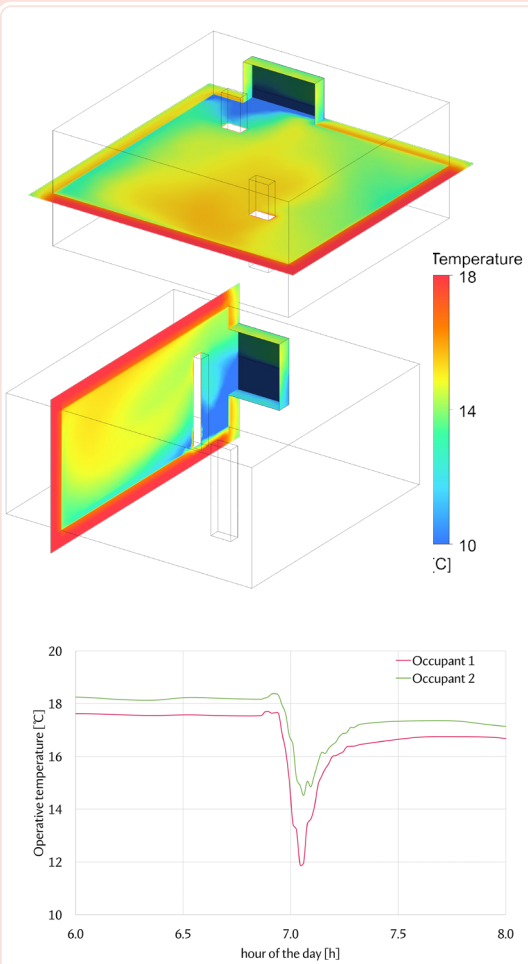
PHYSICS BASED MODELING & DESIGN OPTIMIZATION

THERMAL HETEROGENEITY

using CFD

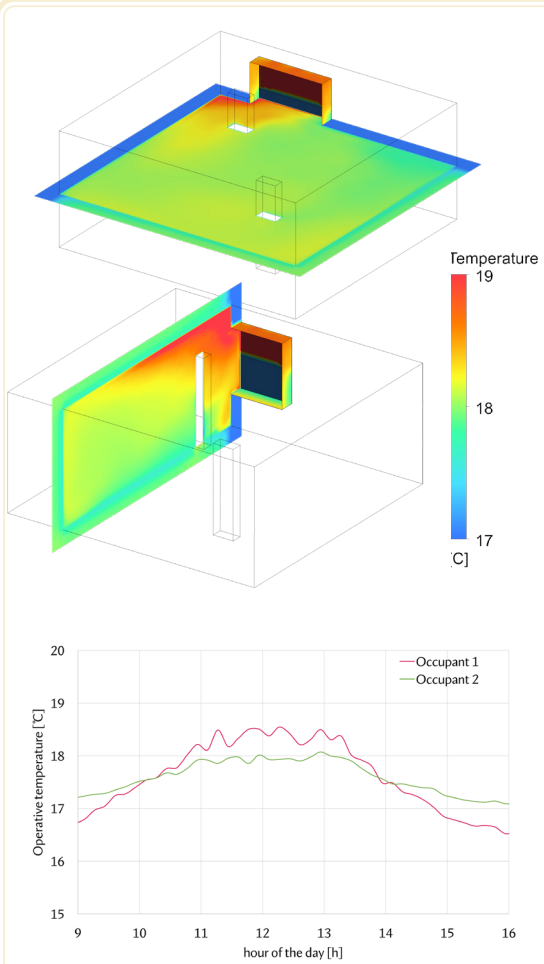
Ventilation

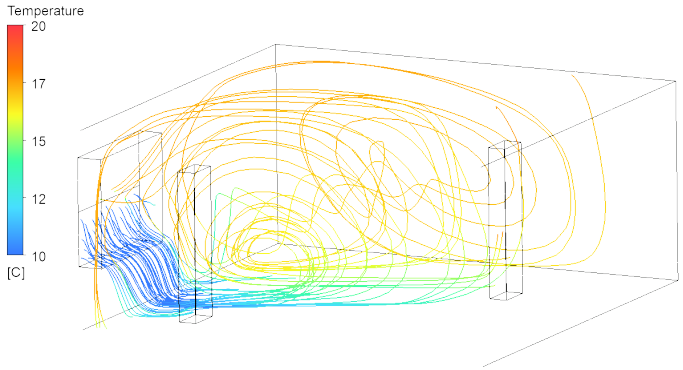
lets cold air in through window and causes thermal heterogeneity in the room until fully mixed.

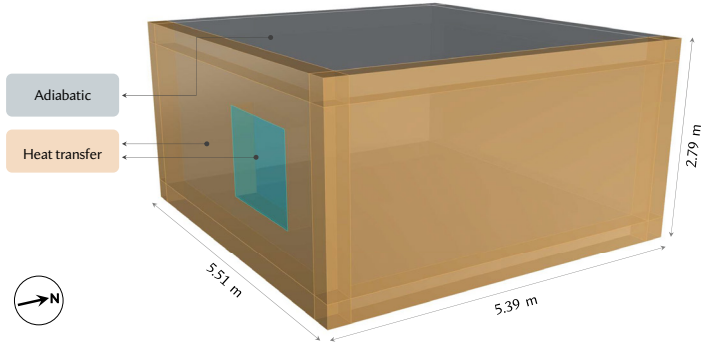


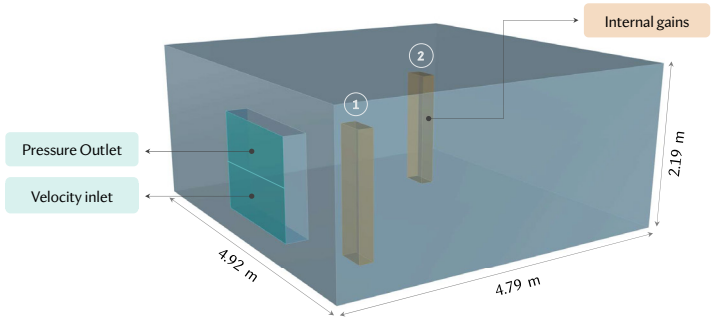
Solar radiation

causes heating up of window surface and thermal heterogeneity due to radiative heat near window.









ENVELOPE BEHAVIOUR

METRICS

- Operative Temperature
- Temperature Gradient
- Predicted Mean Vote
- Wall Temperature

PHYSICS

Heat transfer

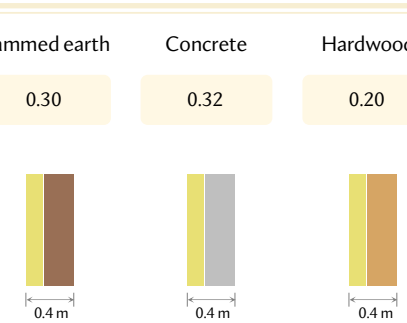
Conduction through solid domain and convection through fluid domain are modelled. Solar radiation is approximated with a heatflux through window.

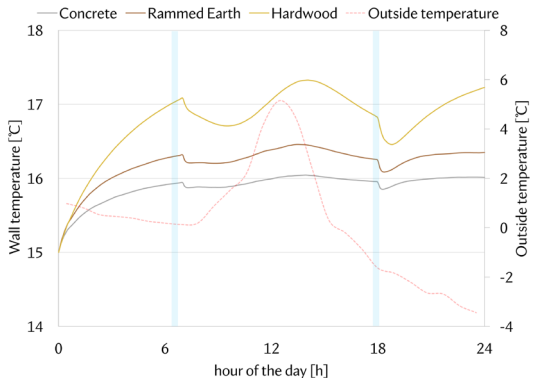
Fluid flow

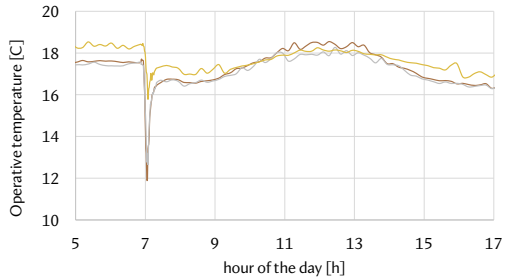
Ventilation through window is modelled with velocity inlet in lower half and a pressure outlet in the upper half.

