17 May 2024

COMPUTATIONAL OPTIMIZATION OF HEMPCRETE INTEGRATION

IMPROVING ENERGY PERFORMANCE AND MINIMIZING EMBODIED ENERGY IN A VARIETY OF BUILDING TYPES AND CLIMATES

By Dimitra Mountaki

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TU Delft

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Introduction

- Background
- Problem Statement
- Objectives
- Research question
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Background

34% overall energy

The building environment consumes 34 % of total final energy

37% CO_2

37% of the global operational energy and process-related CO_2 emissions

3.5 $GtCO_2$

It has approximately 9% of total global emissions

(United Nations Environment Programme, 2022a)

02 Problem of Statement

What is the problem in society?
Climate change and increased global emissions

How to minimize the problem?
Reduce operational energy on building sector and use biobased materials

What exist?
Studies focusing on energy consumption, global warming potential or early design methods

The lack of computational methods that combines strategies to minimize operational energy and global warming potential to support preliminary designs with hempcrete.

03 Objectives

DEVELOP AN EFFICIENT OPTIMIZATION WORKFLOW FOR ENERGY AND ECO-EFFICIENT HEMPCRETE STRUCTURES TO BE USED IN THE INITIAL PHASE OF DESIGN

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Map the different parameters that mostly influence the design with hempcrete in a variety of climates and functions.

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Map the different parameters that mostly influence the design with hempcrete in a variety of climates and functions.

Examine if different hempcrete compositions can have a significant effect on the energy optimization or the layout.

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DEVELOP AN EFFICIENT OPTIMIZATION WORKFLOW FOR ENERGY AND ECO-EFFICIENT HEMPCRETE STRUCTURES TO BE USED IN THE INITIAL PHASE OF DESIGN

Map the different parameters that mostly influence the design with hempcrete in a variety of climates and functions.

Examine if different hempcrete compositions can have a significant effect on the energy optimization or the layout.

Develop a tool to explore different layout options with hempcrete in every circumstance, to reduce time and cost in early design stages

How can a computational method optimize hempcrete's integration in various type of buildings across diverse climates, with the objective to support preliminary designs that achieve high energy performance and minimize global warming potential?

04 Research questions

Hempcrete

- How can multi-objective optimization identify the ideal hempcrete composition for thermal conductivity in different climates?
- Which ways can a workflow define the impact of hempcrete thickness on thermal and visual comfort in buildings across different regions?
- How may operational energy and global warming potential optimization influence hempcrete thickness in different contexts?

- How can a computational workflow be used to establish a balance between energy efficiency and occupants comfort preferences, in hempcrete buildings?
- In which way can this workflow be evolved into a useful tool for reducing the required time during the first design stages and promote the use of hempcrete?

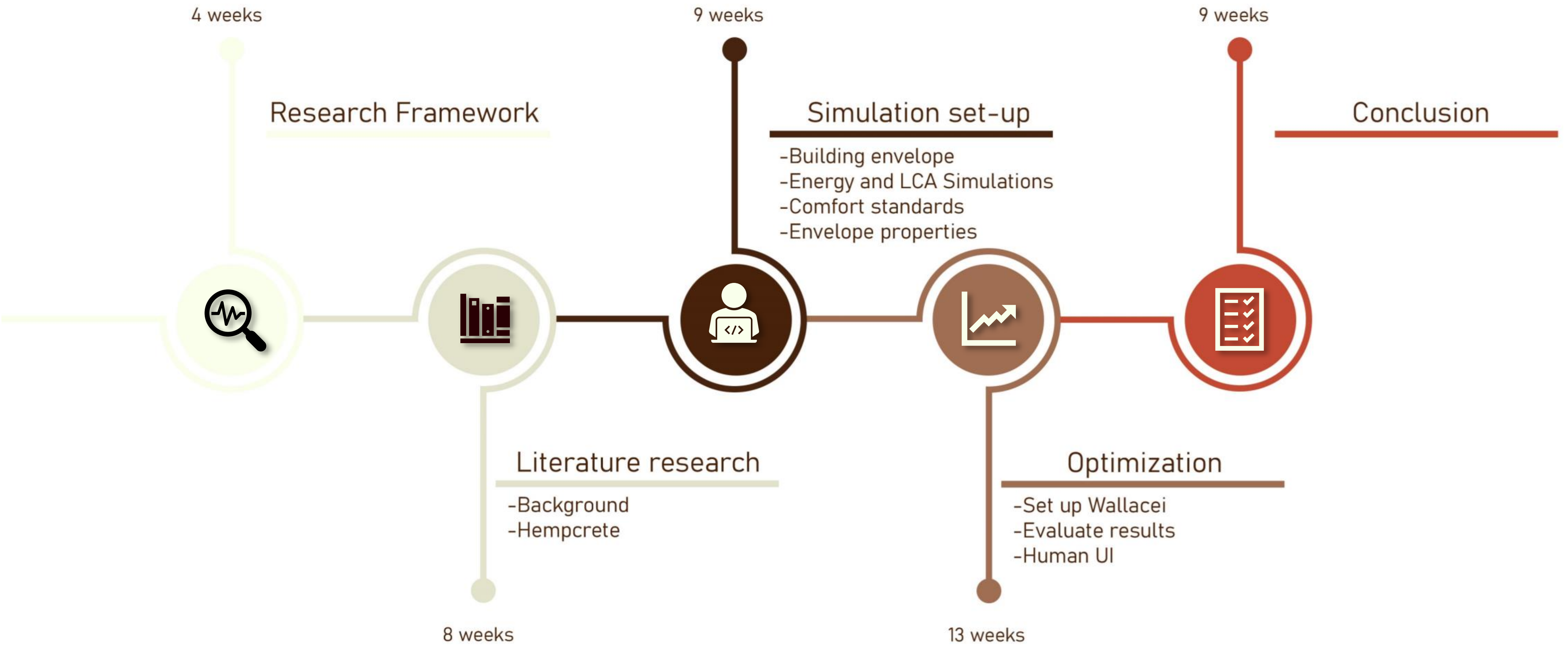
04 Research questions

- How can multi-objective optimization identify the ideal hempcrete composition for thermal conductivity in different climates?
- Which ways can a workflow define the impact of hempcrete thickness on thermal and visual comfort in buildings across different regions?
- How may operational energy and global warming potential optimization influence hempcrete thickness in different contexts?

Workflow results

- How can a computational workflow be used to establish a balance between energy efficiency and occupants comfort preferences, in hempcrete buildings?
- In which way can this workflow be evolved into a useful tool for reducing the required time during the first design stages and promote the use of hempcrete?

05 Timeline


4 weeks
Research Framework
8 weeks
Literature research
-Background
-Hempcrete
9 weeks
Simulation set-up
-Building envelope
-Energy and LCA Simulations
-Comfort standards
-Envelope properties
13 weeks
Optimization
-Set up Wallacei
-Evaluate results
-Human UI
9 weeks
Conclusion

02

Hempcrete

- Background
- Hempcrete use
- Lifecycle analysis
- Existing studies

01 Background

Hempcrete is a bio-aggregate-based material, made by combining hemp shives (the chopped stem core) with a lime-based binder and water (Allin, S., 2012).

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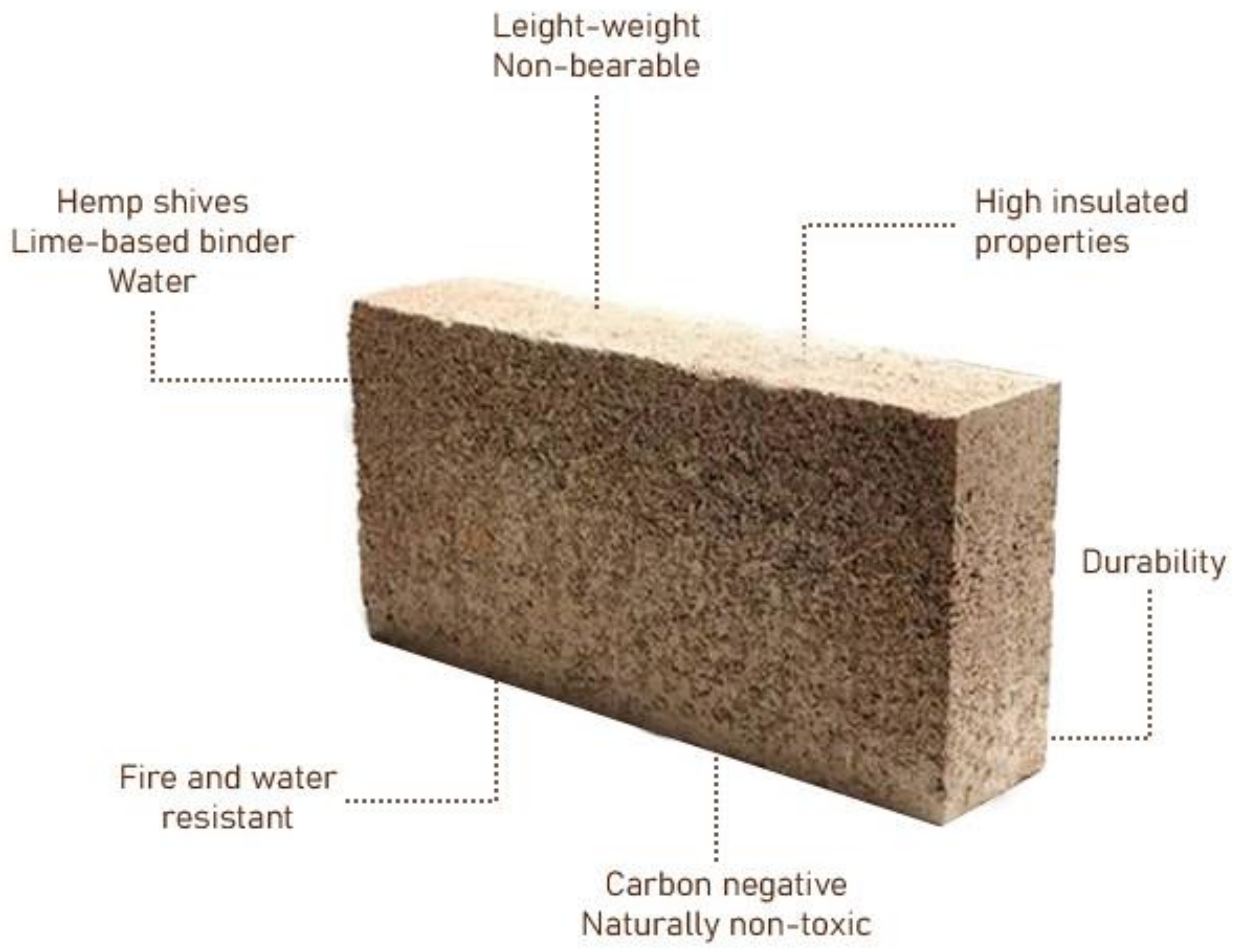
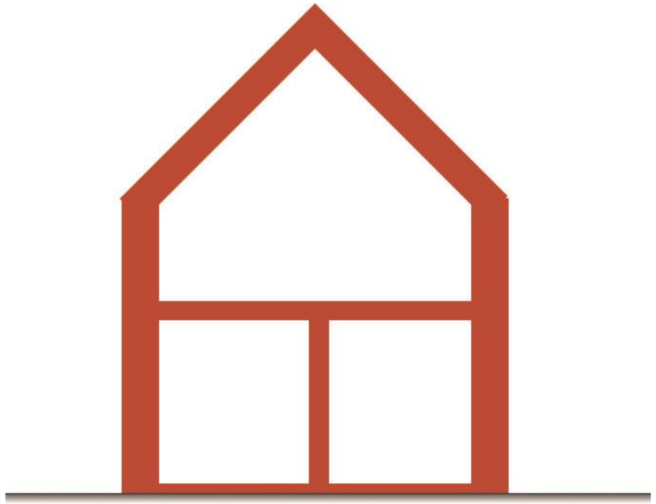


02 Hempcrete use



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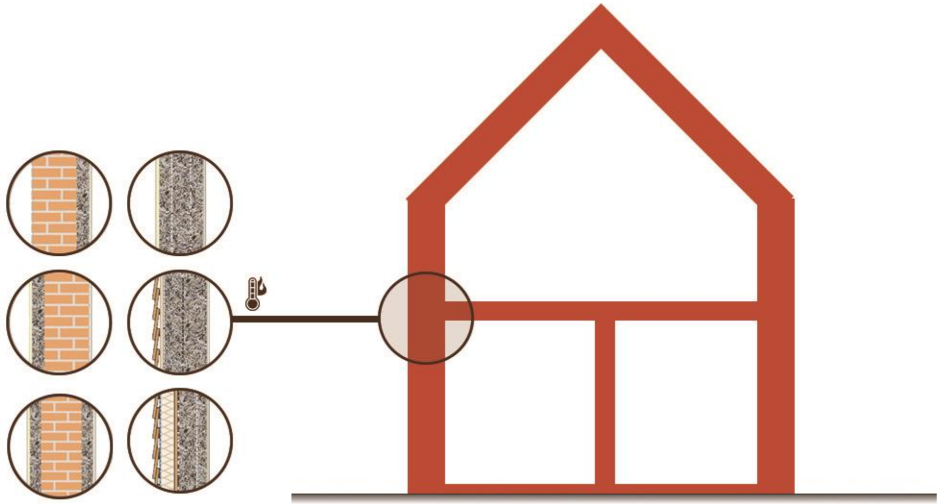

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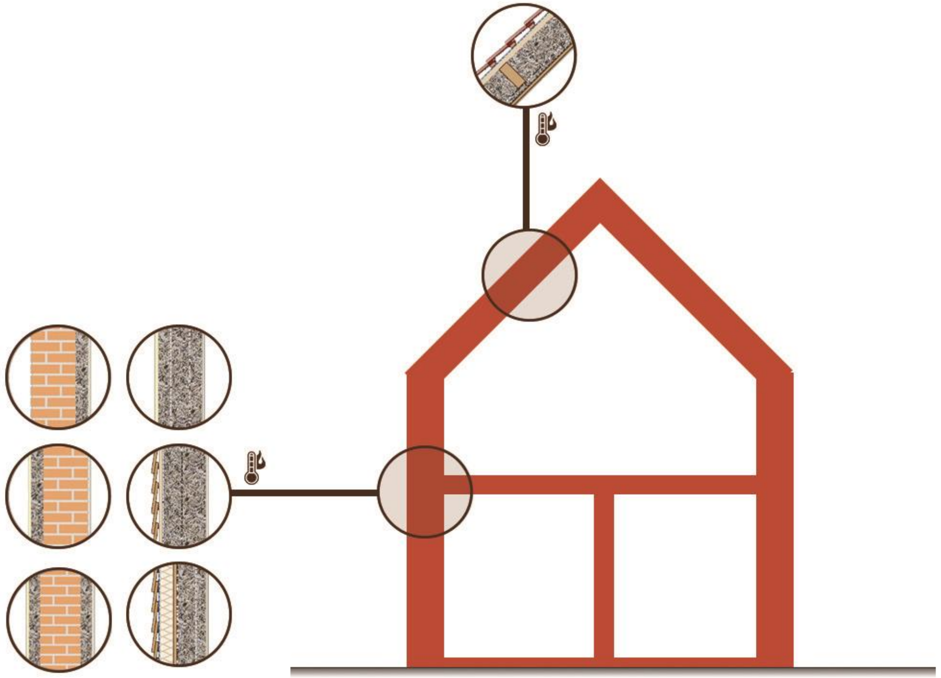

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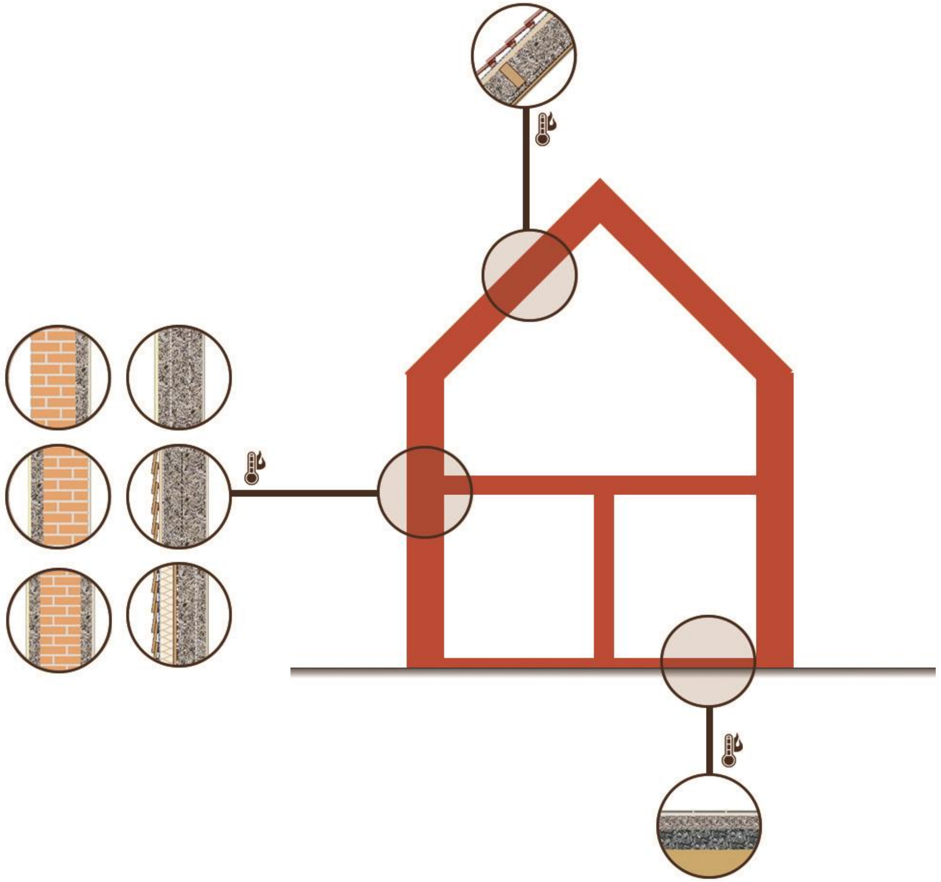
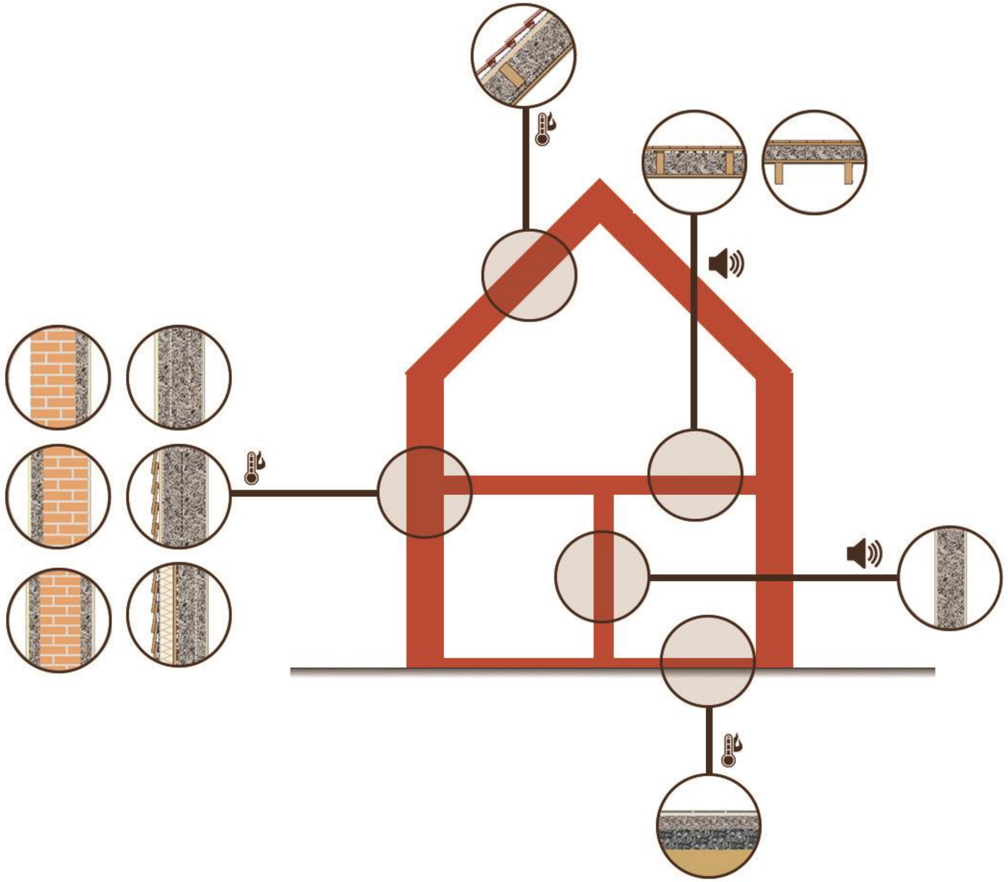


