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

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Problem statement

EUROPE Extreme Maximum Temperature (C) July 9 - 15, 2023



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.

"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).

"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**?"

"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?

"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?

"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?"



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

"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?"



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?

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



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Supporting functions

Detailed supporting functions

	Deviate loads wind loads	\vdash	Create stiffness perpendicular to surface
. –	Deviate impact loads	\vdash	Fix to primary structure of building
	Carry self weight		Integrate joints to allow movement
	Handle loads from structural and thermal expansion		Allow damage free movement
ı	Secure a air and vapour tight construction		Allow vapour tight connection of parts
<u> </u> -L	Secure a rain- and water tightness		Increase vapour barrier properties from inside to outside
	Prevent material deterioration		Incorporate water sealing system
_	Allow exchange of materials and components		Create internal drainage system
	Allow maintenance and cleaning	-	Allow surface treatment
	Consider responsibilities of design team	Ì	Allow constructive protection
	Consider responsibilities of building team	i –	Separate materials when needed
	Create interfaces between different crafts	i –	Allow disconnection
	Define level of standardization	i –	Make façade accessible
<u> </u>	Create sections to limit weight/seize		Allow connection of cleaning machinery
, L	Allow tolerances during assembly		
	Define level of prefabrication		Block radiation
	Control daylight radiation		Let radiation pass
	Control air exchange rate	h	Ventilate excessive heat
' -	Prevent unwanted energy losses	HL	Maintain air tightness
, L	Prevent surface temperature differences		Provide thermal insulation
	Control air exchange rate		
,	Adapt façade to changing climate		
\vdash	Adapt façade to changing climate		
	Add mechanical building services		
	Acoustic insulation of façade plane		
. –	Acoustic insulation of façade plane		
-	Insulation of connection to dividing walls		
	Insulation of floor connection		
	Provide a comfortable daylight level		Create transparent façade areas
\vdash	Provide glare protection	\vdash	Redirect daylight
	Allow visual contact		Provide sun shading

	Adapt to changing climatic conditions	
-	Prevent energy losses	
-	Allow natural lighting of interior	
\vdash	Provide sun protection	
	Adapt according to orientation of building	
_	Reduced material quantities	
<u> </u>	Choose materials with low impact	
_	Minimize spatial distances in the supply chain	
-	Allow production with low use of energy	
	Allow separation of components	
	Choose recyclable materials	
	Collect solar thermal energy	
	Collect solar energy	
_	Include thermal mass	
	Include components for artificial thermal mass	
_	Protect against fire	
	Prevent structural damage	
	Protect against attacks from the	
	Protect against toxic loads	
	Protect against falling out of the window	
_	Provide good handling for the end user	
	Allow for facility management	
_	Monitor façade performance	
	Ensure Low running costs	
	Guarantee energetic performance	
	Service and cleaning of components	Γ
	Bridge knowledge gap between stakeholders	F
	Allow architectural variety	ŀ
	Support architectural design intentions throughout process	
_	Choose appropriate materials and technologies (meaning)	-
	Arrange components spatially	+
	Design visual, acoustic, haptic perception	

-	Induce arrangement
_	Induce shape
_	Induce proportion
	Induce scale
-	Apply texture
-	Apply colour
-	Apply material
_	Induce rhythm



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Literature review

+

- Lightweight
- Durable
- 100% Recyclable

- 100% manmade
- toxic ingredients
- 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

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 definition of a larger amount of design options and their evaluation

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NSGA II algorithm - niching approach

Walacei



Revit-Grasshopper integration

Energy simulation workflow

• Shading system definition

• Static analysis





Revit-Grasshopper integration

Energy simulation workflow

• Shading system definition

• Static analysis











Multi-objective optimization





Multi-objective optimization





Multi-objective optimization

Actual Workflow





Static analysis









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BIM model - Piraeus Tower





BIM model - Rooms definition

Revit-Grasshopper integration

BIM model - Bearing structure



Exsiting facade system



Exsiting facade system



Energy model geometry



Revit-Grasshopper integration

• rooms geometry



- curtain wall
- walls
- beams
- columns
- slabs

Energy model assembly



Energy simulation workflow Revit-Grasshopper integration

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.



Shading system design



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





























Static analysis loads



Static analysis cross section



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

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



Static analysis loads



Static analysis



Static analysis results



Axial forces calculation

Bending moments calculation



Static analysis for whole structure



Axial forces calculation

Supports and reactions

Multi-objective optimization parameters



parameter 1: diagrid scale



parameter 3: diagrid offset



parameter 2: width to height ratio



parameter 4: amount of shading

Multi-objective optimization objectives

objective 1: Total mass [kg]



objective 2: Maximum displacement [cm]



Multi-objective optimization

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Multi-objective optimization workflow



parameter	Gene
parameter	Gene
parameter	Gene
parameter	Gene

	objective
ze	objective
mize	objective
mize	objective

Multi-objective optimization solution space





Multi-objective optimization objective values trends



Multi-objective optimization

Multi-objective optimization results clustering in Wallacei





Multi-objective optimization results export



Multi-objective optimization results export

		-
	-	
F F F		
		× 1 1 1 1 1 1
Gen: 5 Ind: 0	Gen: 12 Ind: 3	Gen: 13 Ind: 1
FV. 1 : 183346.060207	FV. 1 : 199551.6279	FV. 1 : 170801.572151
FV. 2 : 0.186567	FV. 2 : 0.158983	FV. 2 : 0.21645
FV. 3 : 61266.096198	FV. 3 : 48447.522537	FV. 3 : 46748.74075
FV. 4 : 0.010519	FV. 4 : 0.101092	FV. 4 : 0.08328



Simulation results for original facade - Extreme hot week analysis period







For the typical levels under investigation:

Total cooling demands: 16449.86 KWh/ehw

Multi-objective optimization results



Revit-Grasshopper integration Energy simulation workflow

Shading system definition

Static analysis

Multi-objective optimization

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Simulation results for extreme solutions - Extreme hot week analysis period



Simulation results for extreme solutions - Extreme hot week analysis period


Simulation results for extreme solutions - Extreme hot week analysis period

FO1: mass

FO4: Avr DA





Best solution for minimizing cooling demands (Obj3)

For the typical levels under investigation:

Total cooling demands: 16271.06 KWh/ehw



Simulation results for extreme solutions - Extreme hot week analysis period



Simulation results for extreme solutions - Extreme hot week analysis period





Total cooling demands: 16449.86 KWh/ehw

Optimized proposed shading



Total cooling demands: 16271.06 KWh/ehw

e.h.w= extreme hot week



The cross section selected allowed minimal range for displacement values making it an objective with relatively small influence on the solutions generated.

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Filtering solutions and identifying their position in the design space is not possible in the current workflow.

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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!



Connections