Equal thickness study

	Rammed earth	Concrete	Hardwood	
U-Value	0.30	0.32	0.20	W/m²K
Thermal mass	456	570	273	kJ/m²K

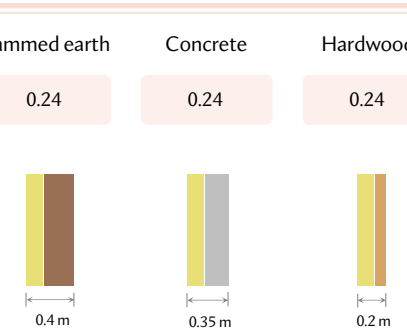


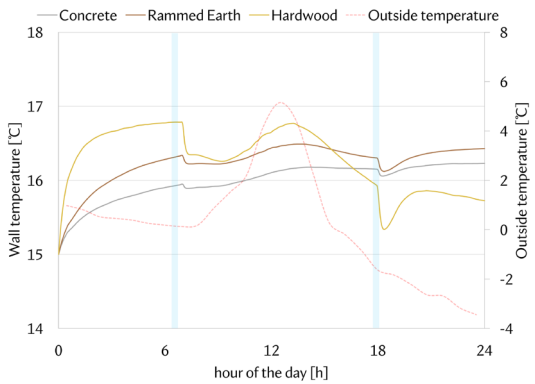


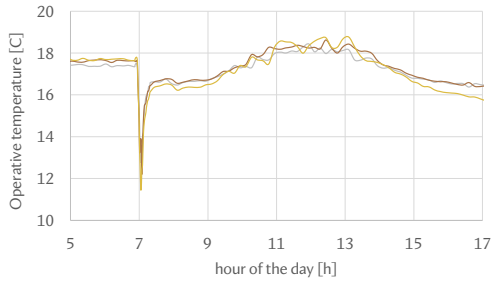


Equal U-Value study

	Rammed earth	Concrete	Hardwood	
U-Value	0.24	0.24	0.24	W/m²K
Thermal mass	456	380	45	kJ/m²K

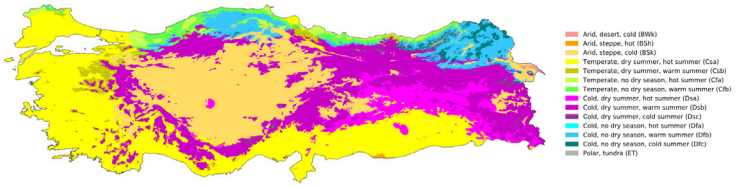


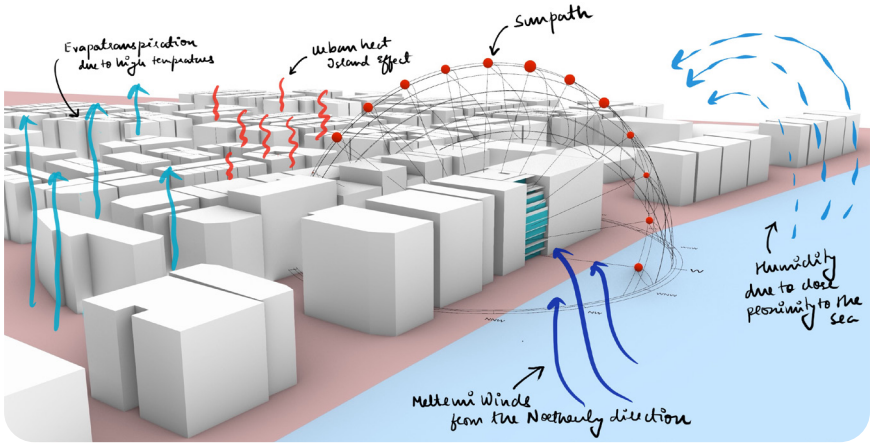




CLIMATE & ENERGY BASED DESIGN

An office building in Izmir, Turkey



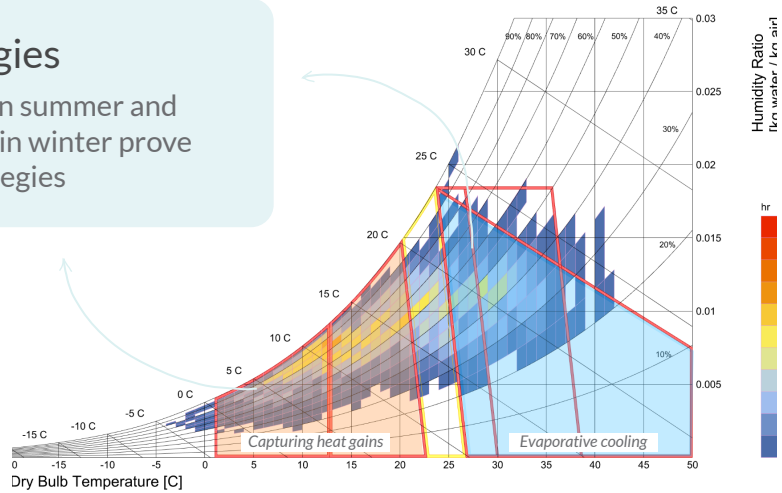


Mediterranean climate

Dry warm summers and wet mild winters due to the shift of Azores high in the Atlantic. Proximity to the sea moderates summer temperatures.

Passive strategies

Evaporative cooling in summer and *capturing heat gains* in winter prove to be effective strategies



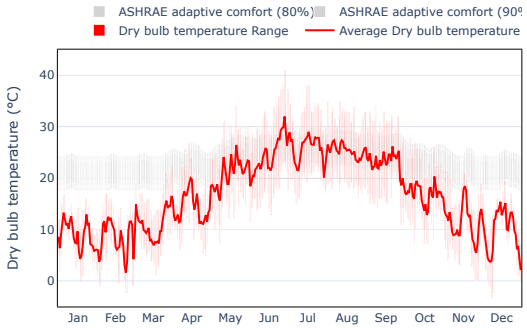
Summer discomfort

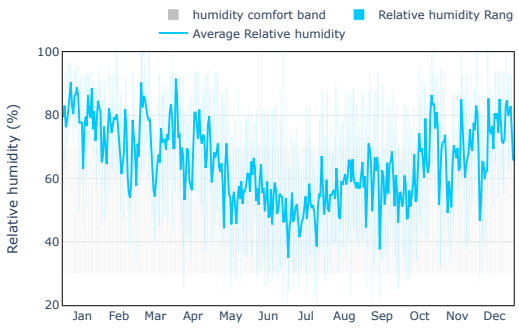
Summer discomfort is mainly due to higher indoor temperatures due to trapped internal heat gains

&

Winter discomfort

High relative humidity further lowers perceived temperature causing discomfort in winter





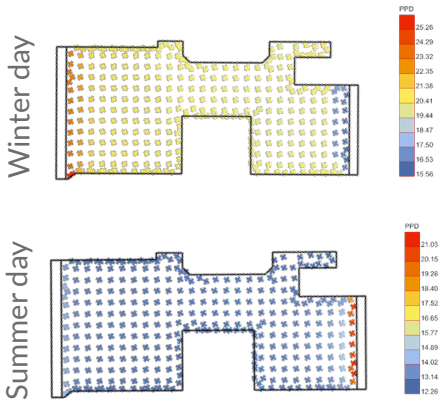
OPTIMIZATION

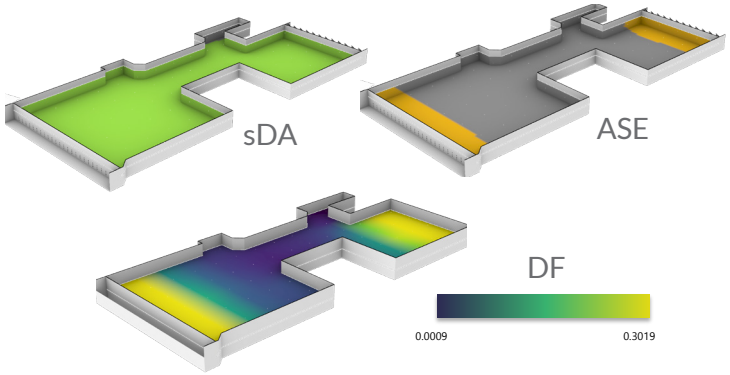
Minimize discomfort

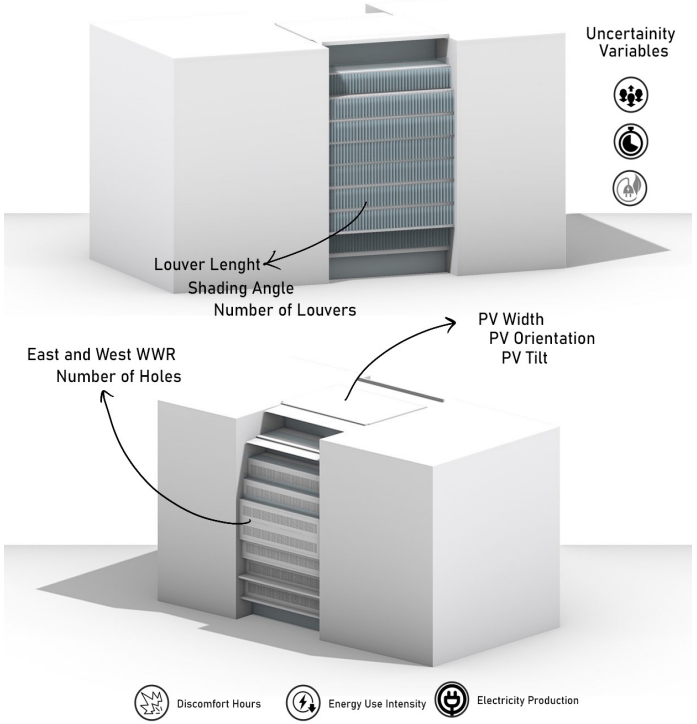
in summer and winter using passive strategies