02

Hempcrete use



Lifecycle analysis

1MJ/kg

Embodied energy is relatively low for hemps production

0.3-1.0KgCO2/kg

The overall embodied carbon of hempcrete with lime's emissions

100 years lifespan

Hempcrete had a long-lifespan and is durable

Overall hempcrete is considered **carbon negative** since it absorbs more carbon dioxide that it emits during manufacture in use in 100 years

Bas et al., 2022b; Essaghouri et al., 2023b; Florentin et al., 2017b; Pandian et al., 2023; Vontetsianou, 2023b).

04 Existing studies

Research on its properties:
- Mechanical
- Thermal
- Hygroscopicity
- Regulatory framework

Research on hempcrete's behavior on buildings:
- Insulated properties
- Comparison with traditional materials
- Life-cycle analysis

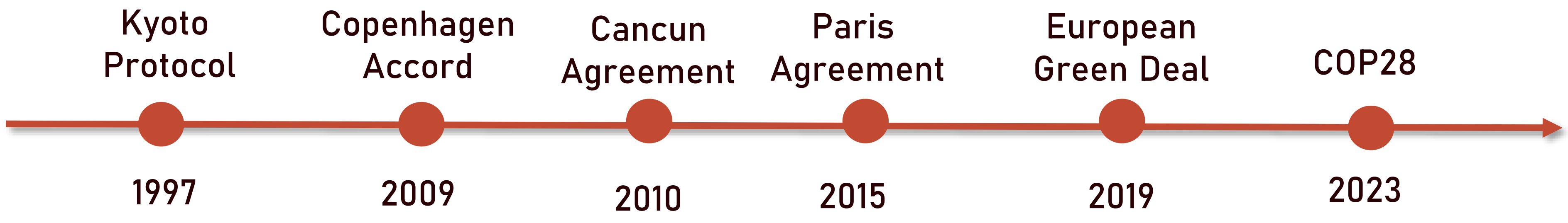
Hempcrete optimization:
- Climate optimization
- Thickness optimization
- Energy efficient buildings

03

Energy demand and comfort

- Background
- Climate data
- Comfort standards
- Global warming potential

01 Background



Reference: International treaties for climate change. Figure created by the author

02 Climate data

SSP2-4.5: max 2.7°C

03 Comfort and Energy standards

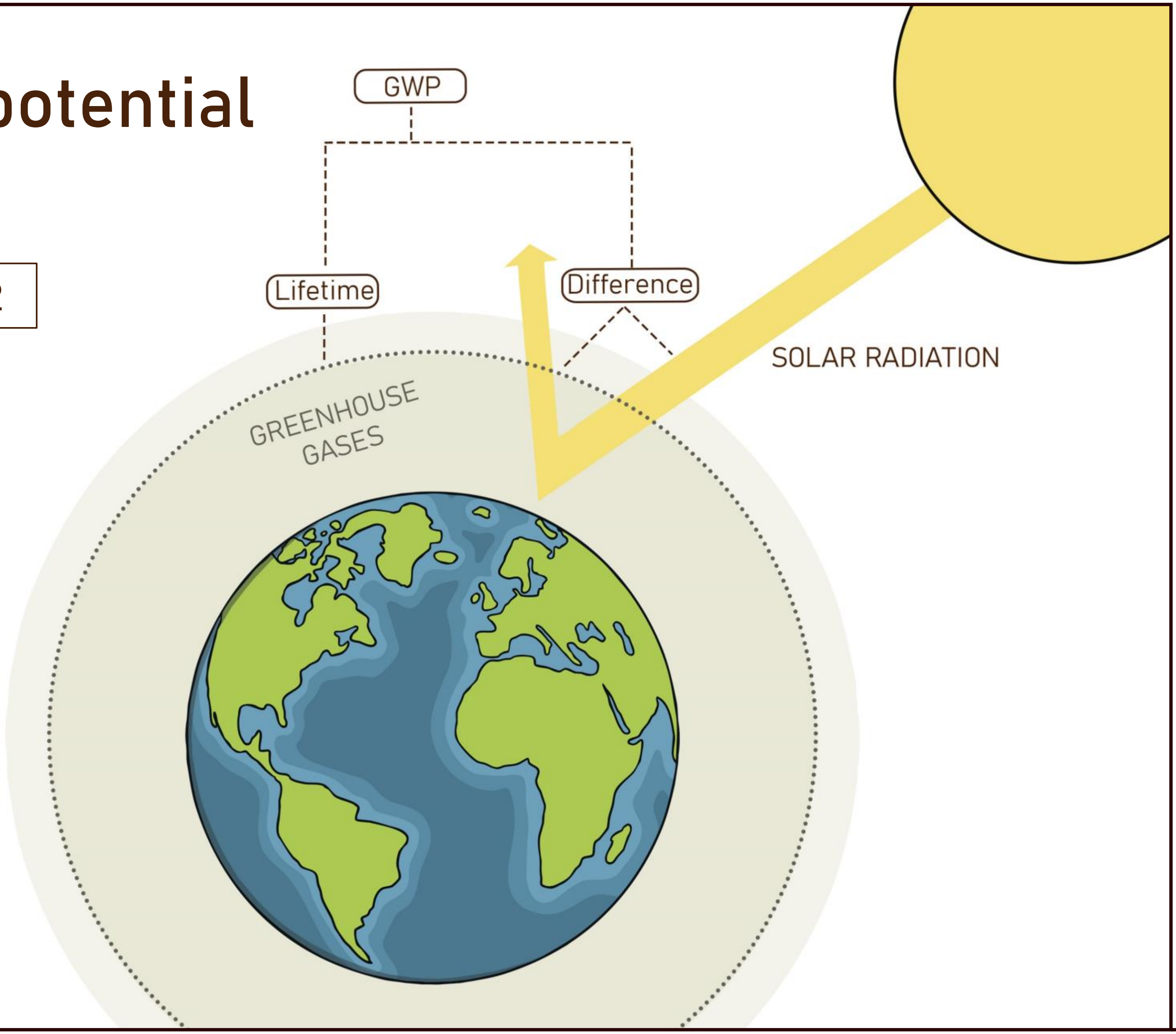
Function	Energy requirement [kWh/m2yr]	Primary fossil energy [kWh/m2yr]	Share of renewable [%]	Avg. Illuminance [lux]	Min. area to comply [%]	Ventilation rates [l/s]	Indoor ambient noise level [dB]
Residential	65*	50	40	>100 lux for 3450 h/year	100	7 (II), 10 (I)	35-40
Office	90*	40	30	>300 lux for 2000 h/year	80	14 (II), 20(I)	40-50
Accommod ation	100*	130	40	>100 lux for 3450 h/year	80	7 (II), 10 (I)	35
Retail	70*	60	30	>300 lux for 2650 h/year	80	14 (II), 20(I)	50-55

(Rijksdienst voor Ondernemend Nederland, 2012, BREEAM, 2016)

04 Global warming potential

1ton Gas over 100years = x * 1ton CO2

The larger the GWP, the more that a given gas warms the Earth compared to CO_2 over that time period.



04

Building Overview

- Optimization objectives
- Design parameters
- Envelope

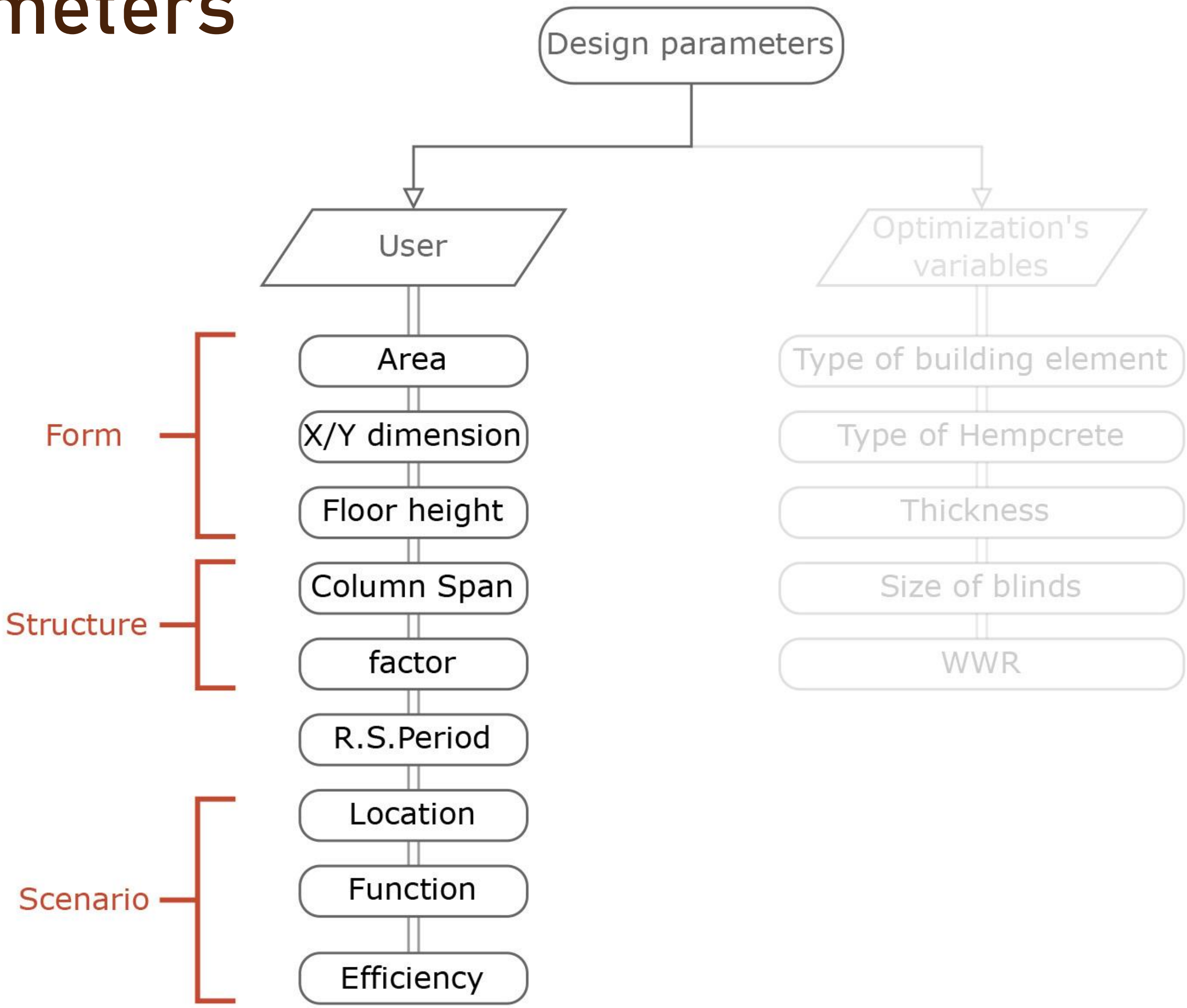
01 Optimization objectives

Increase energy performance
Yearly heating, cooling, lighting and equipment is evaluated

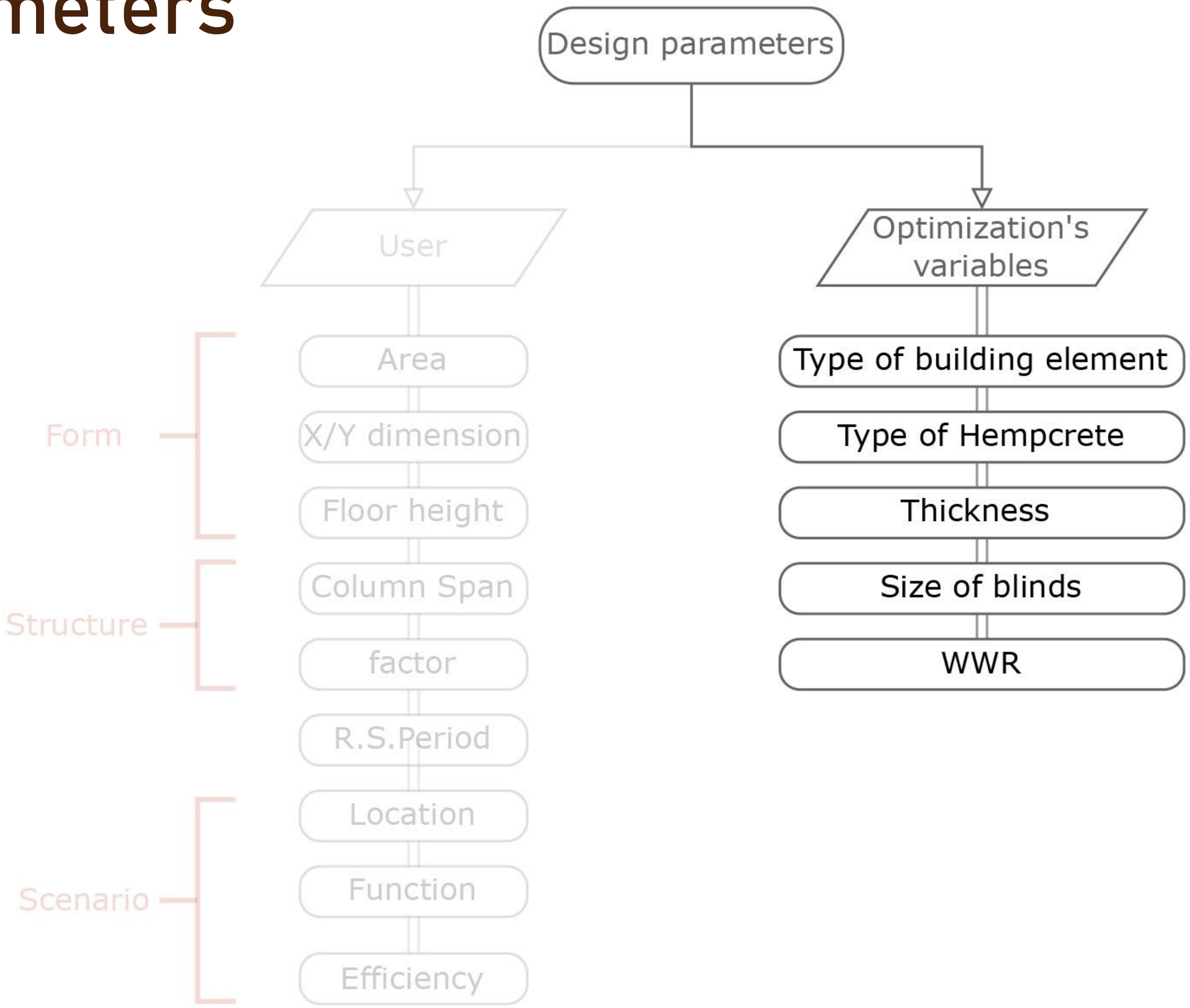
Improve daylight
Maximize usable daylight to achieve BREEAM standards

Minimize global warming potential (GWP)
GWP and primary energy due to the material is calculated

02 Design parameters



02 Design parameters



03 Envelope (Material)

HEMPCRETE 1

- ρ=440 kg/m3
- Porosity (ε_0)= 0.73
- Th. Capacity (Cpo)=1560J/kgK
- Th. Conductivity (λ_0) = 0.115W/mK

(Evrard De Herde, 2009)

HEMPCRETE 2

- ρ=480 kg/m3
- Porosity (ε_0)= 0.71
- Th. Capacity (Cpo)=1550J/kgK
- Th. Conductivity (λ_0) = 0.11W/mK

(Evrard, Arnaud Herde, André 2005)

HEMPCRETE 3

- ρ=405 kg/m3
- Porosity (ε_0)= 0.83
- Th. Capacity (Cpo)=1500J/kgK
- Th. Conductivity (λ_0) = 0.073W/mK

(Pierre et al., 2013)

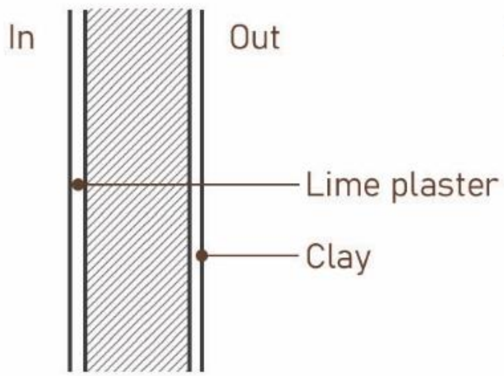
HEMPCRETE 4

- ρ=398 kg/m3
- Porosity (ε_0)= 0.78
- Th. Capacity (Cpo)=1500J/kgK
- Th. Conductivity (λ_0) = 0.094W/mK

