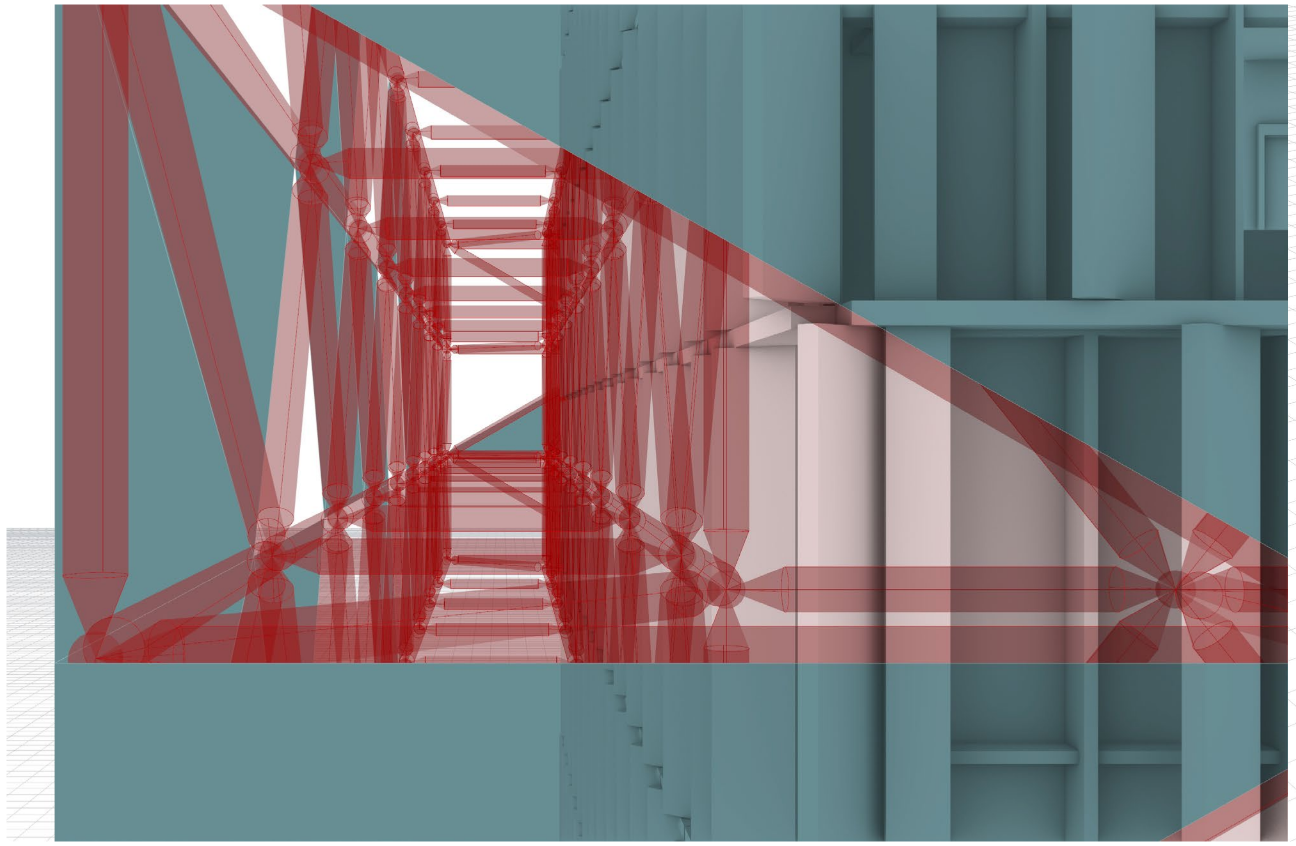
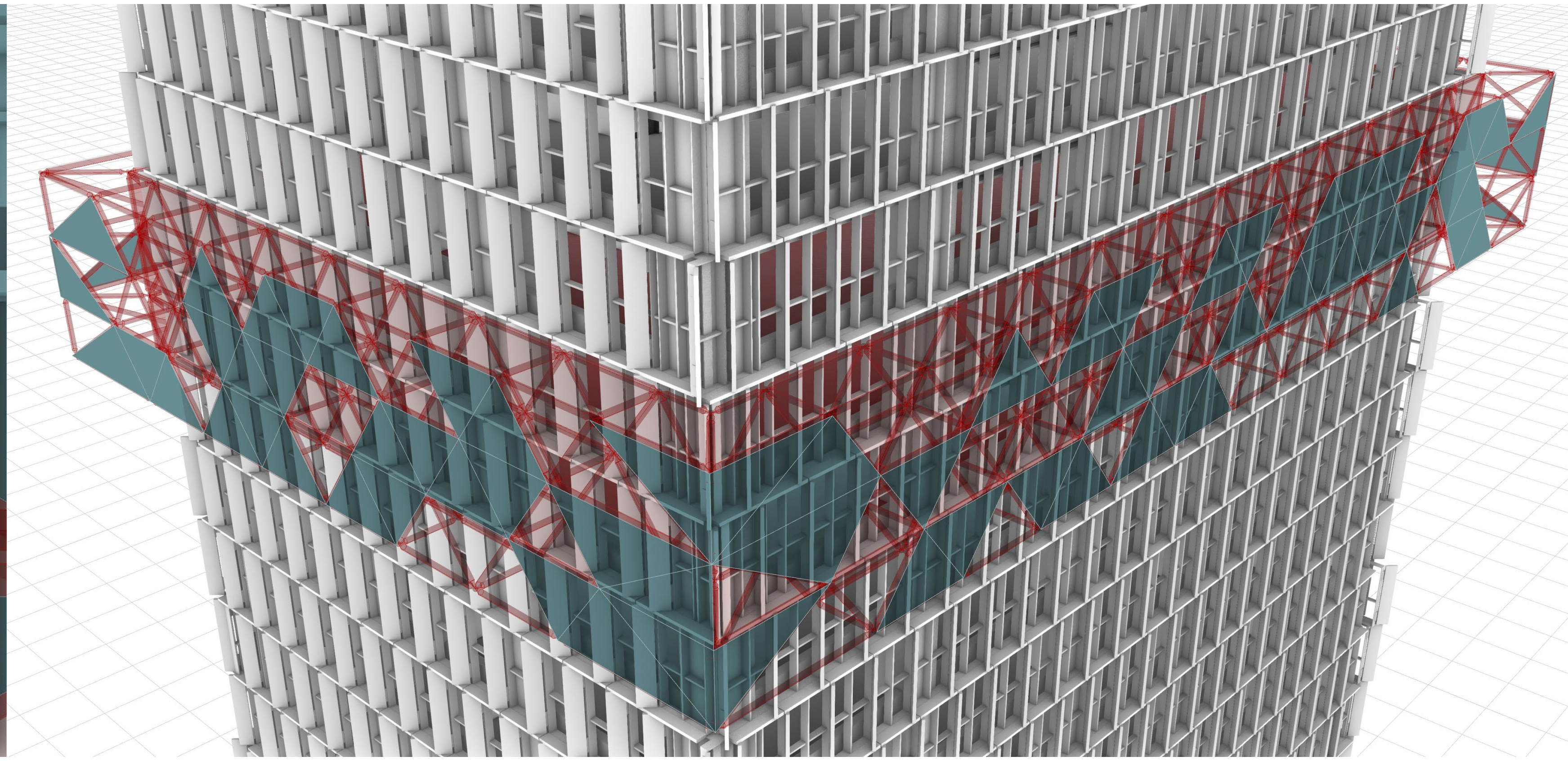
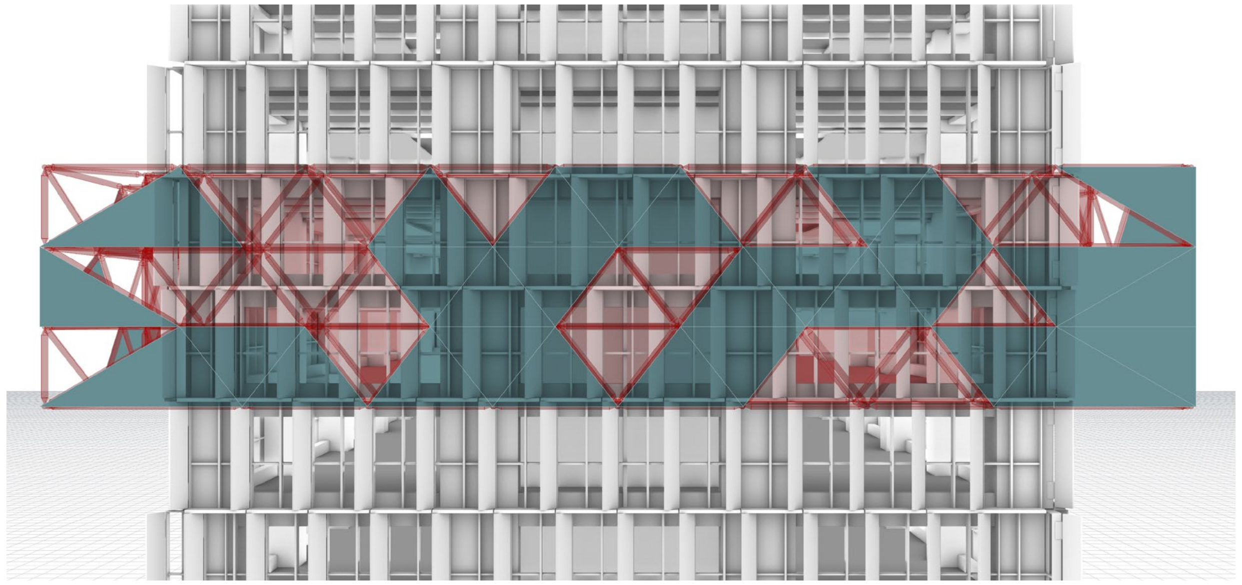
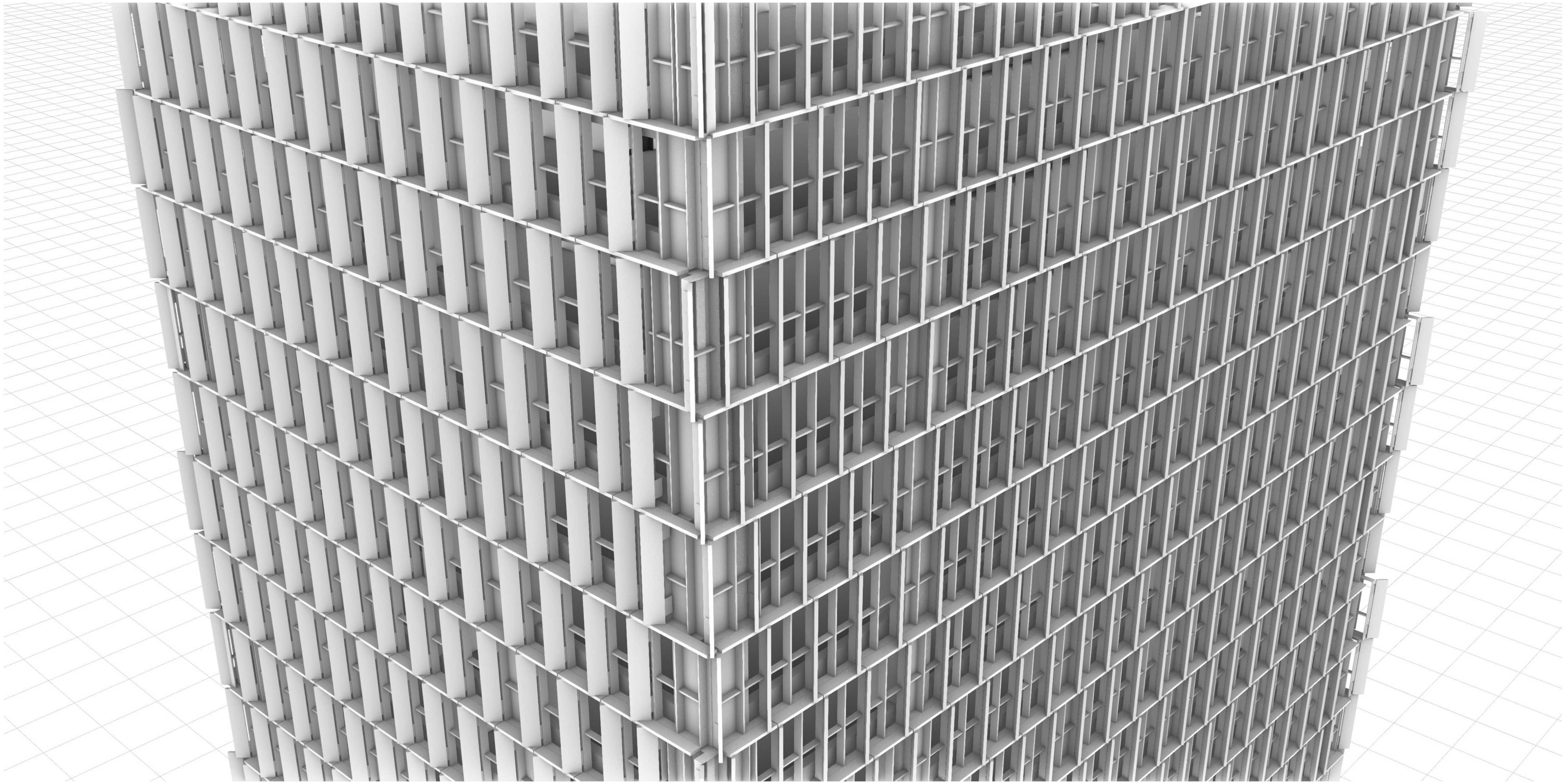




Another approach making the shading system completely independent from the building.



Shading system proposed design



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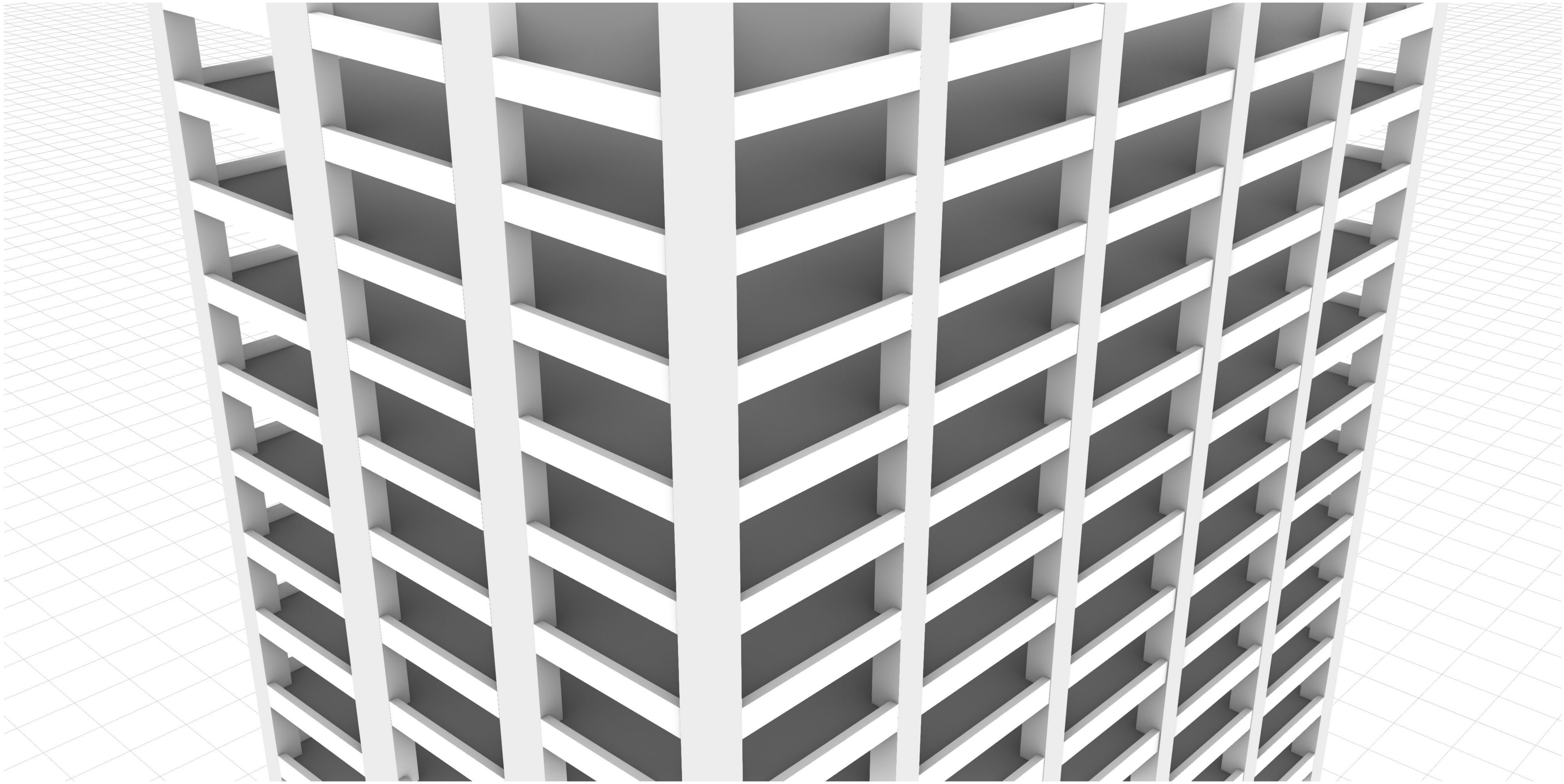

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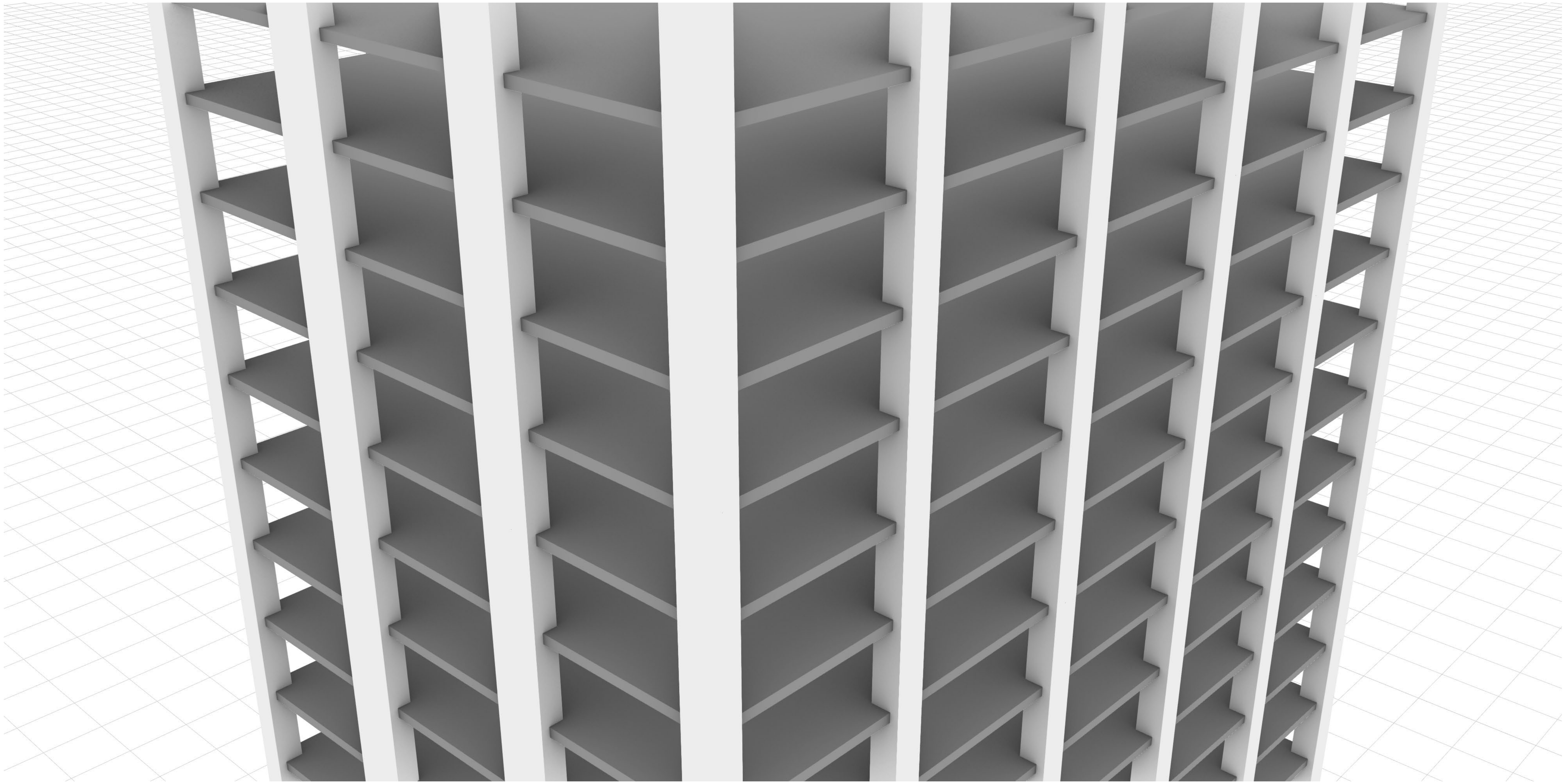

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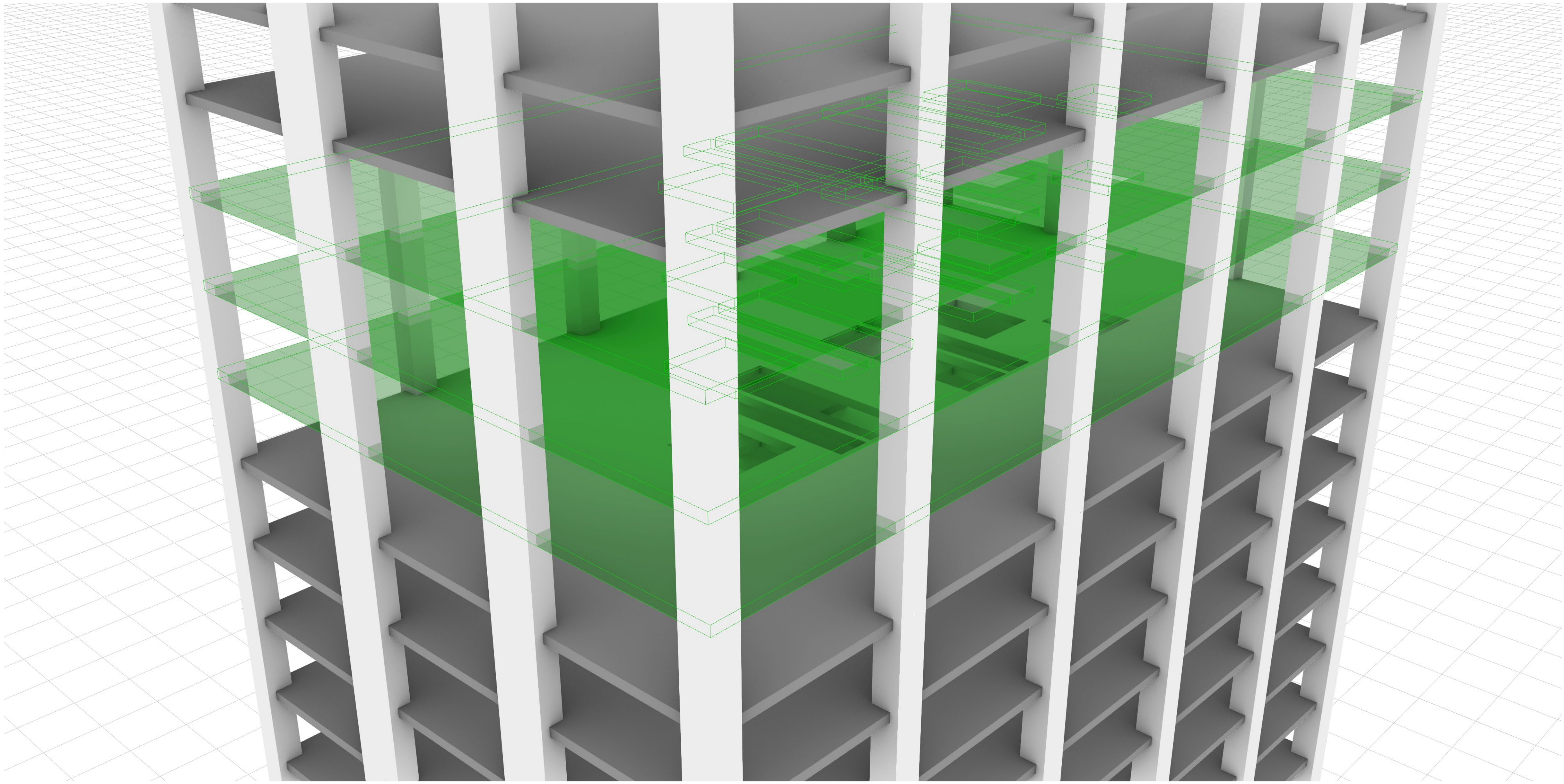

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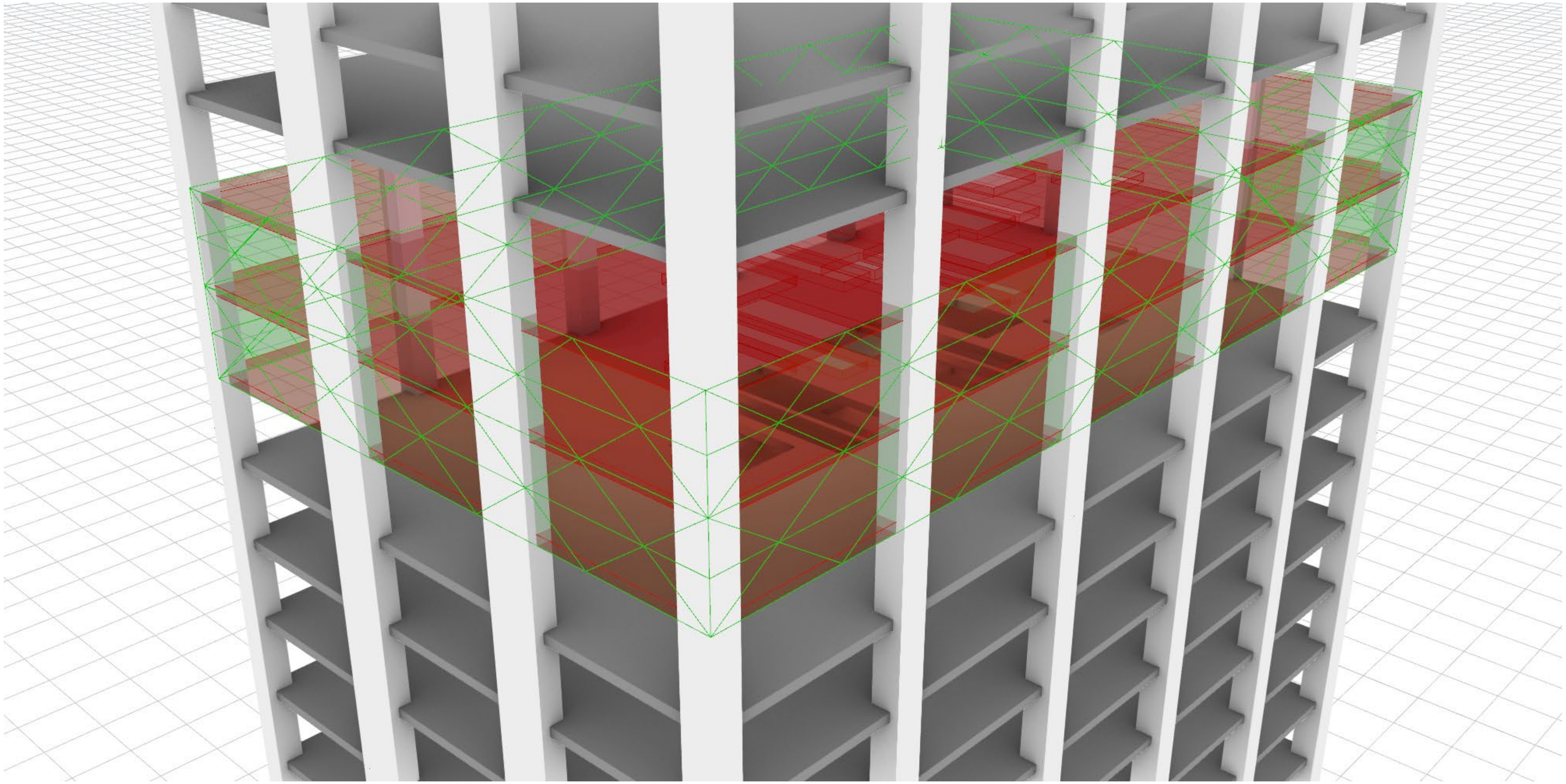