Maximize daylight

reduces energy use intensity of the building while ensuring no glare

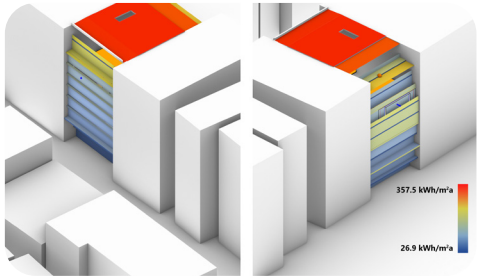


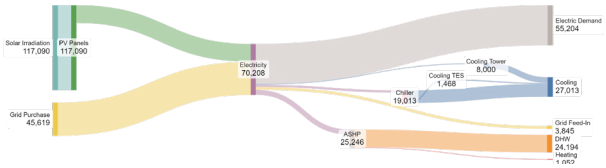


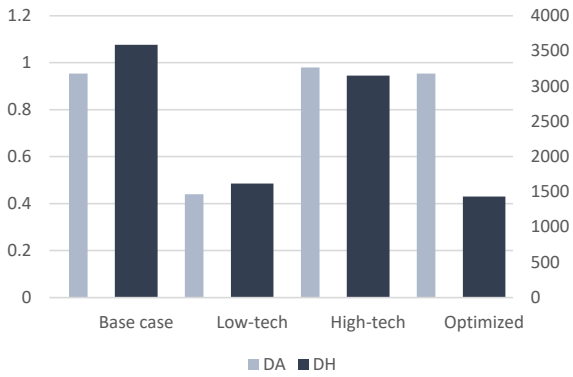


Maximize electricity generation

Optimized PV panel geometry and area for beneficial renewable energy generation





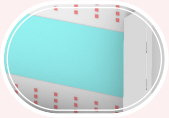


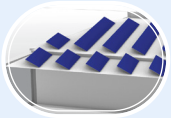
Vertical louvers

On east and west facades for shading

Wall screens

Mashrabiya-like screens for ventilation





PV Panels

On the roof for renewable energy

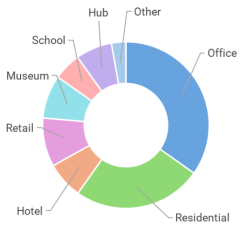
URBAN ENERGY MODELING AND DESIGN

Techno-cultural city design in Shanghai, China

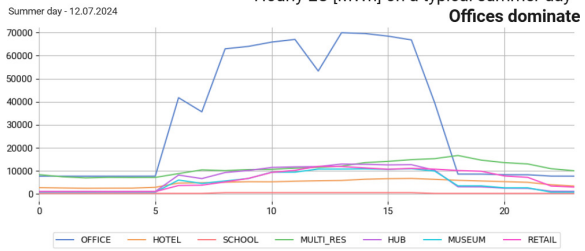
Mix-use

The city is designed to have high floor area ratio in 10 min circles from public transport. The image here shows the urban scape with solar radiation incident on the buildings.

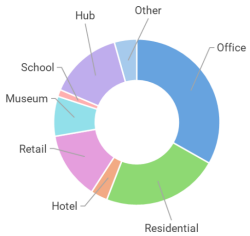
Energy use distribution reflects the use-mix



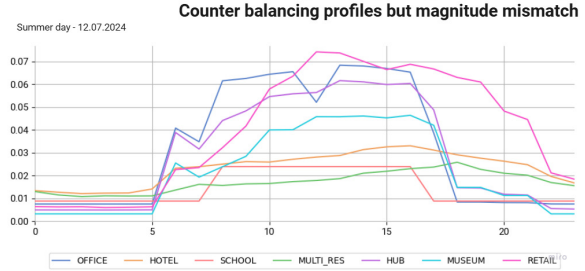
Hourly EU [MWh] on a typical summer day - **Offices dominate**



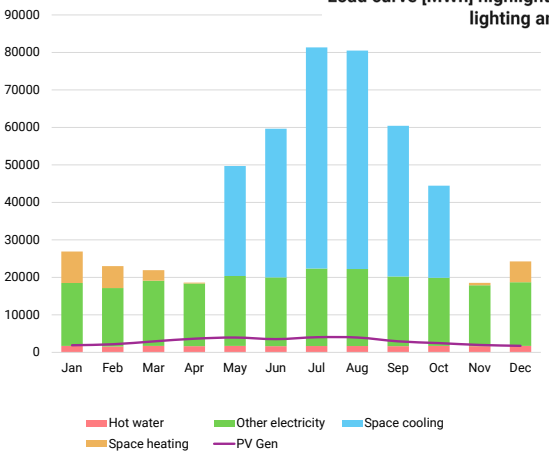
Energy use intensity distribution reveals high intensity use-types like hubs and retail

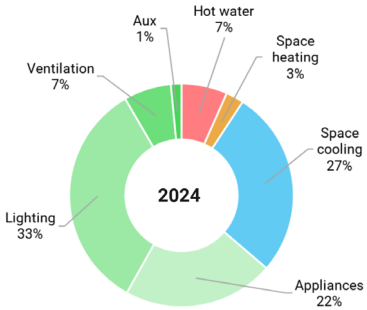


Hourly EUI [kWh/m2] on a typical summer day - **Counter balancing profiles but magnitude mismatch**



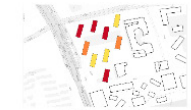
Load curve [MWh] highlights high cooling loads and high share of demand for lighting and appliances reflects the high share of office use.

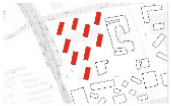


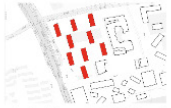


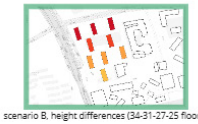
URBAN DESIGN OPTIMIZATION

	Office cluster	Hub cluster	Village cluster
Scenario original	1350 MWh	315 MWh	1090 MWh
Scenario A	1300 MWh	335 MWh	1050 MWh
Scenario B	1320 MWh	320 MWh	1060 MWh
Scenario C	1200 MWh	332 MWh	
Scenario D	1391 MWh	290 MWh	



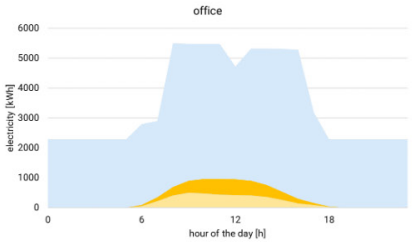




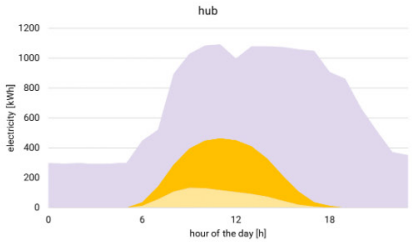


Maximizing passive energy potential

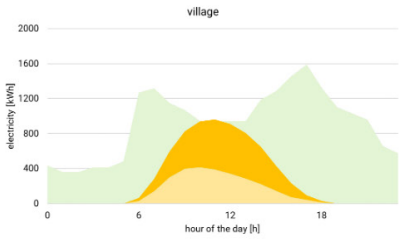
The site has mainly these three clusters, which are optimized to maximize solar energy production improving overall self sufficiency and consumption.



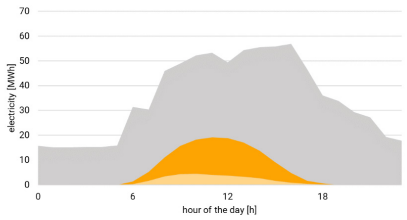
SS 9% SC 100%



SS 20% SC 100%



SS 28% SC 92%



SS 16% SC 100%

Demand
Façade PV
Roof PV

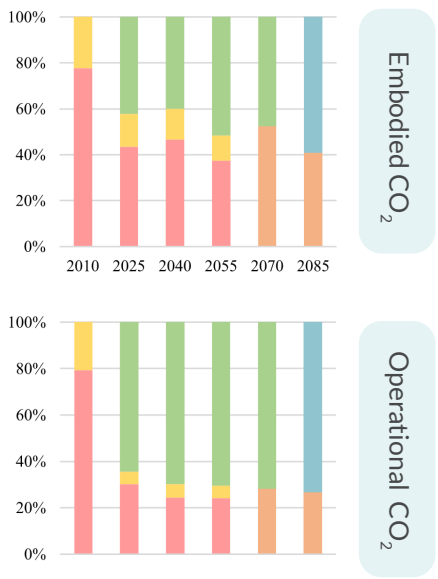
URBAN SCALE LCA AND FUTURE SCENARIOS

Embodied vs Operational CO_2

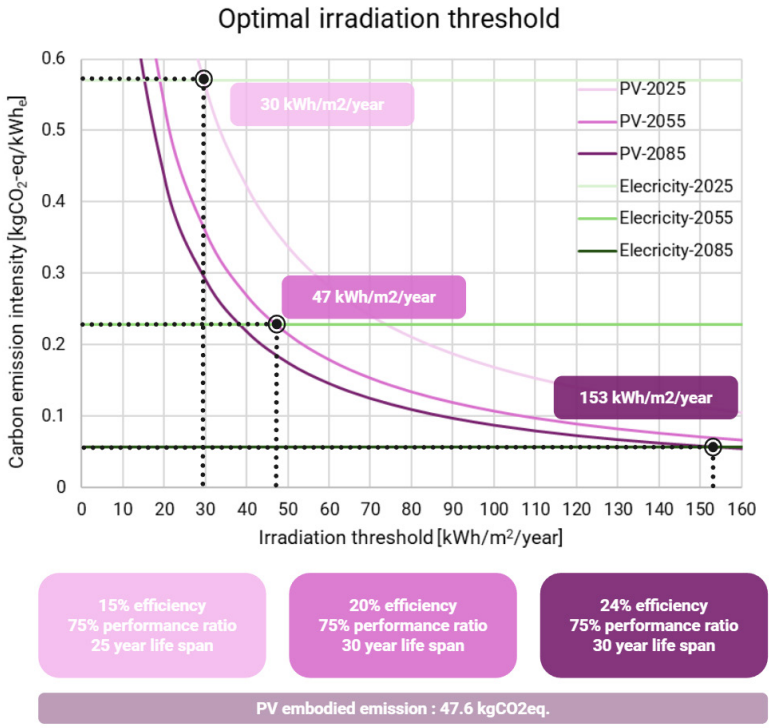
Embodied emissions remain insignificant until sufficient decarbonization of grid in Shanghai. Current focus needs to be on reducing the enormous operational emissions.