(Pierre et al., 2013)

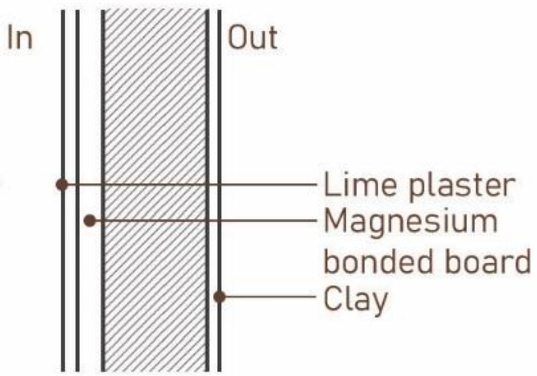
03 Envelope (Building elements)

1



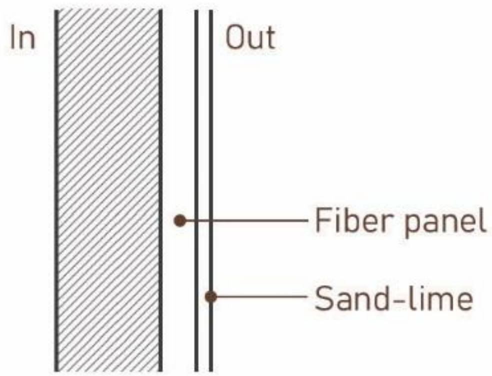
(Vontetsianou, 2023)

2



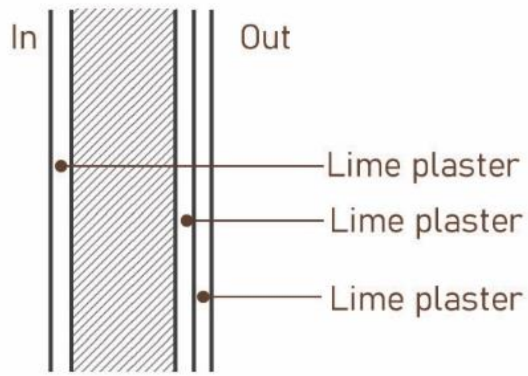
(Townhall Voorst, 2023)

3



(Batylab Datasheet)

4

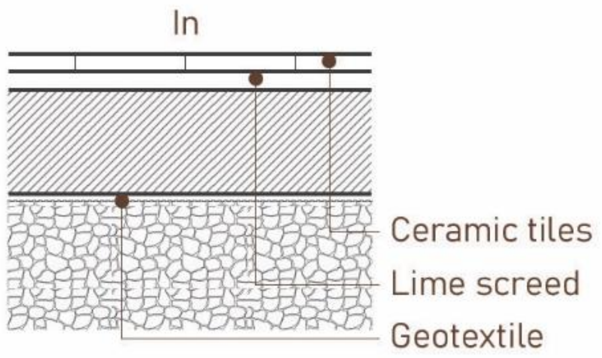


(Tradical Datasheet)

External wall

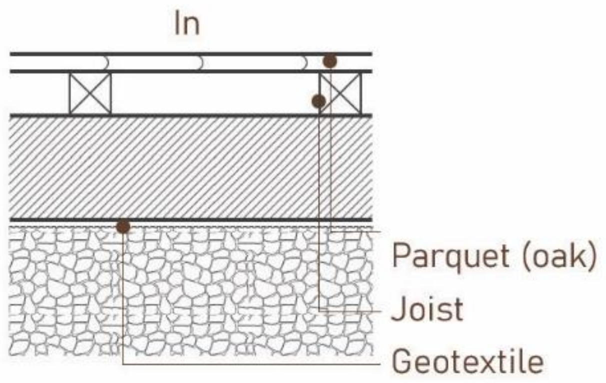
03 Envelope (Building elements)

1



(Saint-Astier Datasheet)

2

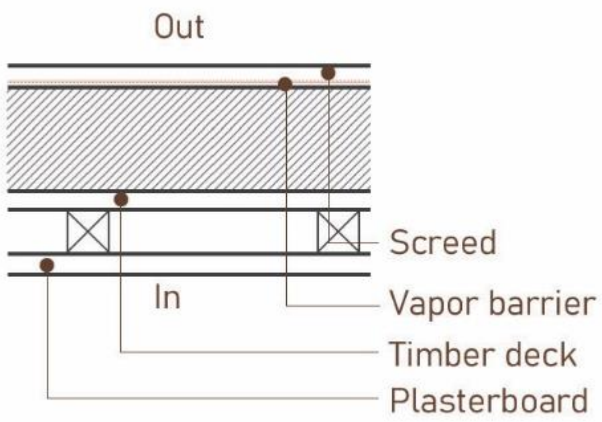


(Saint-Astier Datasheet)

Ground floor

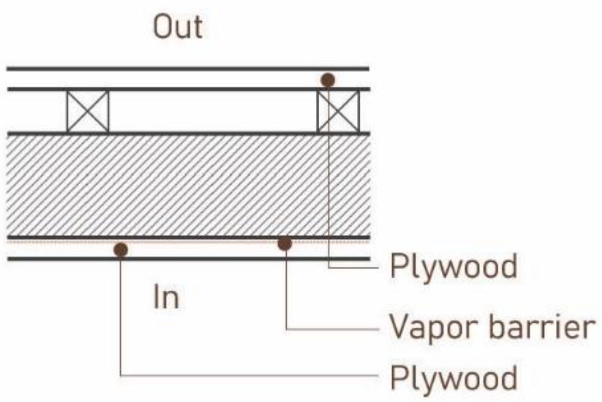
03 Envelope (Building elements)

1



(Nhbc, 2024)

2

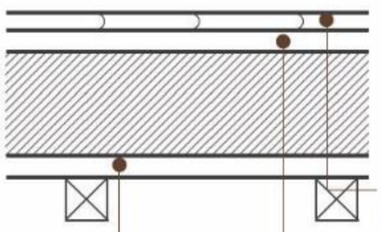


(Nhbc,2024)

Flat roof

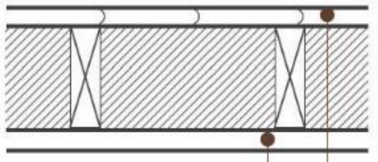
03 Envelope (Building elements)

1



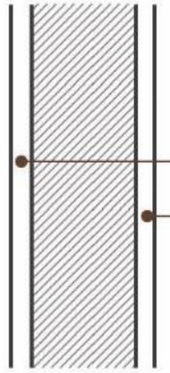
(Tradical Datasheet)

2



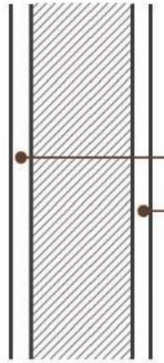
(Tradical Datasheet)

1



(Vontetsianou,2023)

2



(Vontetsianou,2023)

Internal elements + Glazing

03 Envelope (Function parameters)

Function	People /Area (m2/pp)	Lighting (Watt/m2)	Equipment (W/m2)	Infiltration (m3/s per m2)	Schedule	Category	Cool Setpoint (°C)	Heat Set Point (°C)	Humid. Set point (%)
Residential	28.3	3	3	0.001	Varies*	I	26	20	25
Residential	28.3	3	3	0.001	Varies*	II	26	20	25
Accommodation	15	3	5	0.001	Varies*	I	25	21	30
Accommodation	15	3	5	0.001	Varies*	II	25	21	30
Office	12	10	8	0.001	Varies*	-	26	20	25
Retail	17	25	1	0.001	Varies*	-	25	16	25

(EN 16798-1:2019 , 2019)

05

Simulation Setup

- Performance driven architecture
- Performance simulation
- Workflow overview
- Form generation
- Energy simulation setup
- LCA simulation setup
- Optimization
- Final visualization

01 Performance driven architecture

When it started?

The concept was on 1970s but acquired popularity at the end of 20s century.

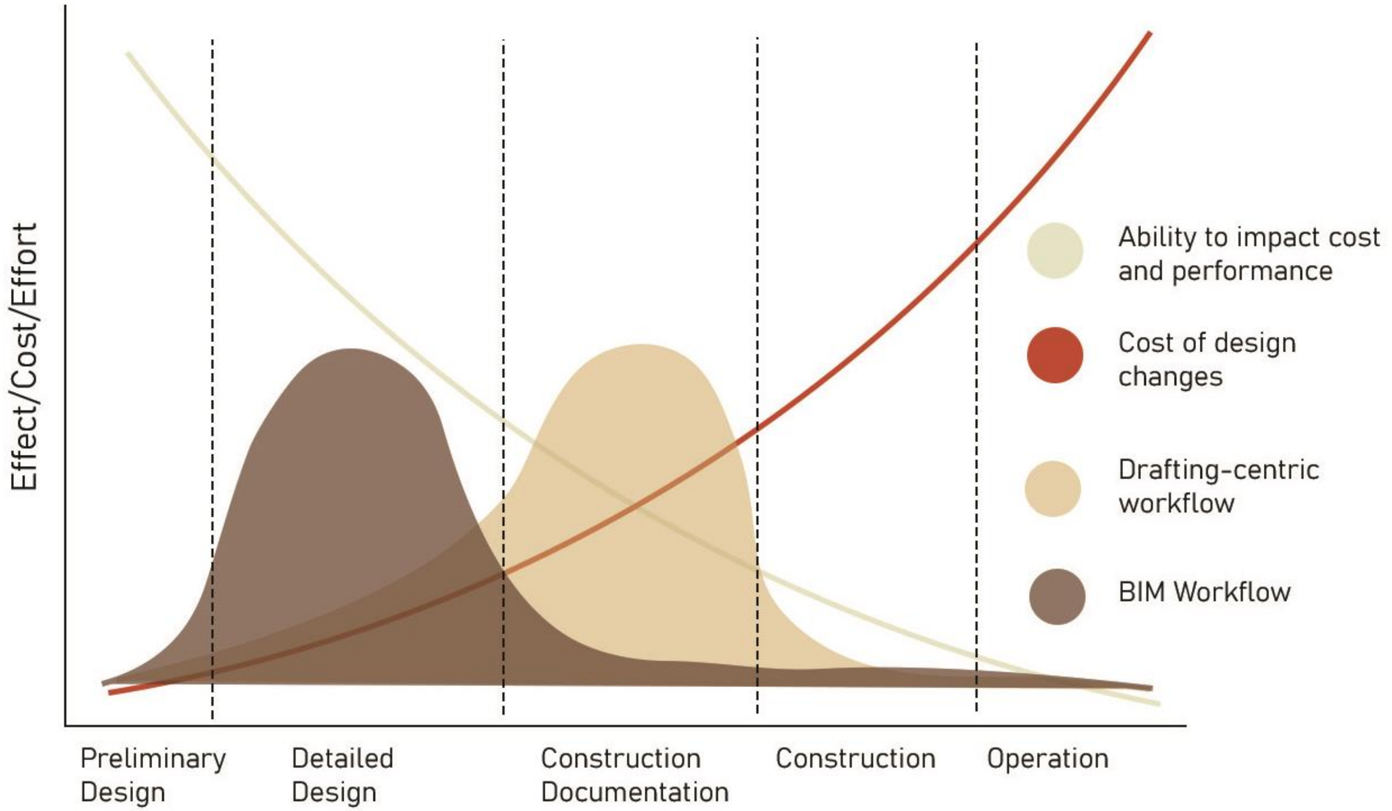
What is its purpose?

In response to environmental problem, simulation tools provide criteria for environmental friendly buildings.

How it helps?

It allows professionals to rapidly and precisely asses building performance. The MacLeamy curve shows that design modifications are less expensive at the initial stages

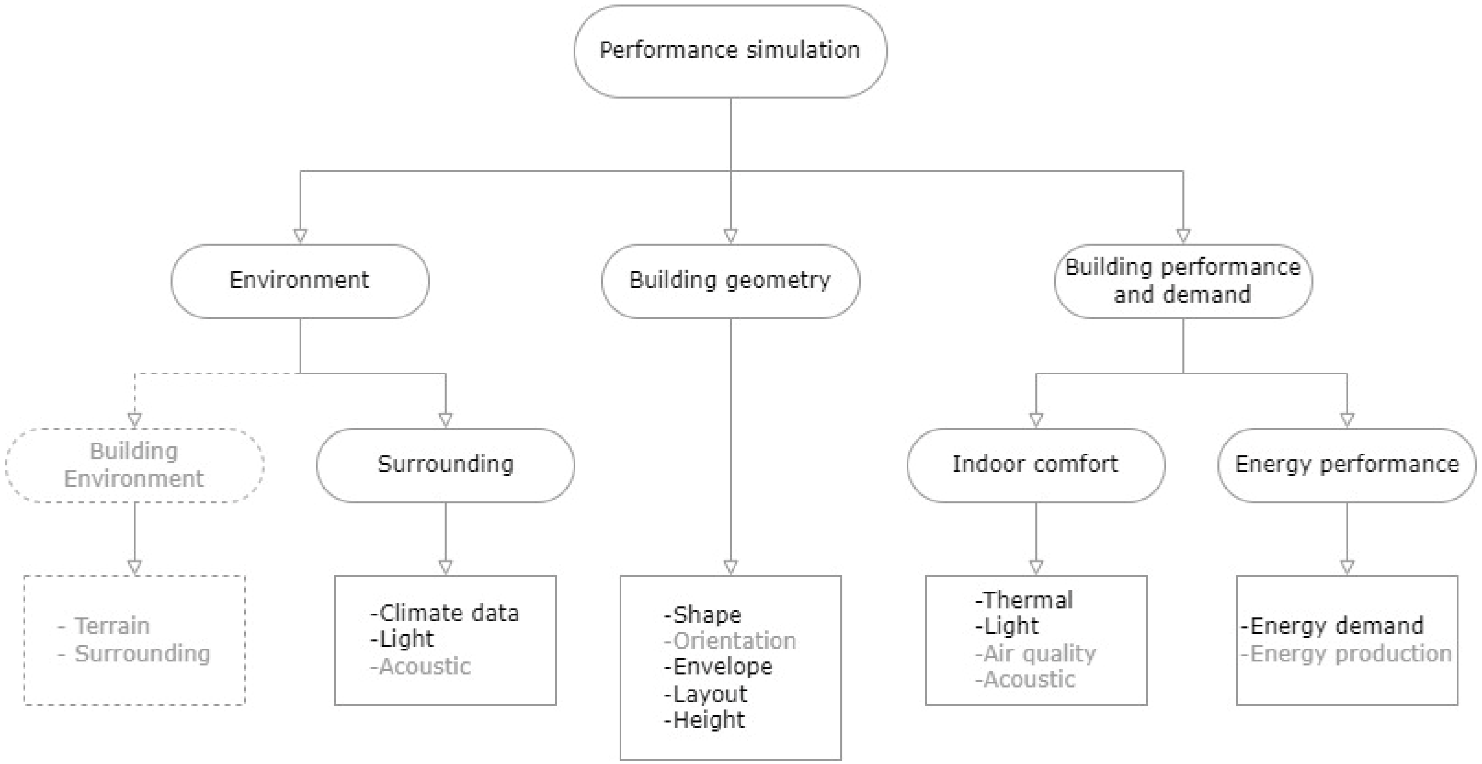
01 Performance driven architecture



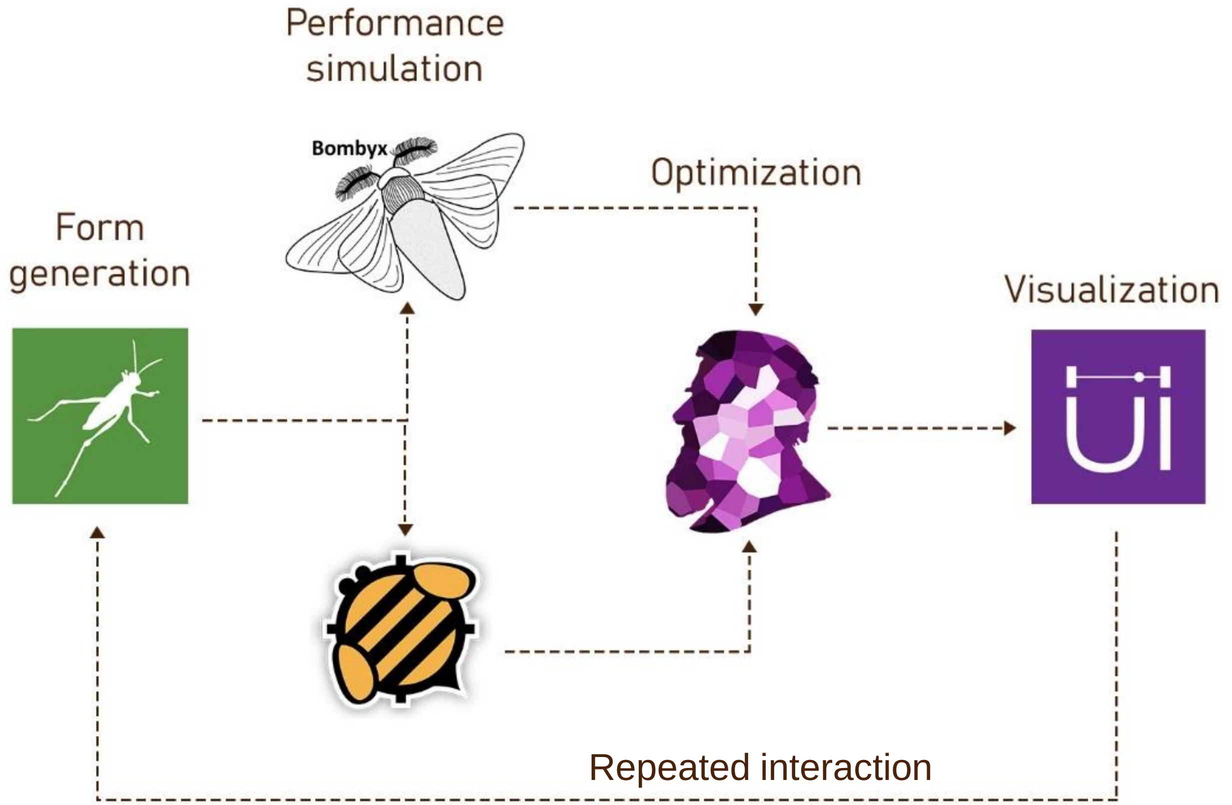
02 Performance driven architecture

Optimization based on performance simulations might result in a significant 40% reduction in energy consumption.