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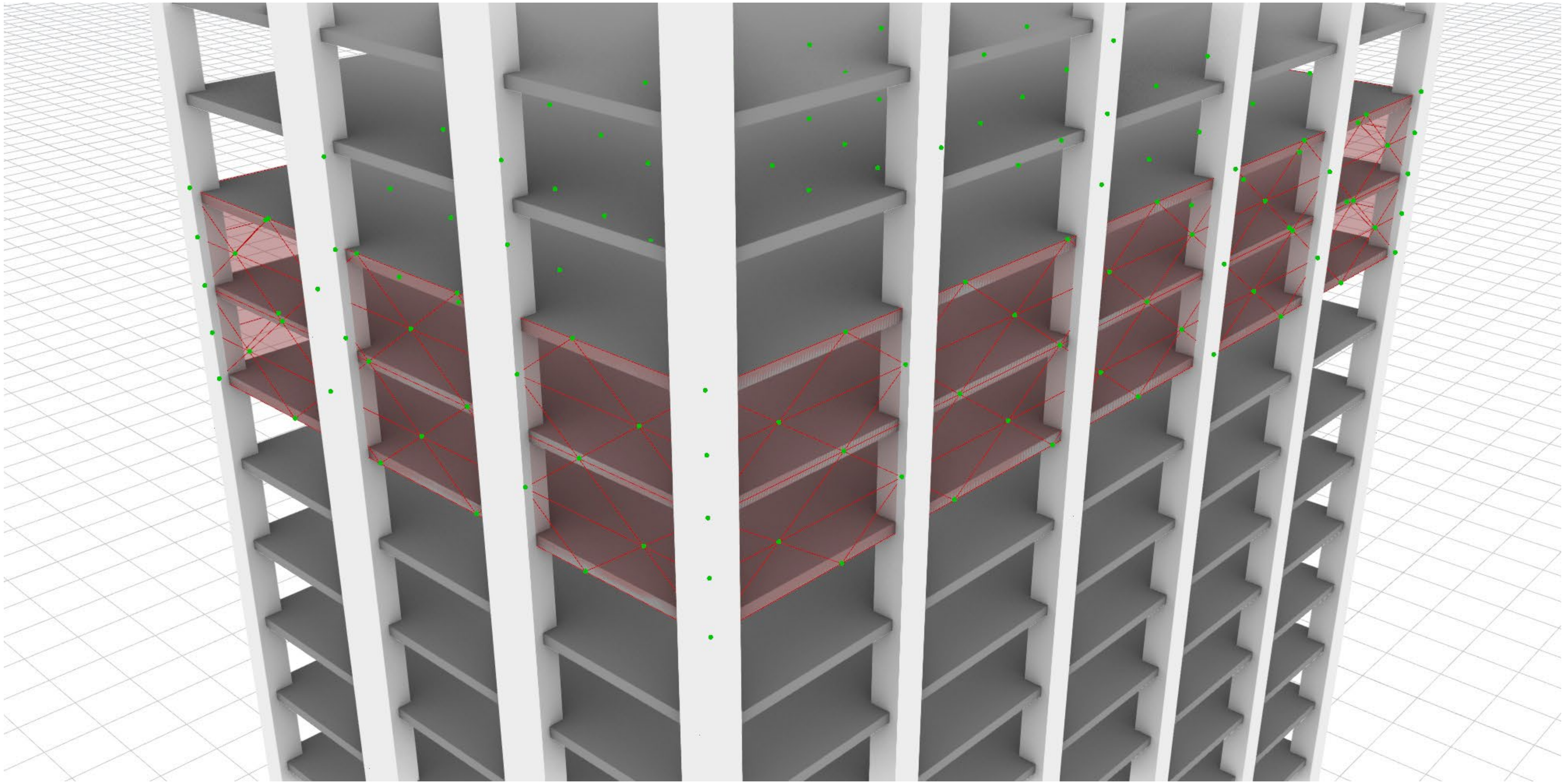

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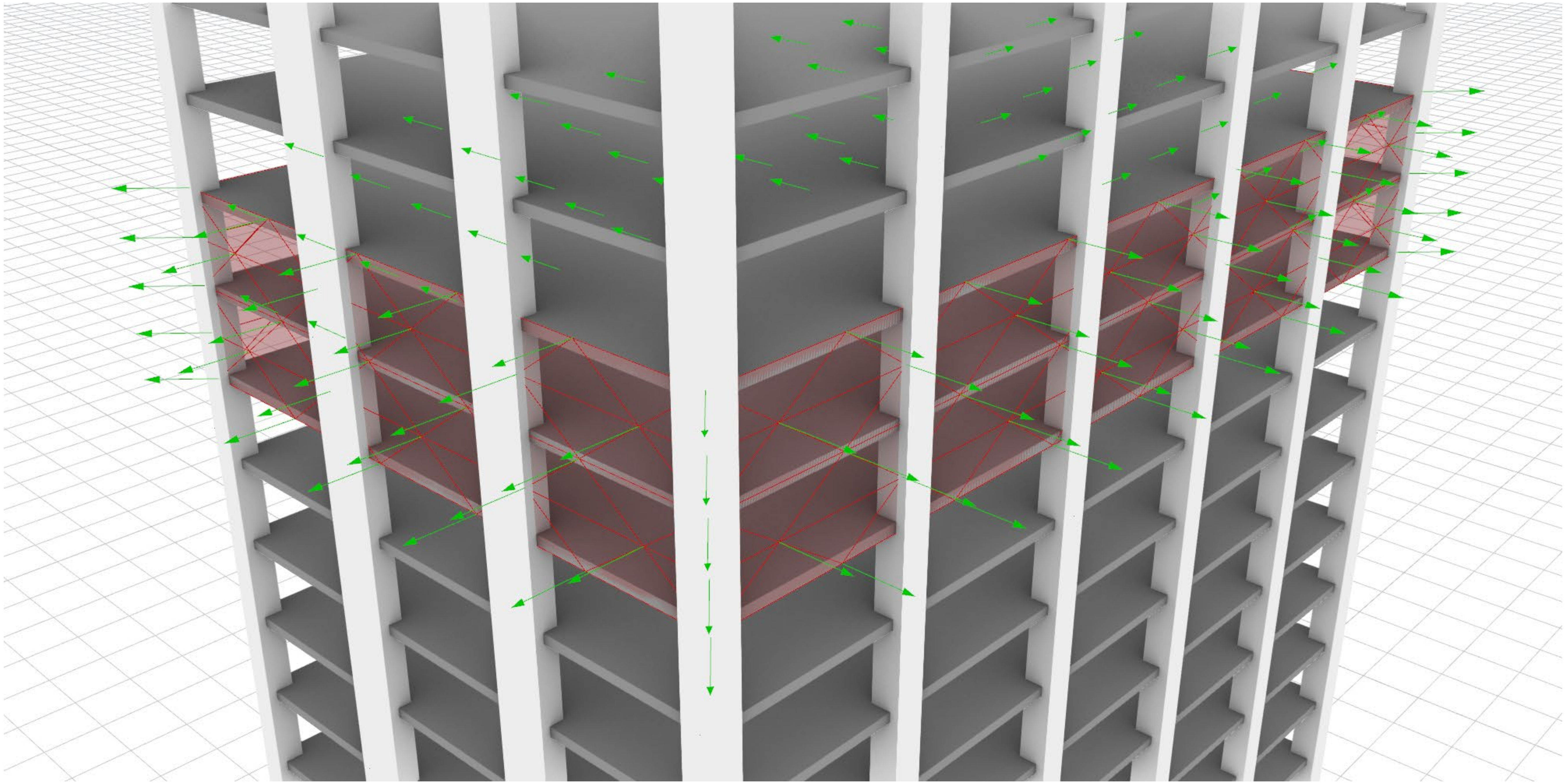
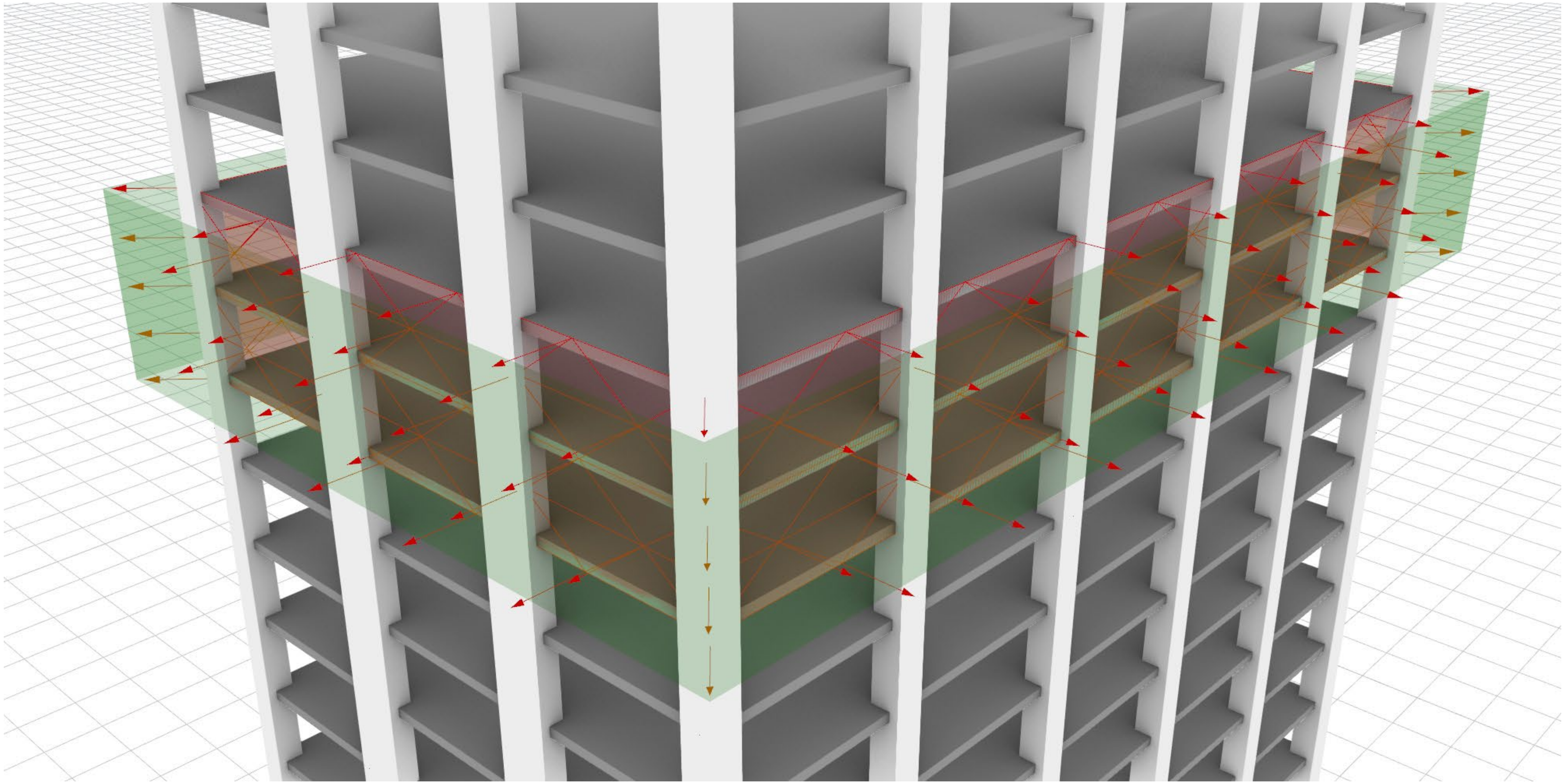
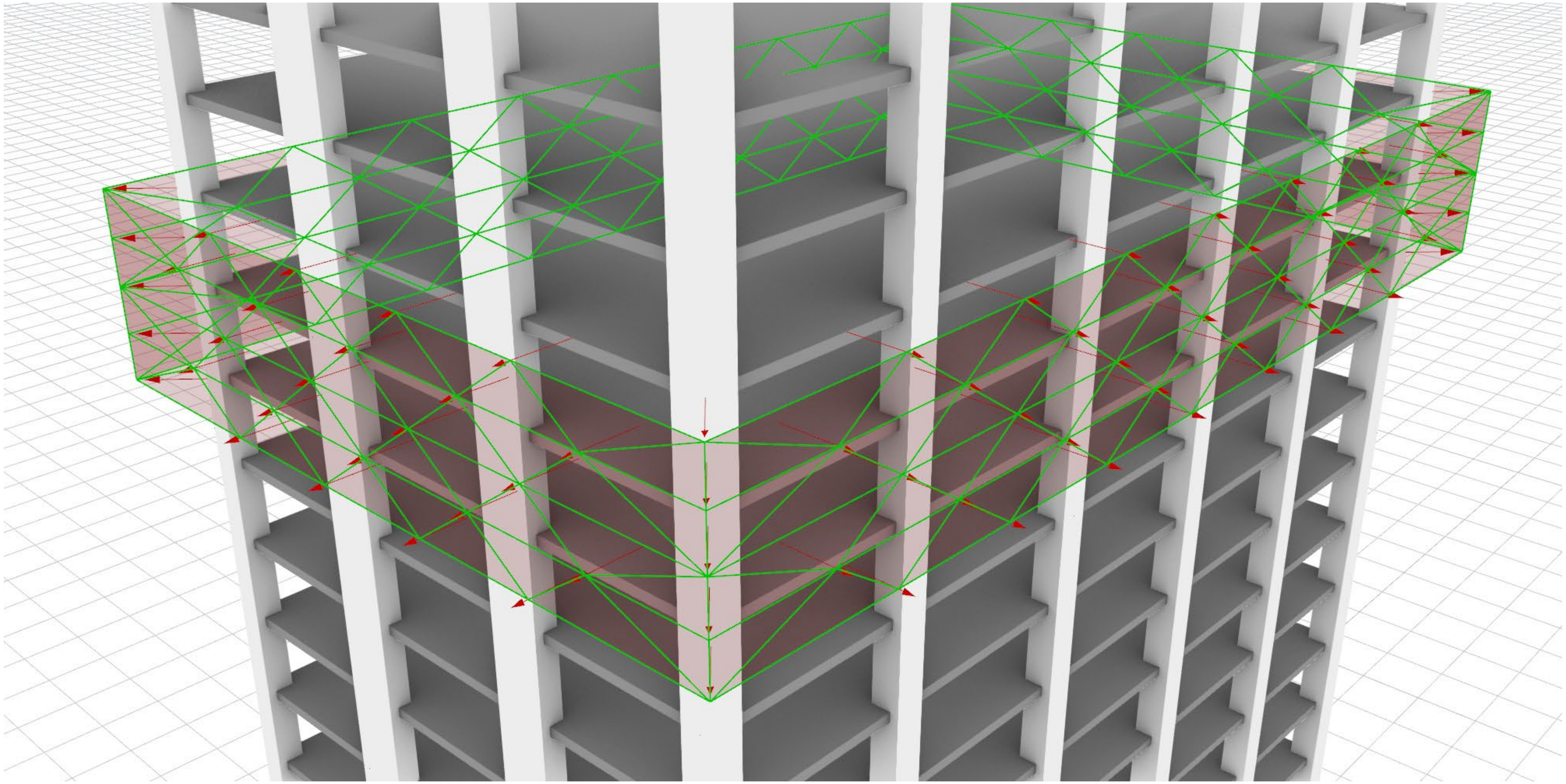