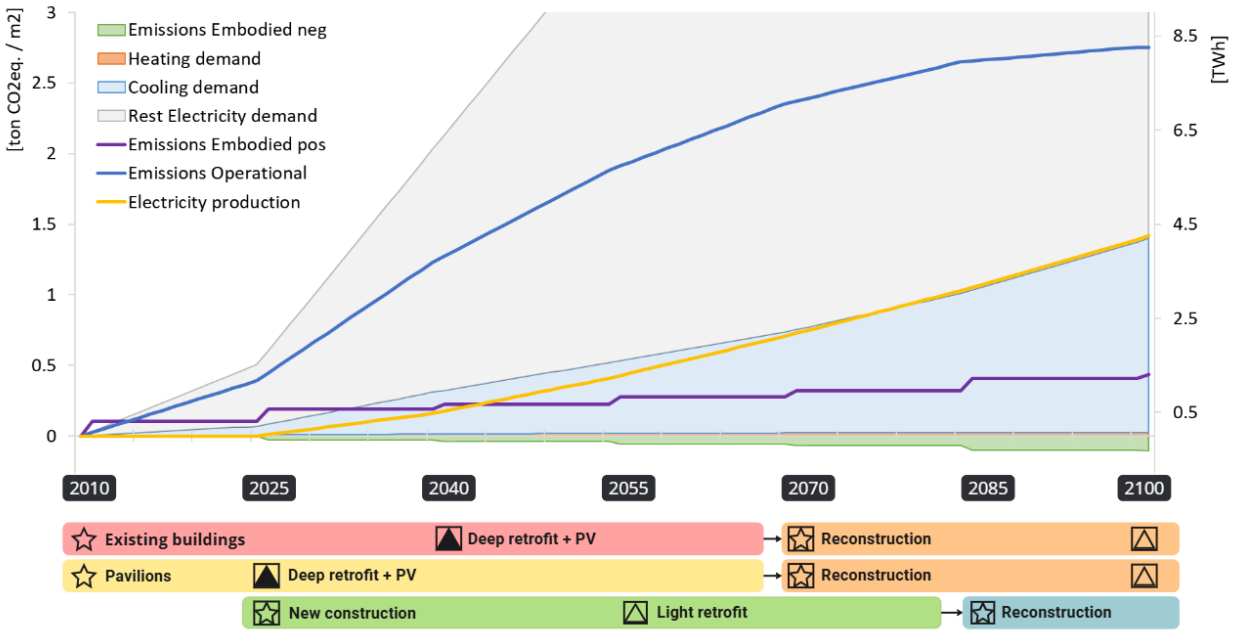
CdTe panels are eco-friendly

Low irradiation threshold indicates that installing CdTe panels is preferred over grid usage in terms of emissions.



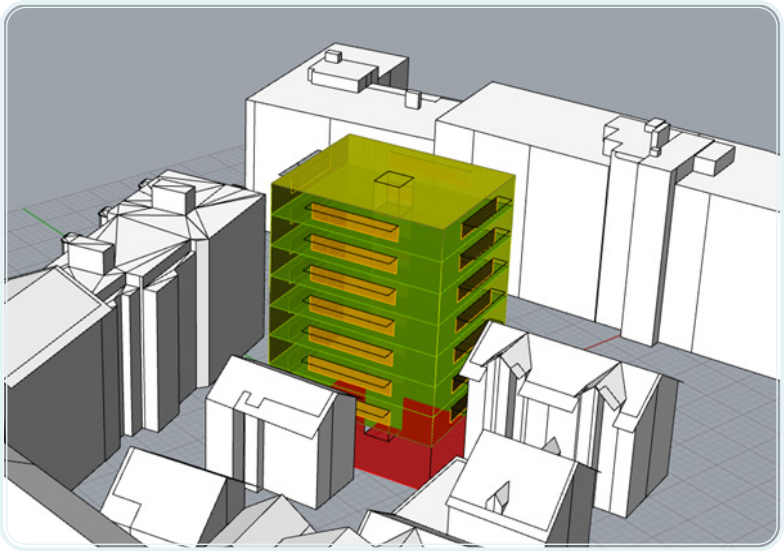
The plot shows timeline of overall emissions considering potential interventions in buildings, decarbonization of grid etc..





DESIGN-INTEGRATED LCA

A parametric design case study



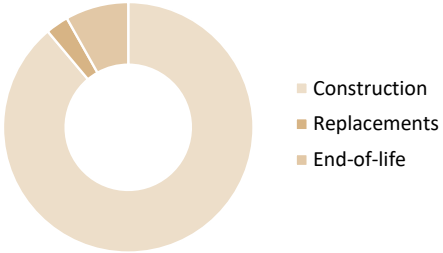
CO_2 emissions as an efficiency metric

Design is parametrized and optimized for minimizing emissions over its life cycle using Bombyx and Hive which uses KBOB database.

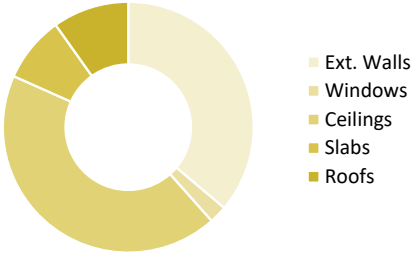
Sensitive parameters

Choice of these design parameters influence emissions in long-run (life cycle). However, the analysis is limited to only envelope and omits structural requirements.