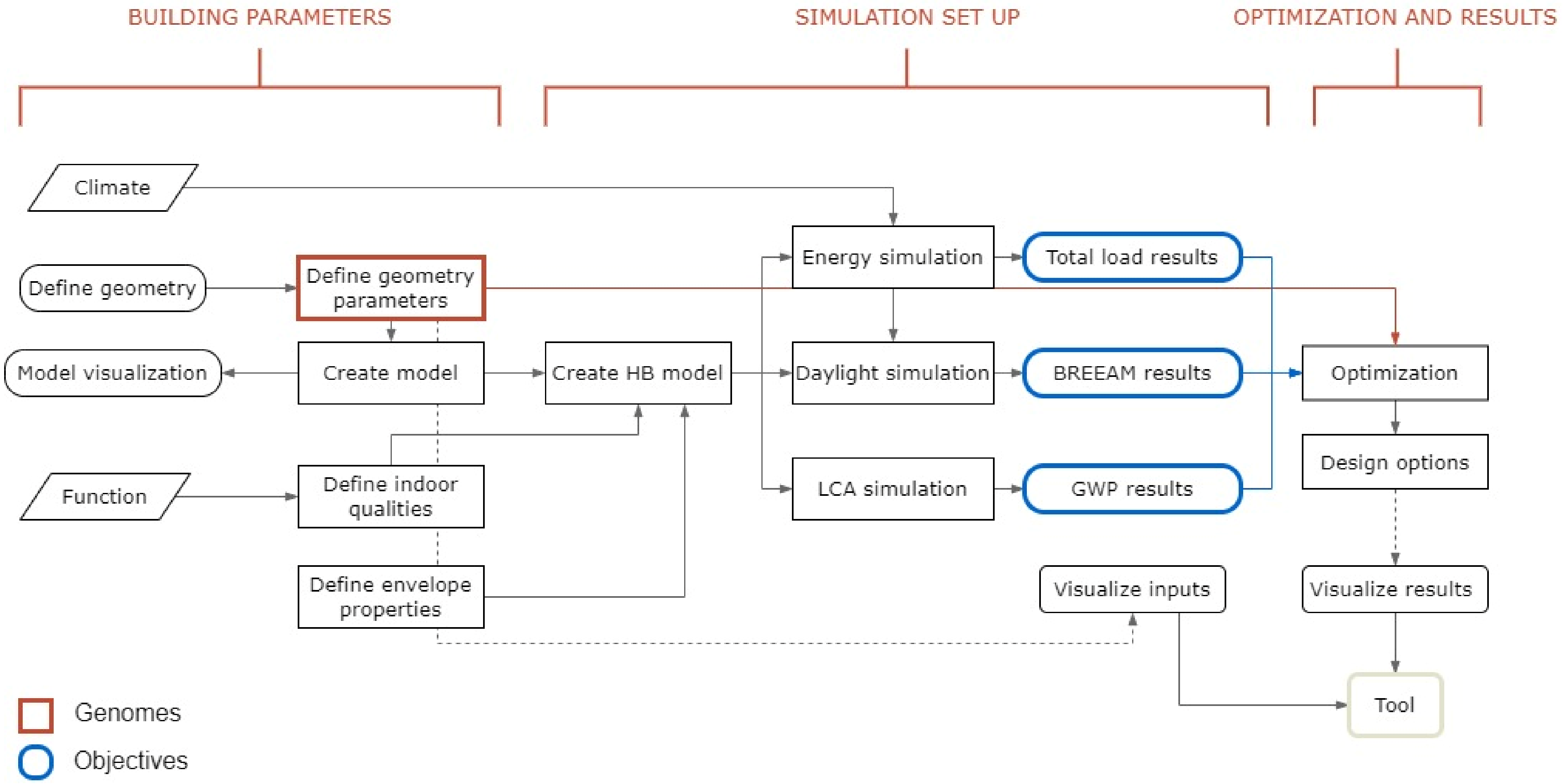
Building performance modeling and optimization consists of three major components



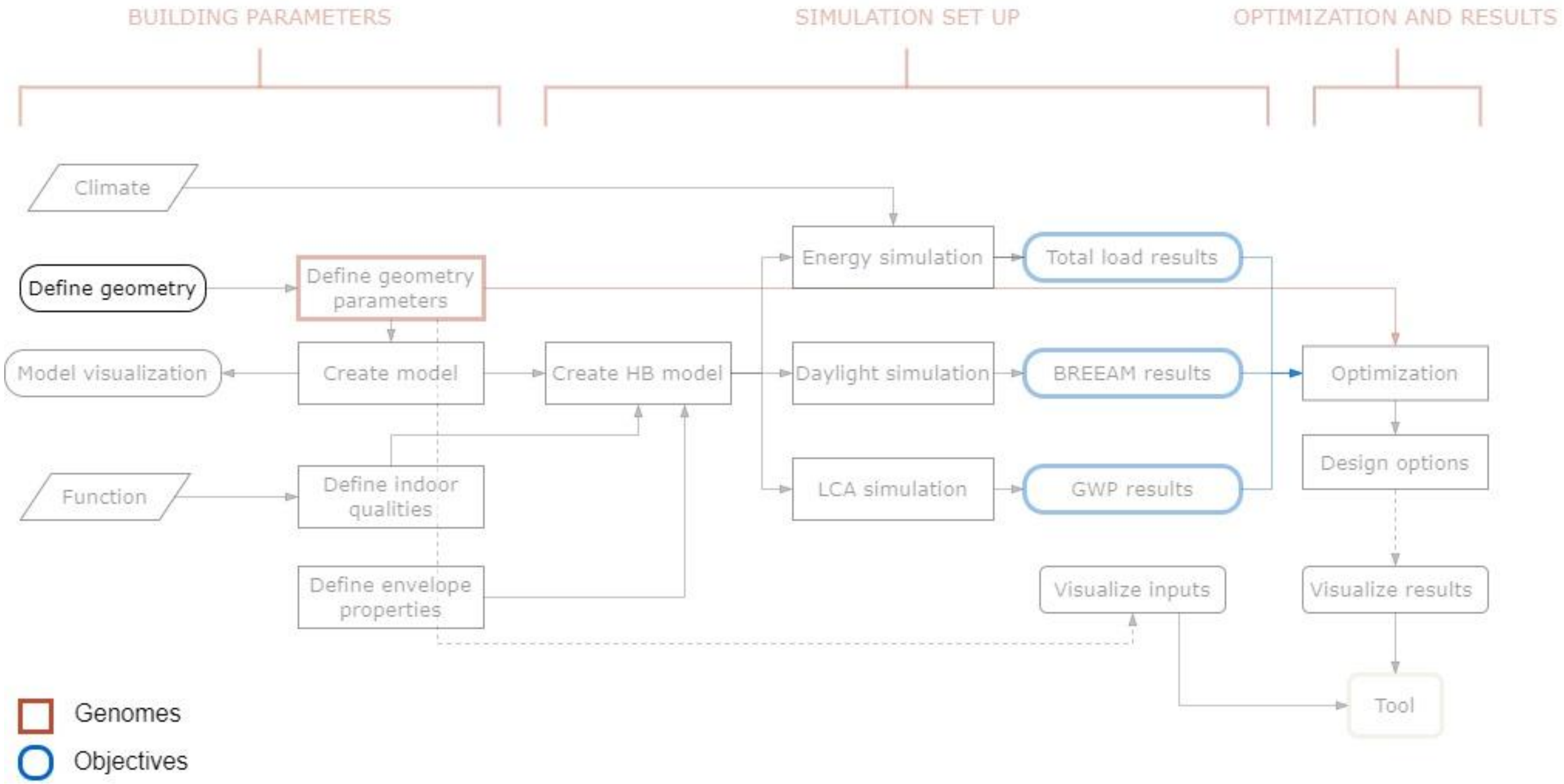
03 Workflow overview (software)



03 Workflow overview



03 Form generation



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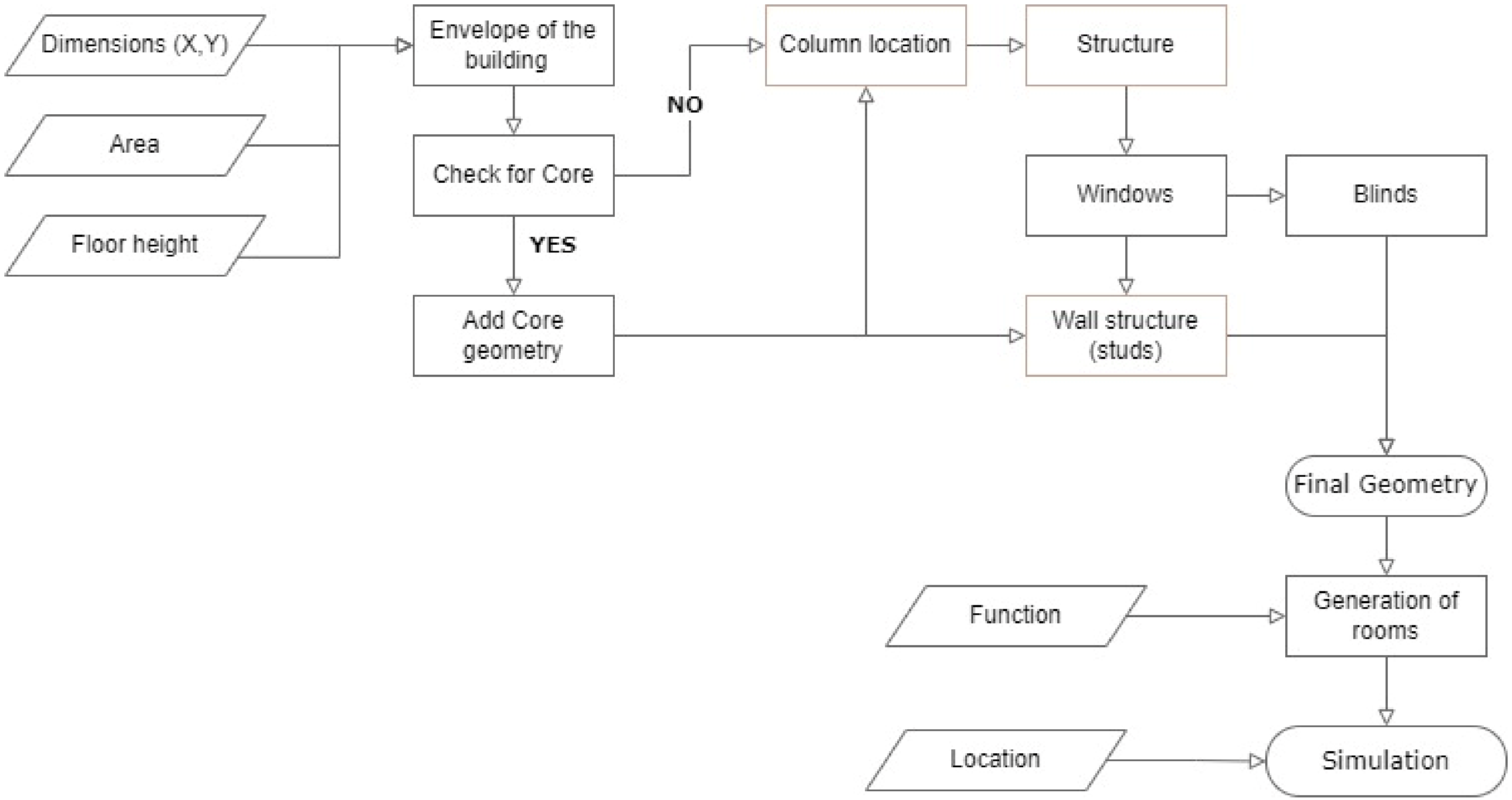
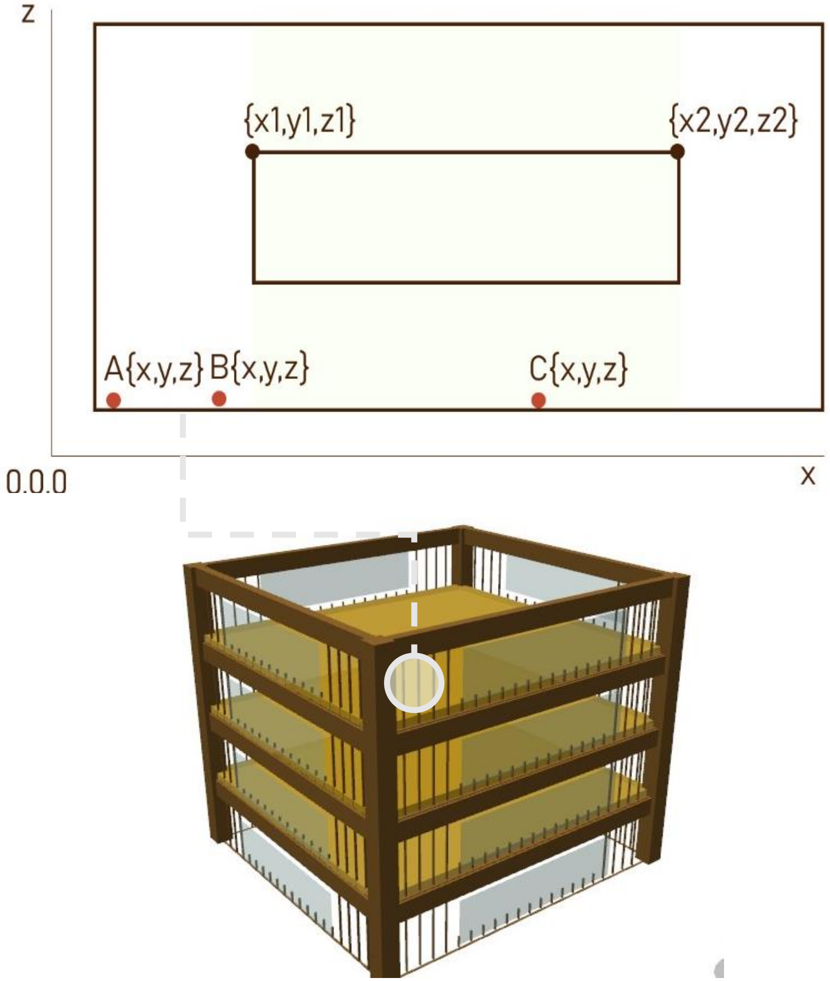


03 Form generation (wall structure)

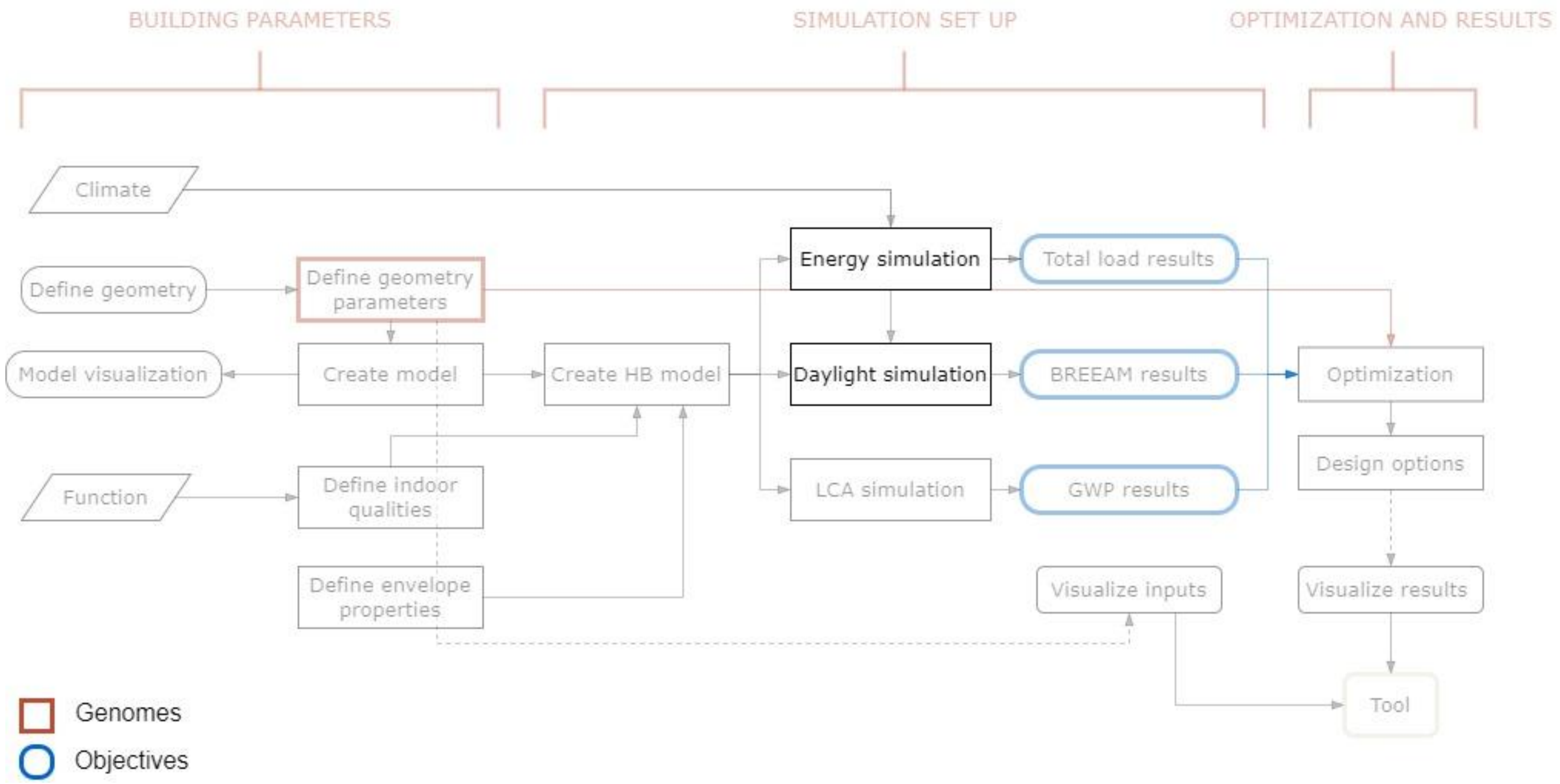
Why?
To ensure a full LCA simulation, the wall was required