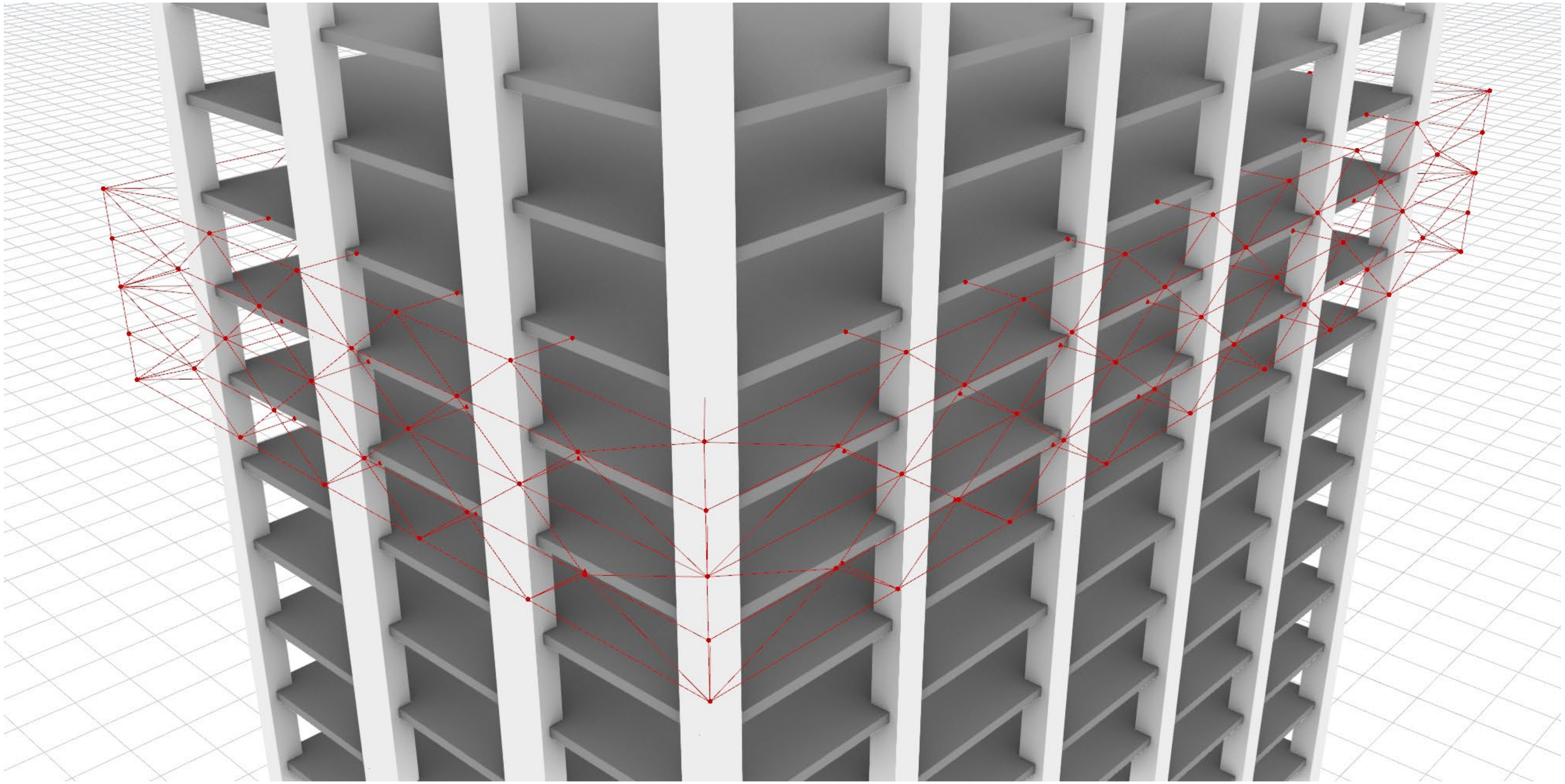
Shading system proposed design



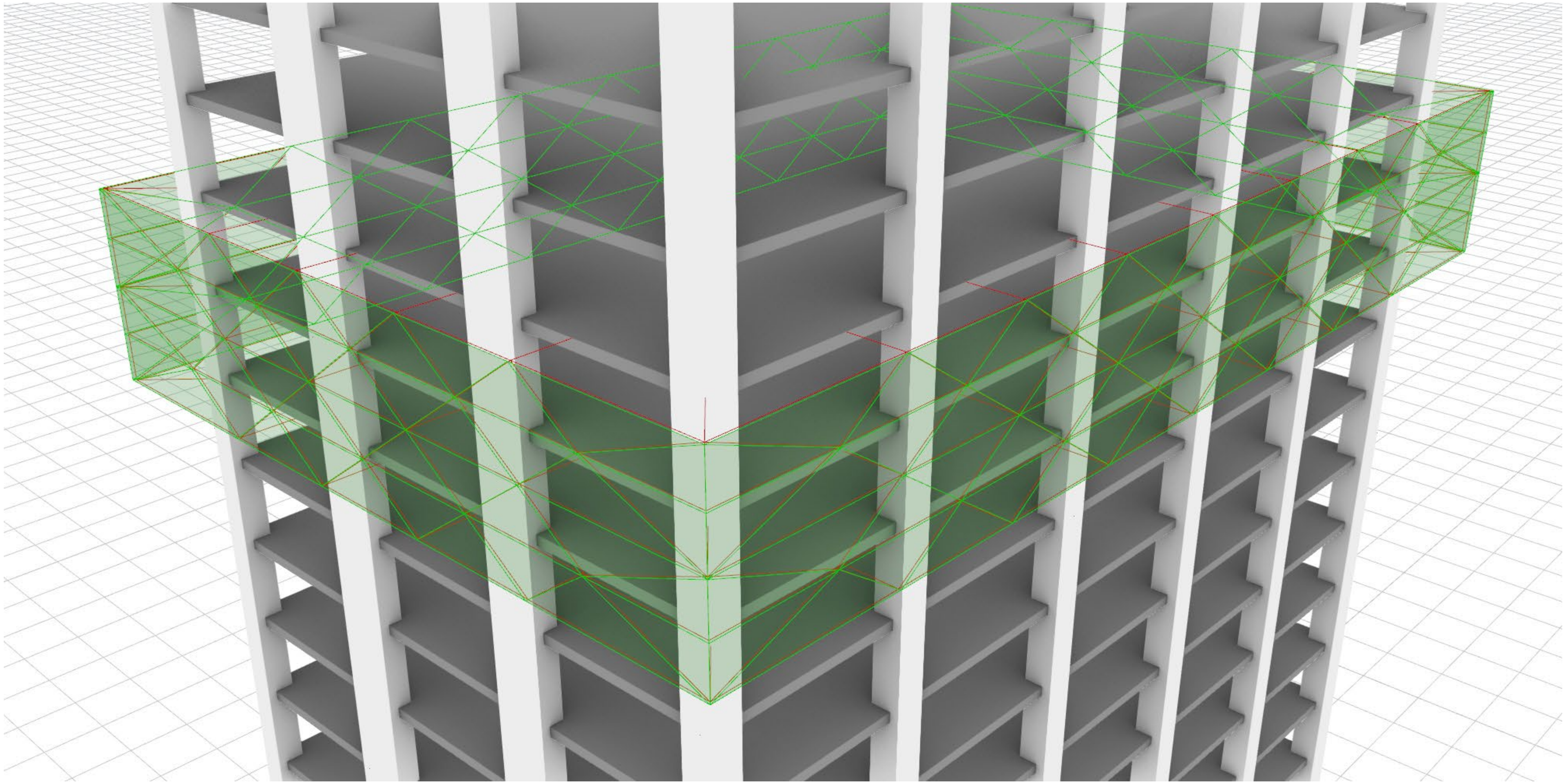
Shading system proposed design



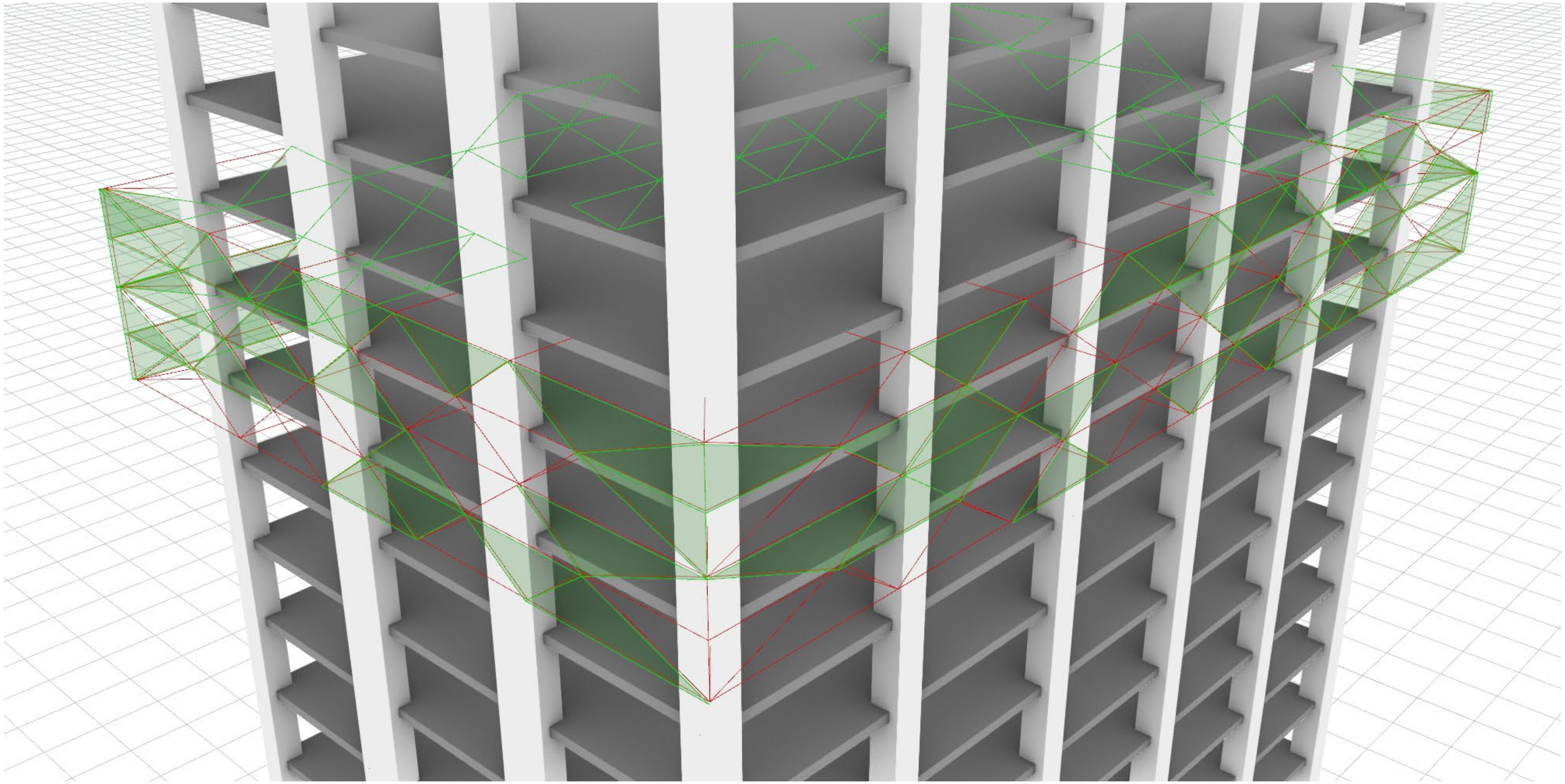
Shading system proposed design



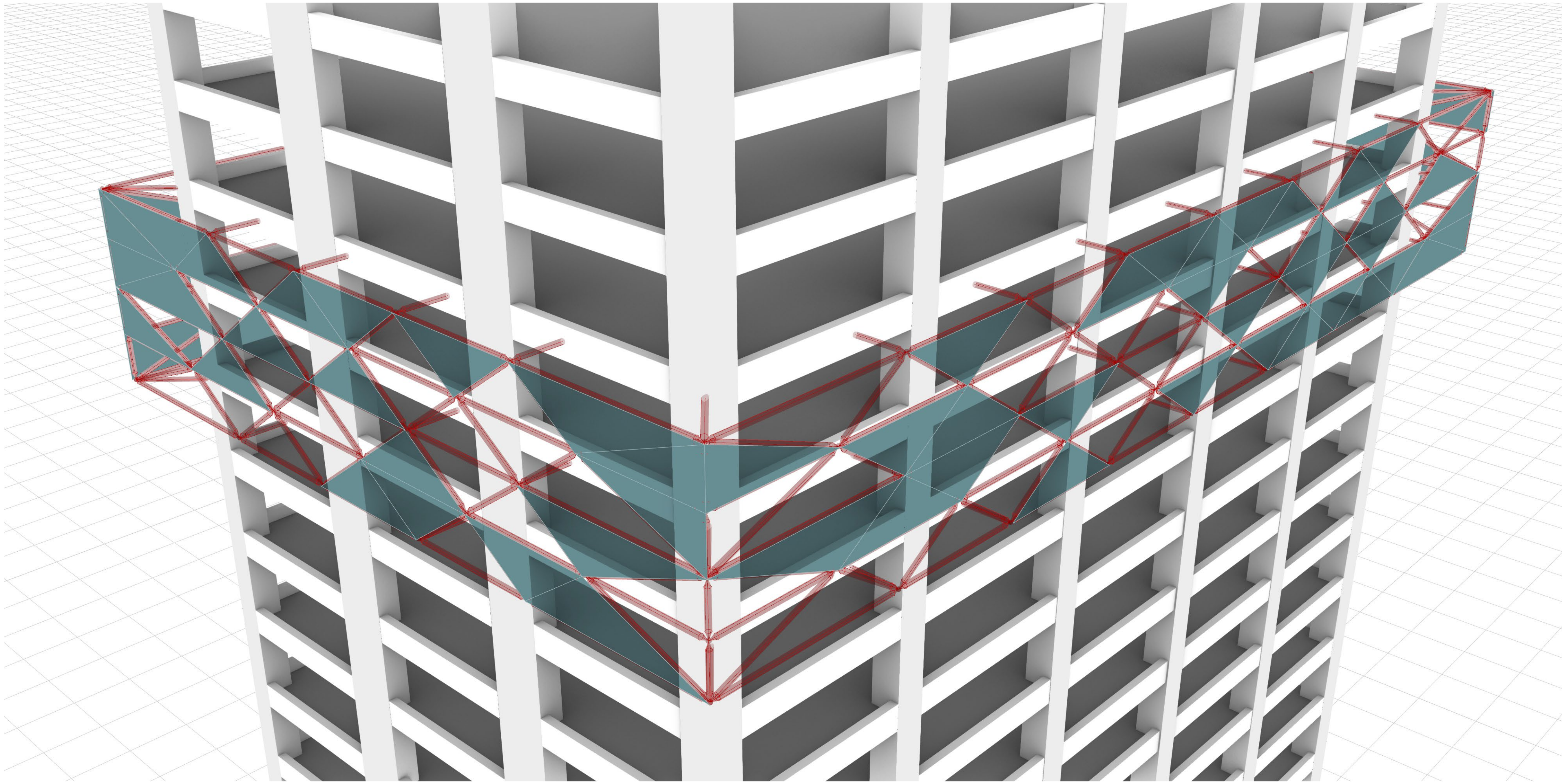
Shading system proposed design



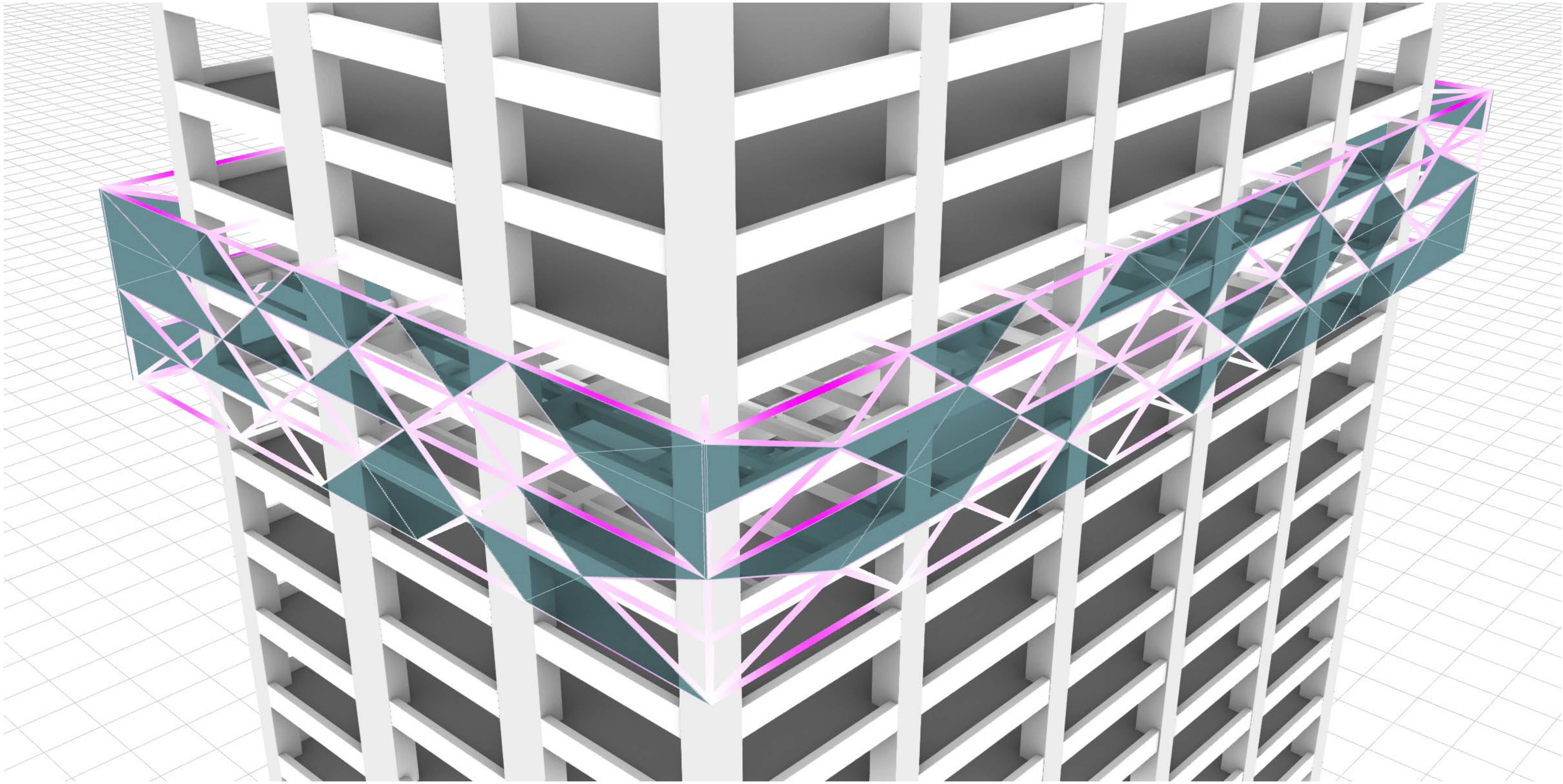
Shading system proposed design



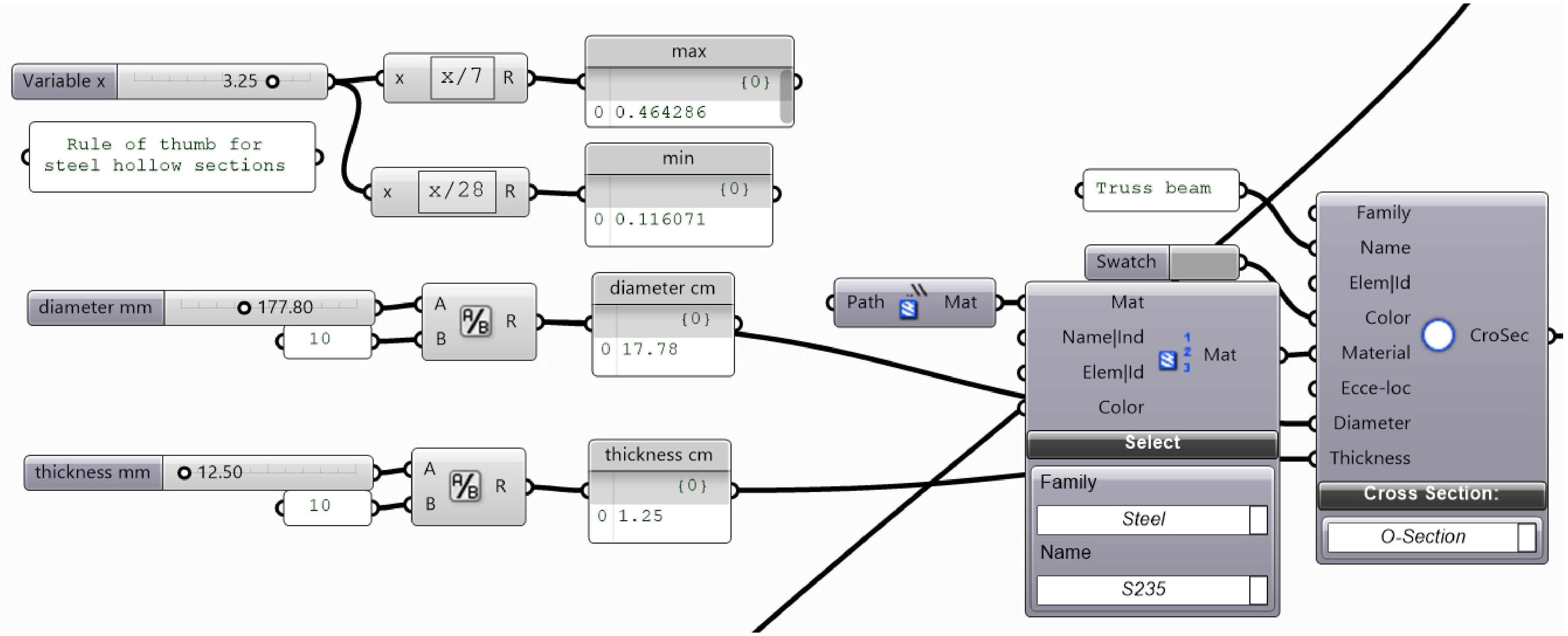
Shading system proposed design



Static analysis loads



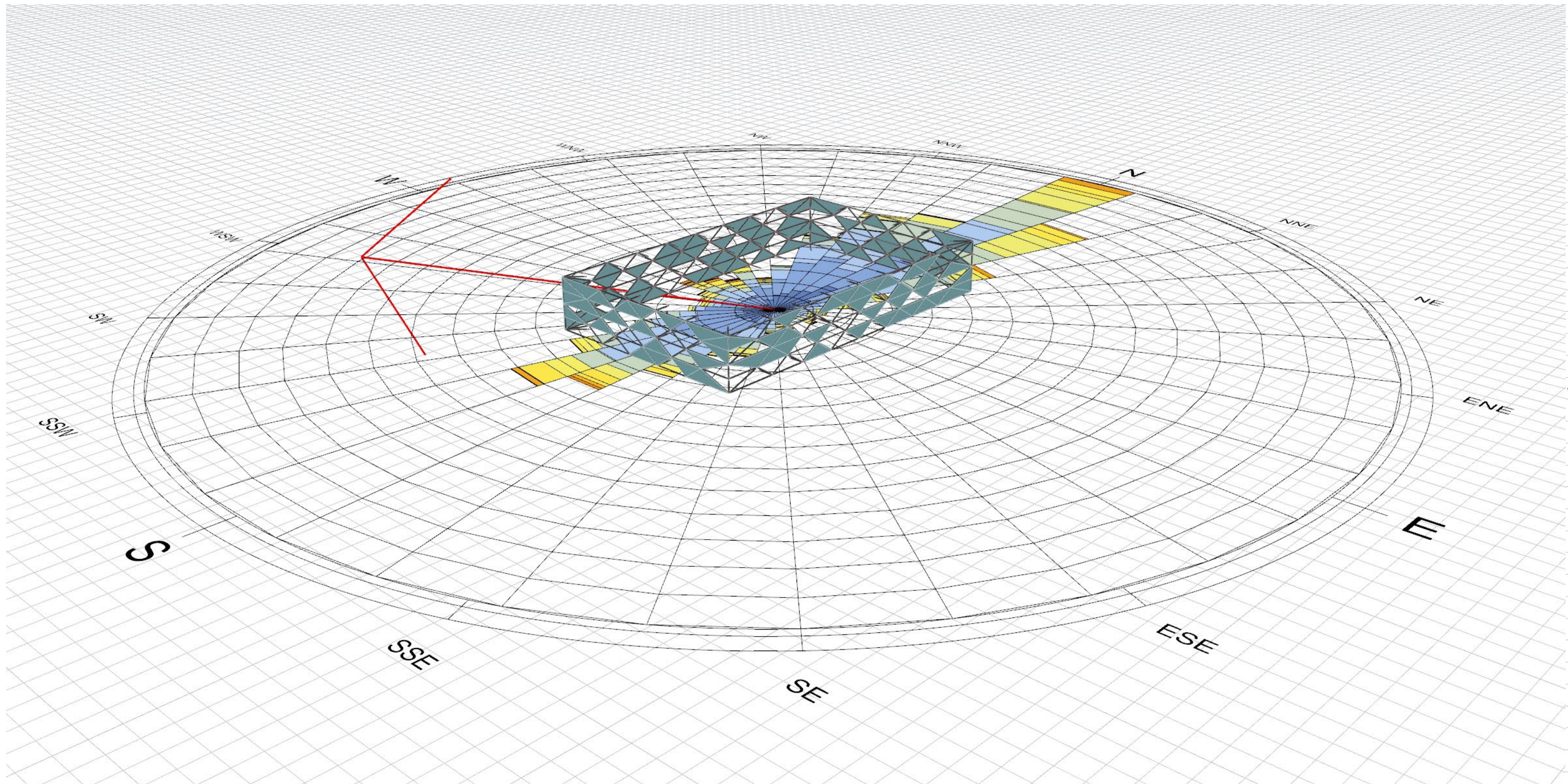
Static analysis cross section

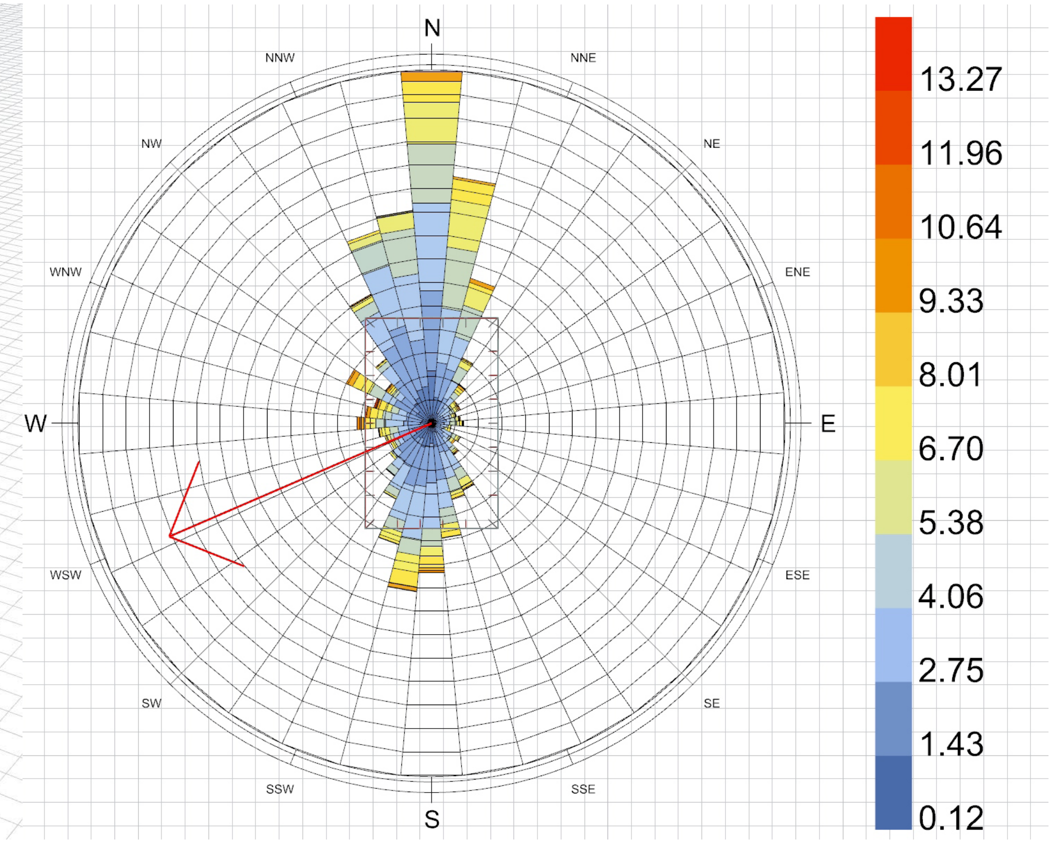


For a multi story building with a given height x and 2m<x<4m we have:

$\min = \frac{x}{28} \quad \max = \frac{x}{7}$ for the diameter for the steel hollow section

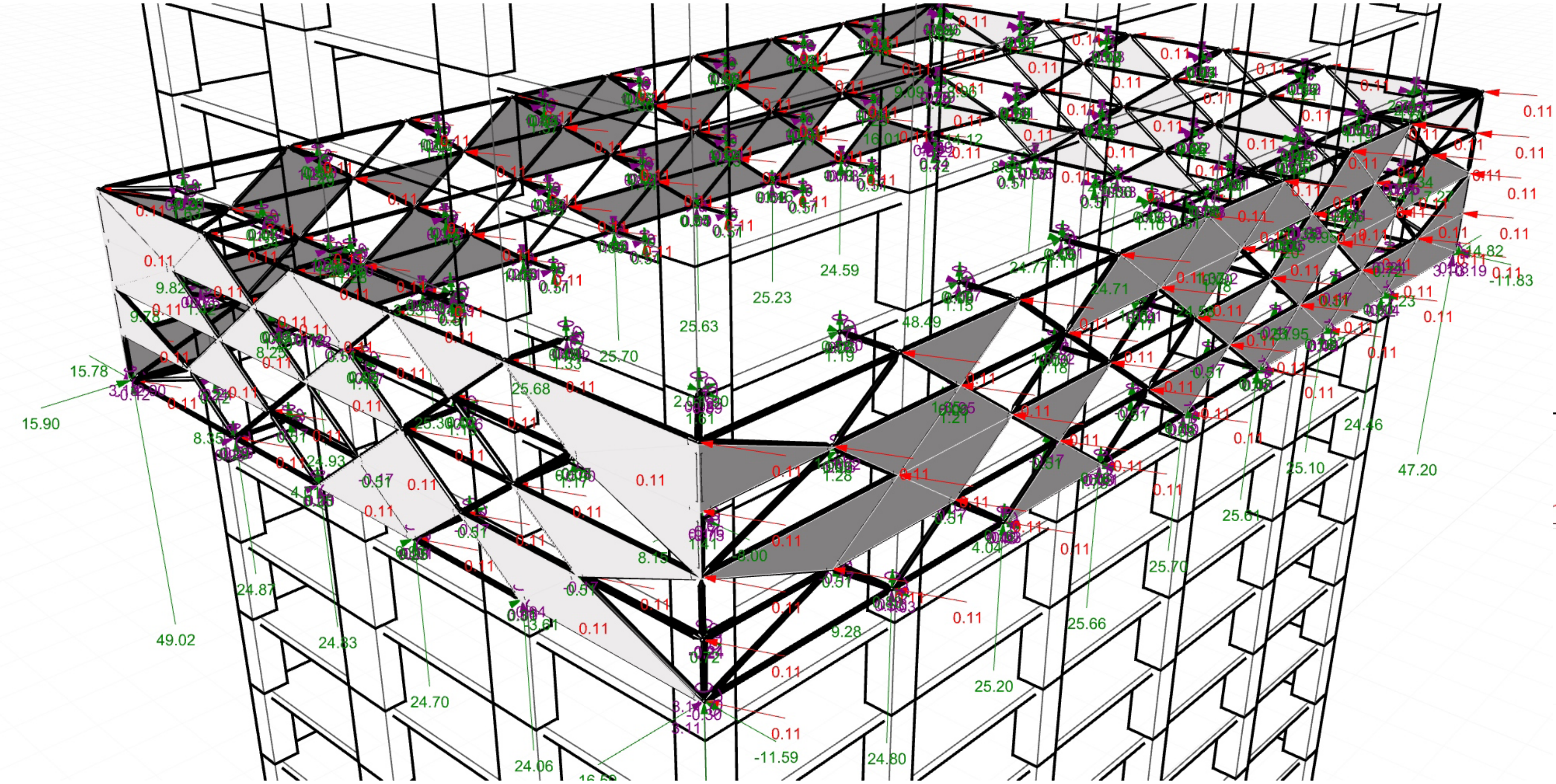
Static analysis loads

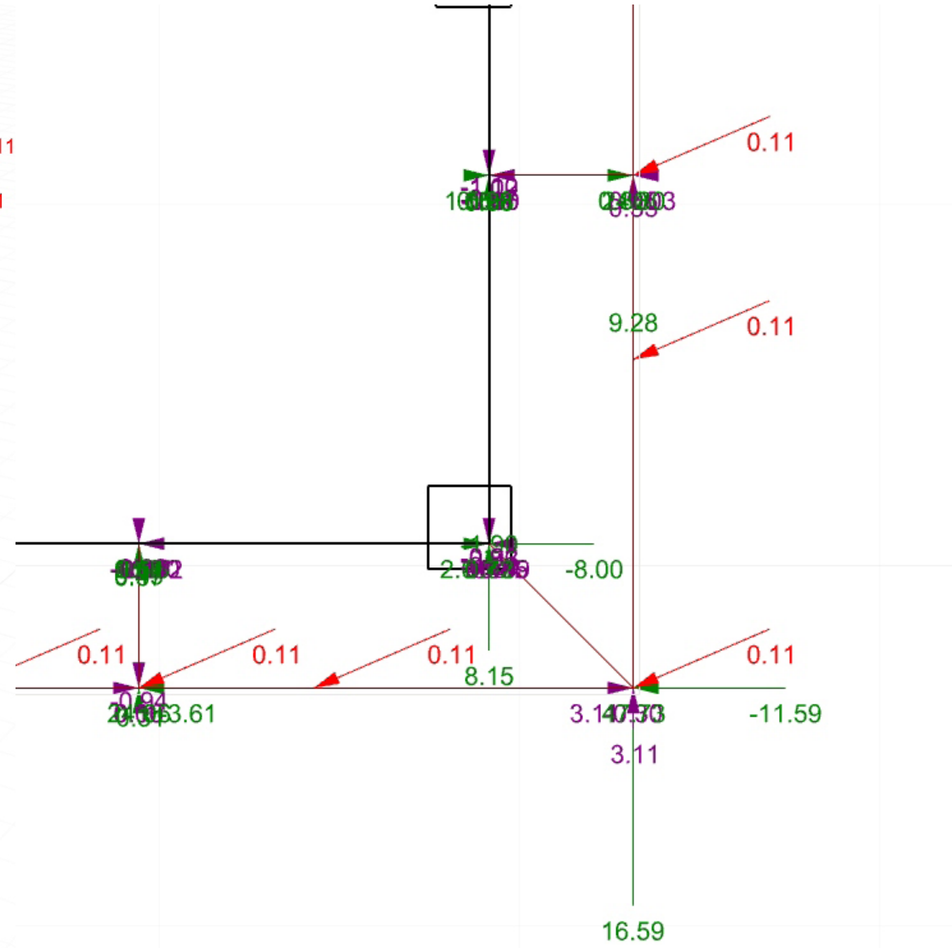




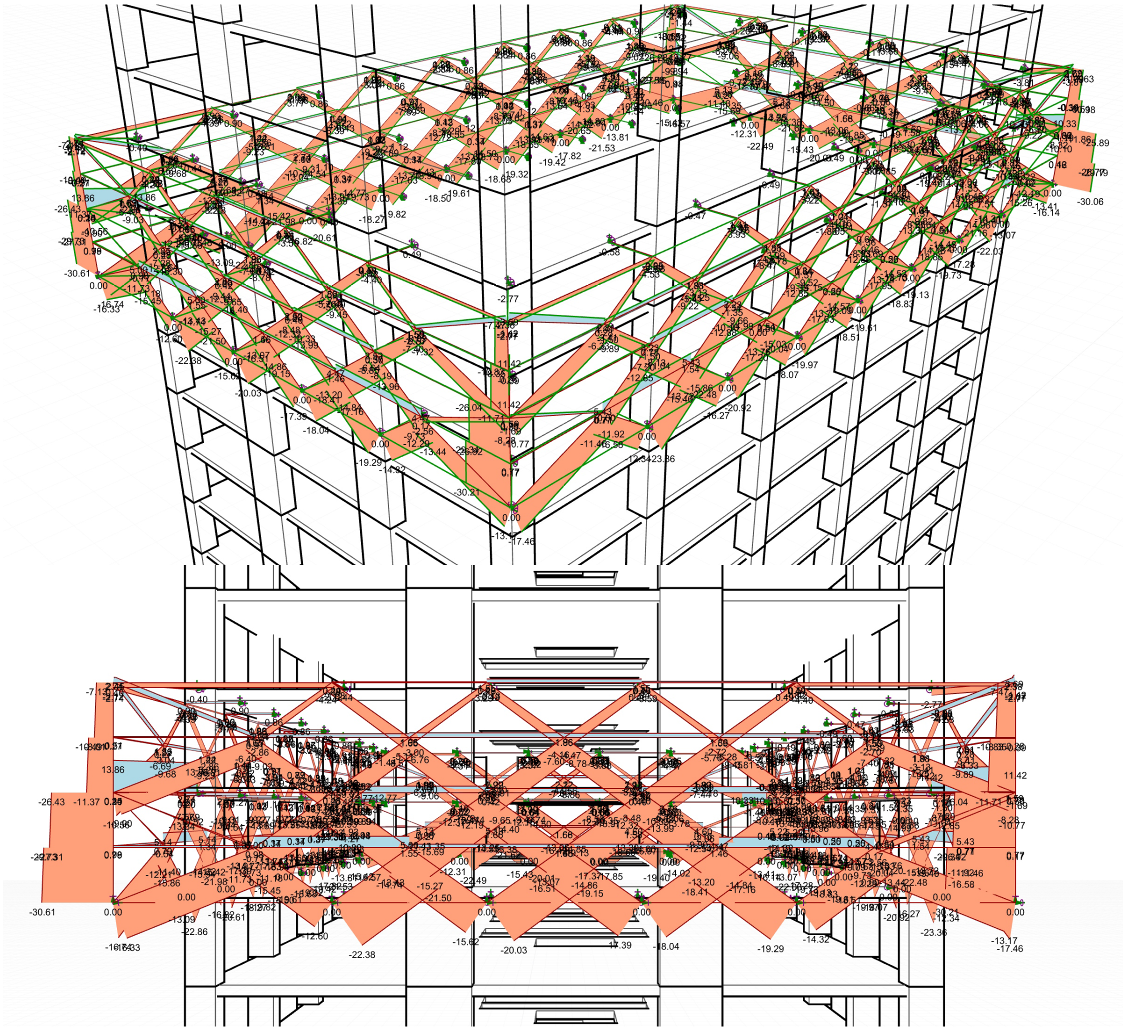
$$P_{wind} = \frac{V^2}{16 \cdot 10}$$ where: V is the air speed measured in m/s and P_{wind} is the air pressure measured in Pa or N/m^2.