Embodied Emissions - Life Cycle Stage



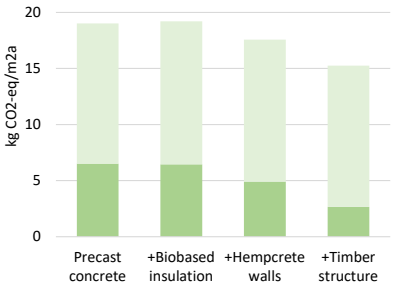
Embodied Emissions - Building Elements



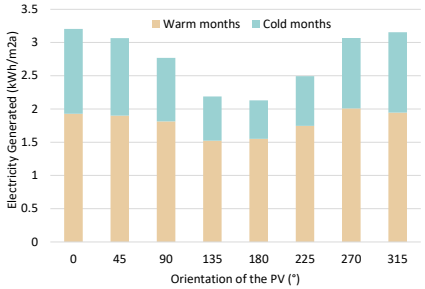
Operational Emissions

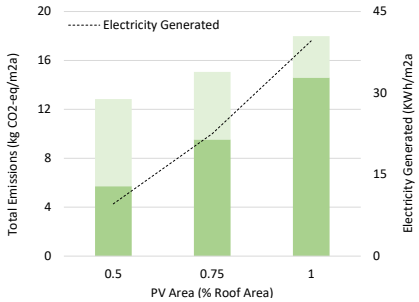
Embodied emissions

Material choice

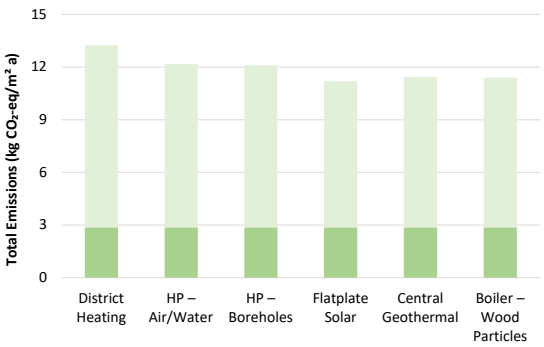


PV panel geometry





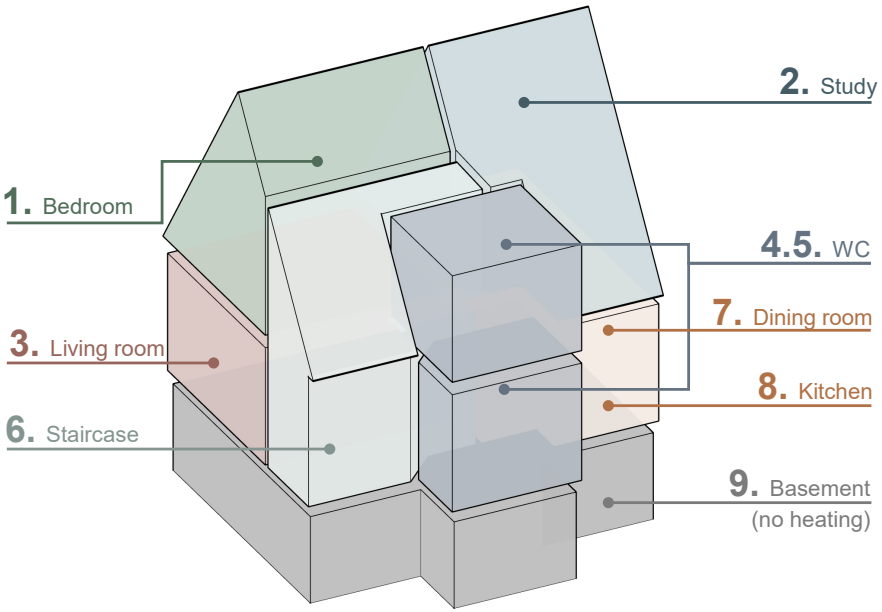
Type of heating system

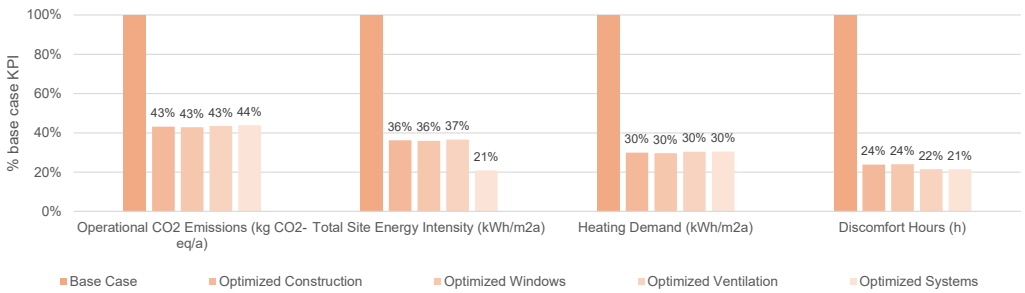


Window to wall ratio

RENOVATION STRATEGIES

Case study of an old house in Olten, Germany

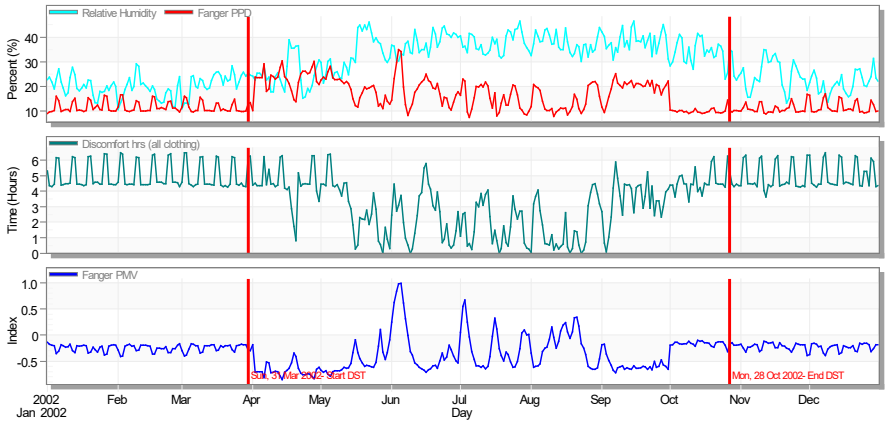




Sequence of building performance improvement

EnergyPlus simulation on base case showed poor performance, which was improved with a series of sensitivity analyses and optimization stages. The objective is mainly to reduce discomfort hours while minimizing life cycle carbon emissions and life cycle costs.

Discomfort results from DesignBuilder



Base Case → Optimized Model 1 → Optimized Model 2 → Optimized Model 3 →

Stage 1

SA-Variables

1. External wall construction
2. Roof construction(pitched and flat)
3. Glazing type
4. Local shading type
5. Window blind type
6. Infiltration rate
7. Natural Ventilation rate
8. Window-Wall-Ratio
9. Heating set point

KPI

1. Life-cycle carbon emissions
2. Discomfort

Optimization-Variables

1. External wall construction
2. Infiltration rate
3. Heating set point temperature

Stage 2

SA-Variables

1. Glazing type
2. Local shading type
3. Window blind type
4. Natural Ventilation rate

KPI

1. Life-cycle carbon emissions
2. Discomfort

Optimization-Variables

1. Natural ventilation rate

Stage 3

SA-Variables

1. Ventilation system
2. Heating system

KPI

Constraint: discomfort hours < 300

1. Life-cycle carbon emissions
2. Life-cycle costs

Optimization-Variables

1. Ventilation system
2. Heating system

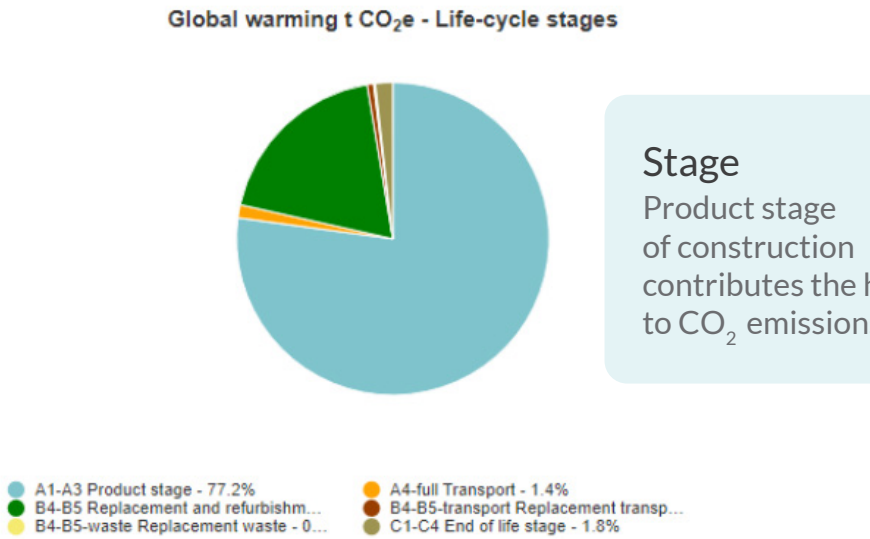
LIFE CYCLE ASSESSMENT OF AN EWS HOUSE

EWS House A house designed for economically weaker sections.

Analysed the building material requirement and performed LCA using tally plug-in through Autodesk Revit.

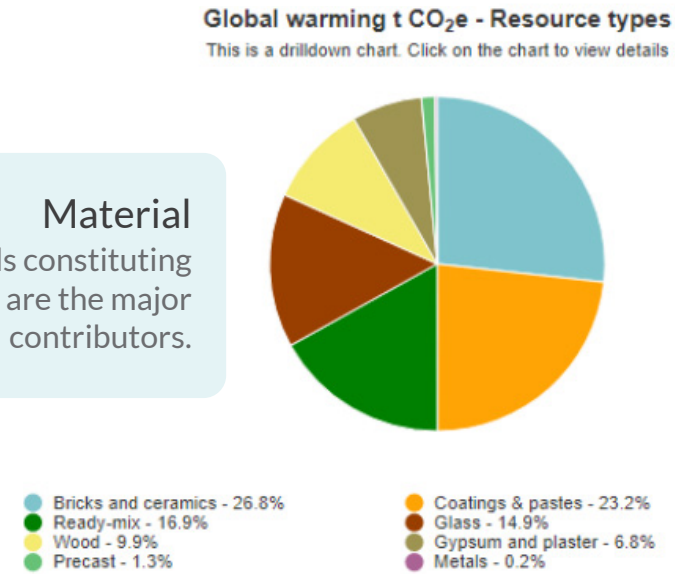
Sustainable alternative

Cement manufacturing process, inspired from coral reefs, from sea water and CO_2 emissions, reduces the carbon footprint by 1.5 times.



Stage

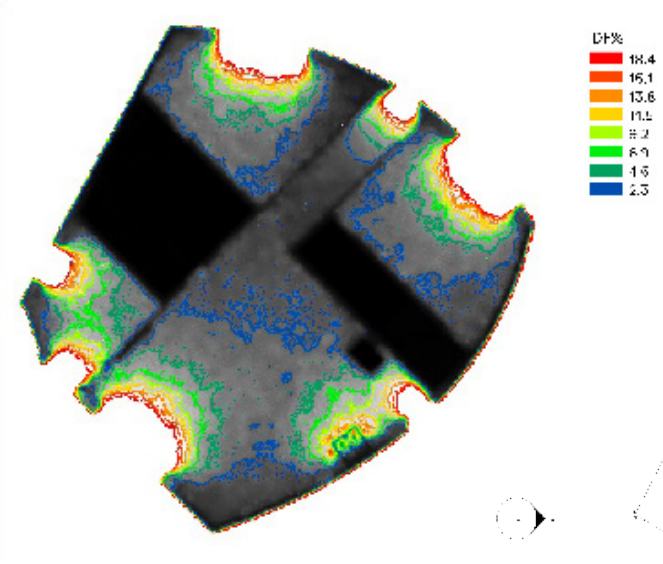
Product stage of construction contributes the highest to CO_2 emissions.