What structure?
Framework proportions derived from existing standards

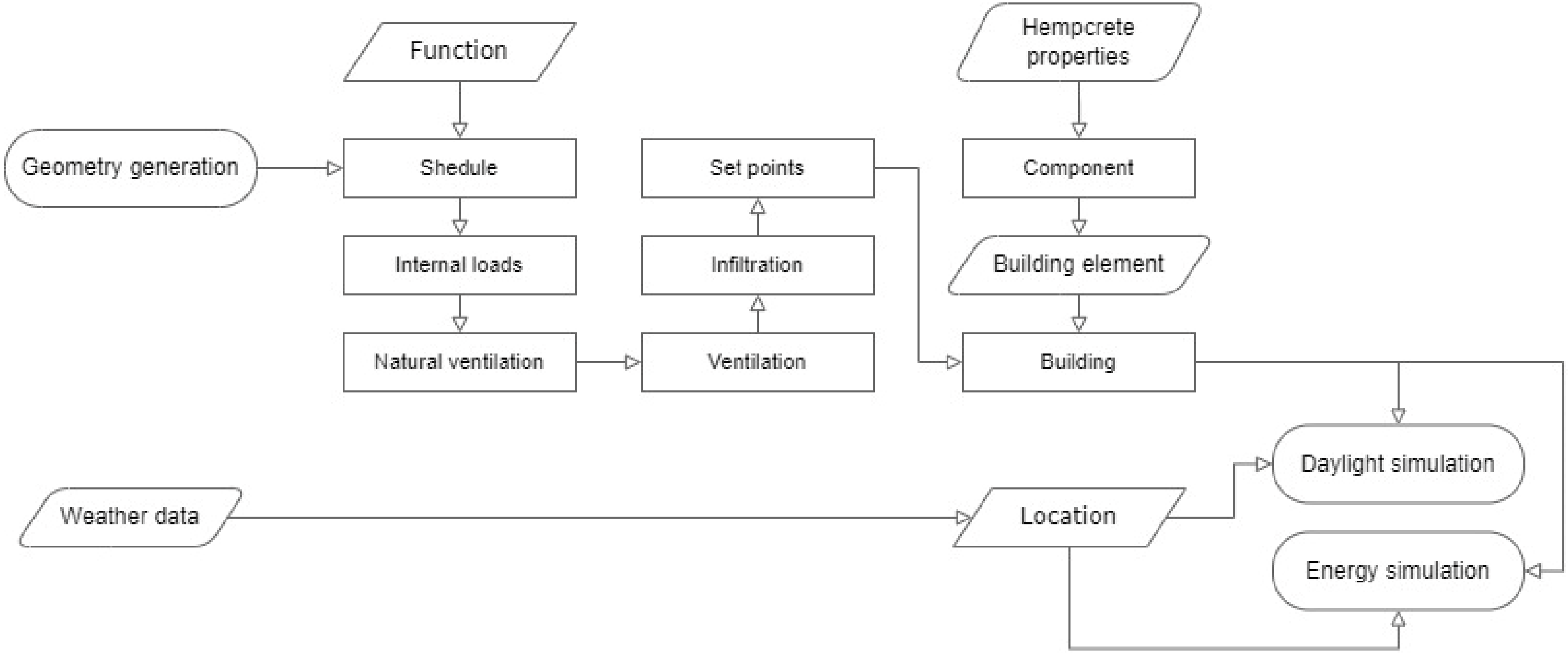
How?
Locations of studs are filtered through Python to generate studs beneath the windows and not.



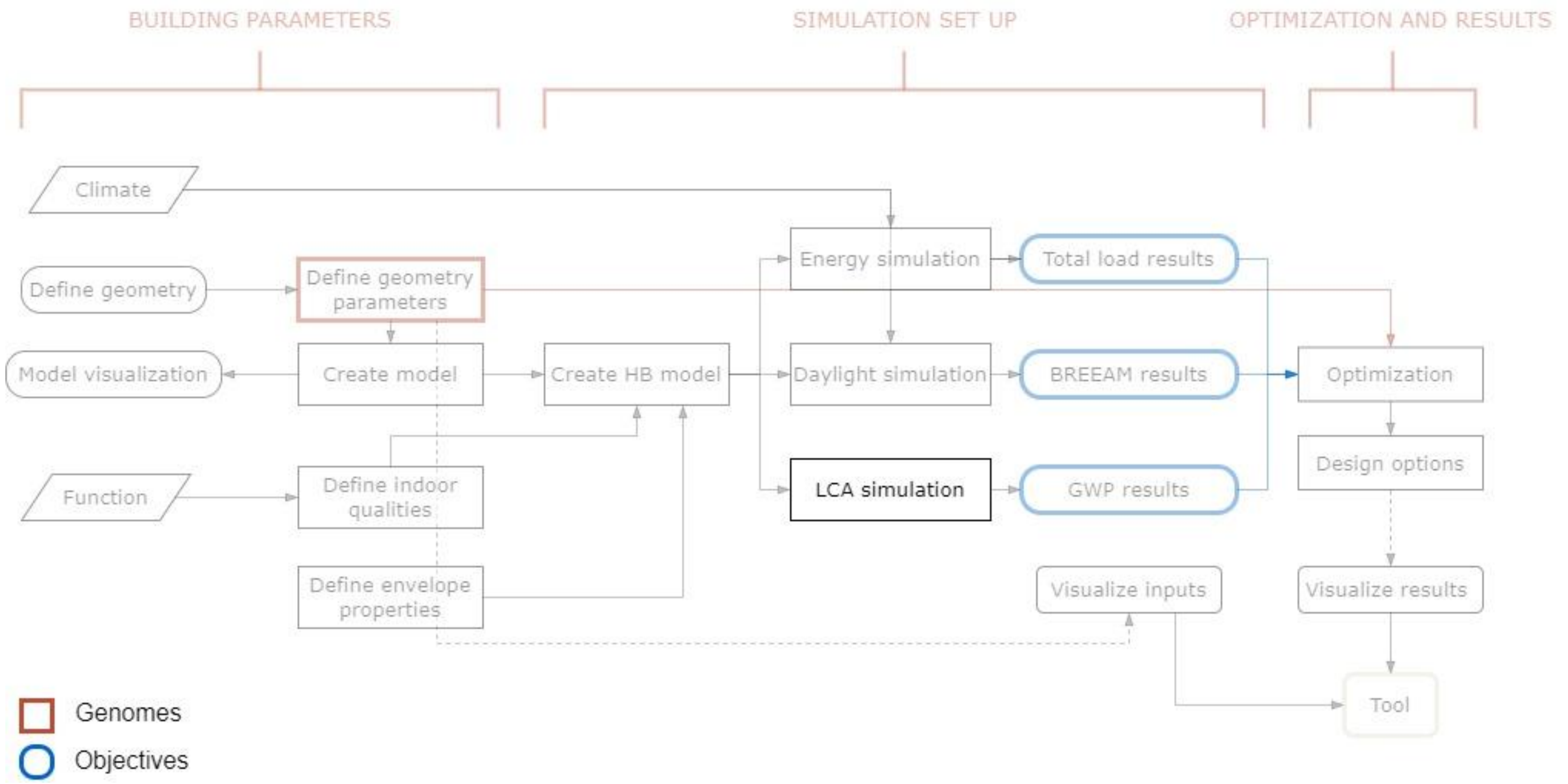
04 Energy simulation setup



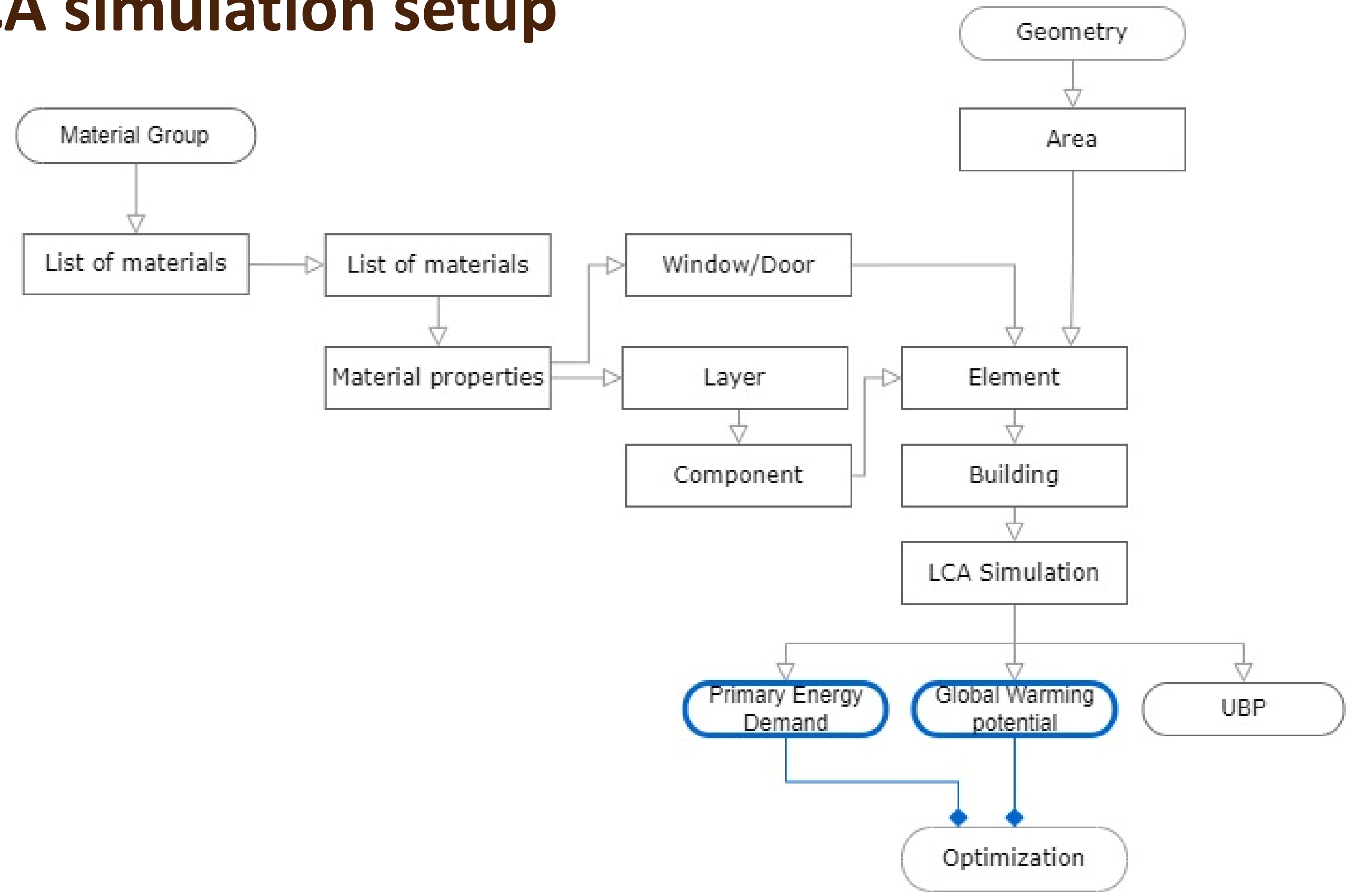
04 Energy simulation setup



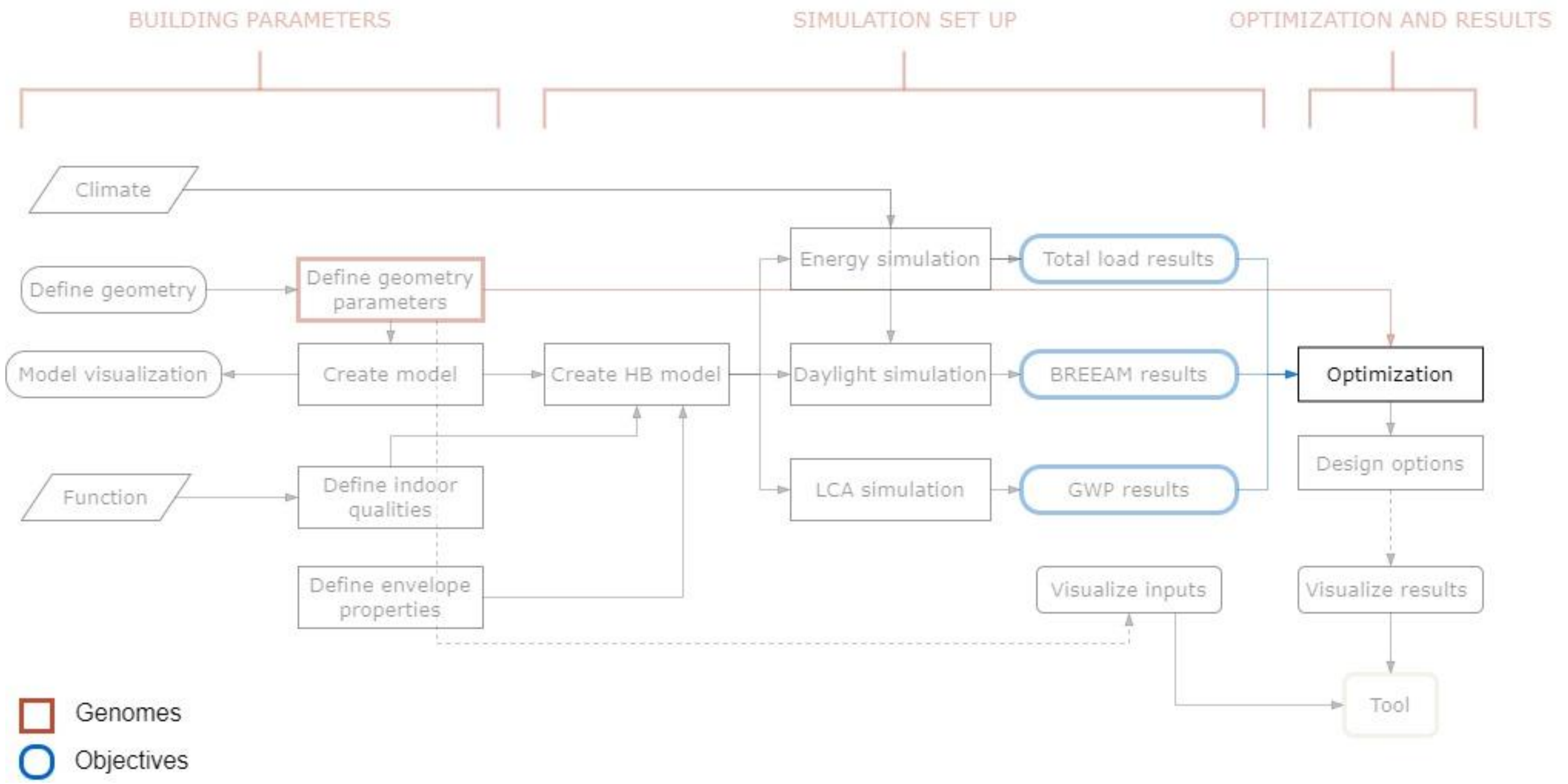
05 LCA simulation setup



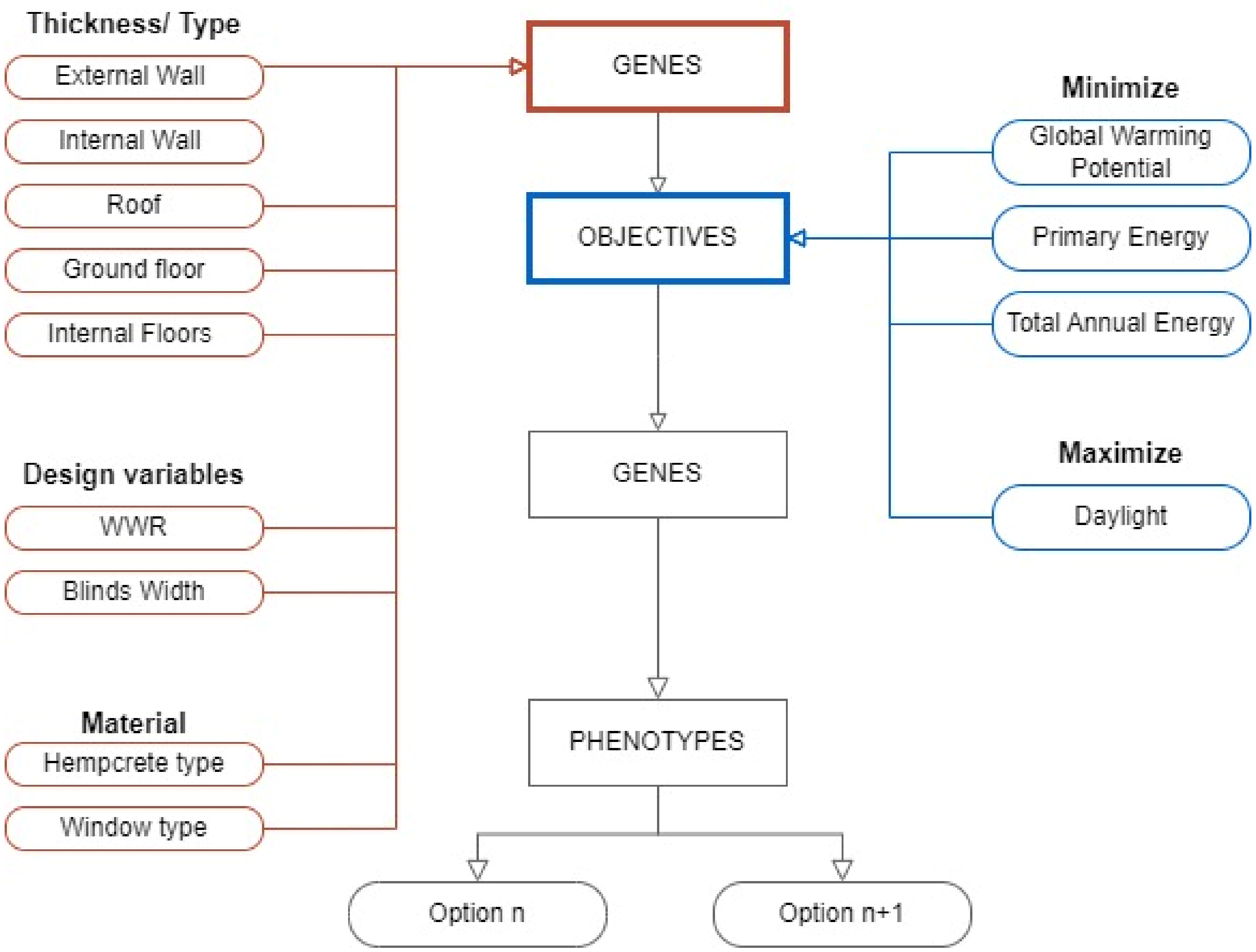
05 LCA simulation setup



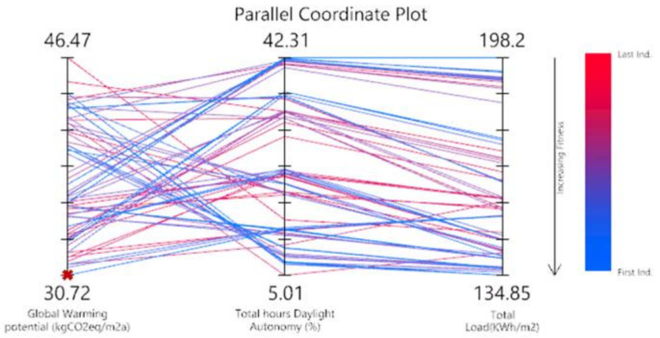
06 Optimization



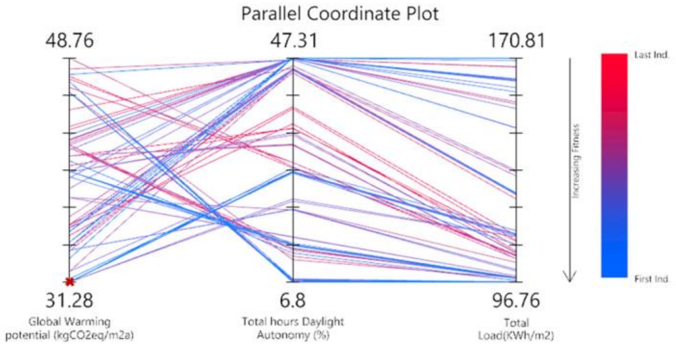
06 Optimization



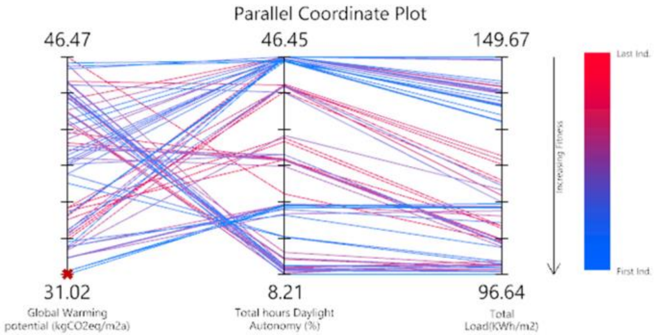
06 Optimization (Results)