Static analysis

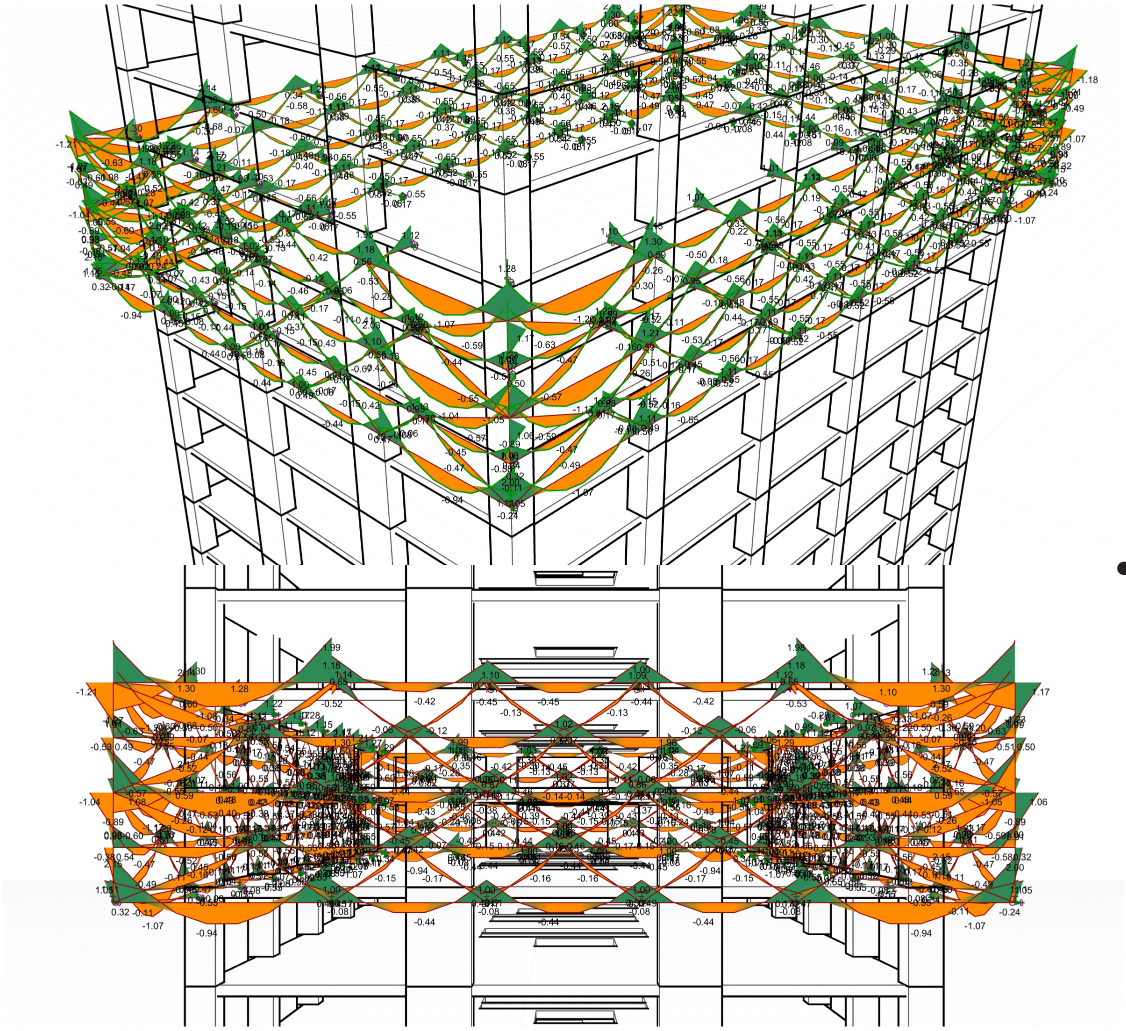




Static analysis results



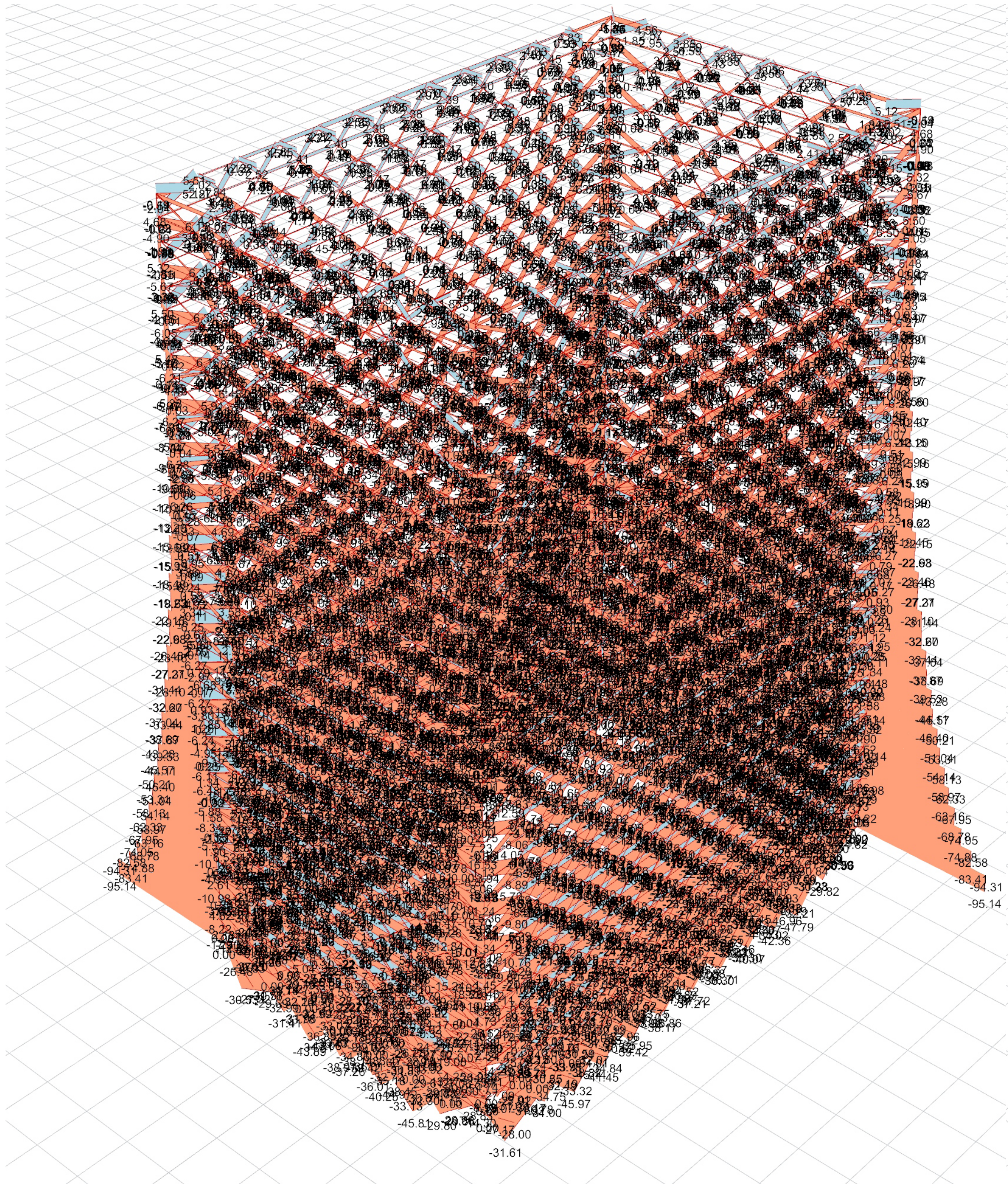
Axial forces calculation



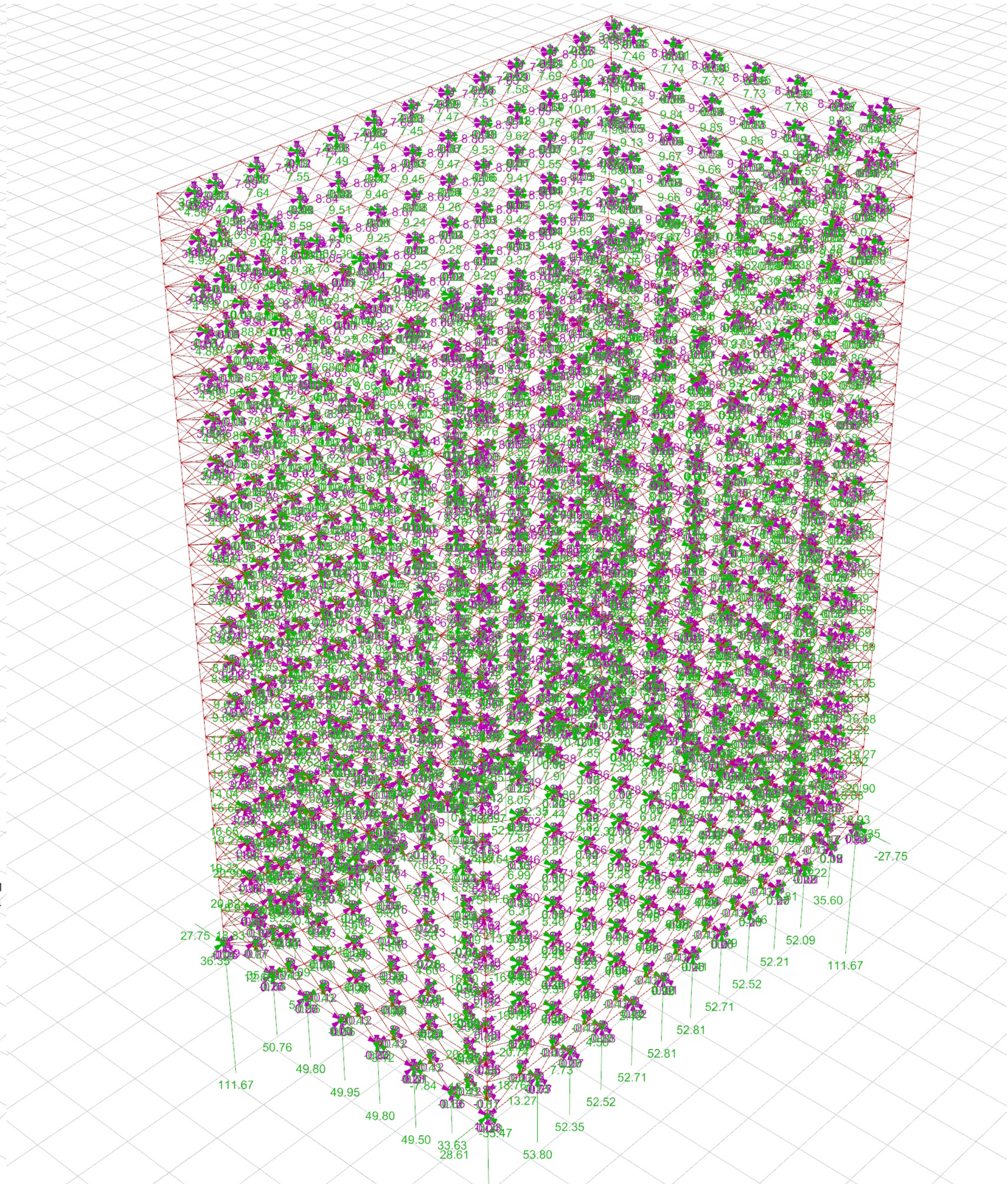
Bending moments calculation

- total mass
- maximum displacement

Static analysis for whole structure

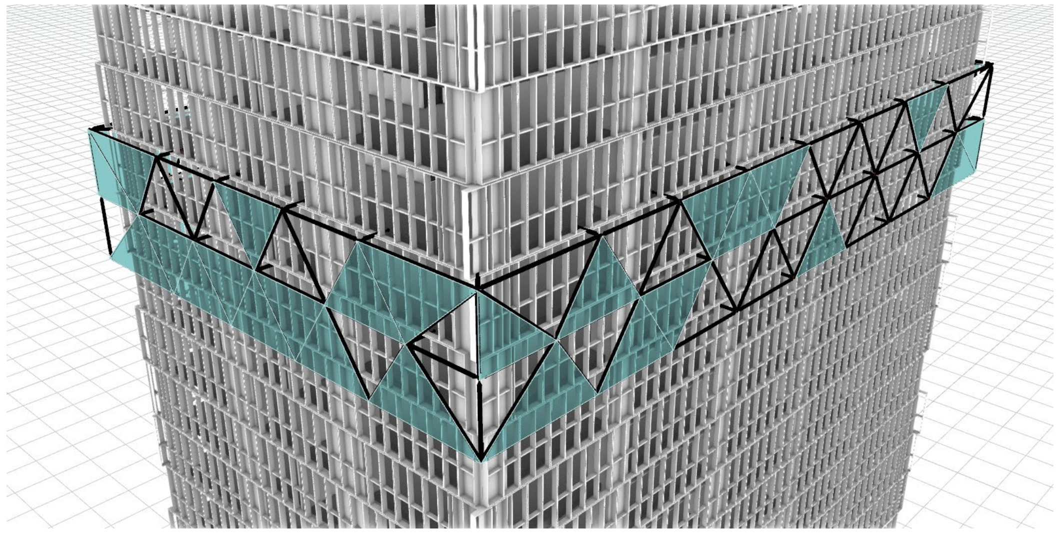


Axial forces calculation

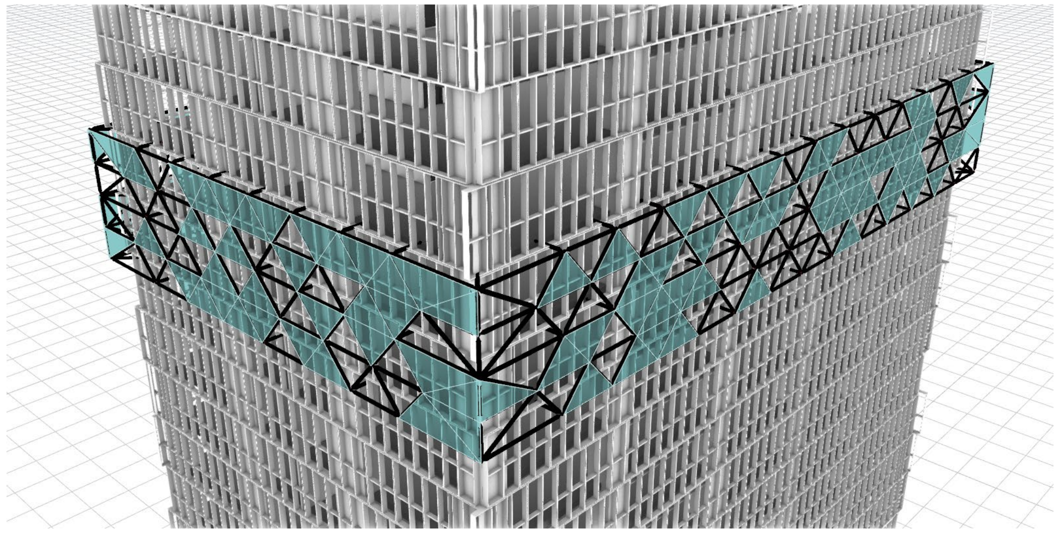


Supports and reactions

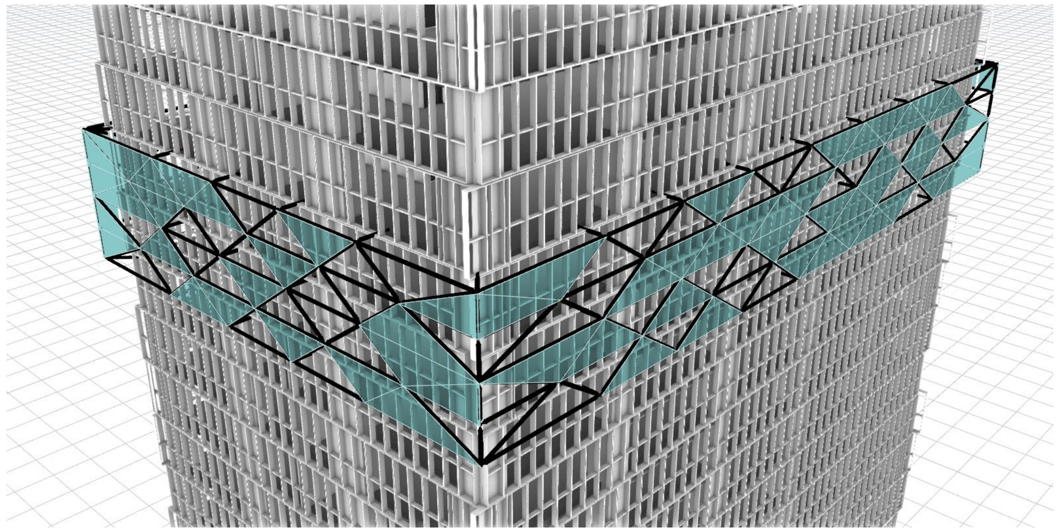
Multi-objective optimization parameters



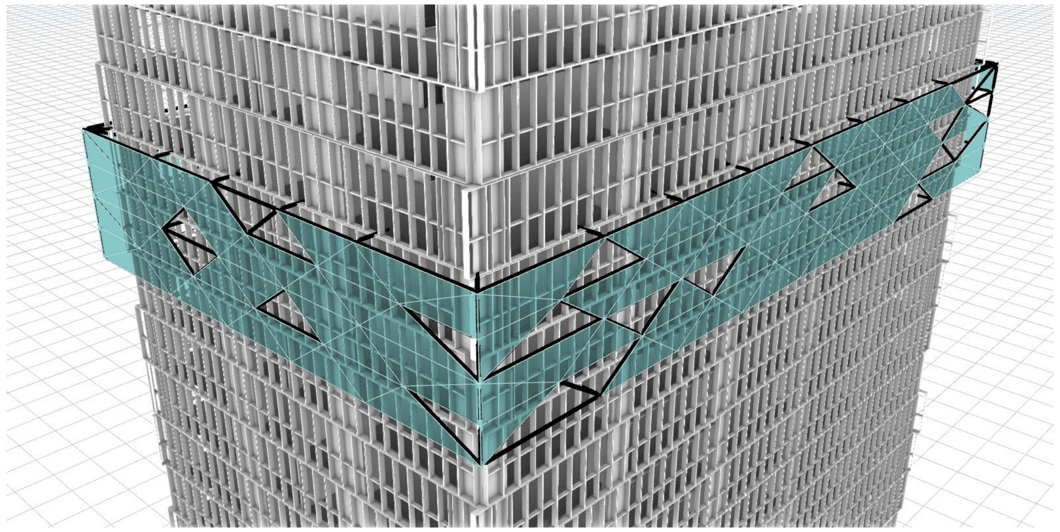
parameter 1: diagrid scale



parameter 2: width to height ratio



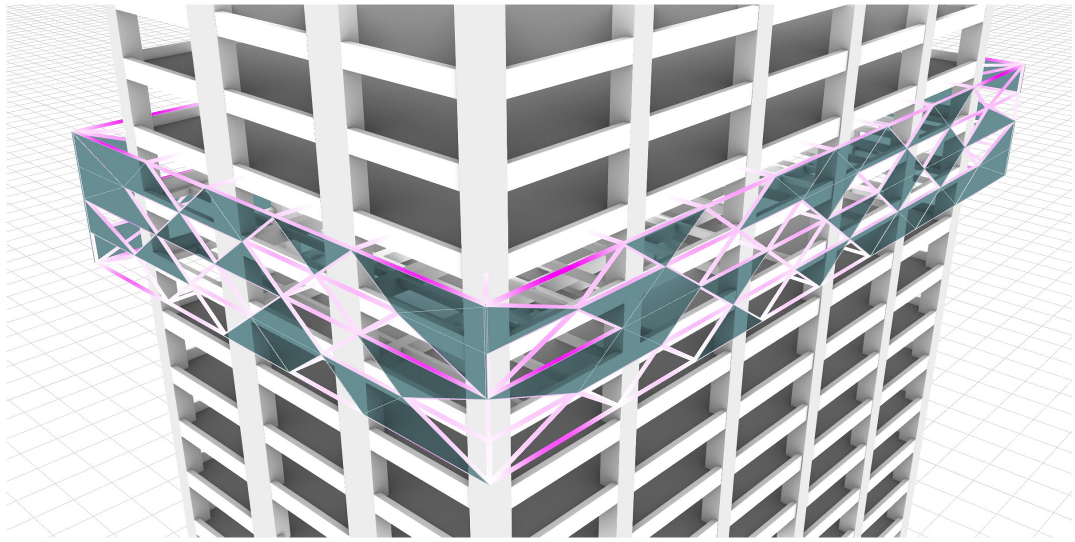
parameter 3: diagrid offset



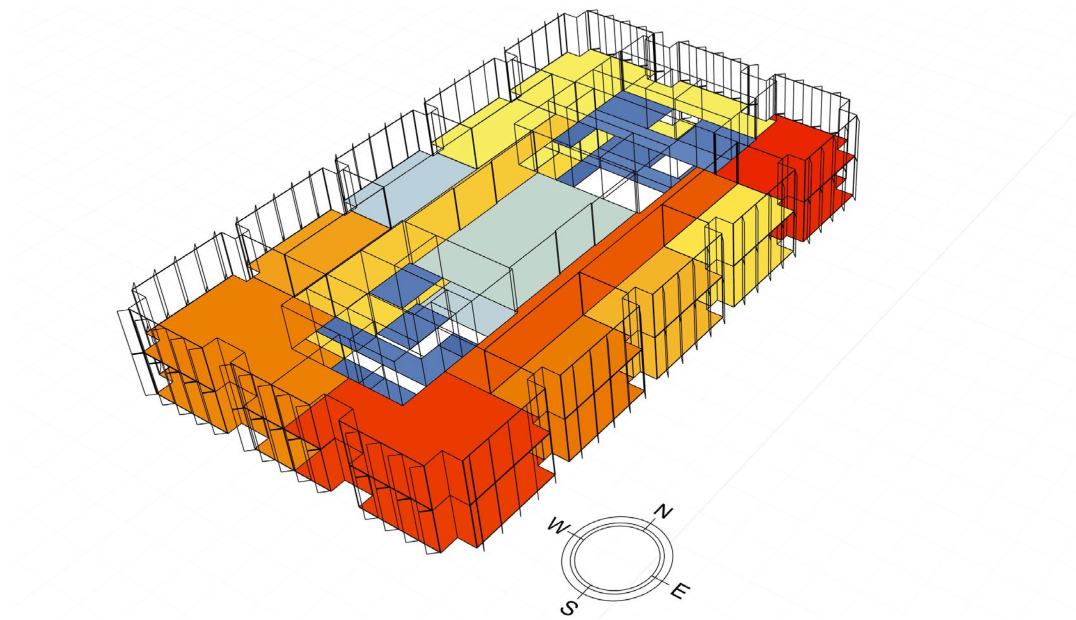
parameter 4: amount of shading

Multi-objective optimization objectives

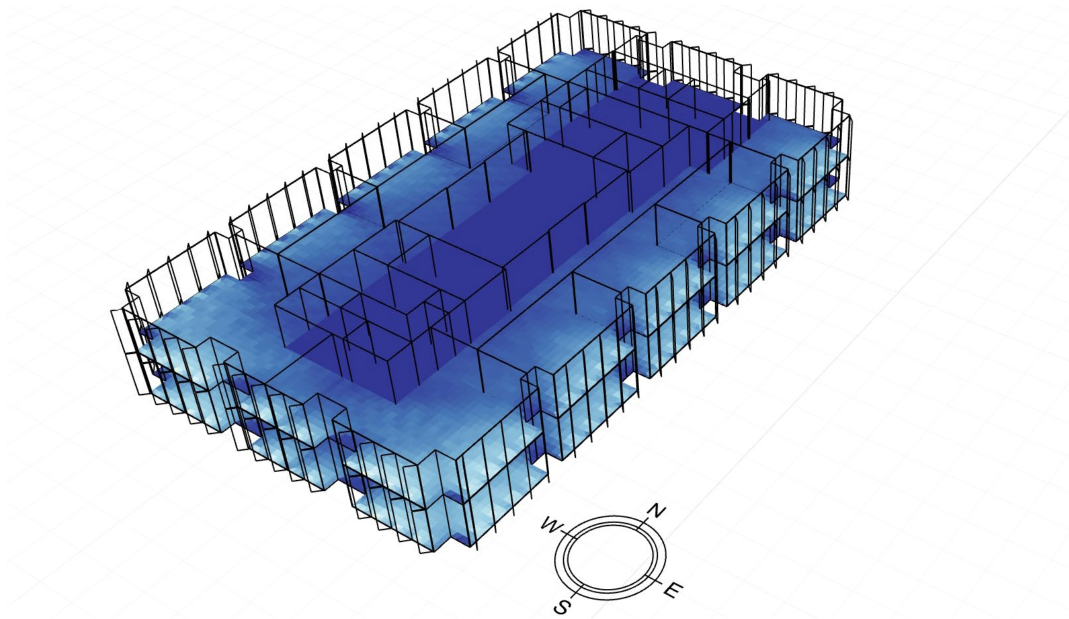
objective 1: Total mass [kg] ↓



objective 2: Maximum displacement [cm] ↓

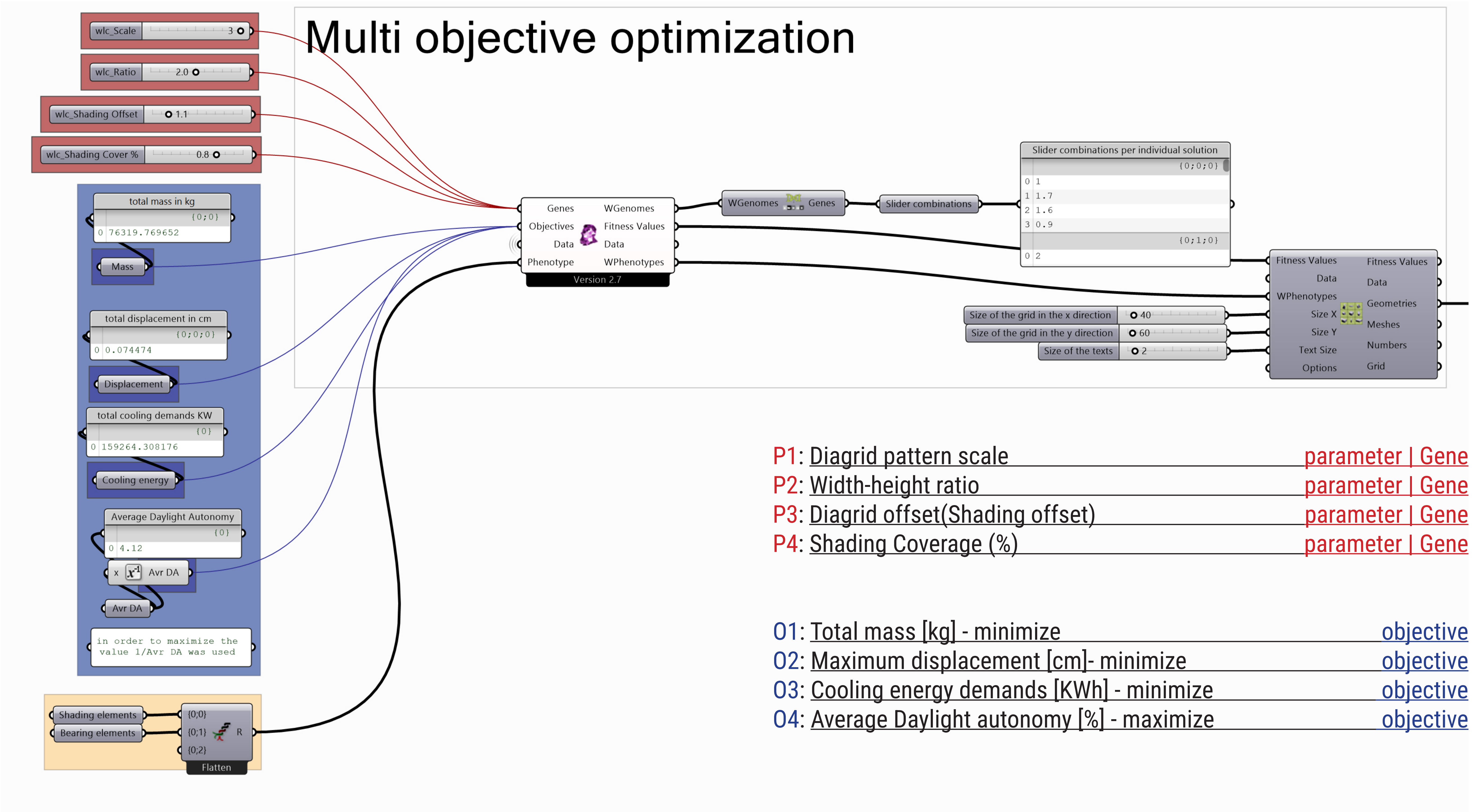


objective 3: Cooling energy demands [KWh] ↓



objective 4: Average Daylight autonomy [%] ↑

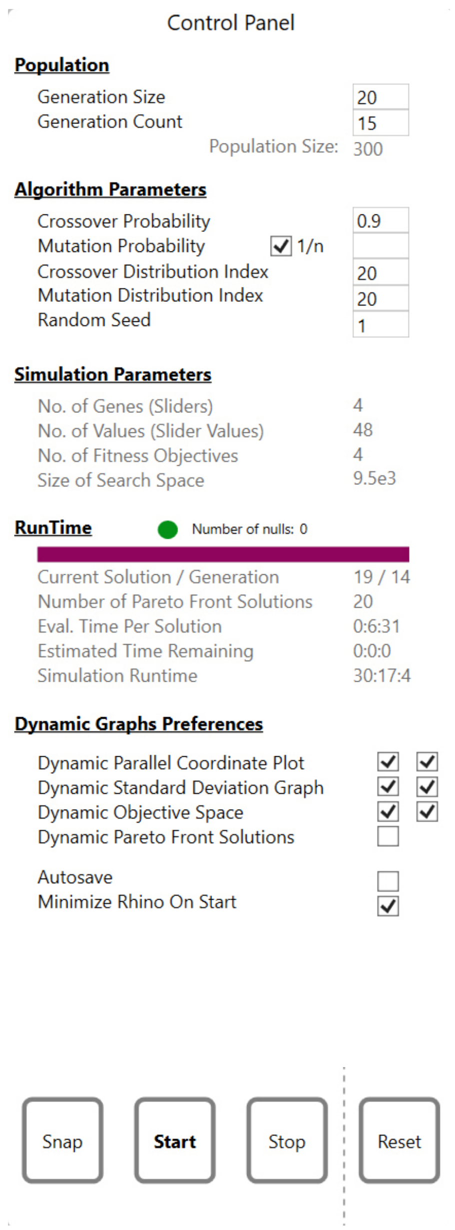
Multi-objective optimization workflow

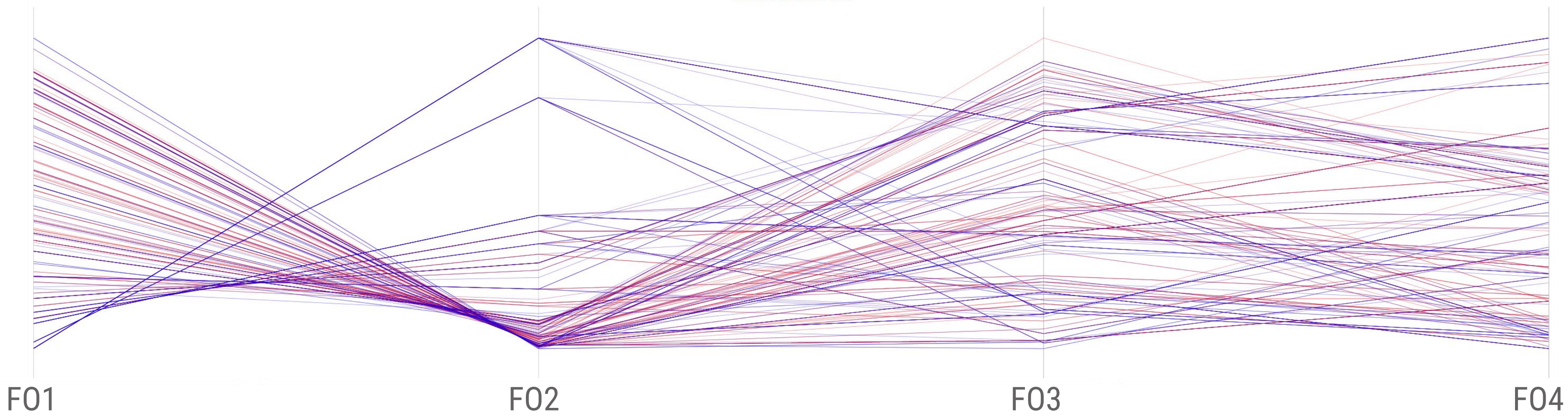


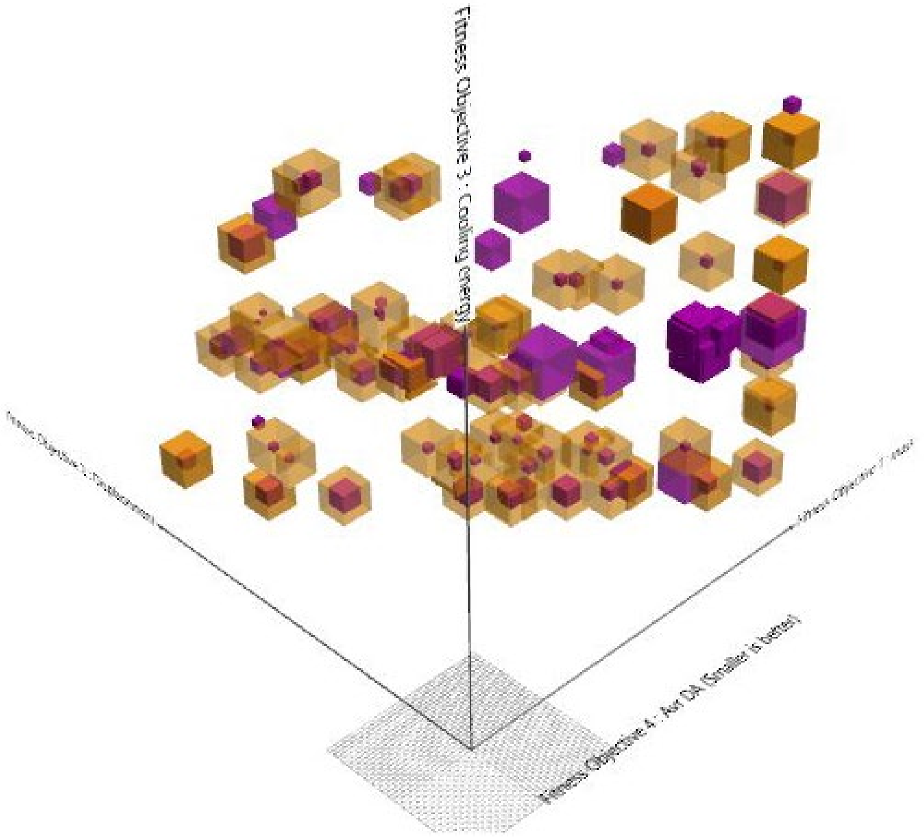
P1: Diagrid pattern scale ______ parameter | Gene
P2: Width-height ratio ______ parameter | Gene
P3: Diagrid offset(Shading offset) ______ parameter | Gene
P4: Shading Coverage (%) ______ parameter | Gene