Material

Materials constituting **cement** are the major contributors.

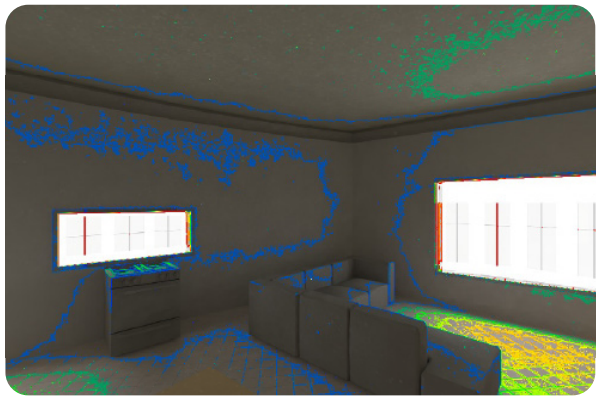
FUNCTIONAL DESIGN

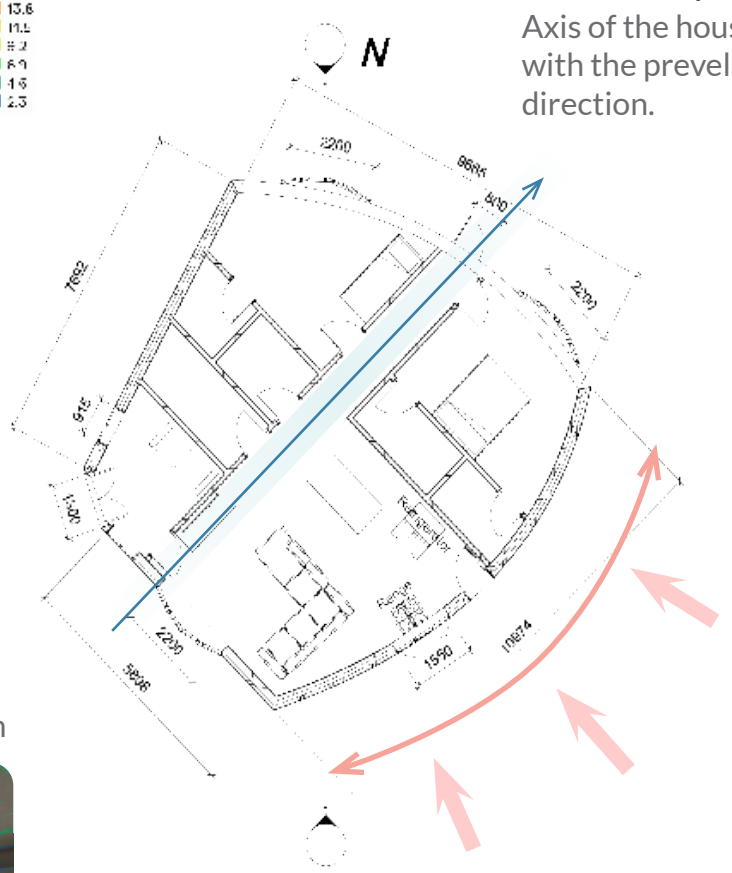


Daylight analysis

Daylight contours showing the sufficiency of natural lighting during the day.

Lighting in the kitchen

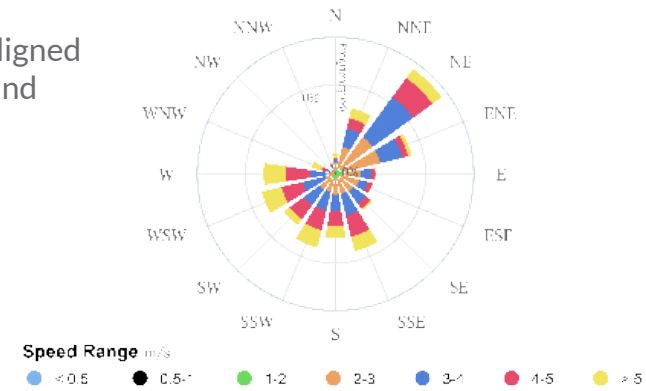




Wind analysis

Axis of the house is aligned with the prevelant wind direction.

Wind Rose Diagram



Thermal comfort analysis

Curved boundary to reduce the surface area in turn minimising heat gain through walls.

Inclined wall profile at the junction with roof to create pressure difference for easy exhaust.

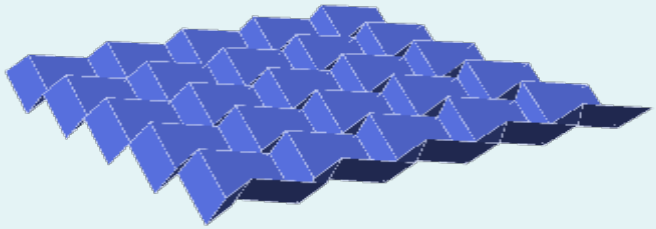
COMPUTATIONAL DESIGN & MATHEMATICAL MODELING

ORIGAMI

TOPOGRAPHICAL DESIGN

using Origami

Design Inputs



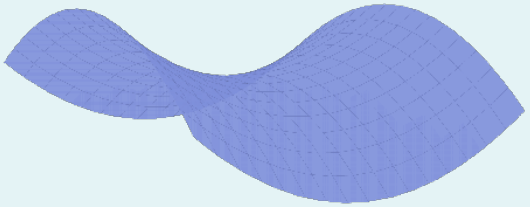
Origami Pattern

The standard Miura - Ori pattern, made of parallelograms, forms two parallel surfaces when folded along its crease pattern.

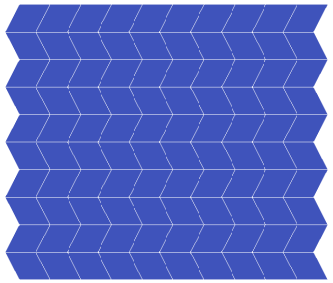
&

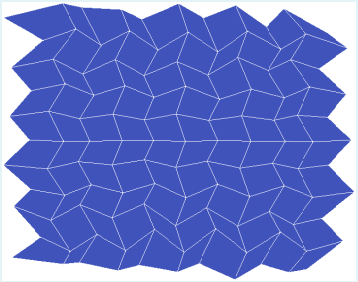
A 3D surface with arbitrary Gaussian Curvature, which the origami solution conforms to.

Target Surface



Folds into

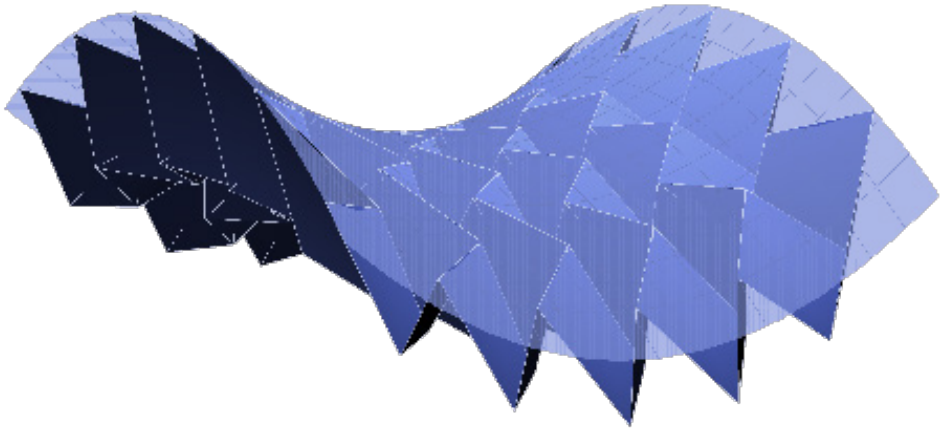




Crease pattern

Starting with the standard Miura crease pattern, the algorithm aims to impose the design constraints and obtain a crease pattern that folds into the solution origami structure.

Folds into

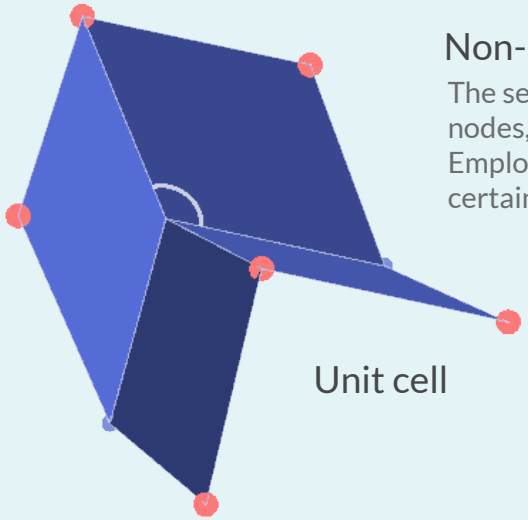


Engineering behind it!