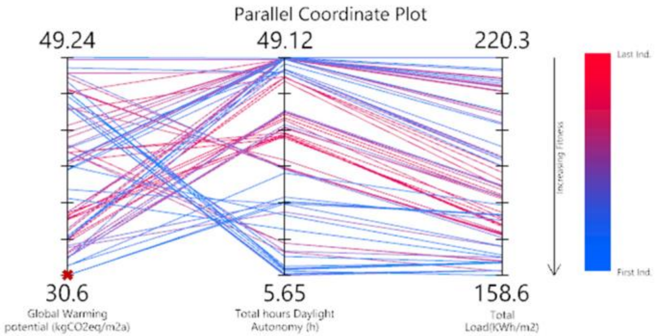
Oslo (sub-polar)



Cairo (Sub-tropical)



Milan (temperate)



Singapore (Tropical)

High = CO2 Low

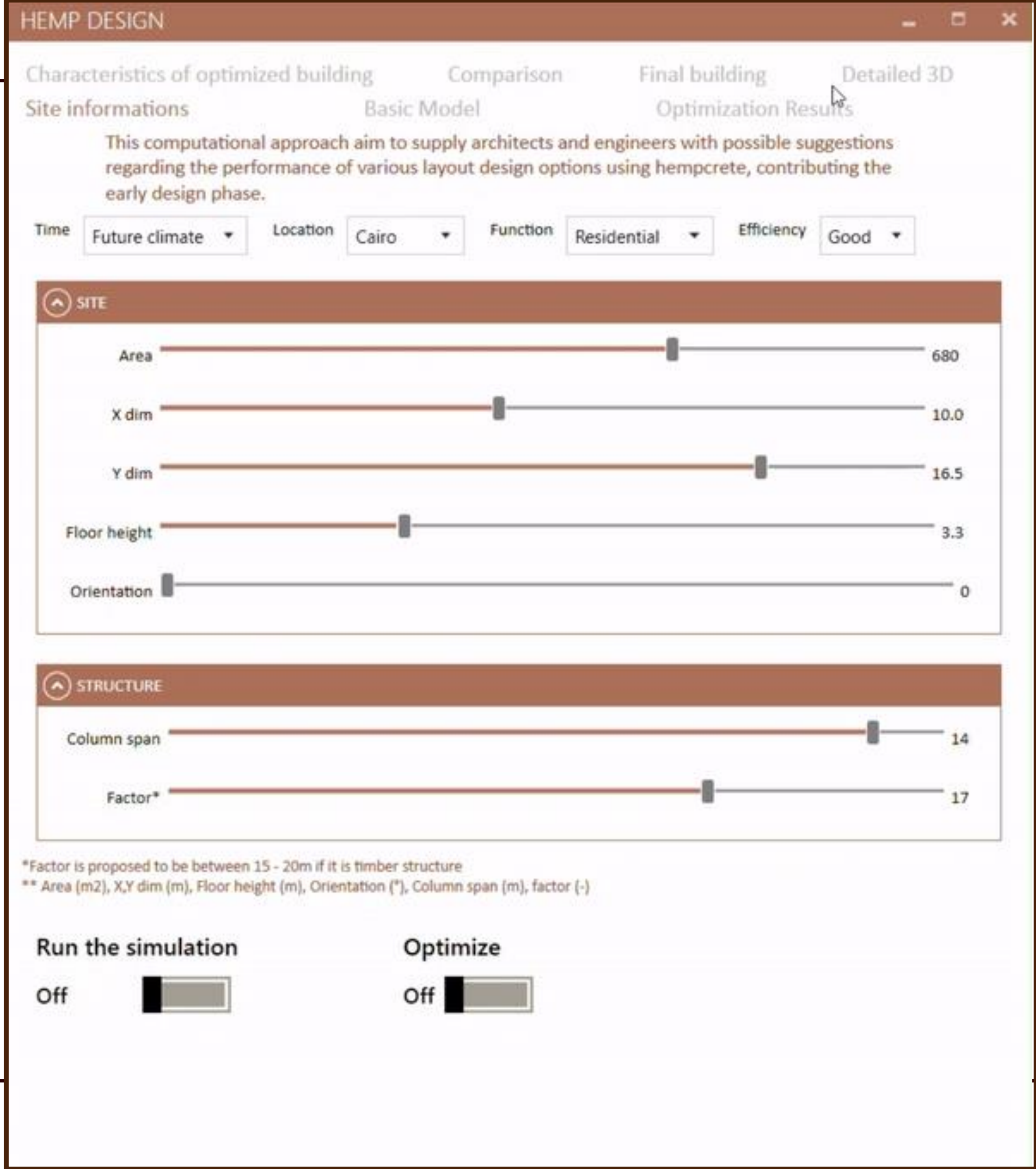
High = High

Too High in Tropical

07 Final visualization

1.Site information

Time,Location, Function, Efficiency, Dimensions, Structure



07 Final visualization

1.Site information
Location, Function, Efficiency, Dimensions, Structure

2.Basic model
Envelope, structure

07 Final visualization

1.Site information
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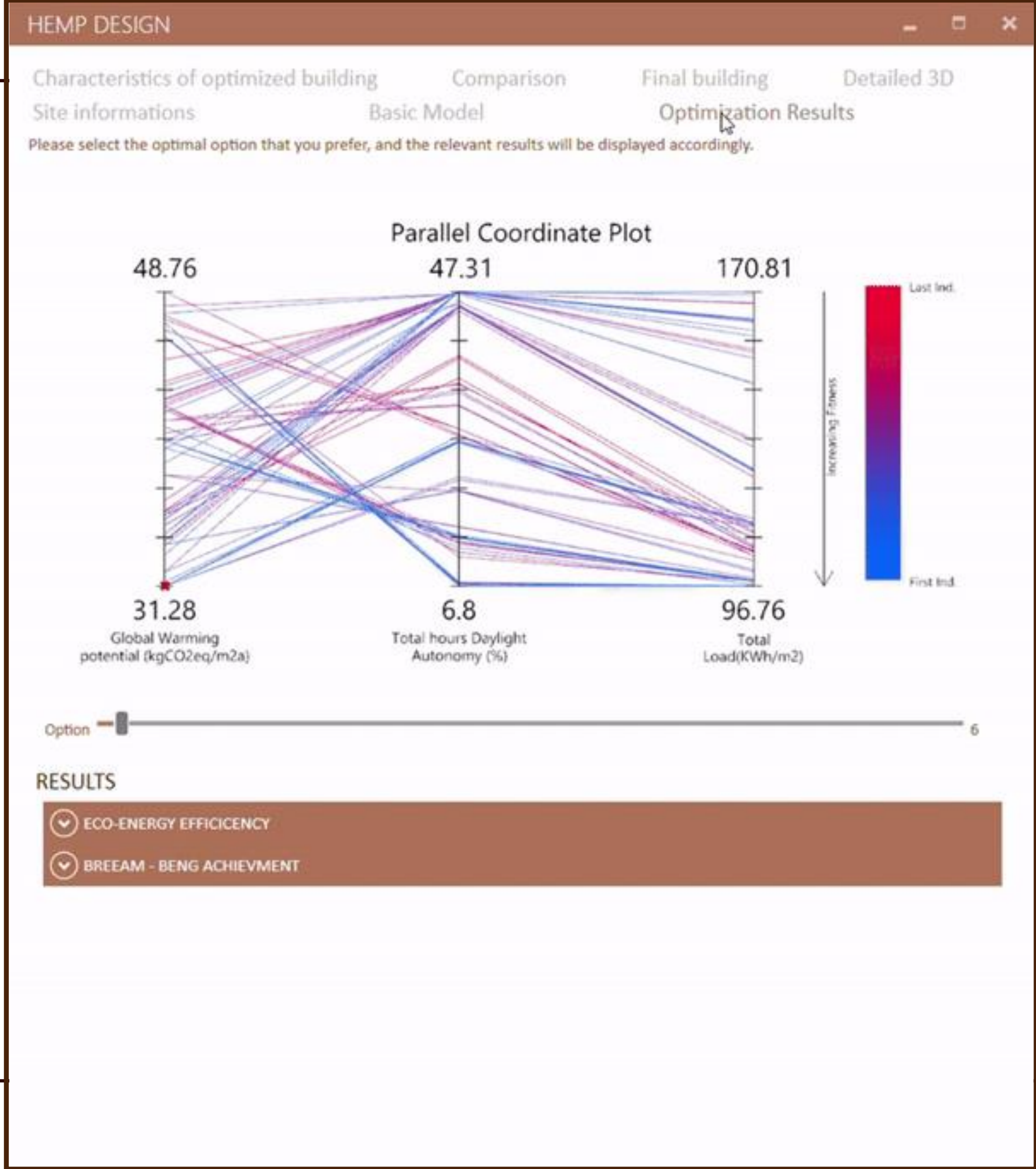
2.Basic model
Envelope, structure

3.Optimization results
Parallel coordinate plot, Energy demand, LCA, BREEAM results



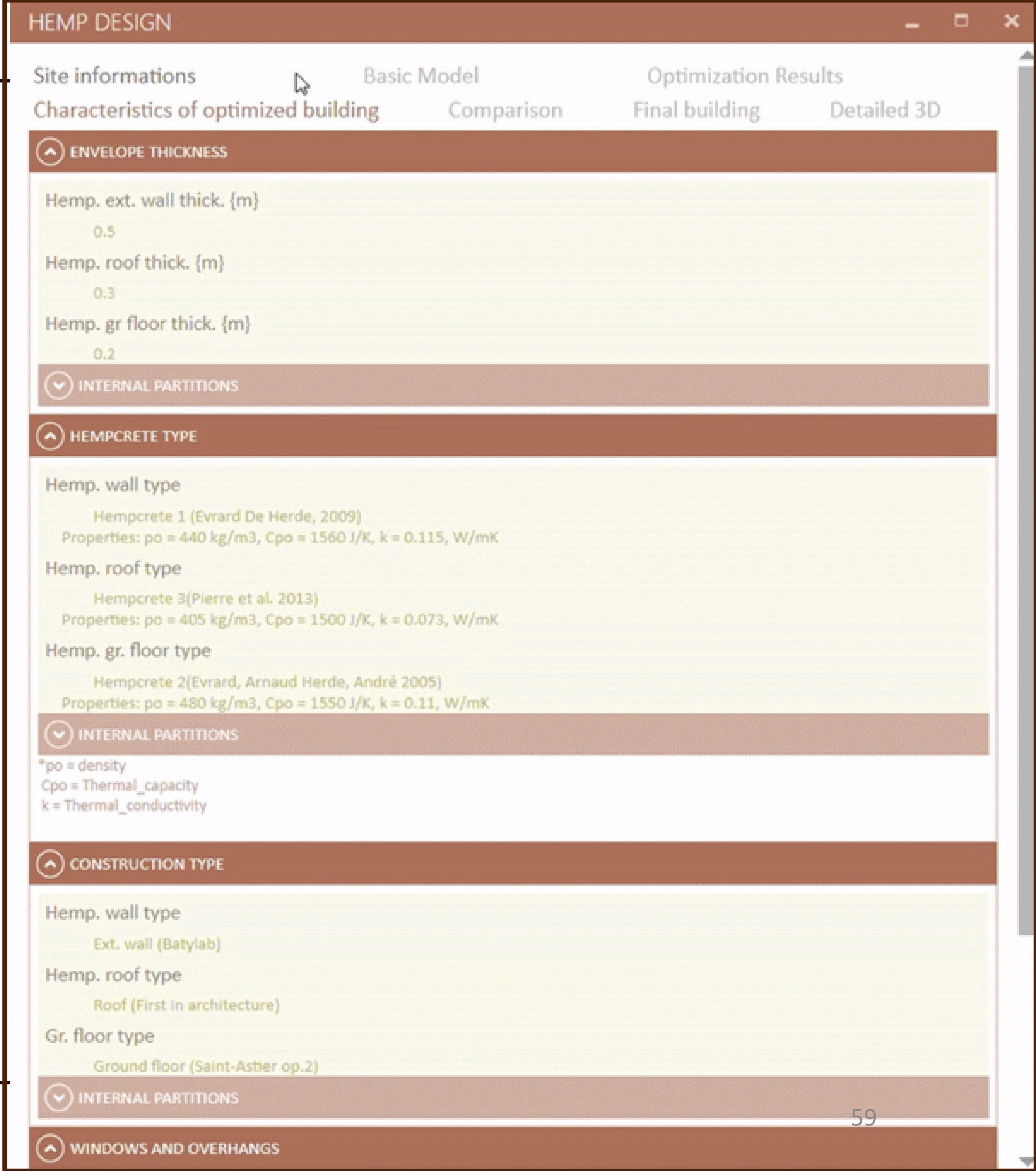
07 Final visualization

1.Site information
Location, Function, Efficiency, Dimensions, Structure

2.Basic model
Envelope, structure

3.Optimization results
Parallel coordinate plot, Energy demand, LCA, BREEAM results

4. Characteristics
Materiality, Building element, Windows, Blind size



07 Final visualization

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5. Comparison
Comparison of 4 designs and their results

07 Final visualization

1.Site information
Location, Function, Efficiency, Dimensions, Structure

2.Basic model
Envelope, structure

3.Optimization results
Parallel coordinate plot, Energy demand, LCA, BREEAM results

4. Characteristics
Materiality, Building element, Windows, Blind size

5. Comparison
Comparison of 4 designs and their results

6. Final design
Final model envelope, structure, detailed construction details

06

Conclusion

- Research question
- Sub-questions
- Workflow key aspects
- Future aspects

01 Research question

HOW CAN A COMPUTATIONAL WORKFLOW OPTIMIZE HEMPCRETE'S INTEGRATION IN VARIOUS TYPE OF BUILDINGS ACROSS DIVERSE CLIMATES, WITH THE OBJECTIVE TO SUPPORT PRELIMINARY DESIGNS THAT ACHIEVE HIGH ENERGY PERFORMANCE AND MINIMIZE GLOBAL WARMING POTENTIAL?