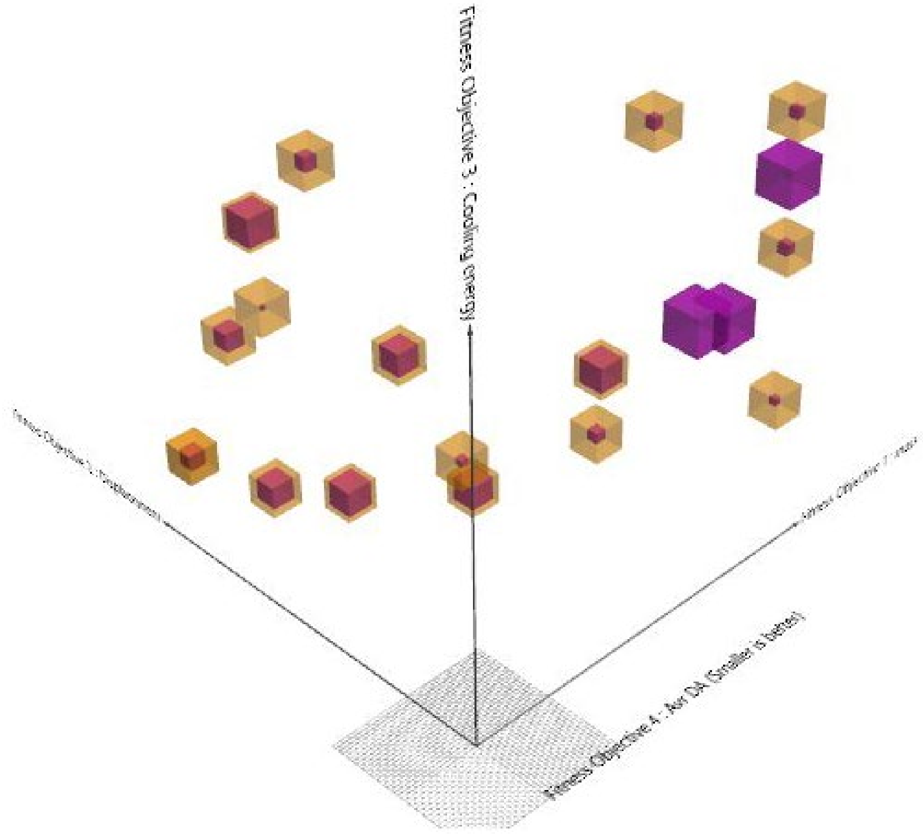
O1: Total mass [kg] - minimize ______ objective
O2: Maximum displacement [cm]- minimize ______ objective
O3: Cooling energy demands [KWh] - minimize ______ objective
O4: Average Daylight autonomy [%] - maximize ______ objective

Multi-objective optimization solution space

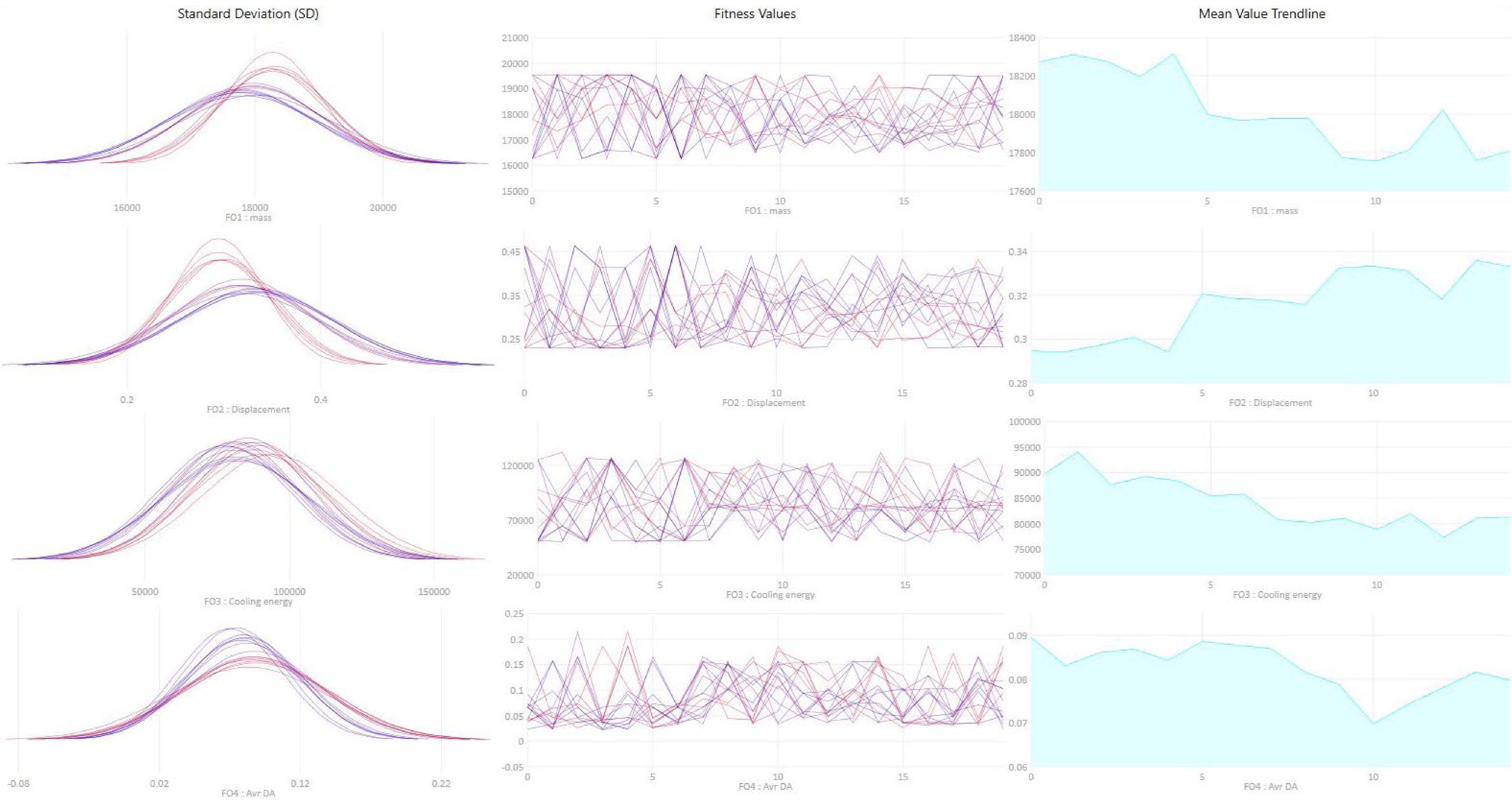




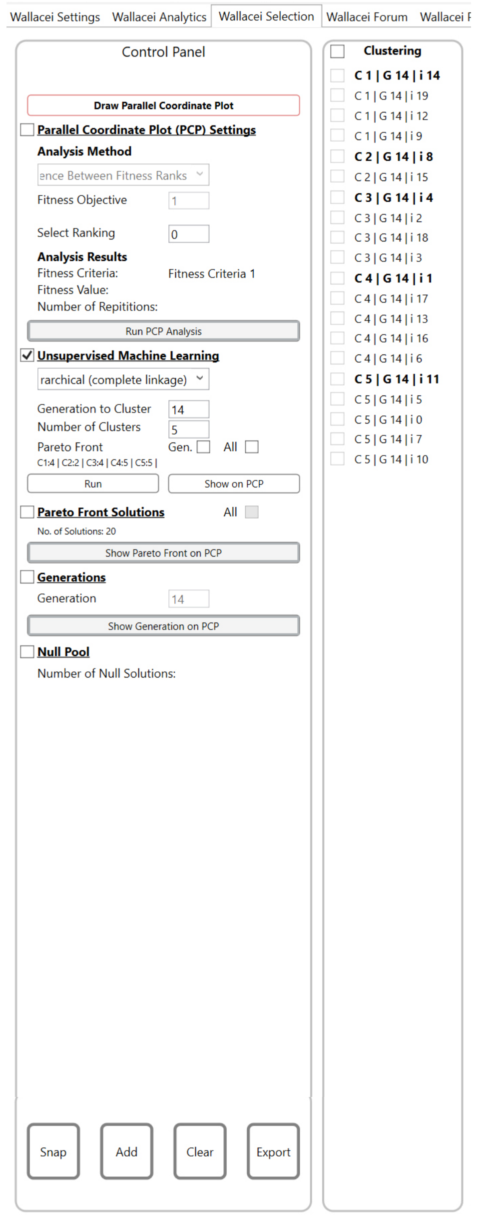


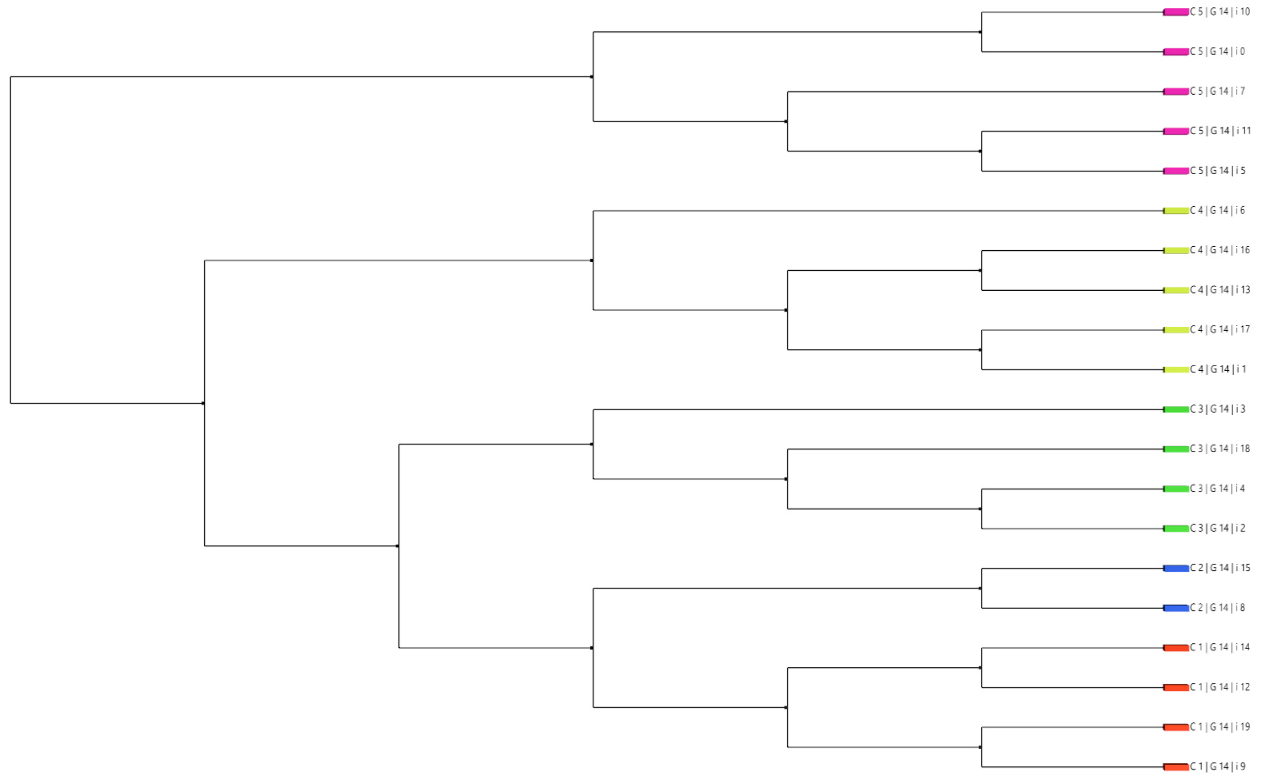


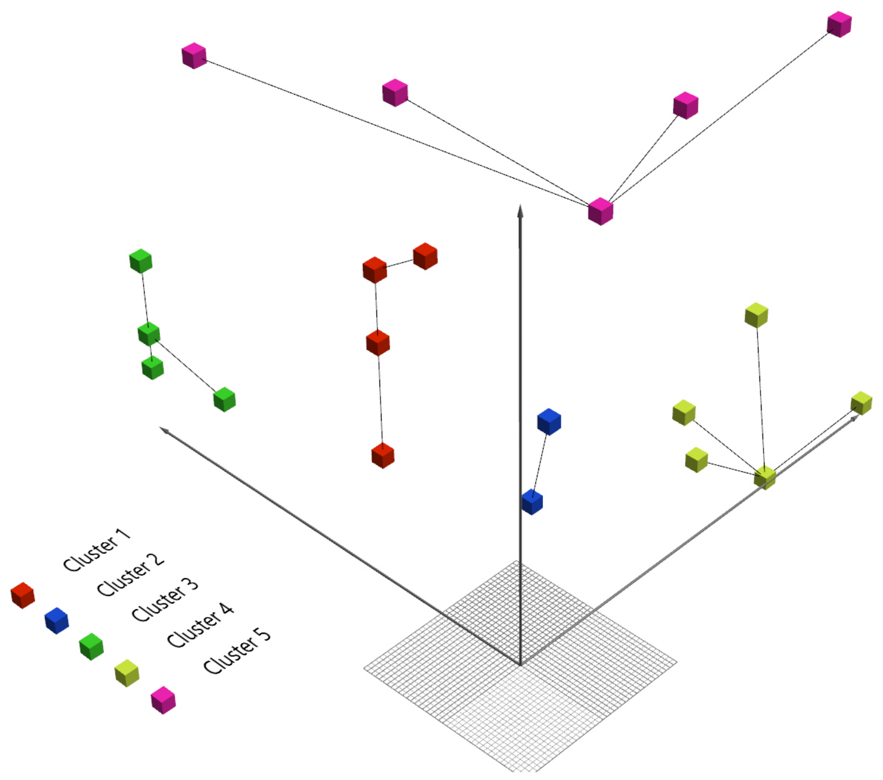
Multi-objective optimization objective values trends



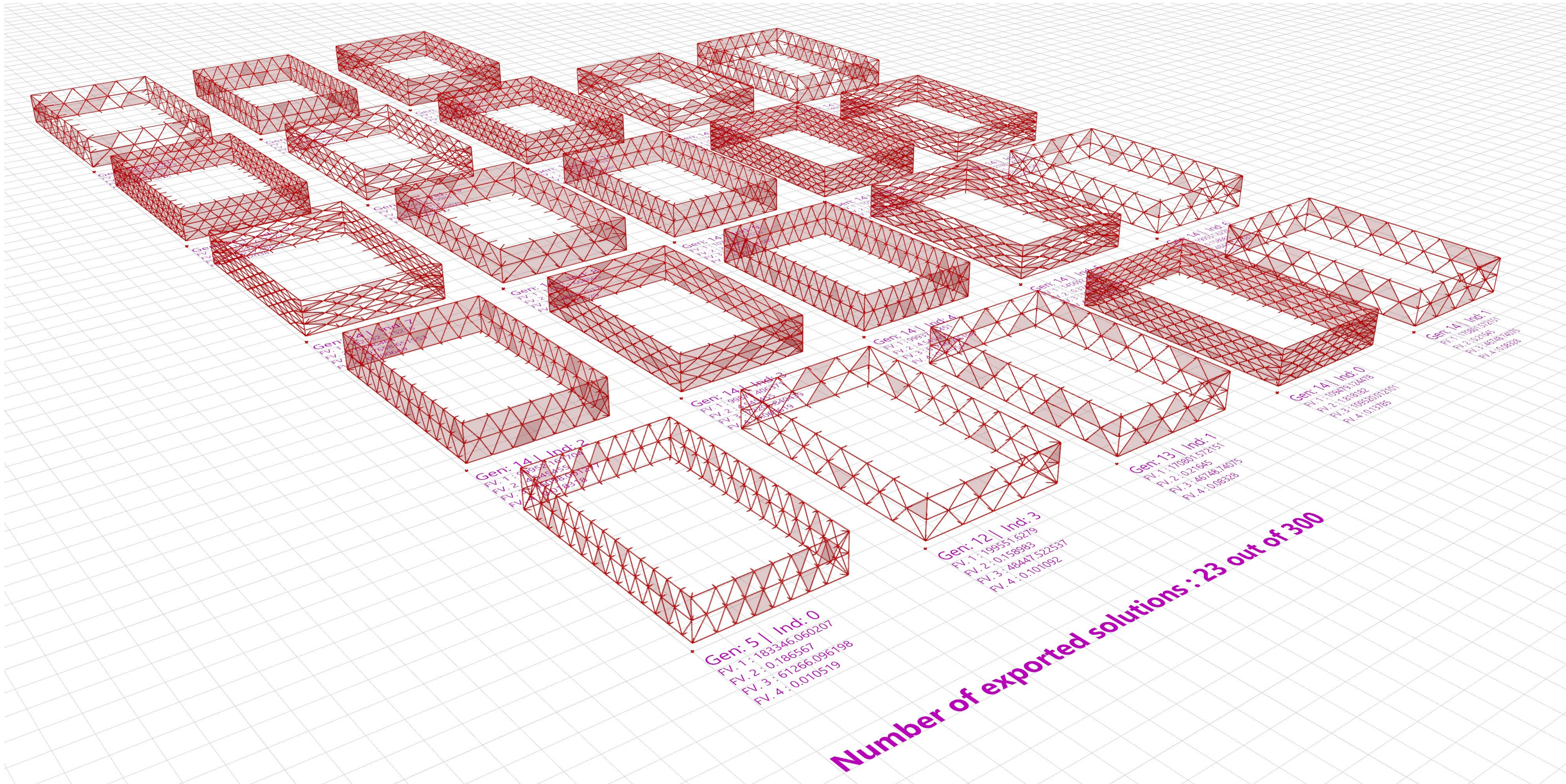
Multi-objective optimization results clustering in Wallacei



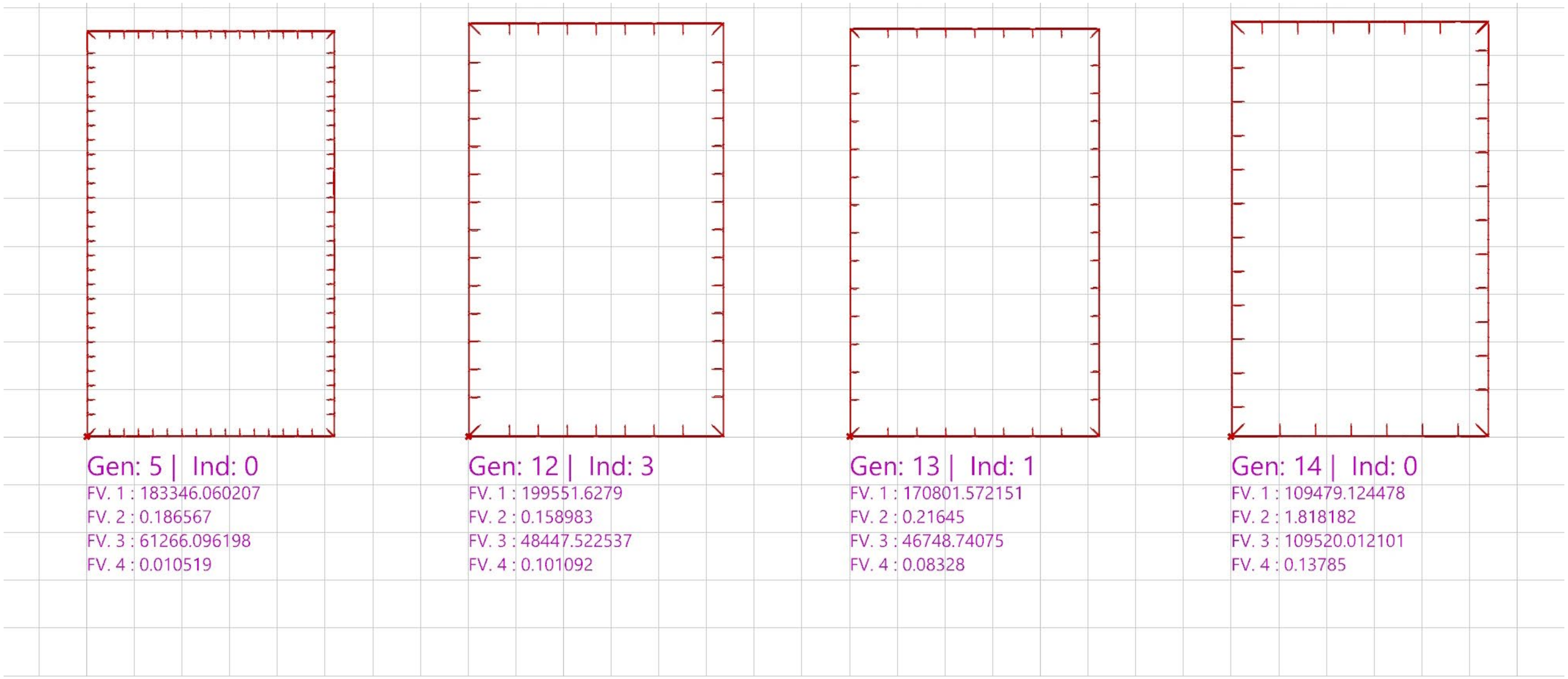




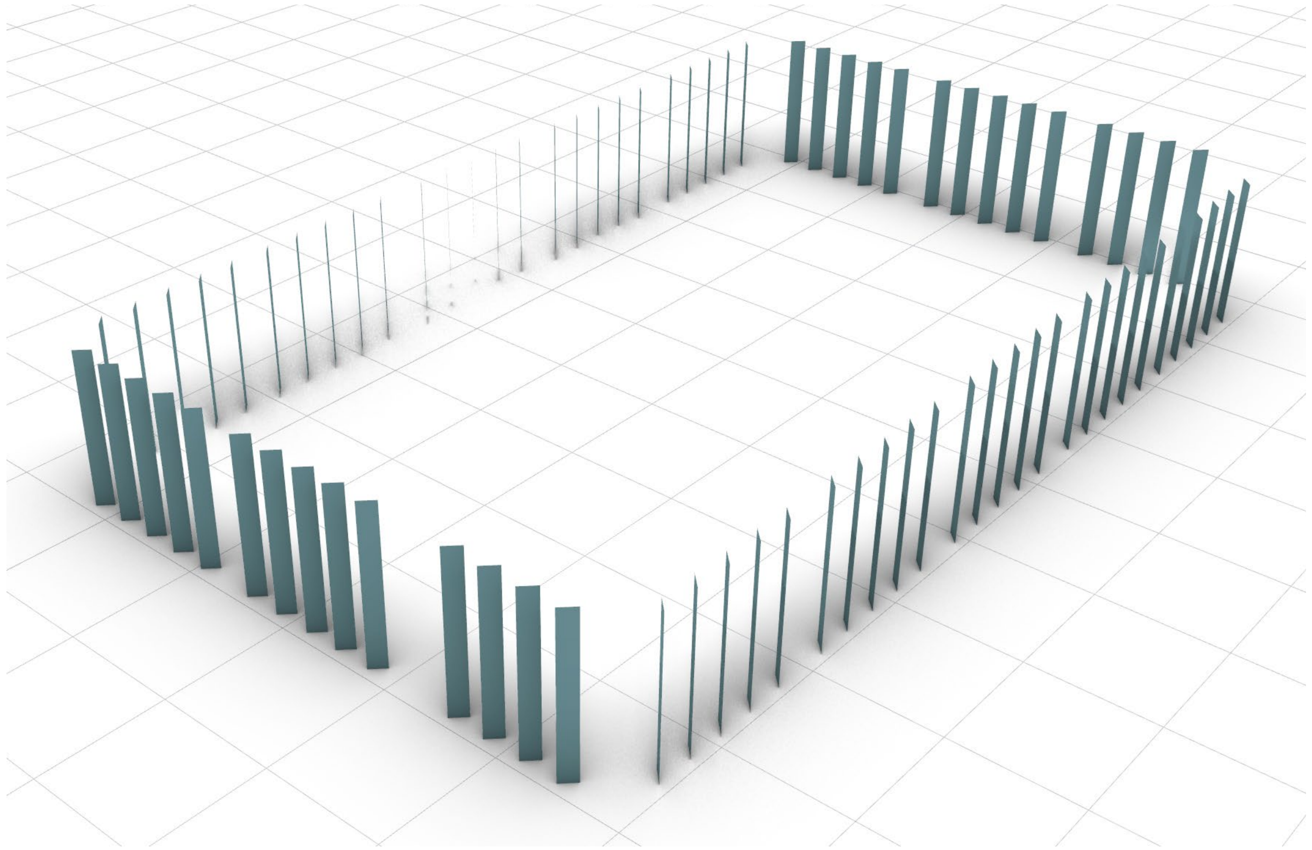
Multi-objective optimization results export