RIGID

Functional constraints

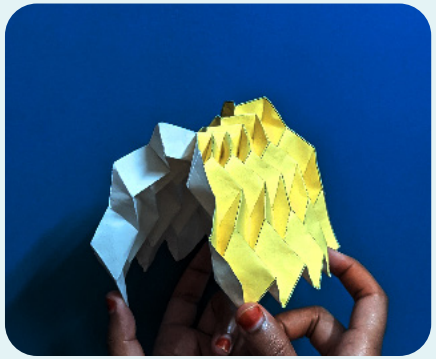
- Developable from flat sheet.
- All faces remain rigidly planar.
- Structure is rigidly foldable.



Unit cell

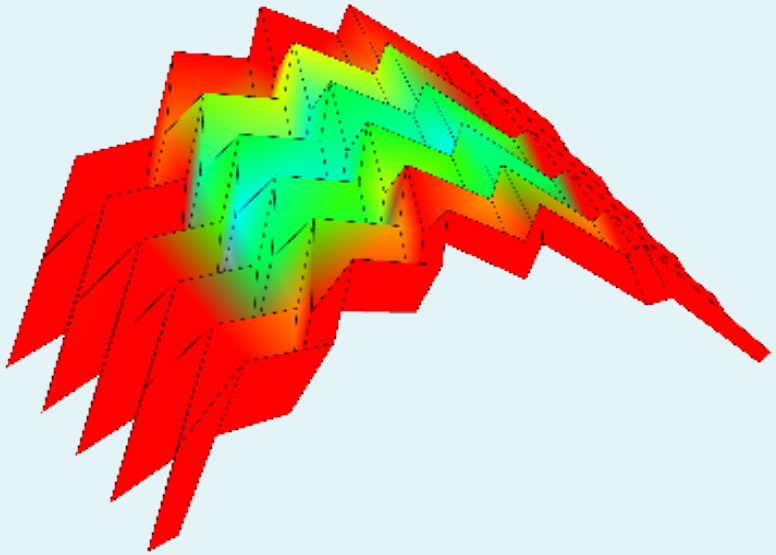
Non-linear system

The set of variables include co-ordinates of the pattern nodes, angles of faces and folds and size of the panels. Employed a least-squares based non-linear solver with a certain tolerance limit on deviations.



Strain visualization

Studied the rigid foldability of solutions by simulating the static strains developed during the folding motion and observed the same with physical models as well.



Publication

The work is published in the conference - link.

Co-authored with Kishore S. Shenoy and Dr. Phanisri Pradeep Pratapa.

IASS 2020/21 SURREY 7

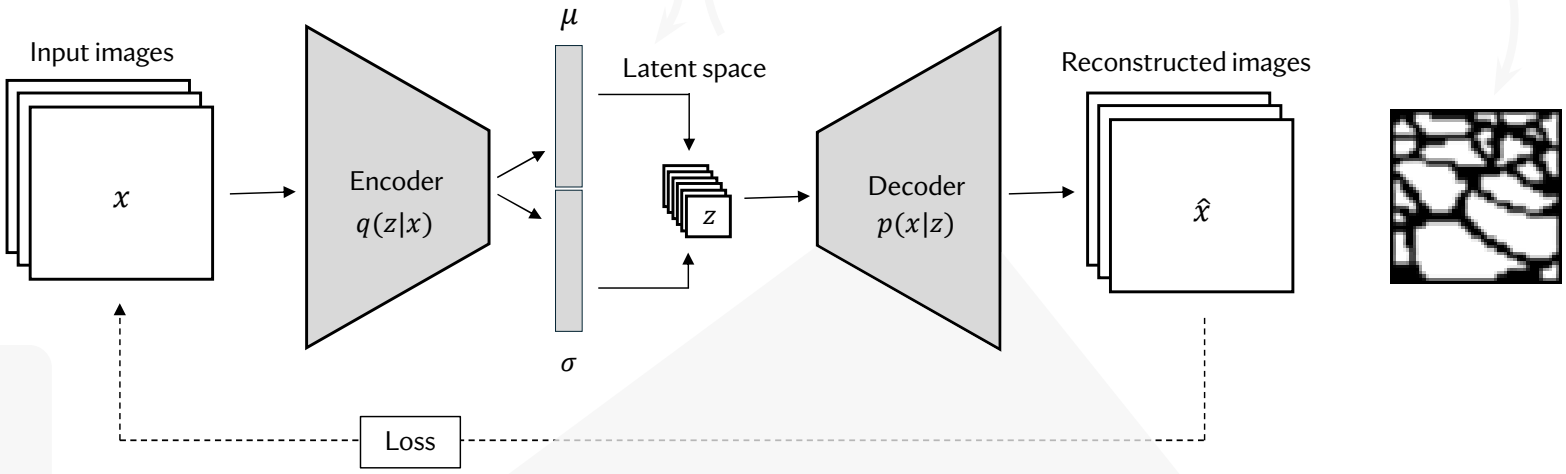
International Conference on Spatial Structures 2021/1

PREDICTION OF GLASS FRACTURE BEHAVIOUR USING ML

The encoder learns to encode the key information specific to the pattern.

The decoder regenerates the pattern using the encoded information.

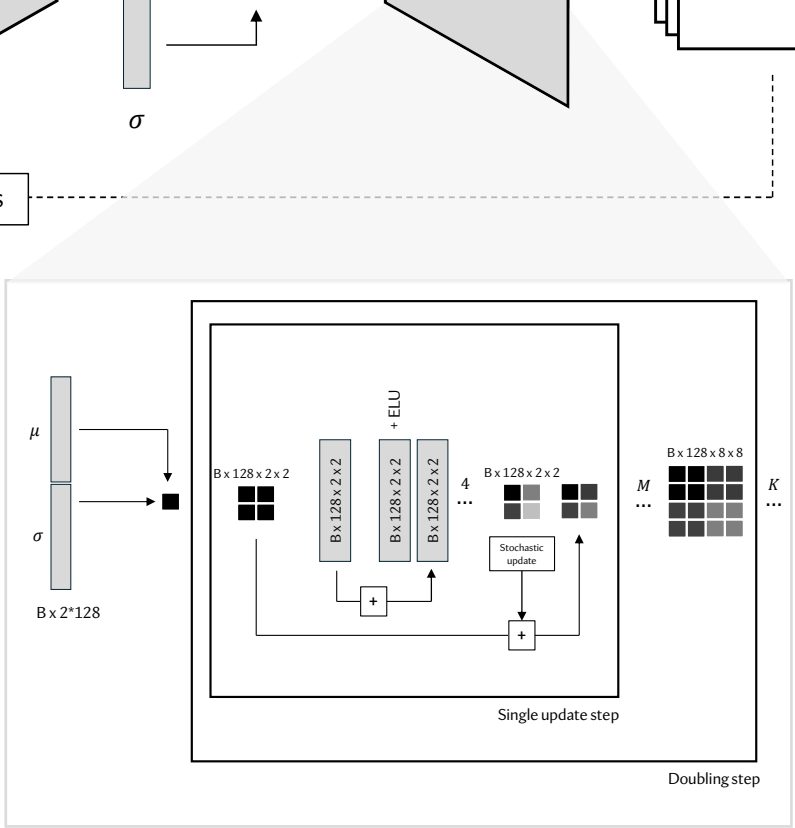
Glass fracture images

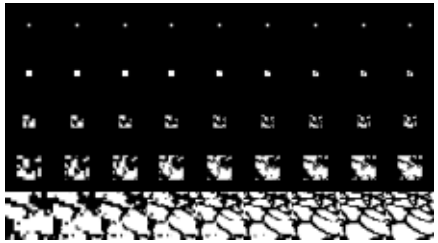


Few key parameters:

- *Residual stress state*
- *Glass thickness*
- *Fragment density*

The pattern growth uses concepts of Neural *Cellular Automata* wherein the rules of life are learned by the decoder network as seen here:





Sequence of a 32x32 pattern regeneration.

COMPUTATIONAL DESIGN - CITY SCALE

Computational design using Grasshopper

The city is designed starting from basic 3D geometric shapes like a cone or a cylinder and further detailed by dividing surfaces iteratively using C# and Mola grasshopper library.

Rendering using AI image generators

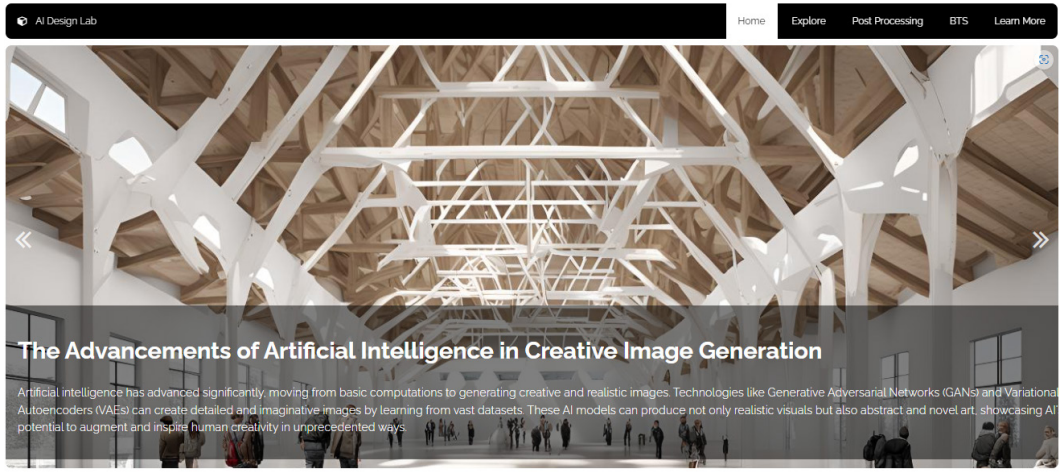
The design is rendered in different styles using an AI image generator with text prompts. The left one is rendered in a dystopian setting while the right one is just a rendering from enscape.