Examine numerous design objectives to find the optimal approach

Optimize hempcrete to achieve maximum performance, useful daylight while CO_2 is reducing

Incorporation of site-specific data and algorithm with multiple function related criteria

Visualization tool with performance feedback and comparison to help on preliminary design stages

Oslo fails BREEAM

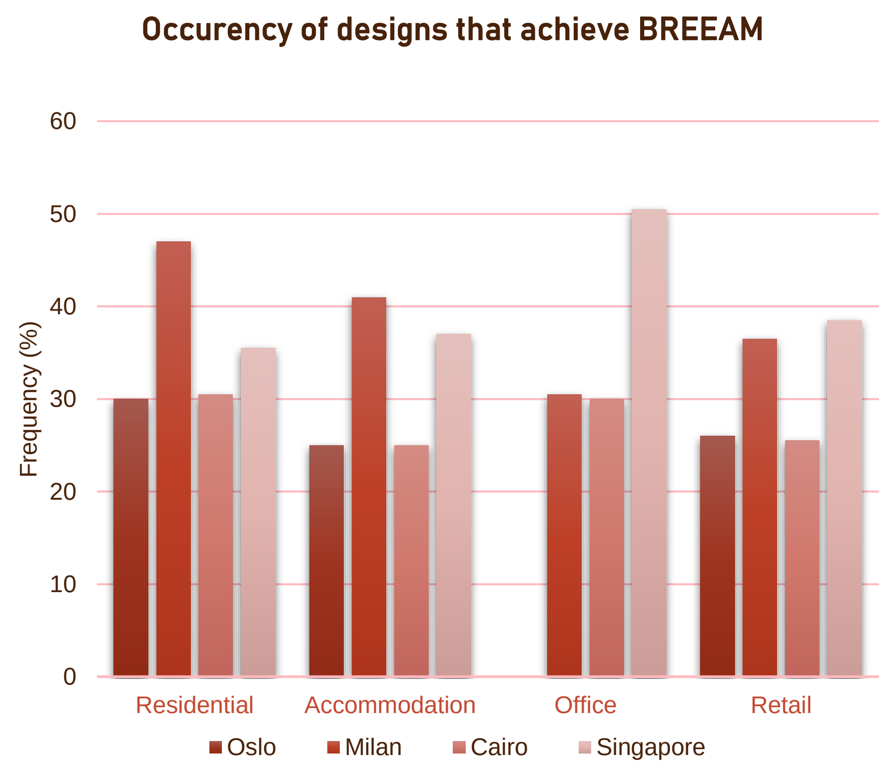
Due to the limited daylight, office in Oslo cannot pass BREEAM

Milan succeed

Milan has promising results since many of them pass

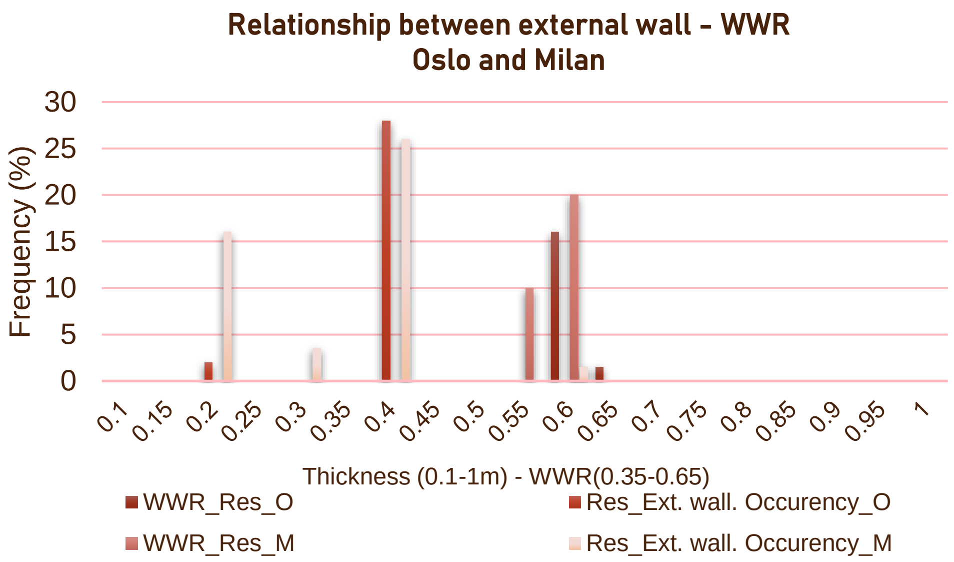
Cairo is constant

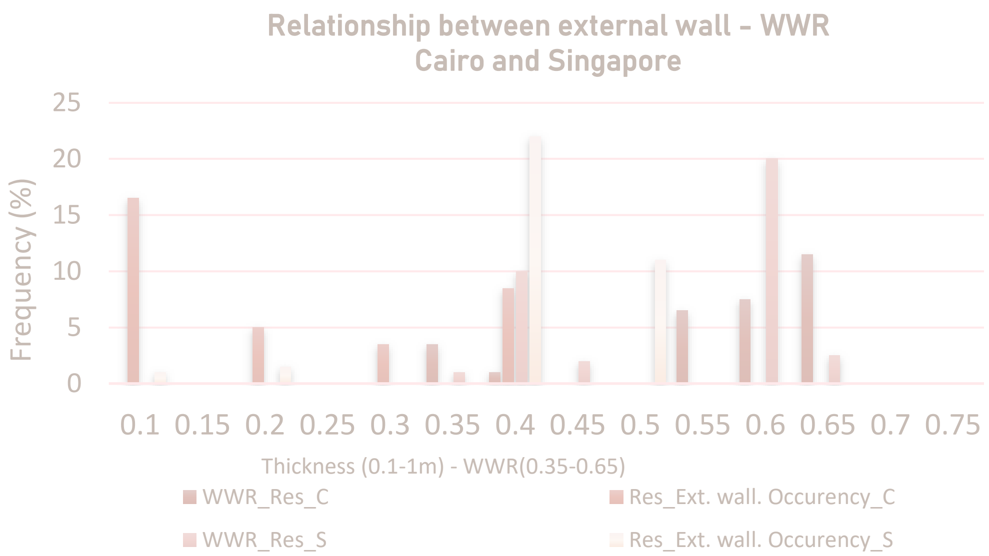
Cairo has smaller WWR to reduce energy demand and therefore it doesn't have many succeed designs for daylight



02 Research sub-questions

Which ways can a workflow define the impact of hempcrete thickness on thermal and visual comfort in buildings across different regions?





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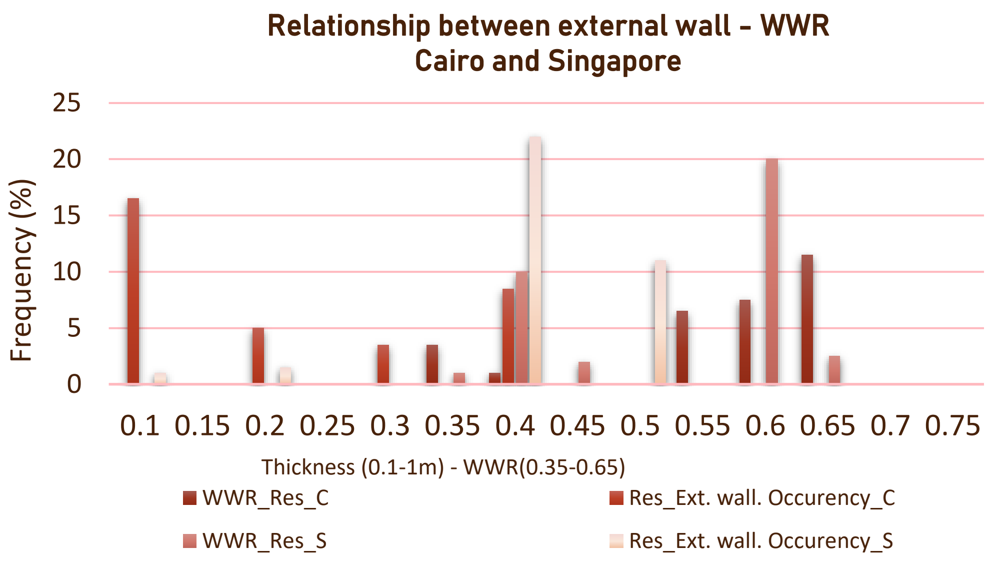

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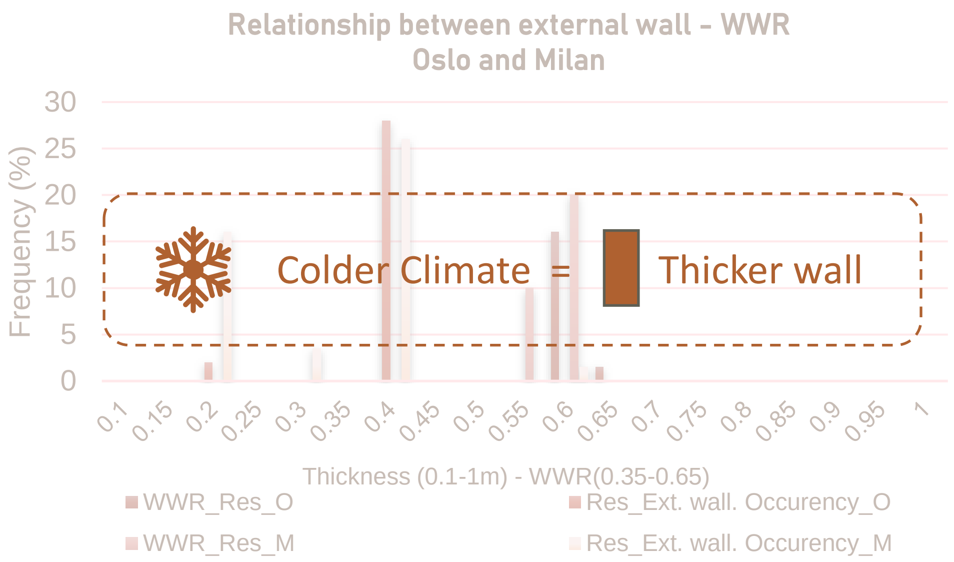

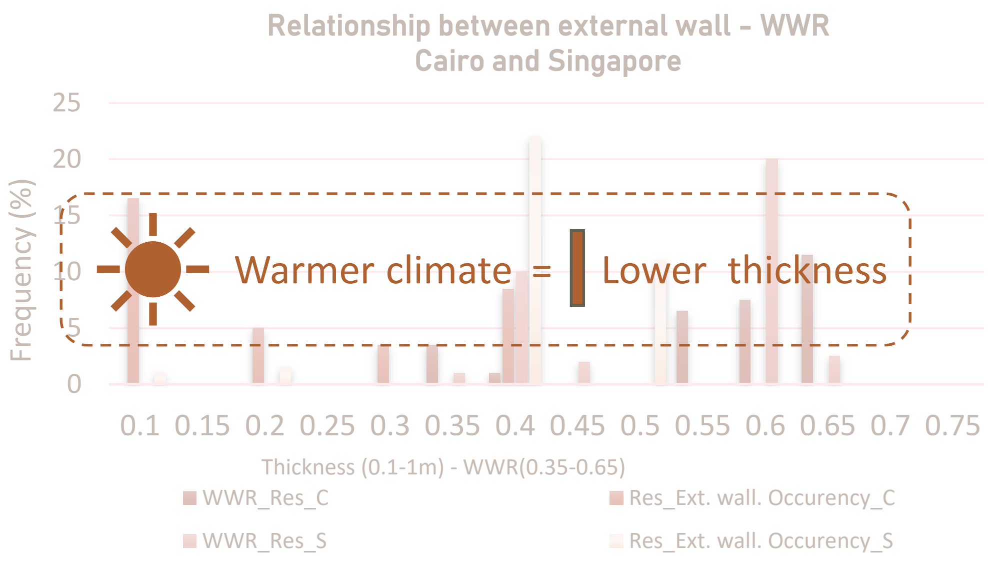

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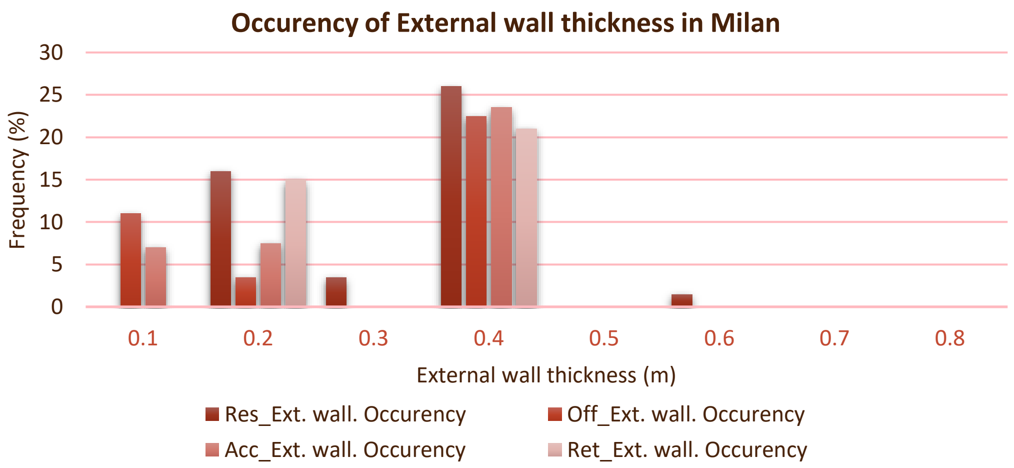

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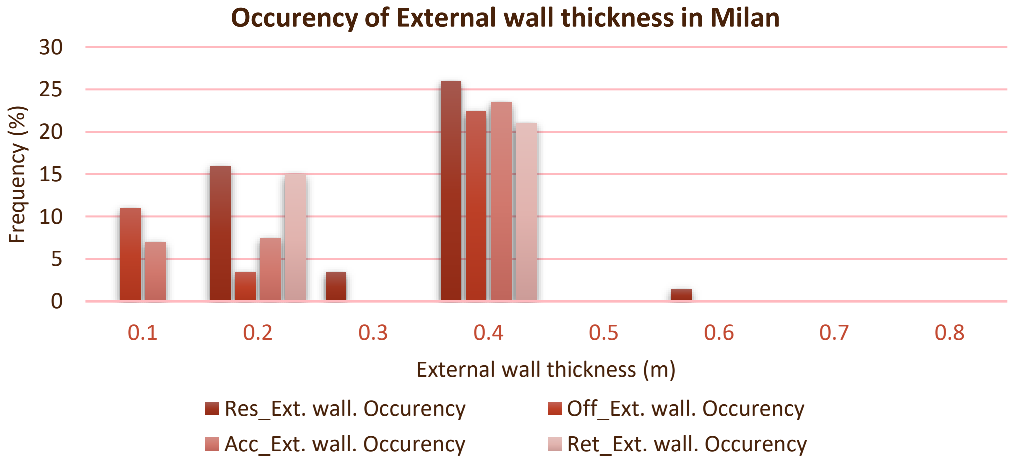

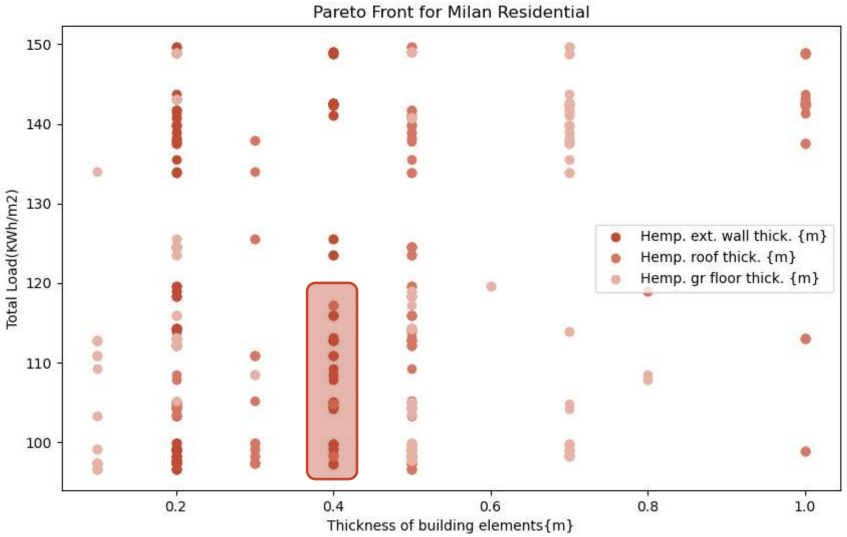

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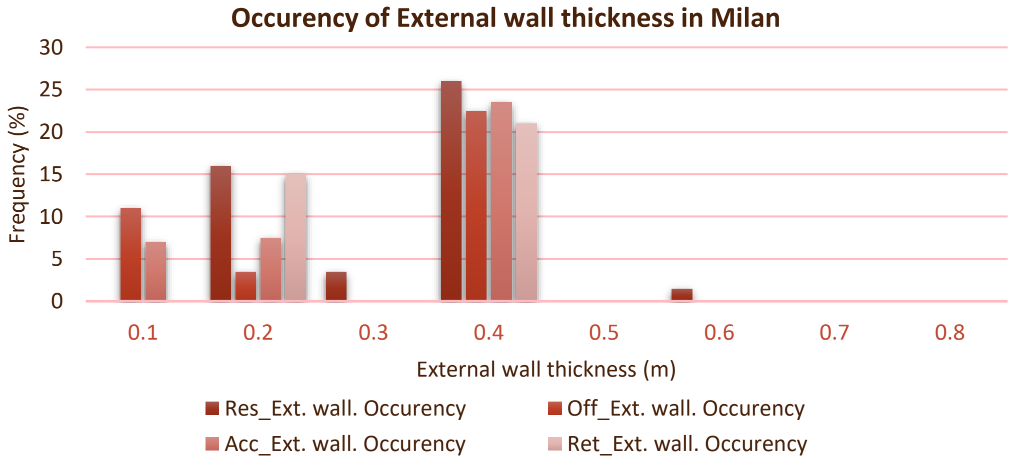

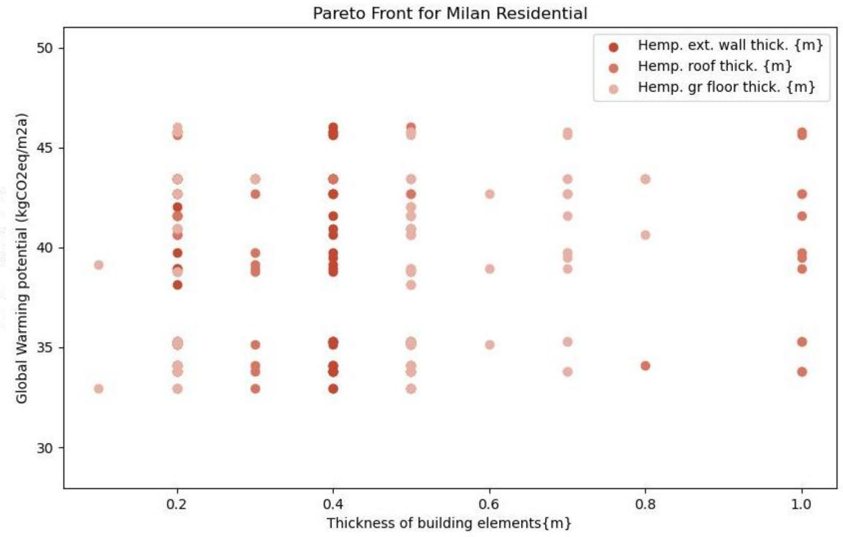

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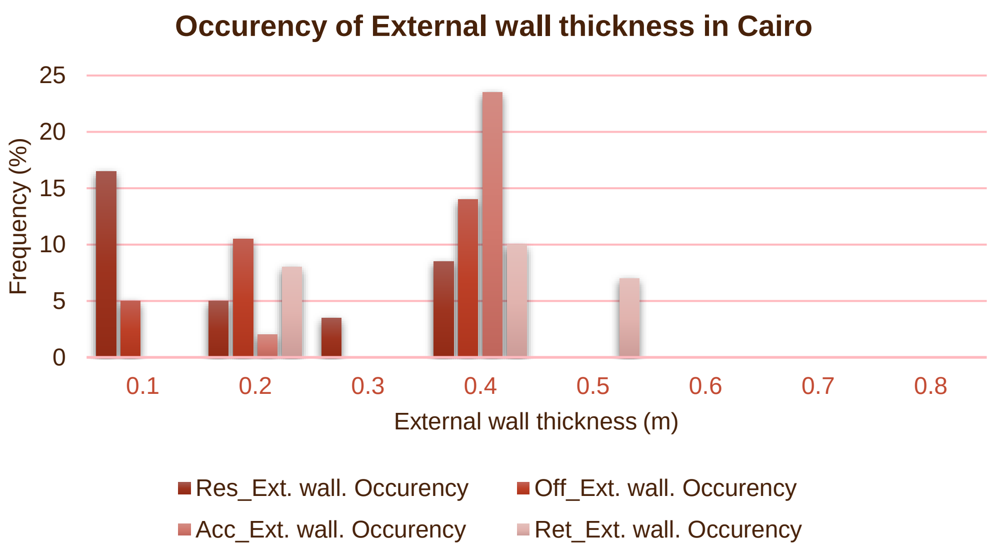