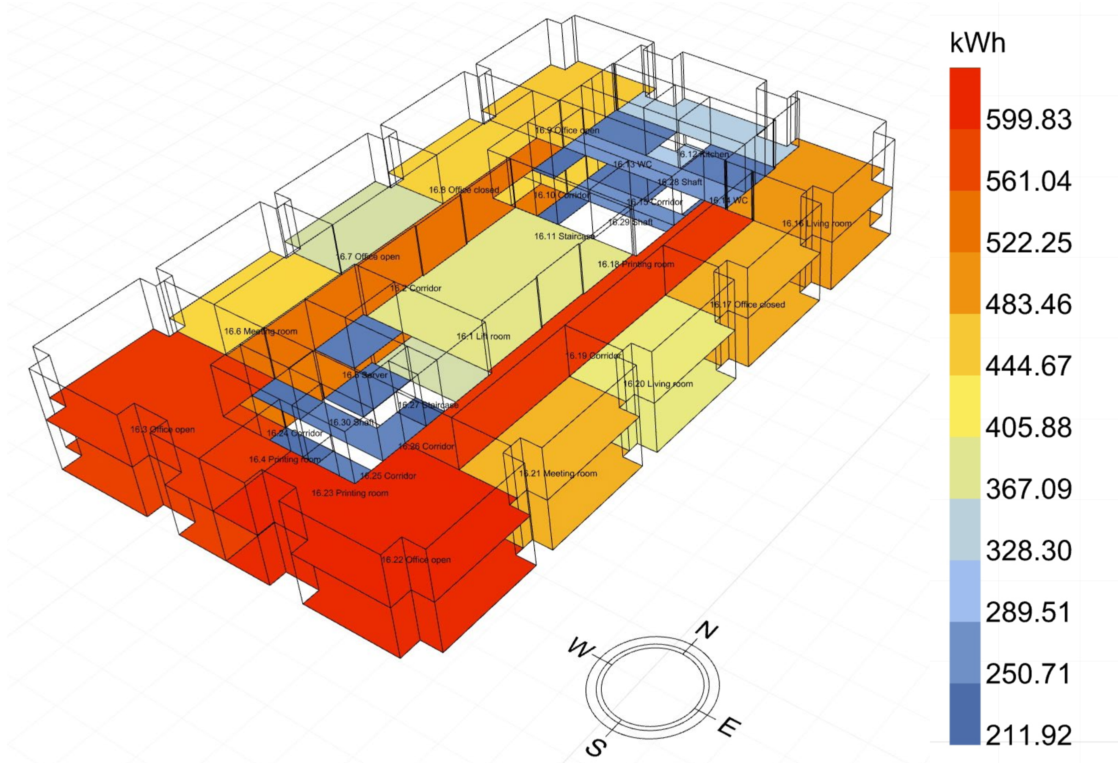


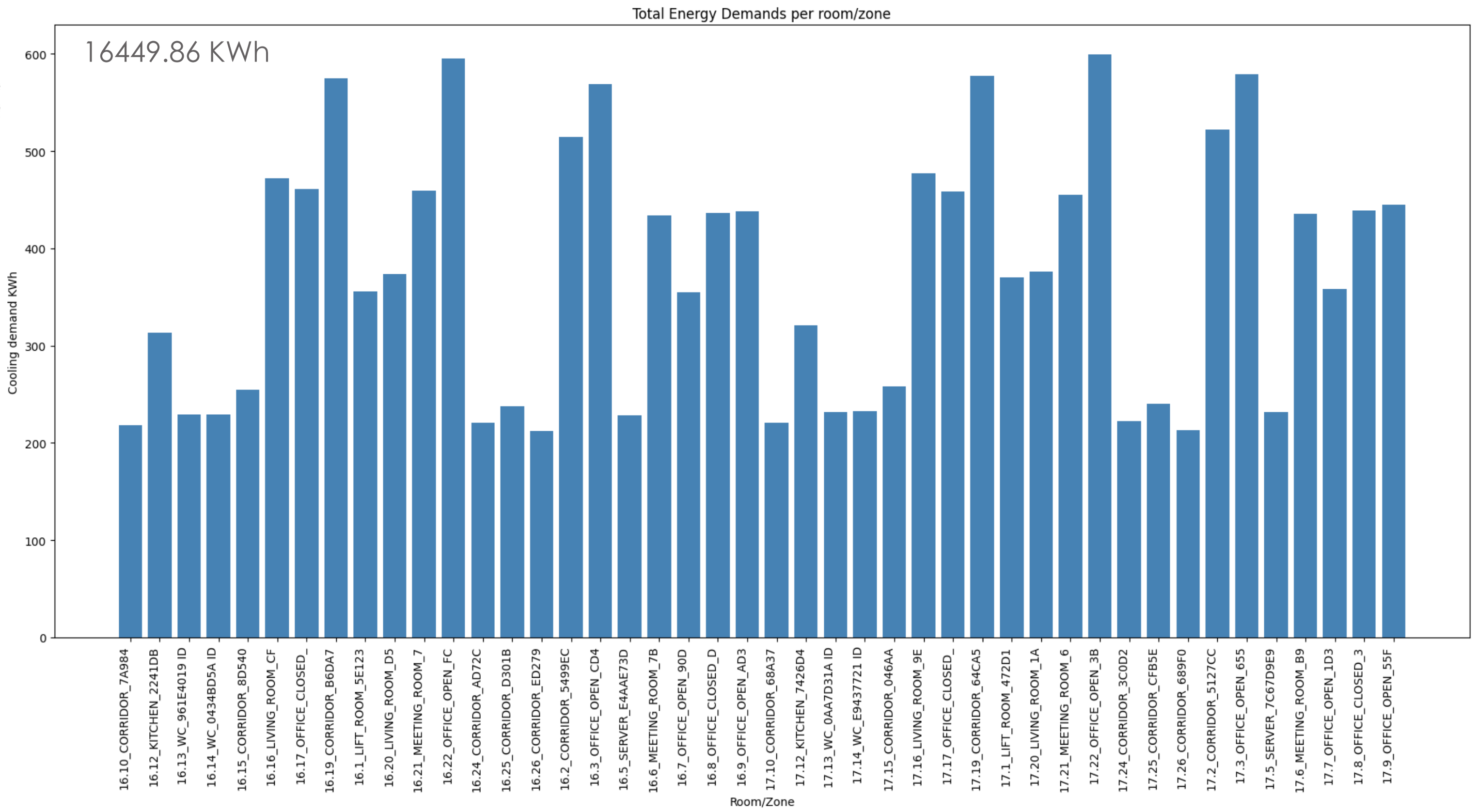
Multi-objective optimization results export



Simulation results for original facade - Extreme hot week analysis period





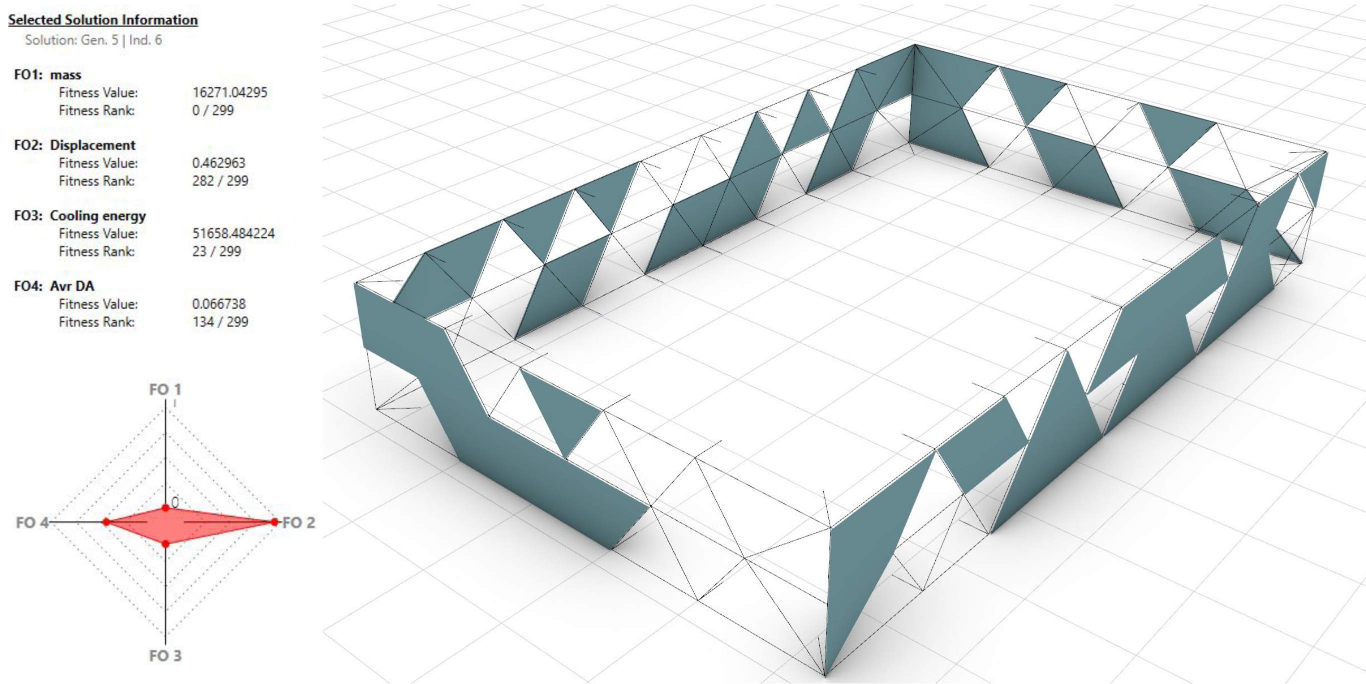


For the typical levels under investigation:

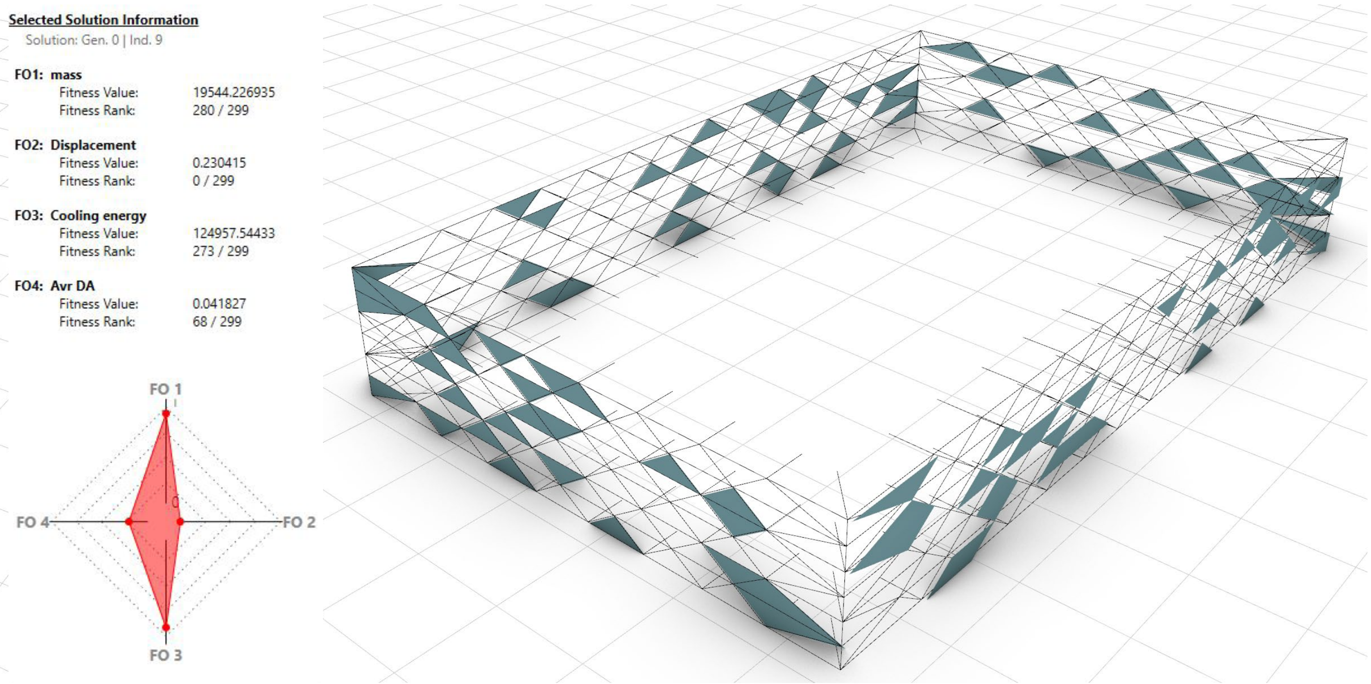
Total cooling demands: 16449.86 KWh/ehw

e.h.w= extreme hot week

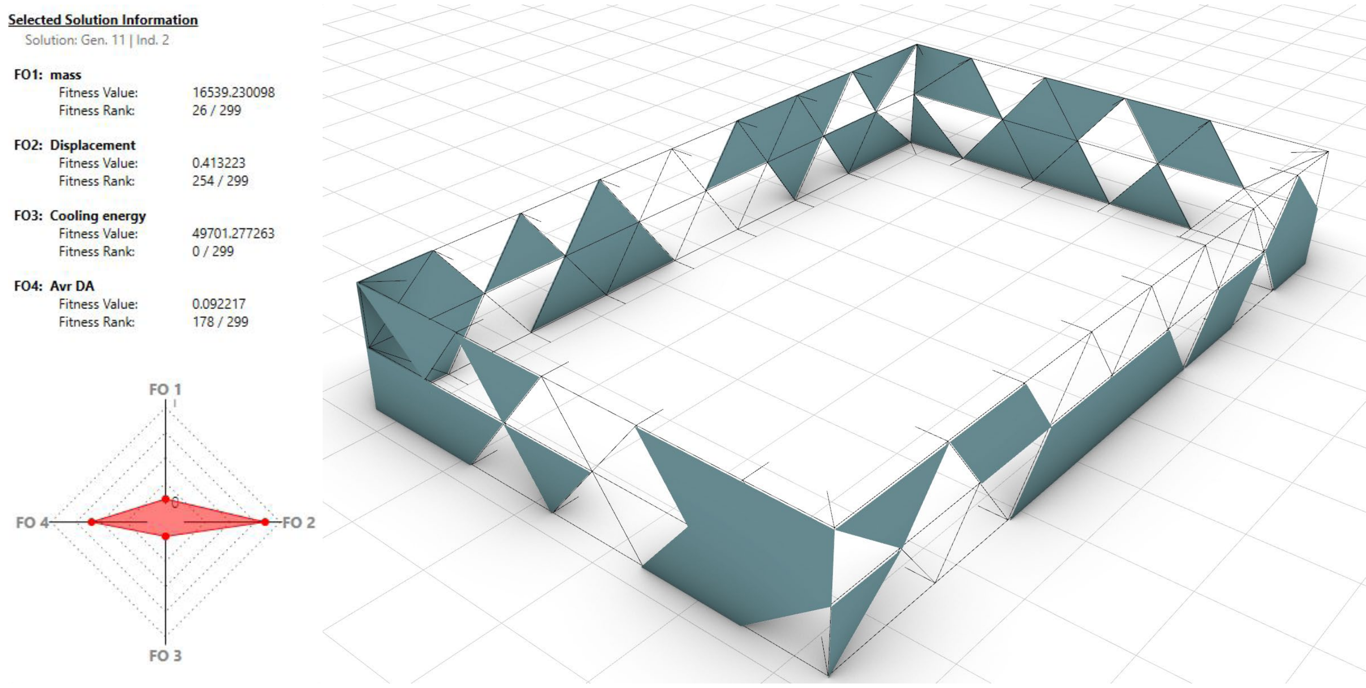
Multi-objective optimization results



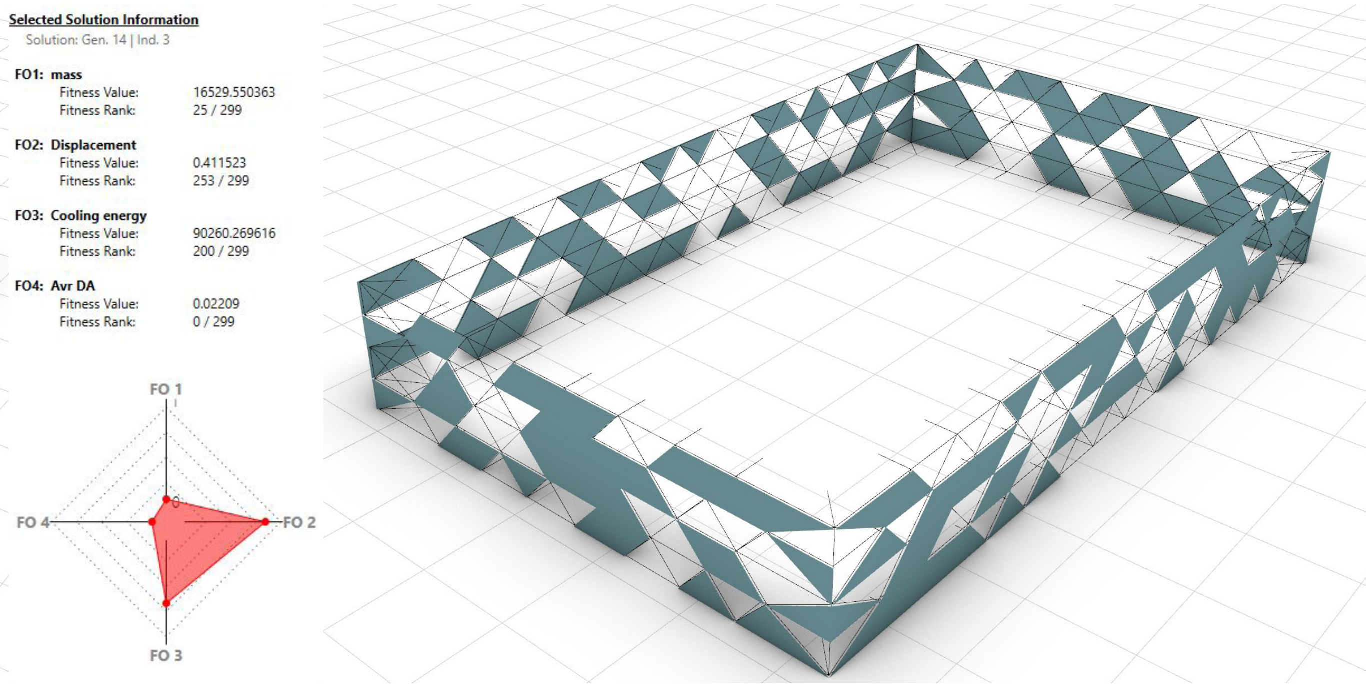
[best for minimizing mass Obj1]



[best for minimizing displacement Obj2]

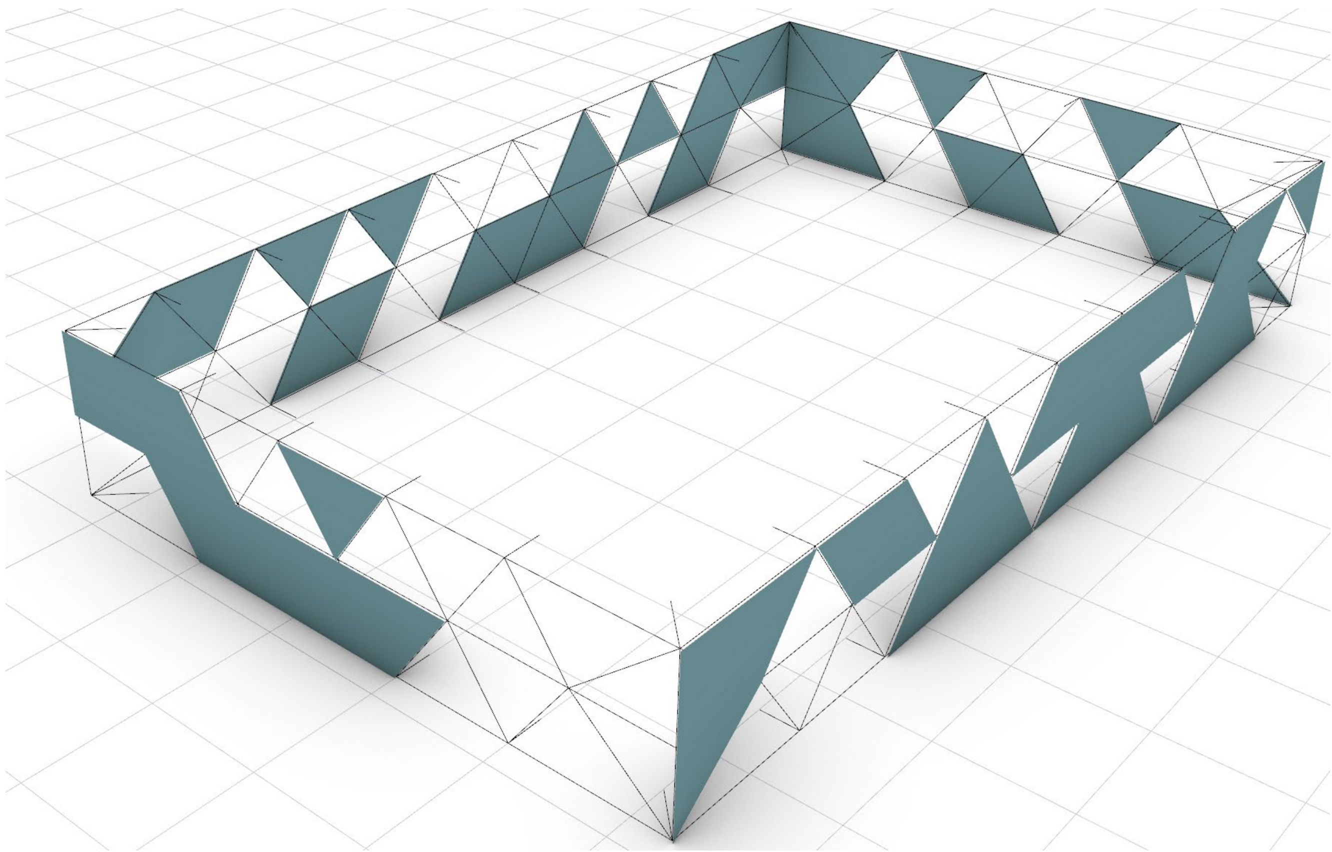


[best for minimizing cooling demands Obj3]



[best for average Daylight autonomy]

Simulation results for extreme solutions - Extreme hot week analysis period



Best solution for minimizing mass (Obj1)

For the typical levels under investigation:

Total cooling demands: 16539.21 KWh/ehw

e.h.w= extreme hot week

Selected Solution Information

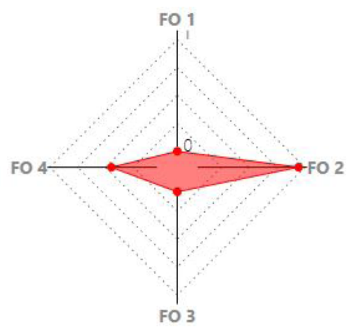
Solution: Gen. 5 | Ind. 6

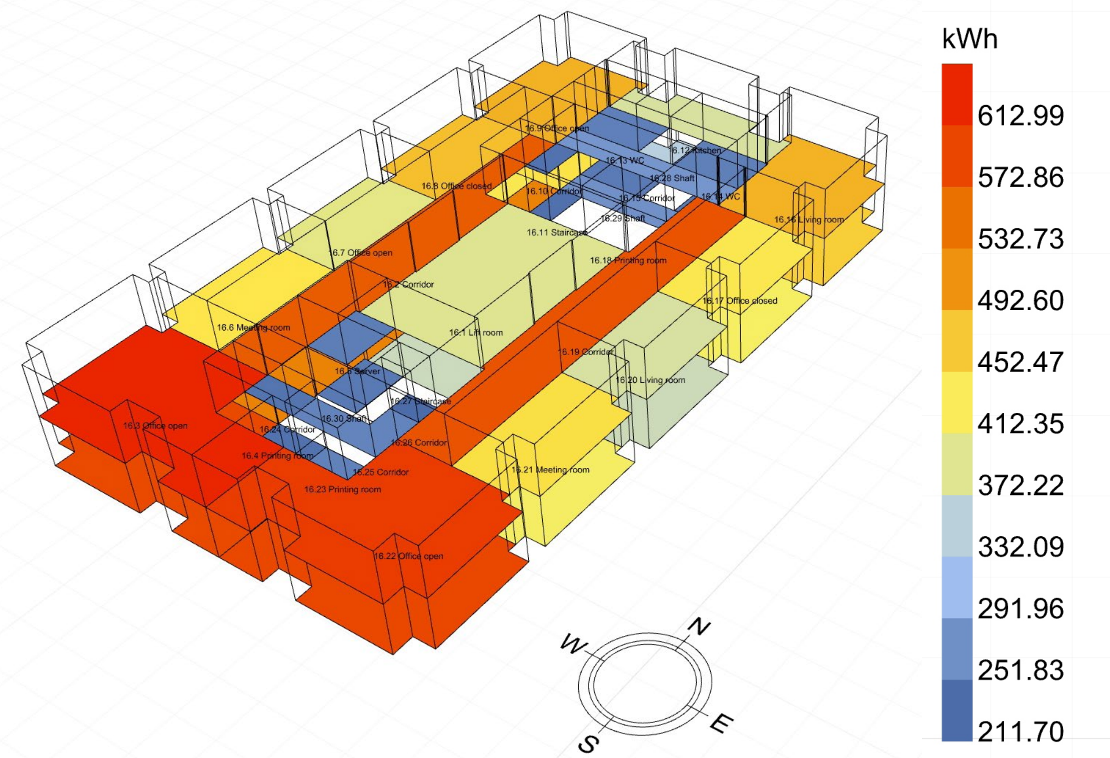
FO1: mass
Fitness Value: 16271.04295
Fitness Rank: 0 / 299

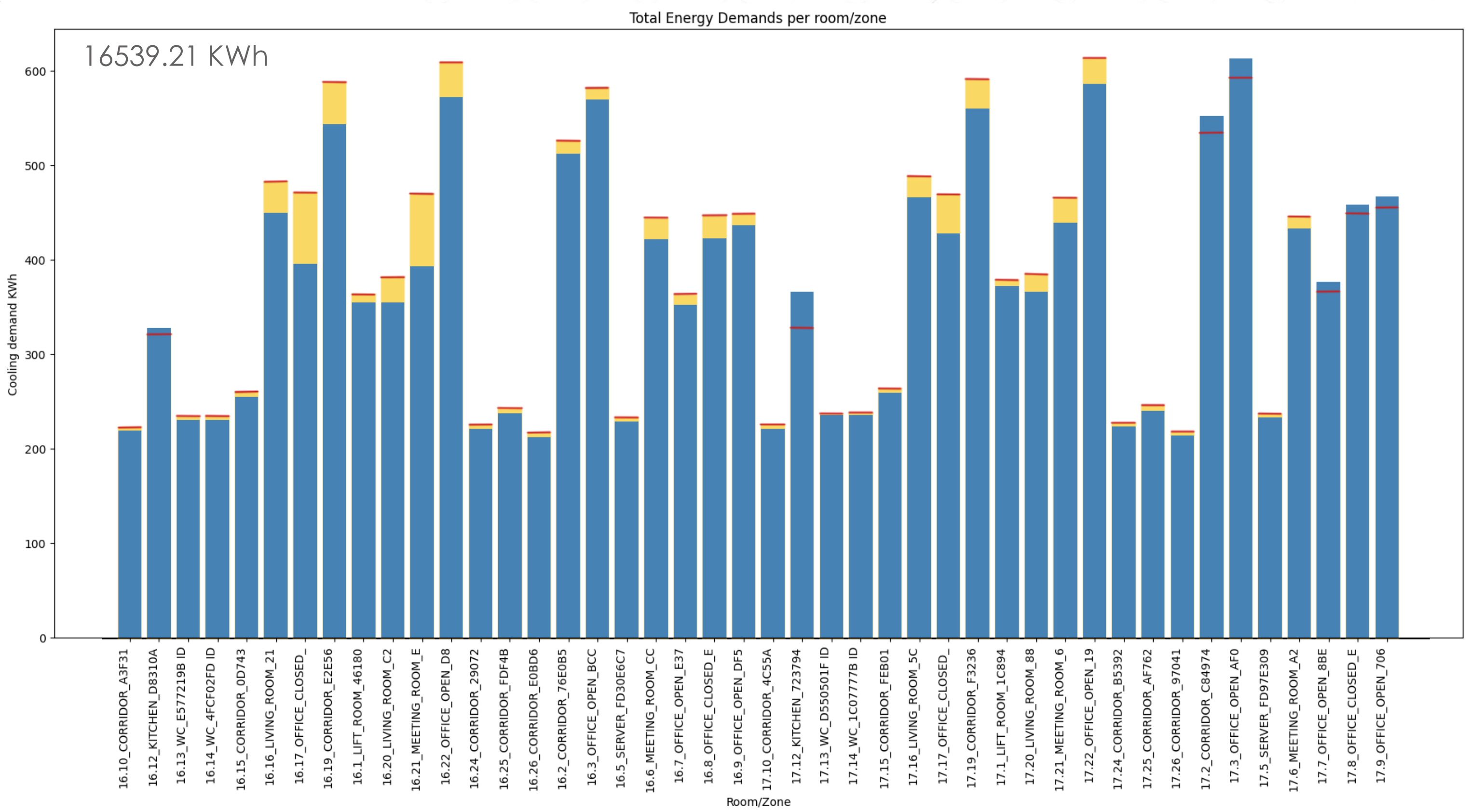
FO2: Displacement
Fitness Value: 0.462963
Fitness Rank: 282 / 299

FO3: Cooling energy
Fitness Value: 51658.484224
Fitness Rank: 23 / 299

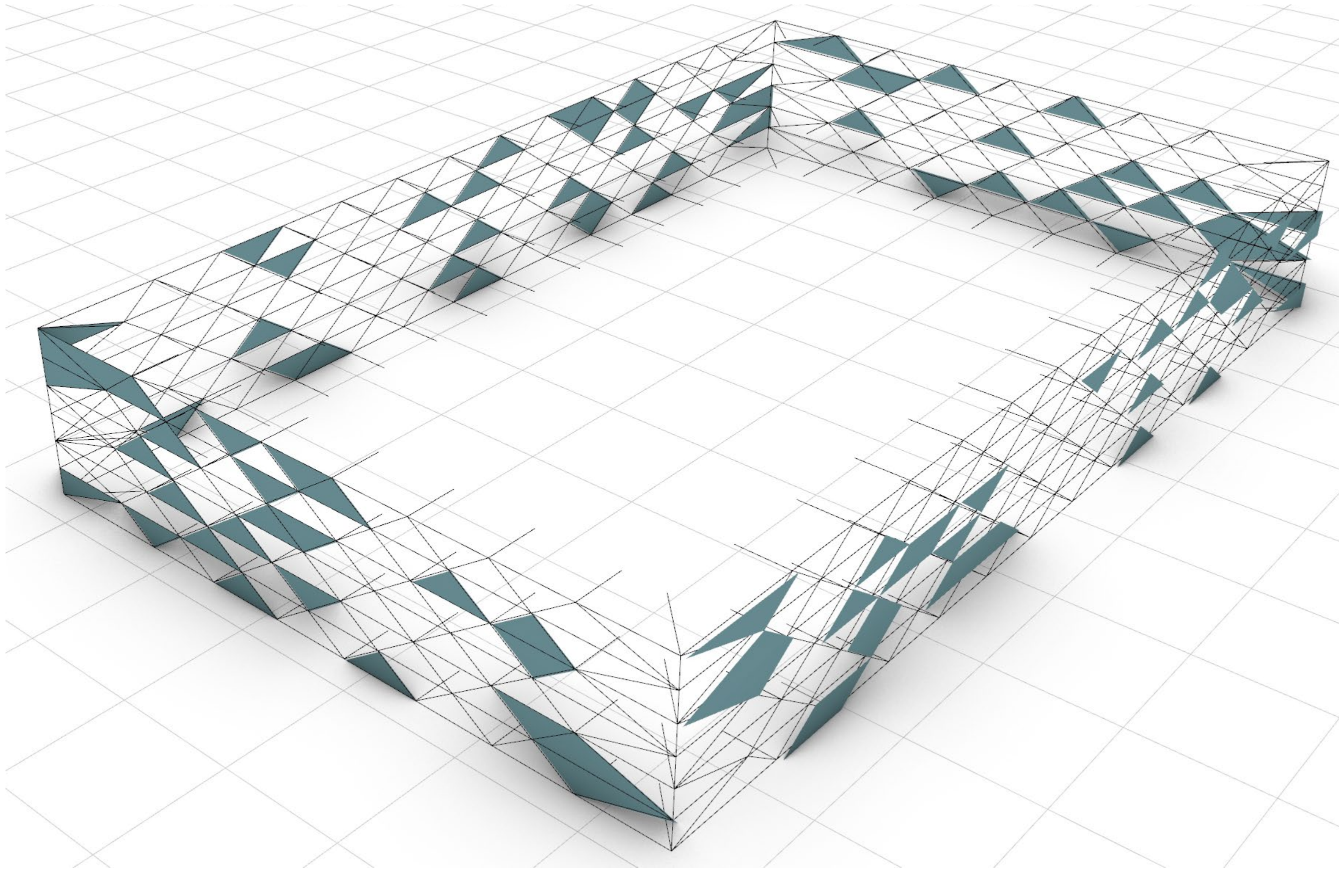
FO4: Avr DA
Fitness Value: 0.066738
Fitness Rank: 134 / 299