Voxel based design

This city is designed using voxels and rules are coded in C# to create the desired open and closed spaces along with the details like shrubs, lake and columns.

OTHER WORKS

AI IN DESIGN FOR CIRCULAR CONSTRUCTION - WEBSITE



We explored several concepts of circularity in design like modularity, etc., using AI image generators like DALL-E, Midjourney, and Runway ML. This website demostrastes the potential and limitations of these tools, by allowing users to tweak the prompt and providing a walk through of the process. Find the working prototype here - link.

Explore

Contextual Design

An exterior photograph from a Mexican contemporary school with focus on the local r ty. The structure must clearly show its elements and how th be disassembled and repurposed.

Swedish
Indian
Chinese

Modularity in design

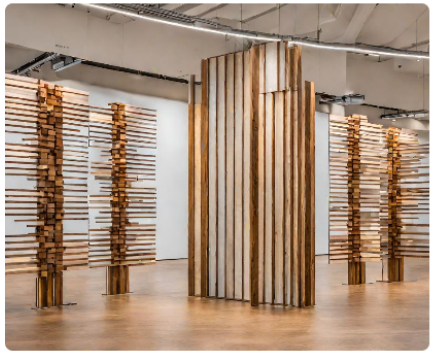
Create an interior space of a modular classroom which could be assembled and disassembled easily. The concept of modularity within construction should be incorporated into the design. As the main building material precast concrete plates should be used. The singular elements need to be distinguishable from one and each other.

Post Processing

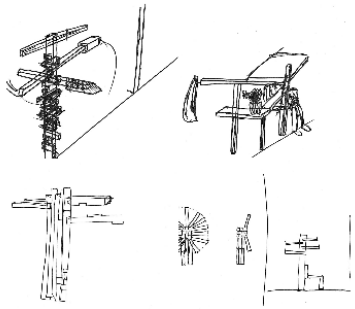
Stage 1: Generating Images using AI

Coat Hanger

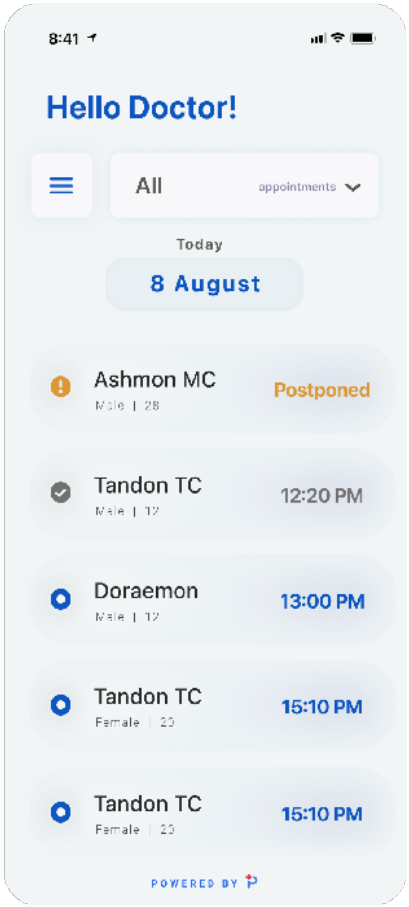
a modular futuristic exhibition wall made with reused polycarbonate planks and wooden beams

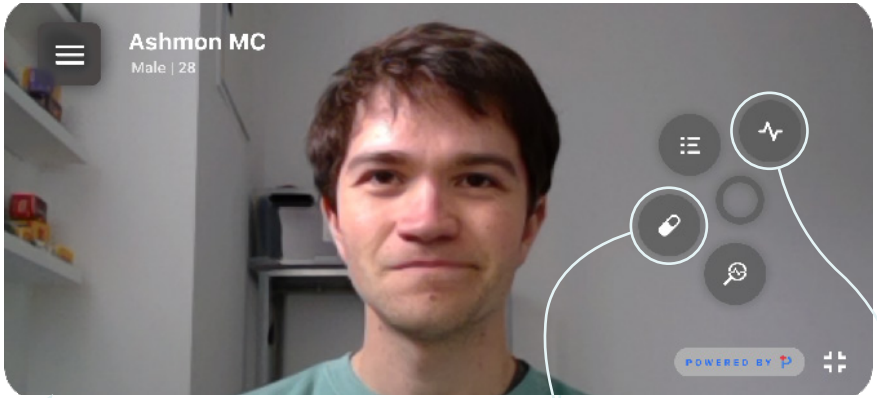


Stage 2: Sketching and prototyping



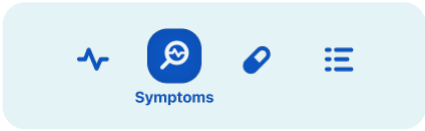
UI/UX DESIGN AND PROTOTYPING - WORKFLOW



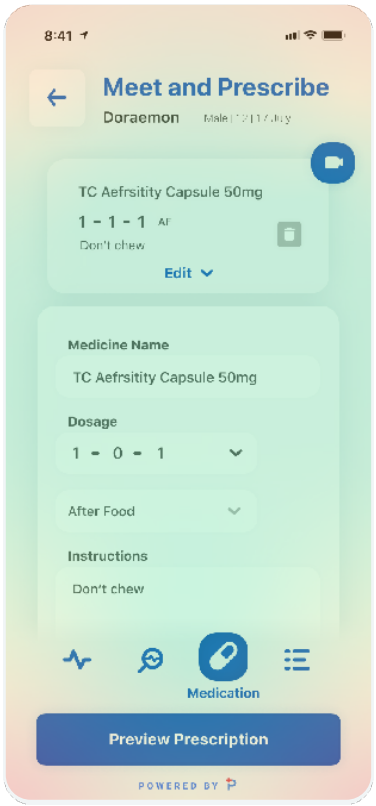


Heatmap analysis shows accessibility and visibility of a particular frame.

Navigation icons



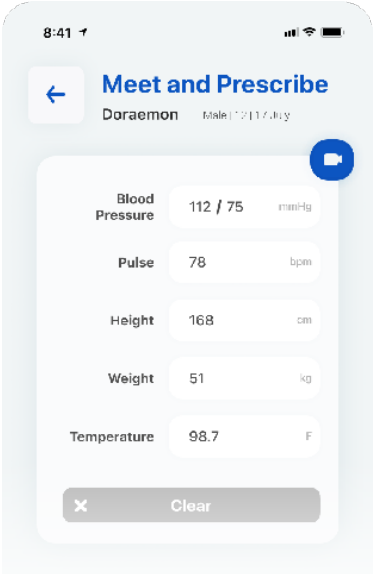
Final proceeding button is always at the bottom of the frame, to create a sense of ending and have a glimpse at the verge of clicking it.



Most accessible wheel position. Draggable too!

Color scheme to indicate *medical* and go with the company logo.

Grey for a sense of subtle warning.

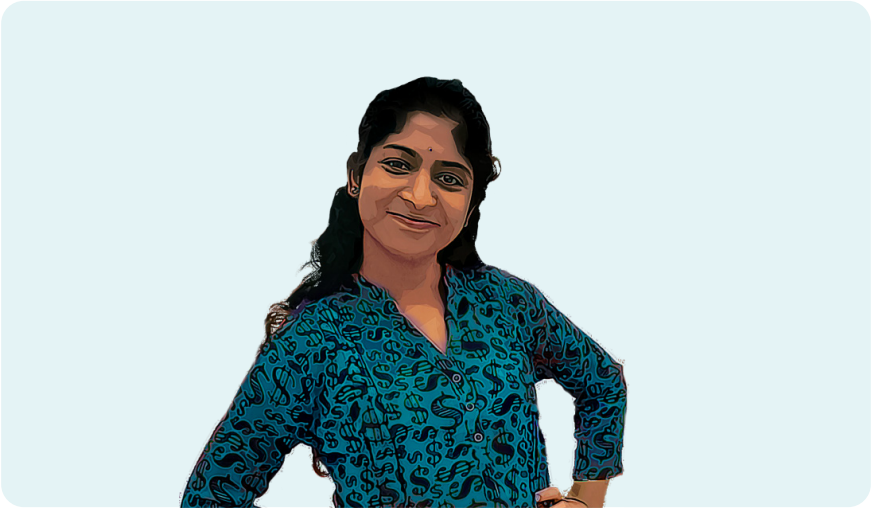


Minimized video button for simultaneous interaction.

USER

The product is designed for a healthcare startup, that allows seamless doctor - patient consultations. Find the working prototype here - link.

Sree Chandana Madabhushi



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