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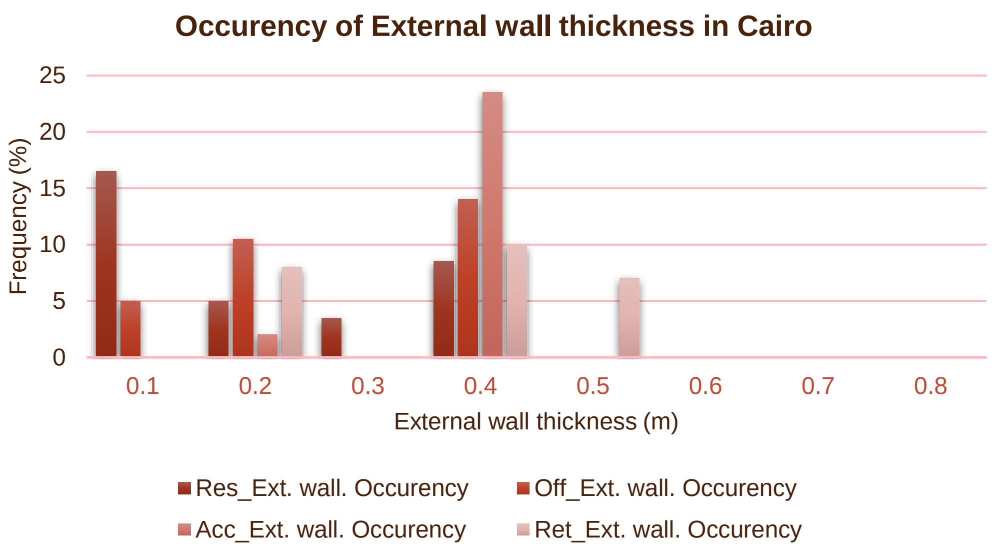

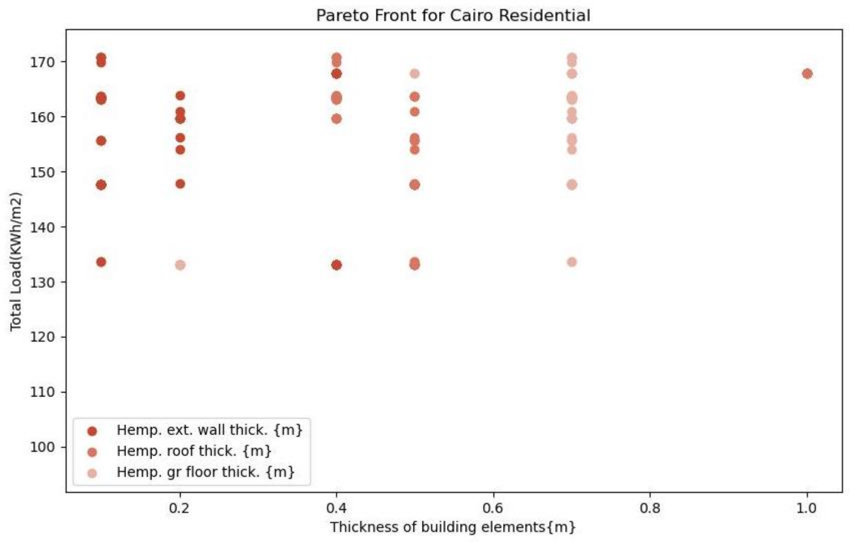

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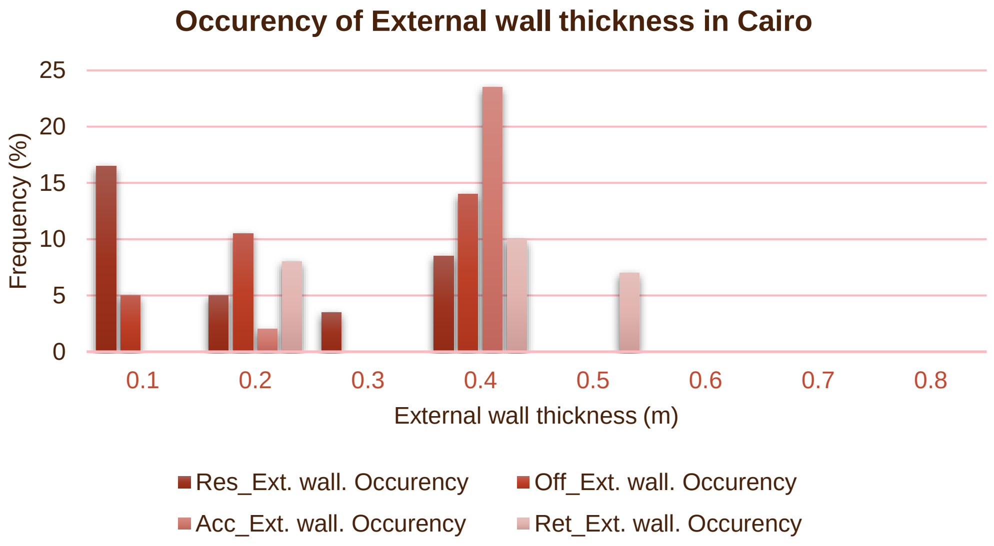

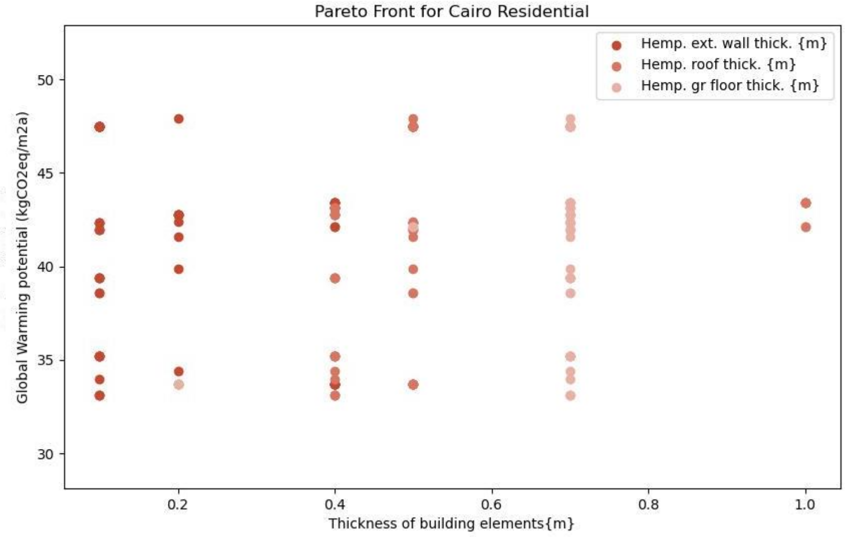

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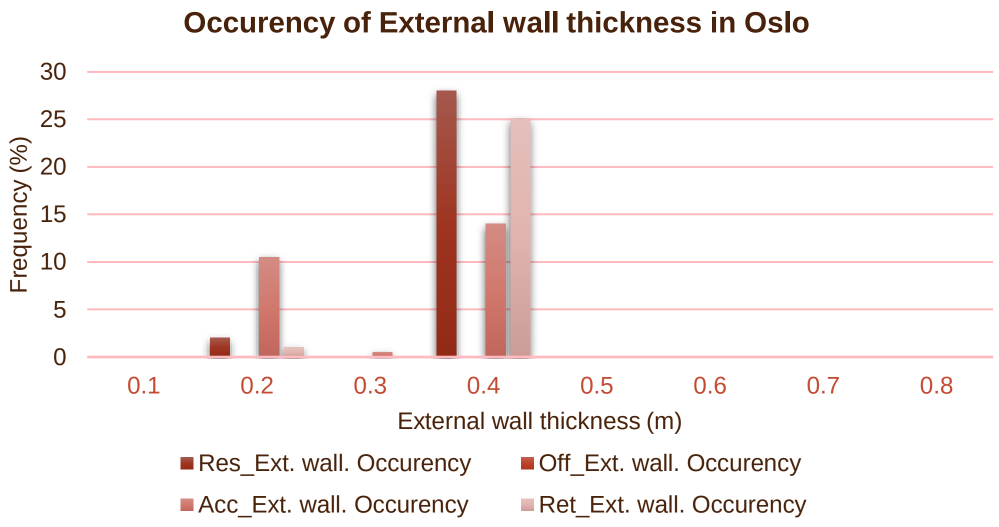

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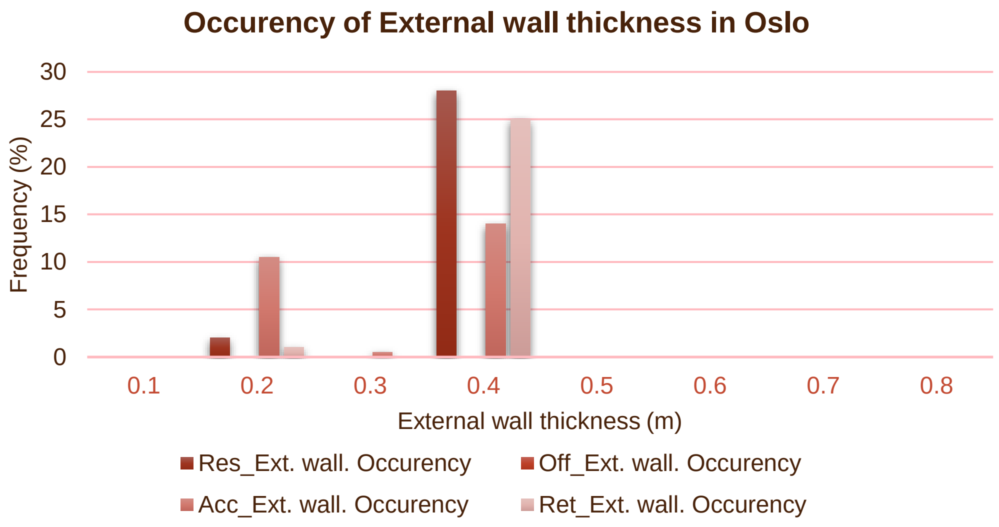

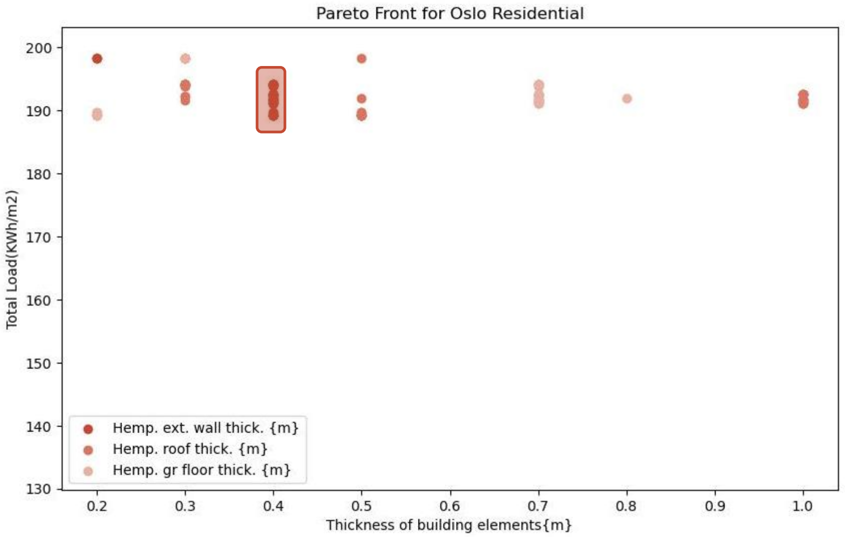

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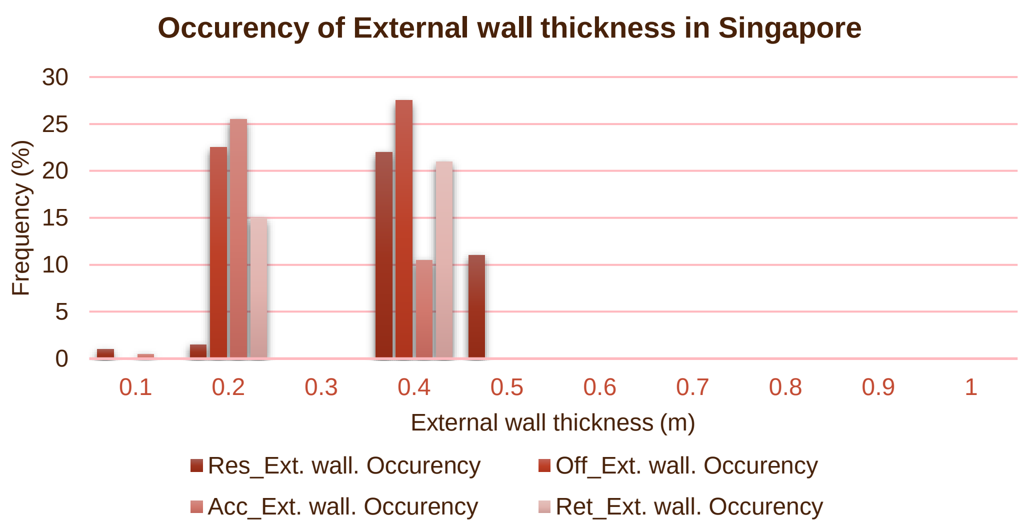

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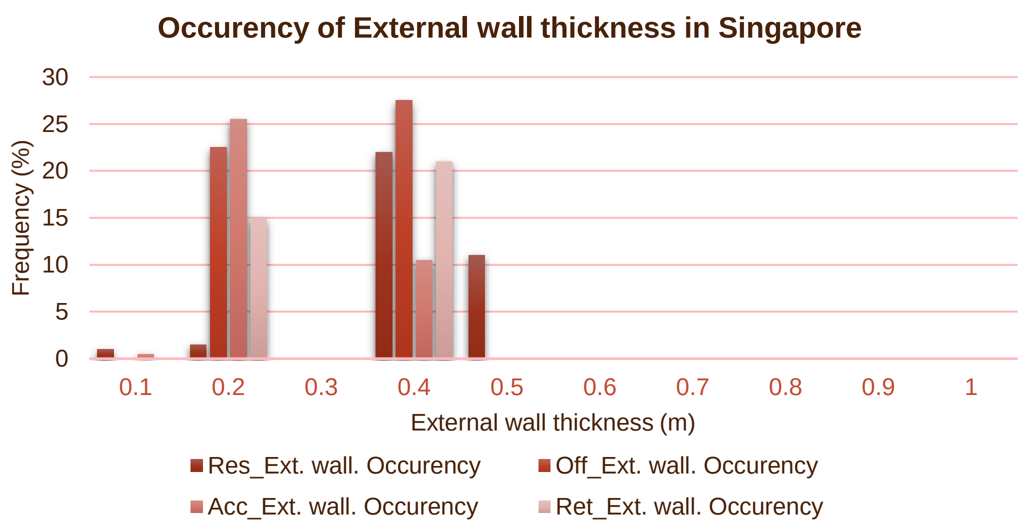

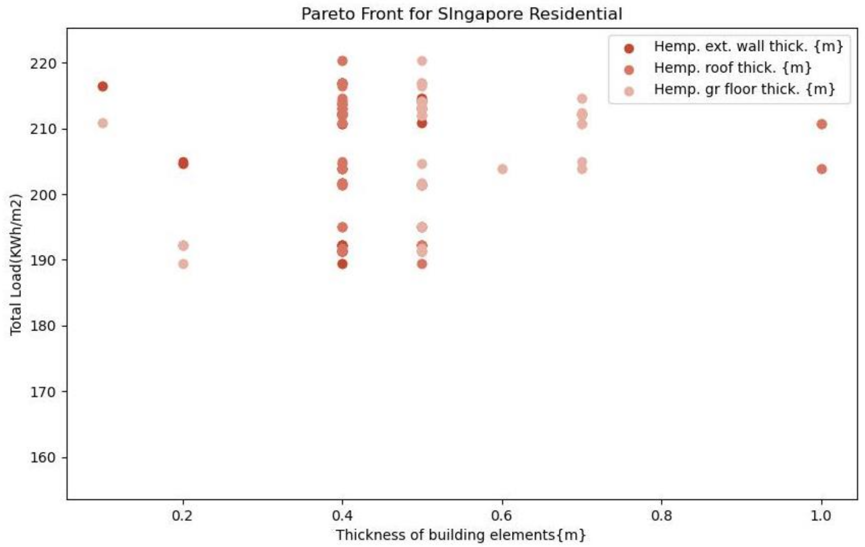

03 Workflow key aspects

1 Hempcrete Integration

- Accessibility
- Extensive datasets
- Paris-proof features
- Sustainable design

2 Parametric modelling

- Multi-objective comparison
- Efficiency
- Reduce time – increase design variables

3 Future climate data

- Climate-proof designs
- Mitigate the effect of climate change

4 Compliance with standards

- BREEAM

5 User-friendly interface

- Human Ui
- Usability
- Efficiency

04 Future aspects

Enhance database
Enlargement of the database for hempcrete

Advanced parametric modelling
More complicated design exploration

Site-specific
Surrounding area impact

User-interface enhancement
Machine learning to accelerate the optimization process and get more

Analysis of results
Detailed analysis how hempcrete influence the design

Questions?

03 Comparison with traditional materials

HEMPCRETE	EPS	GLASSWOOL
○ Most common thermal conductivity λ=0.07 W/mK ○ Embodied energy = 1MJ/Kg	○ Thermal conductivity λ=0.032 W/mK ○ Embodied energy = 155MJ/kg	○ Thermal conductivity λ=0.04 W/mK ○ Embodied energy = 57.5MJ/kg

(Niyigena et al., 2016)
(Demir & Doğan, 2020a; Elfordy et al., 2008b)
(https://www.yourhome.gov.au/materials/embodied-energy)