Simulation results for extreme solutions - Extreme hot week analysis period



Best solution for minimizing displacement (Obj2)

For the typical levels under investigation:

Total cooling demands: 18504.95 KWh/ehw

Selected Solution Information

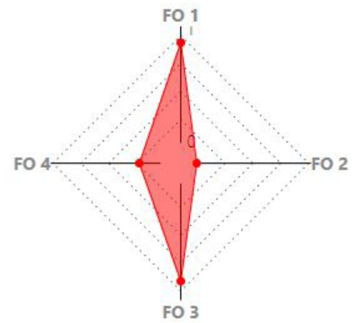
Solution: Gen. 0 | Ind. 9

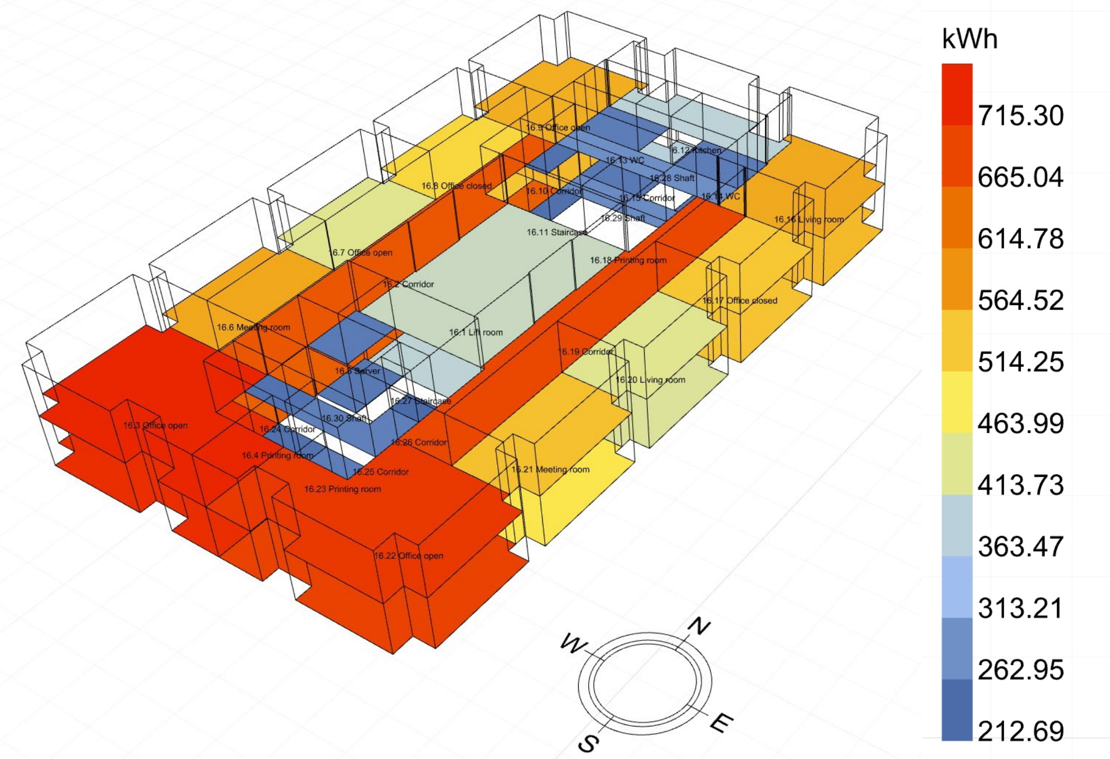
FO1: mass
Fitness Value: 19544.226935
Fitness Rank: 280 / 299

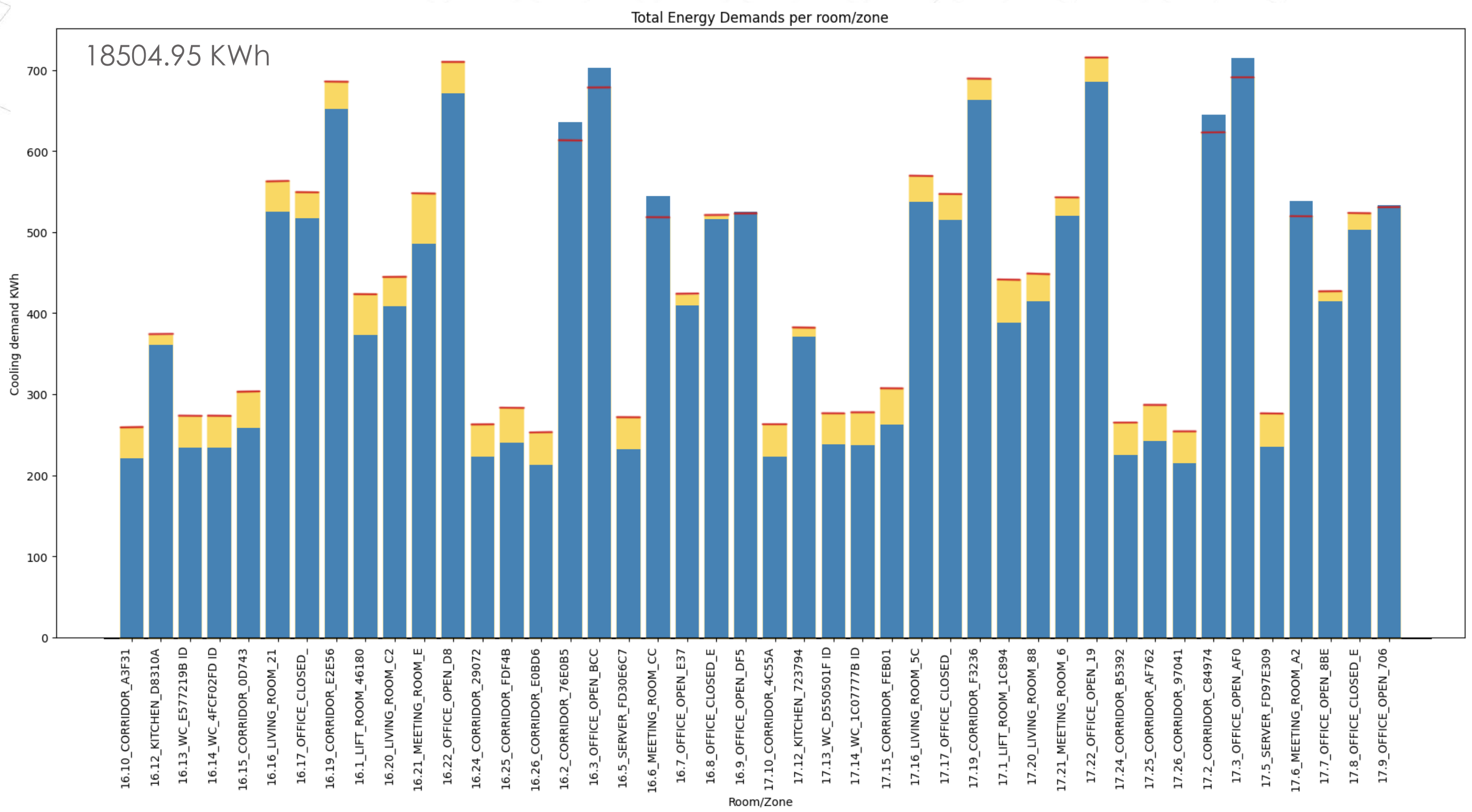
FO2: Displacement
Fitness Value: 0.230415
Fitness Rank: 0 / 299

FO3: Cooling energy
Fitness Value: 124957.54433
Fitness Rank: 273 / 299

FO4: Avr DA
Fitness Value: 0.041827
Fitness Rank: 68 / 299

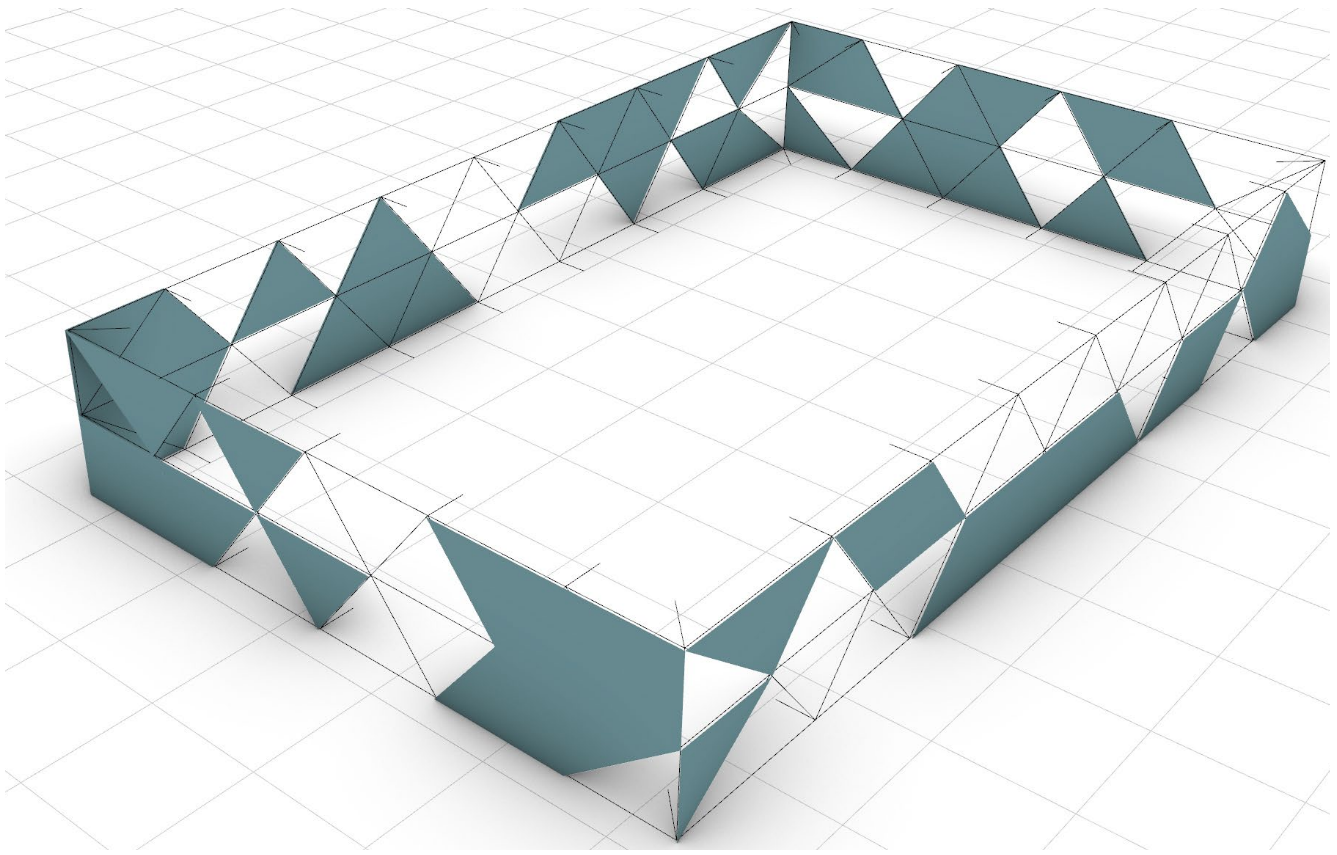


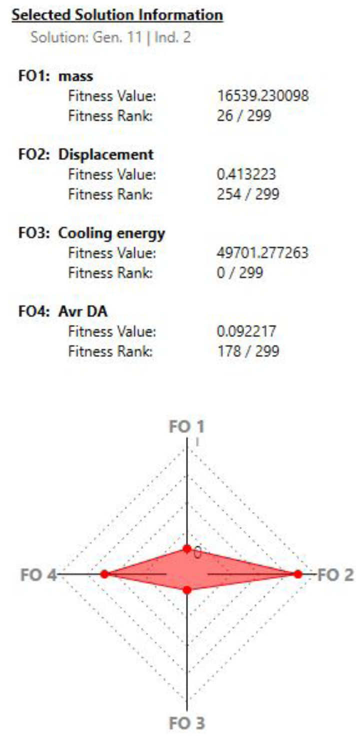


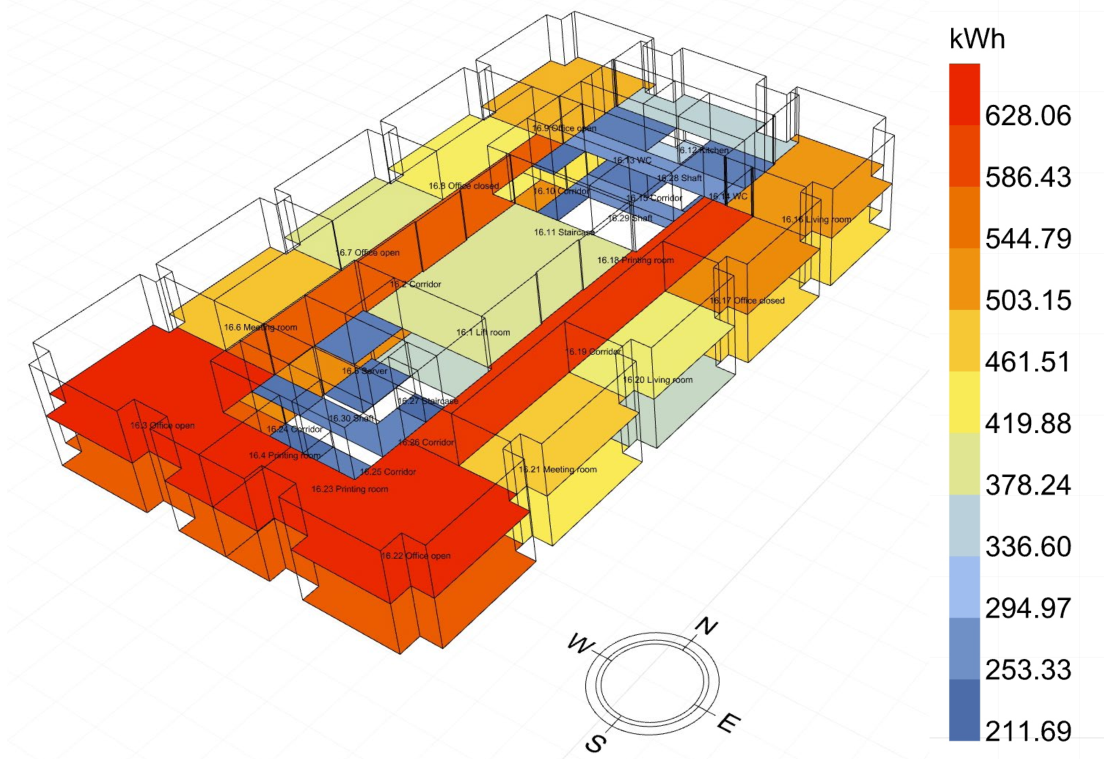


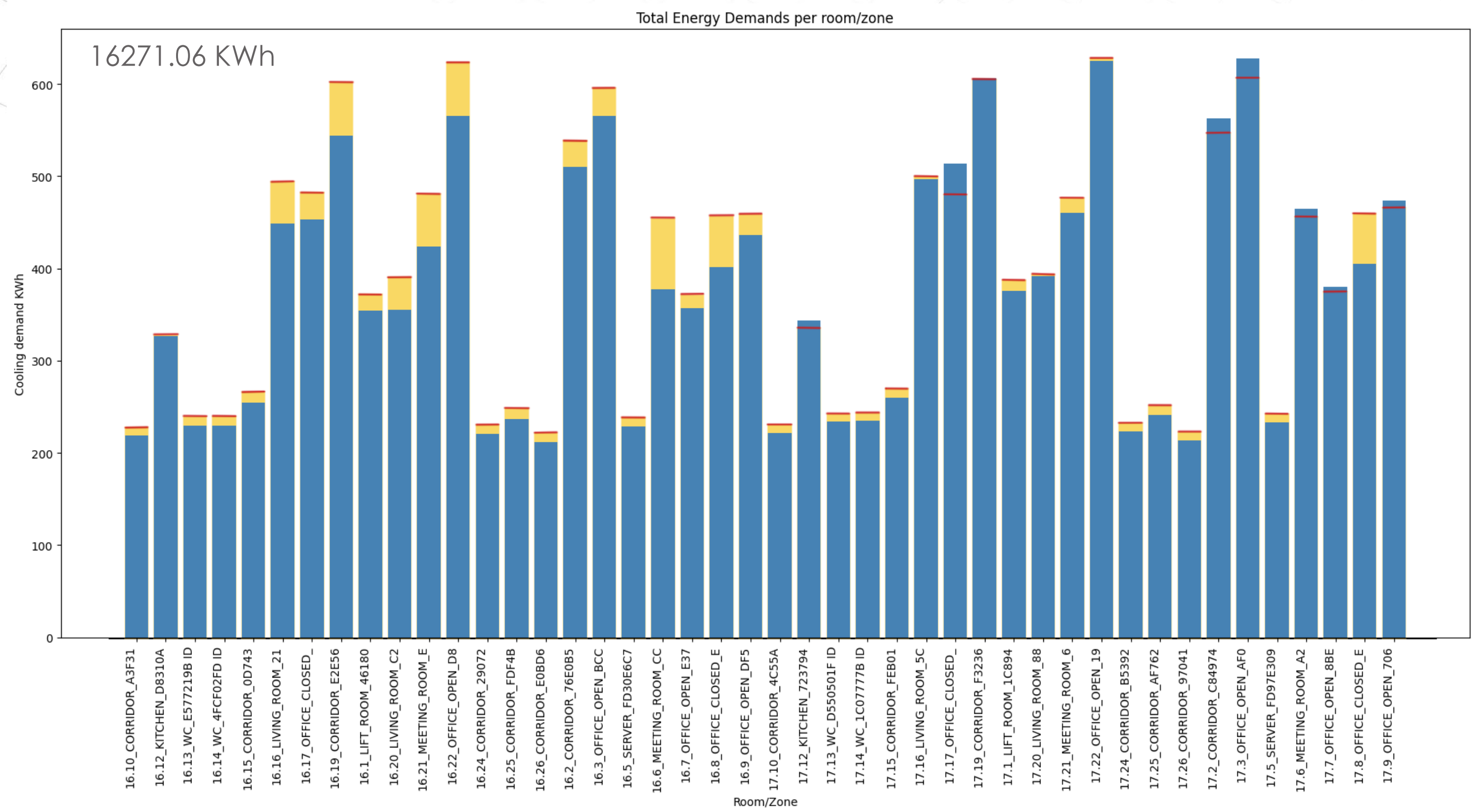
e.h.w= extreme hot week

Simulation results for extreme solutions - Extreme hot week analysis period









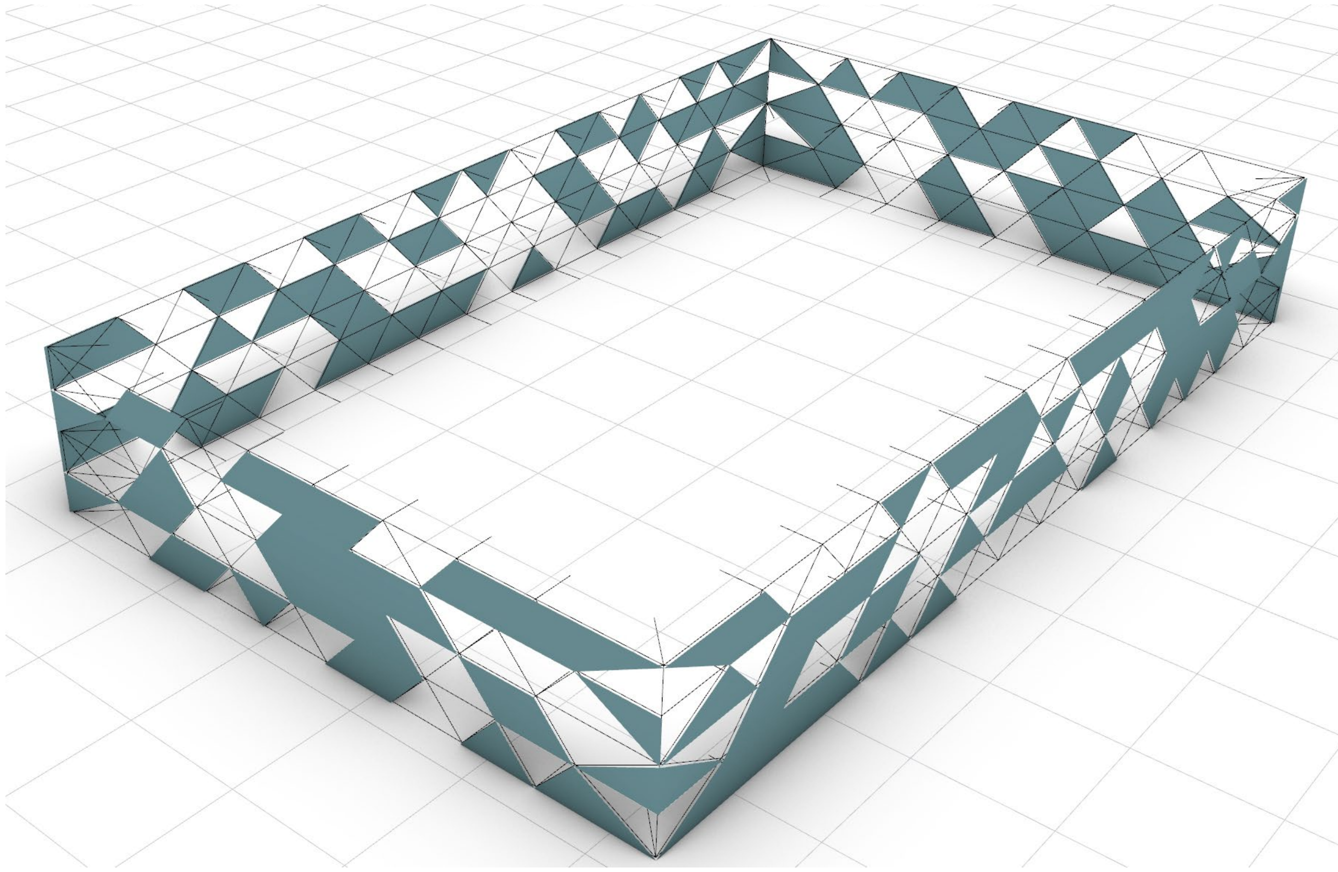
Best solution for minimizing cooling demands (Obj3)

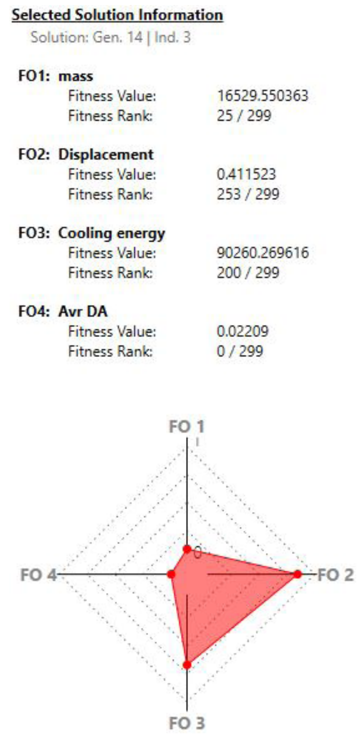
For the typical levels under investigation:

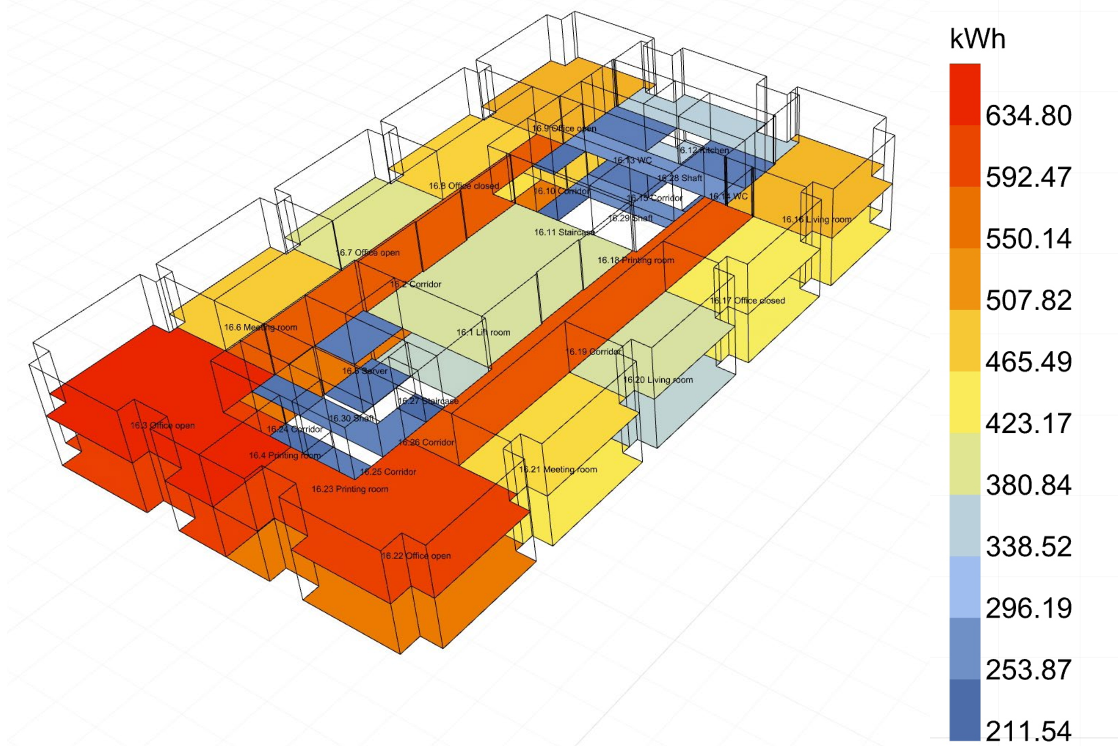
Total cooling demands: 16271.06 KWh/ehw

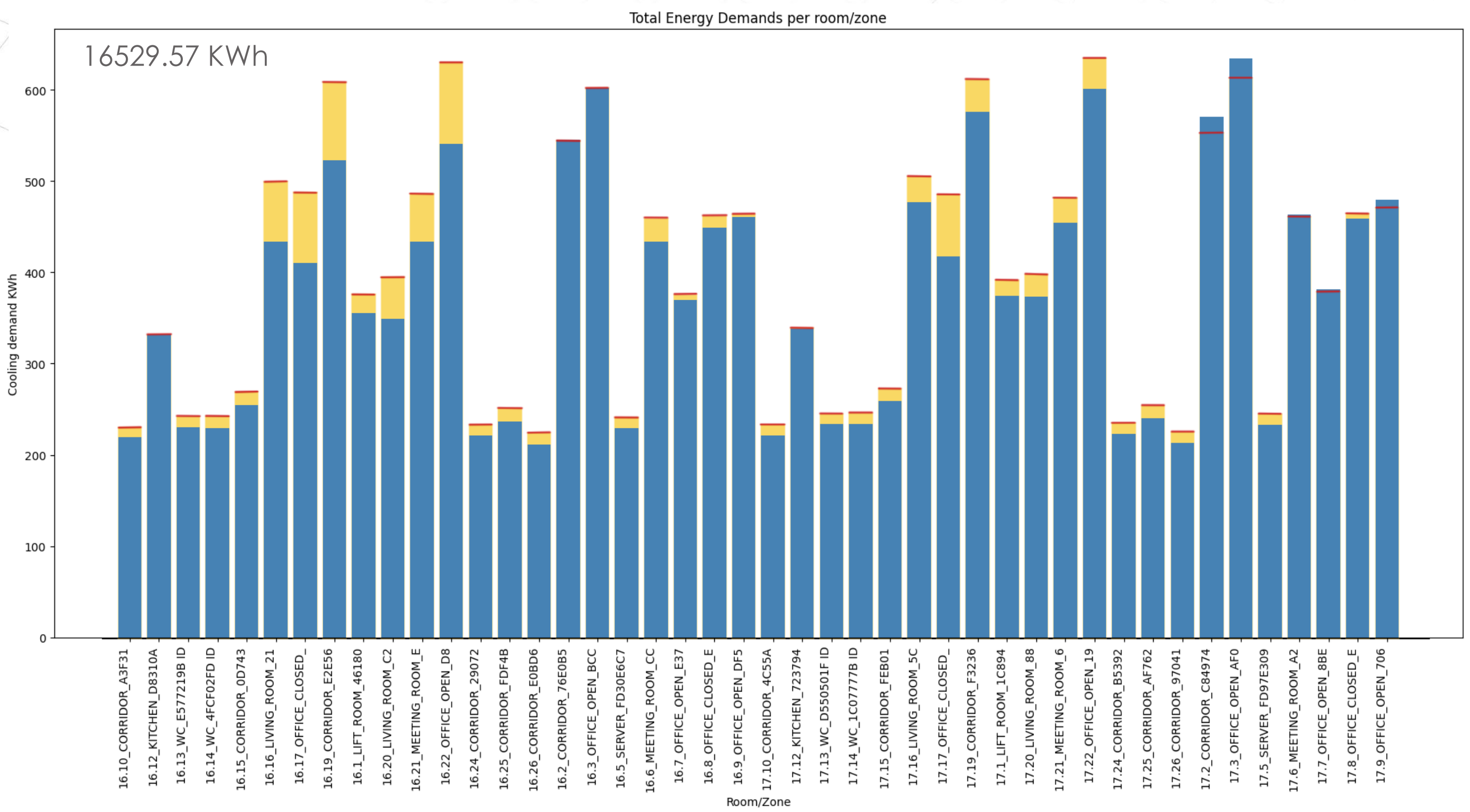
e.h.w= extreme hot week

Simulation results for extreme solutions - Extreme hot week analysis period









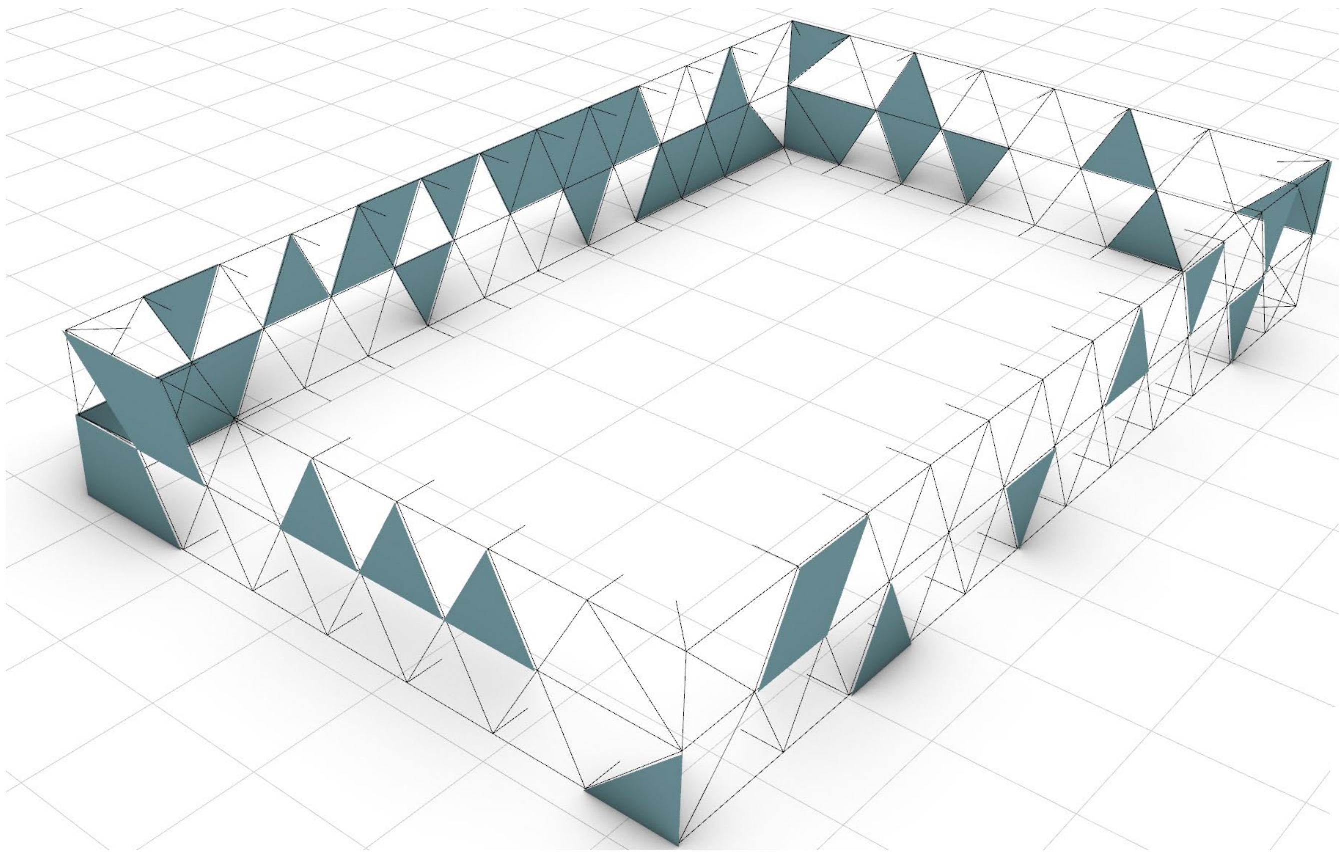
Best solution for maximizing daylight autonomy (Obj4)

For the typical levels under investigation:

Total cooling demands: 16529.57 KWh/ehw

e.h.w= extreme hot week

Simulation results for extreme solutions - Extreme hot week analysis period



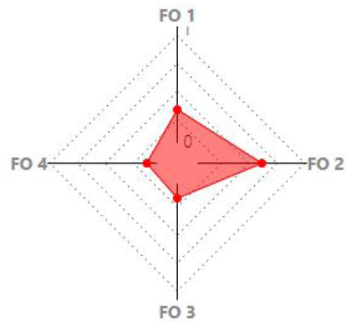
Selected Solution Information
Solution: Gen. 9 | Ind. 15

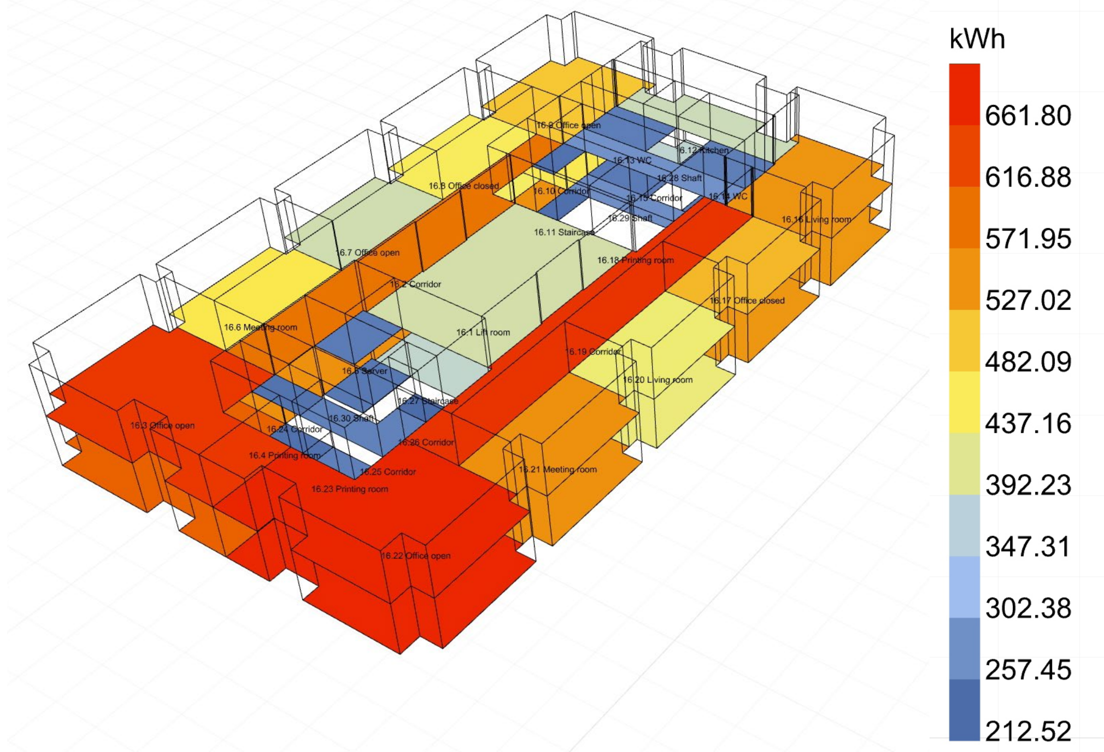
FO1: mass
Fitness Value: 17473.360814
Fitness Rank: 101 / 299

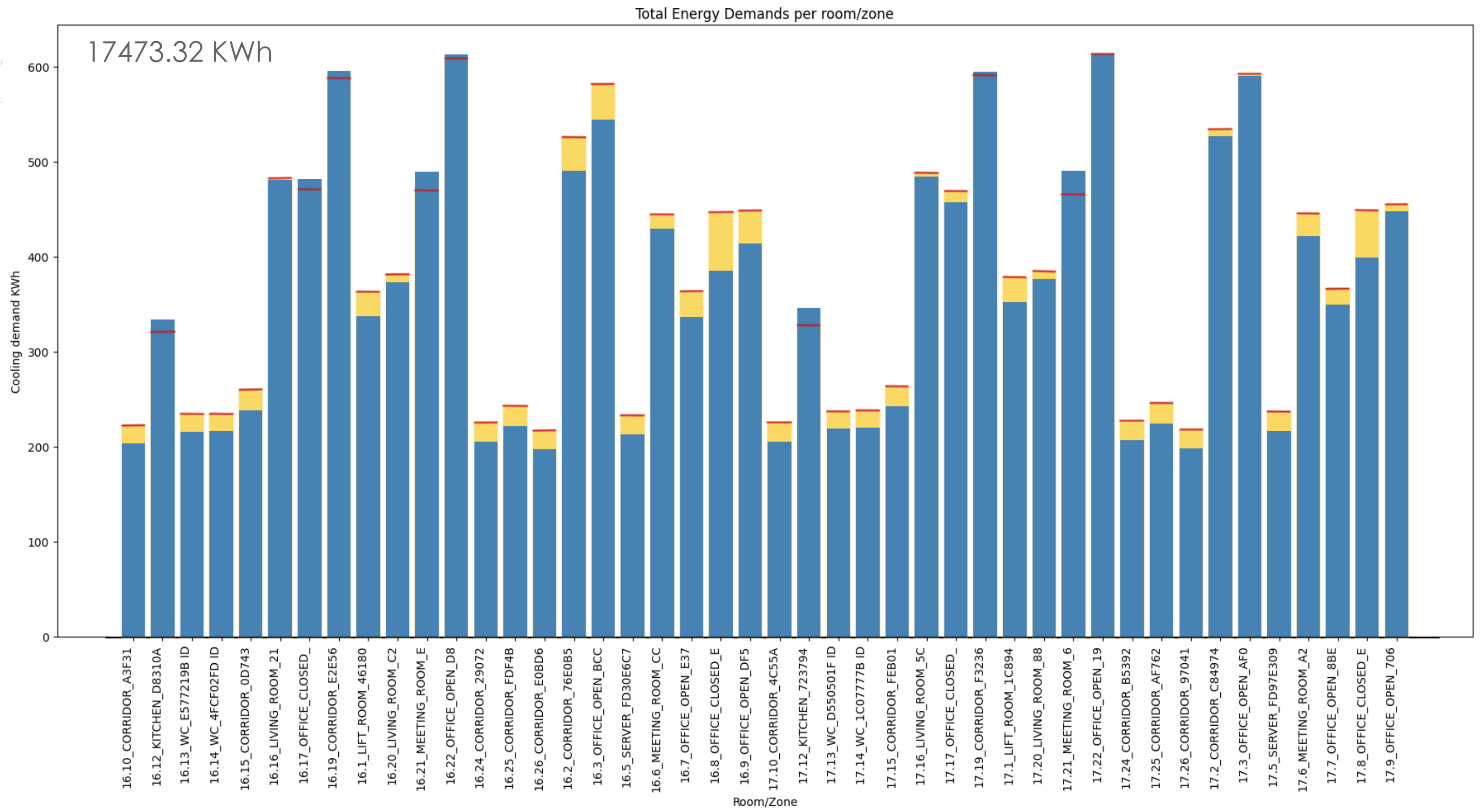
FO2: Displacement
Fitness Value: 0.330033
Fitness Rank: 184 / 299

FO3: Cooling energy
Fitness Value: 59082.176279
Fitness Rank: 51 / 299

FO4: Avr DA
Fitness Value: 0.036398
Fitness Rank: 39 / 299







Not the best solution for all criteria

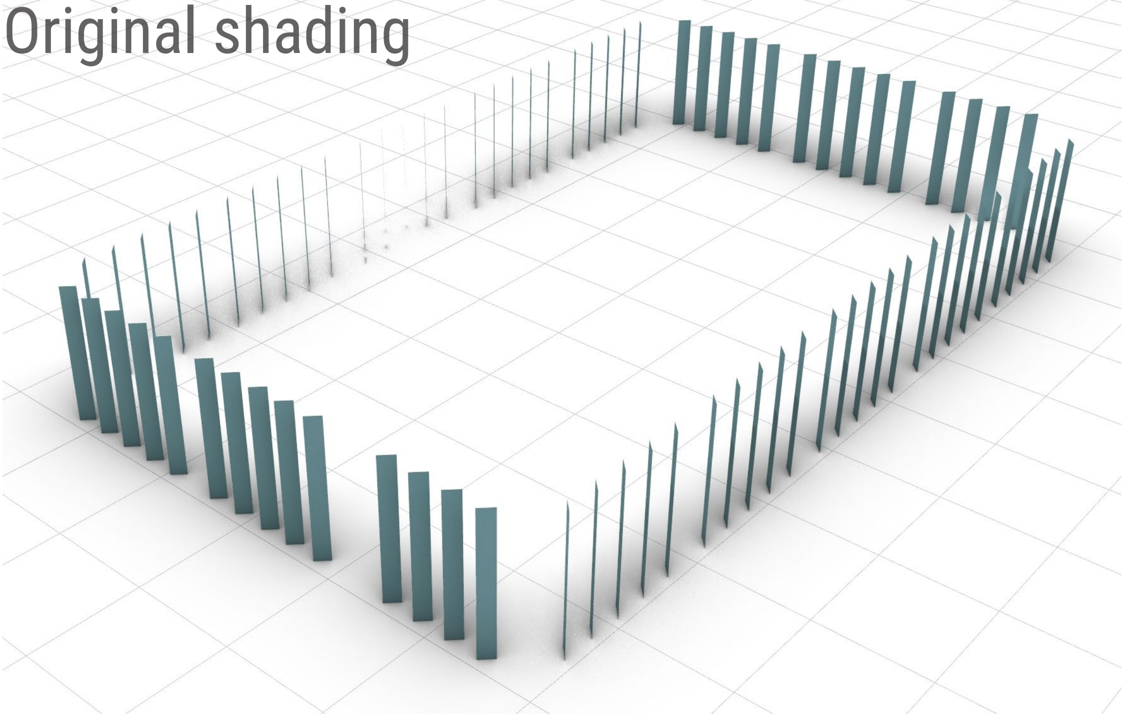
For the typical levels under investigation:

Total cooling demands: 17473.32 KWh/ehw

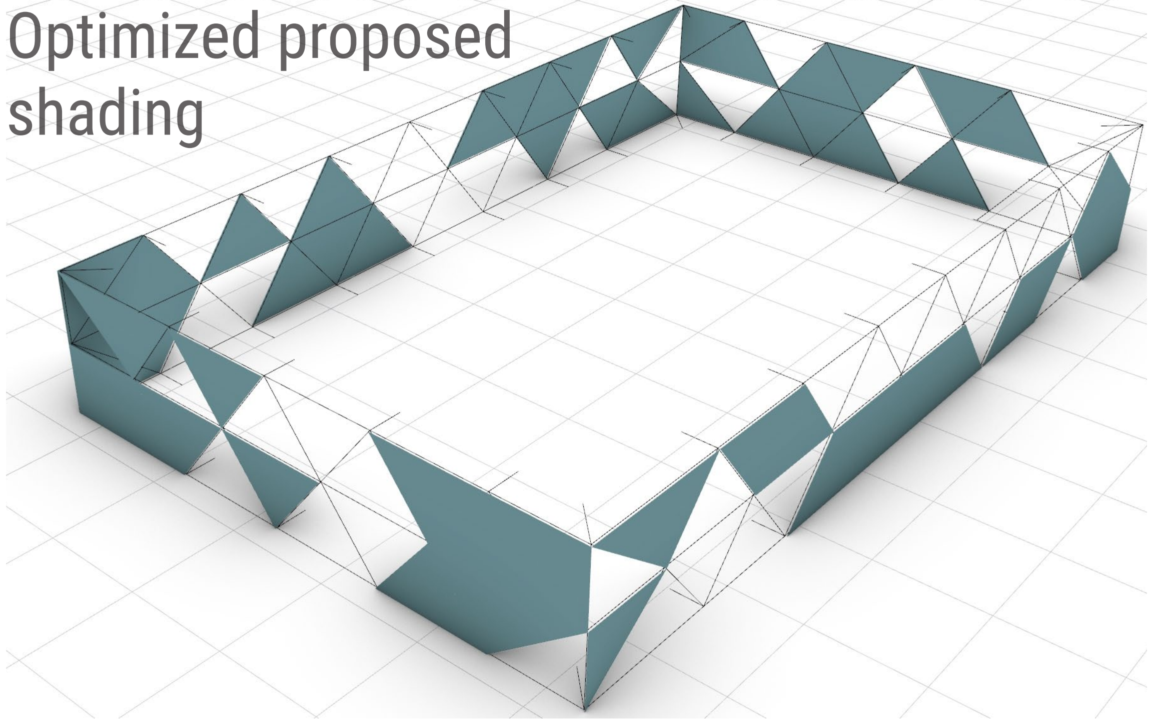
e.h.w= extreme hot week

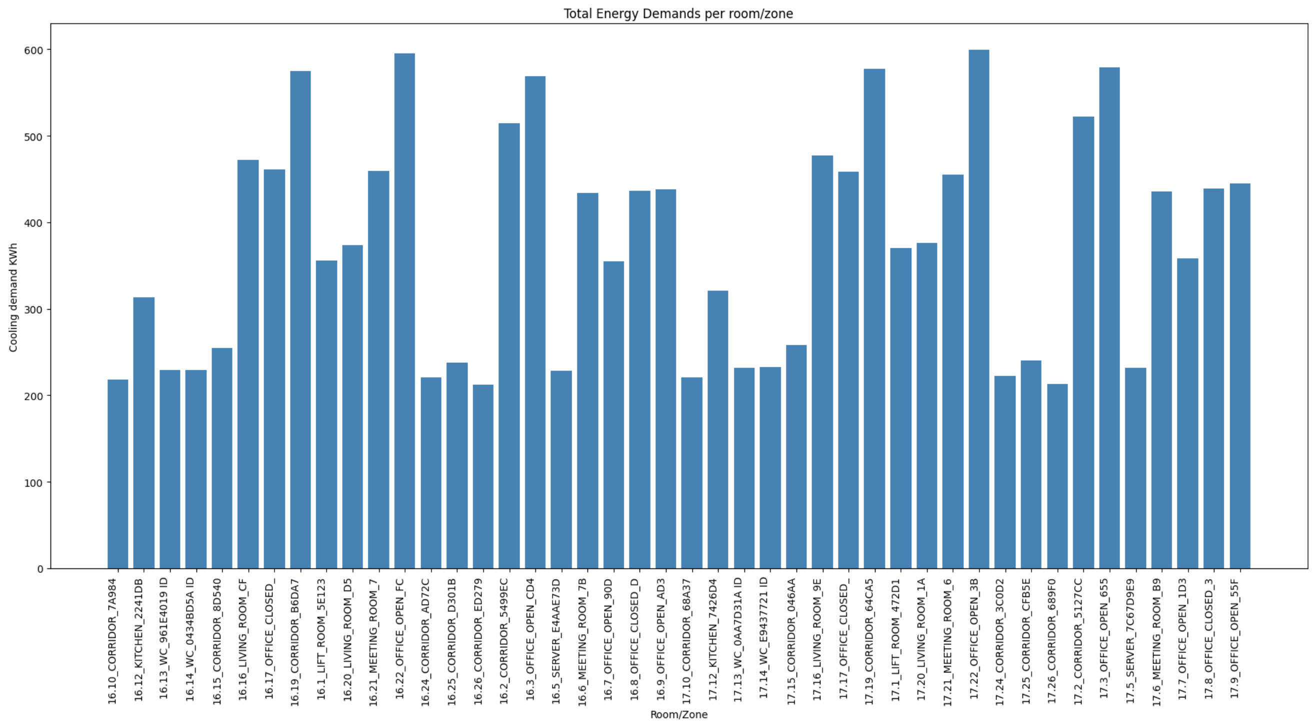
Thermal Resilience enhanced?

Original shading

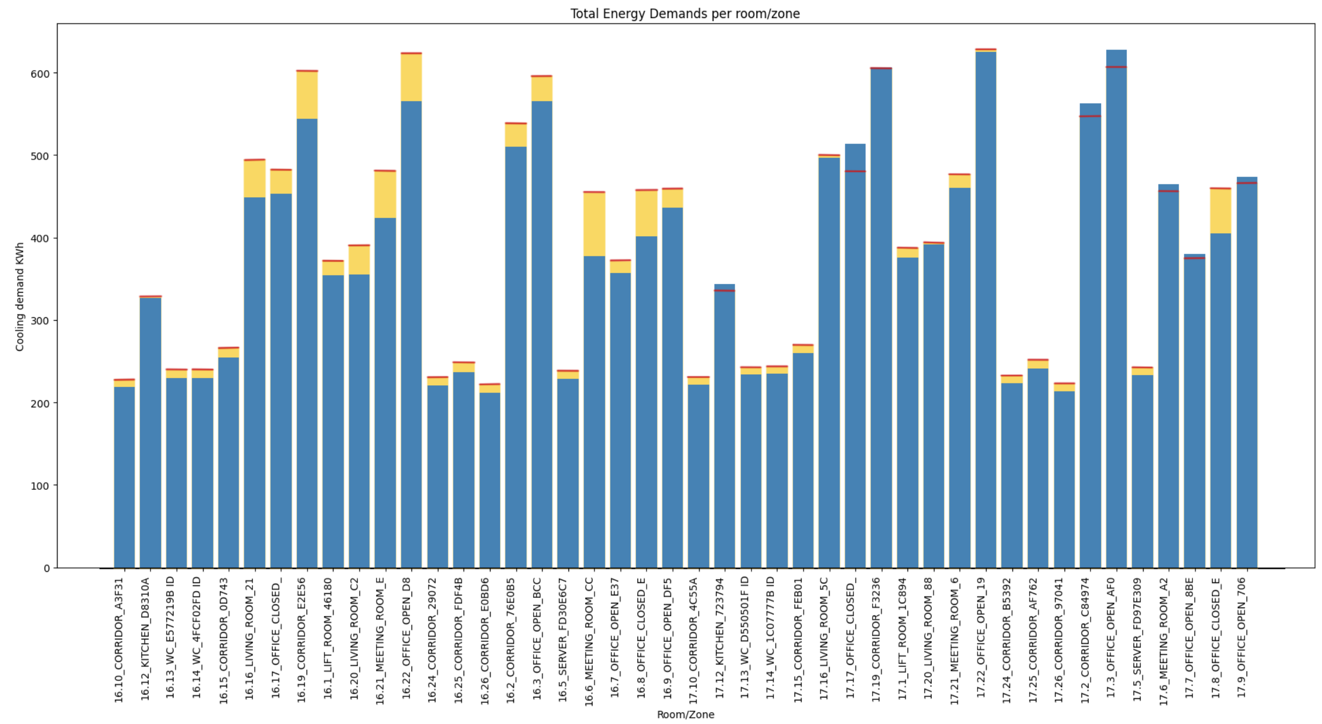


Optimized proposed shading





Total cooling demands: 16449.86 KWh/ehw



Total cooling demands: 16271.06 KWh/ehw

e.h.w= extreme hot week

Workflow conclusions

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Materiality of the shading elements, HVAC system used for mechanical ventilation, future weather data estimation, sensitivity analysis between the energy demand types, cost and the mass of the structure, cross section parametrization, solution filtering, criteria decision trees..... are only some of the possible branches of this workflow.

Design conclusions

Best solution?...

Design conclusions

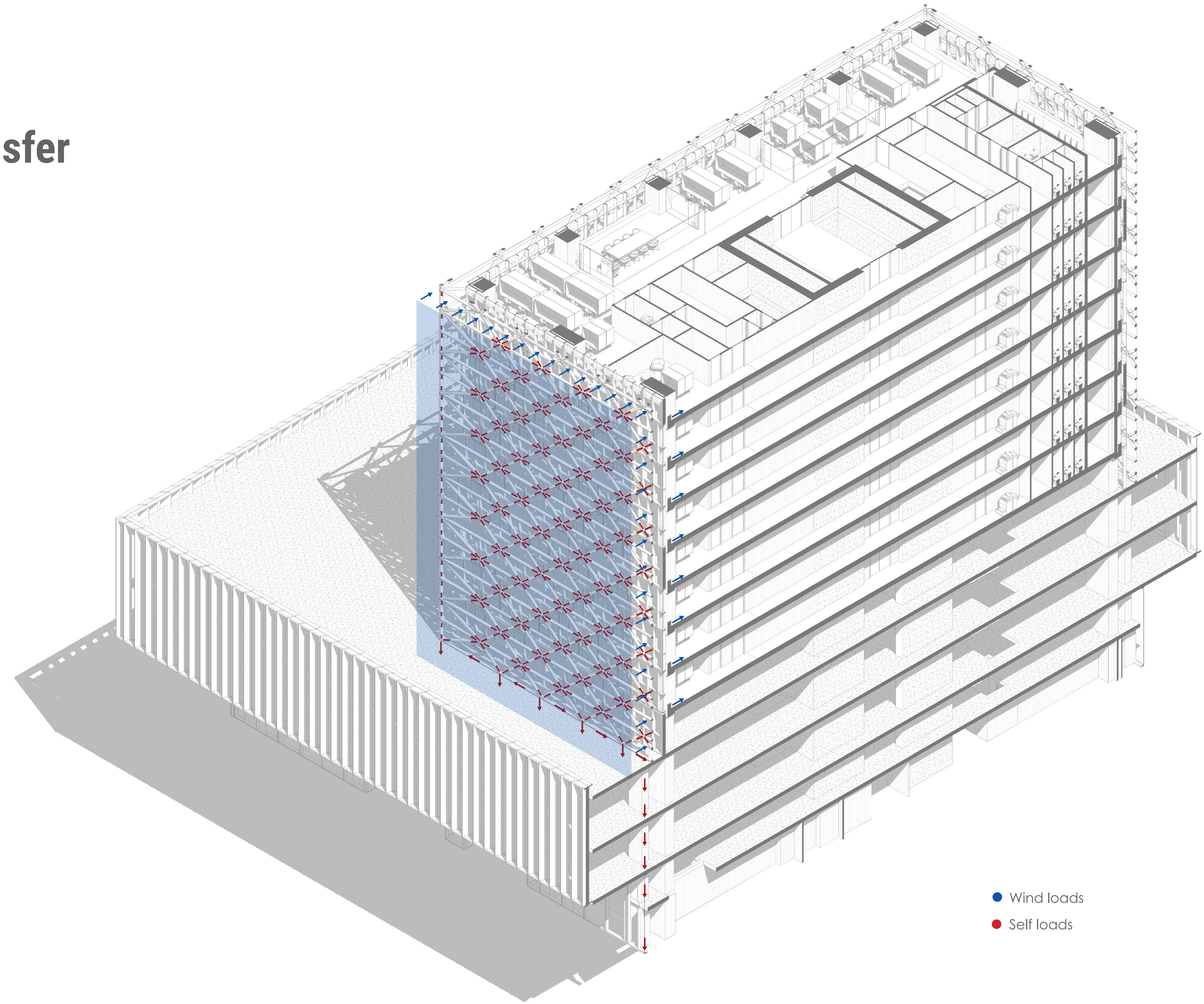
There is no best solution, a perfect solution is always relative to a criterion.

Goals

- To be able to evaluate the energy performance of existing buildings. ✓
- To provide instant interdisciplinary feedback in a design team. ✓
- To improve an existing envelope's energy performance by reducing its cooling demands (with an optimized design). ✓ ✗
- Find the best solution. ✗

Thank you for your attention!

Load transfer



Connections