Performance-Driven Design

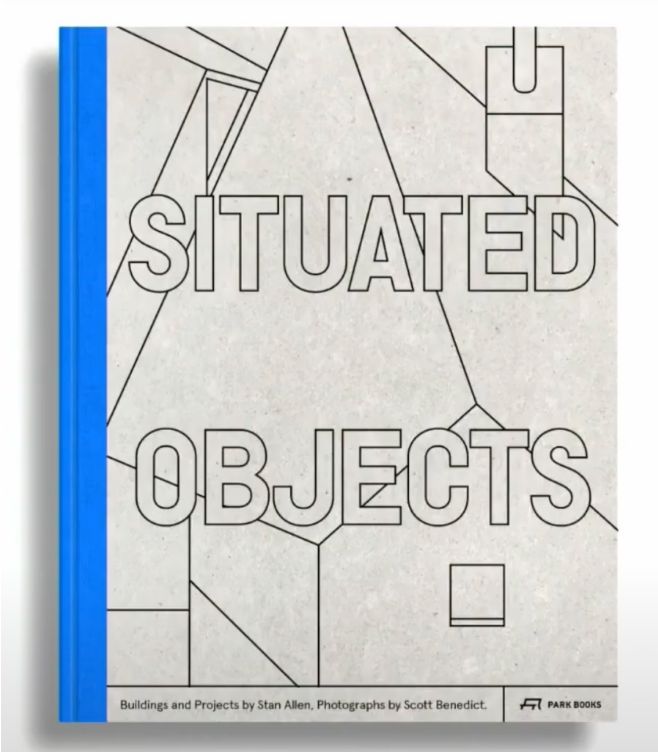
DM II Week 11

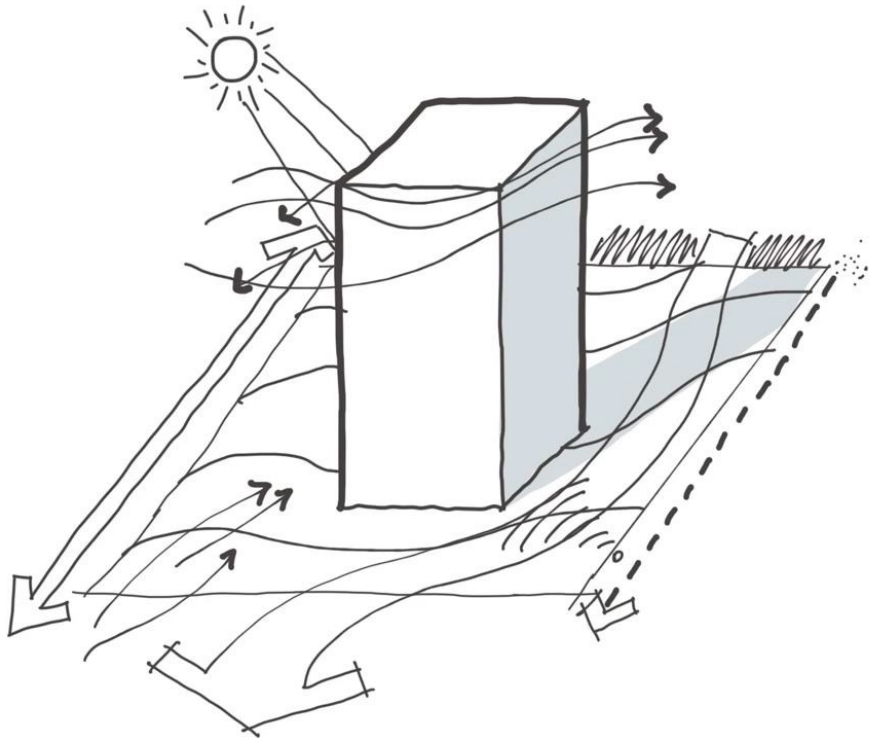
DES 212| Winter Term 2 | 2026 | 3 Credits
Instructor: Xun Liu

Content

1. Structural Performance: Gravity as Designer
2. Environmental Performance: The Sun as Form Generator
3. Simulation as Design Syntax · GH Learning Path
4. Assignment 3

- Performance = any force the designer surrenders authorship to
- Object: autonomous form imposed by the architect
- Field: form emerging from contextual forces
- Forces can be cultural, programmatic, regulatory, climatic
- The designer defines the system — the forces shape the form

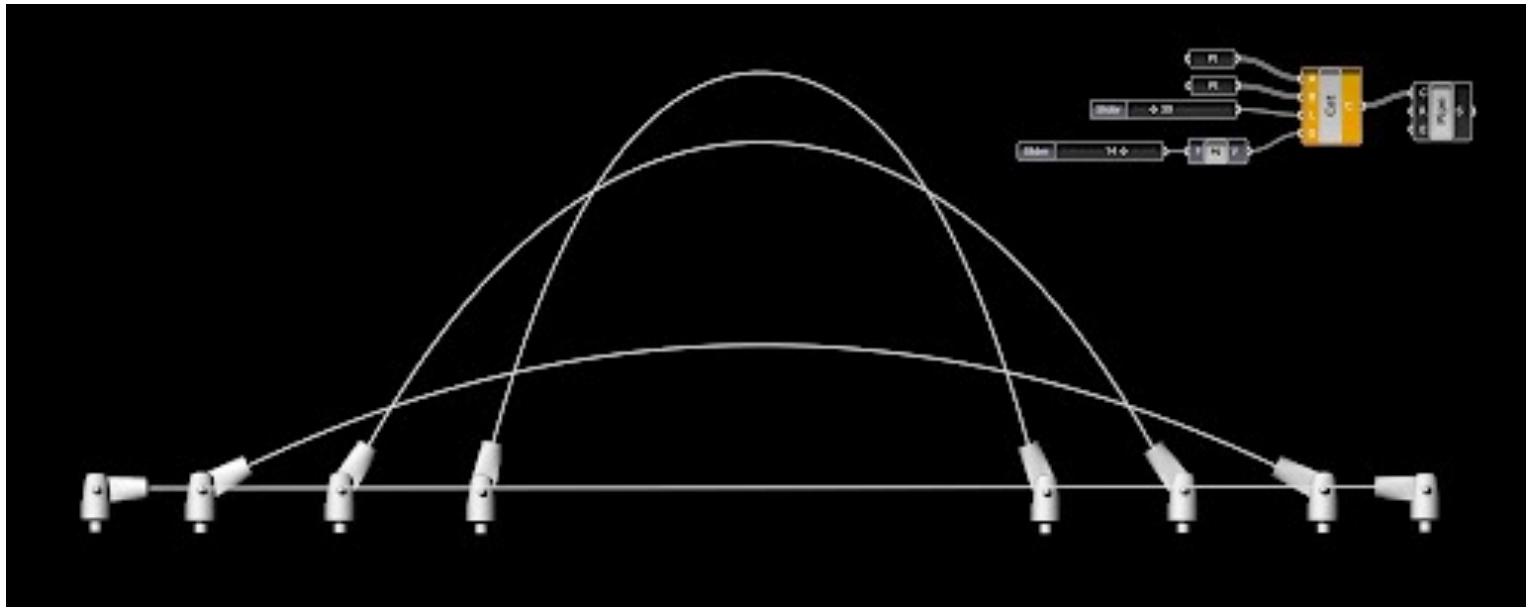




Resource: Situated Object

Structural Performance

Structural Performance



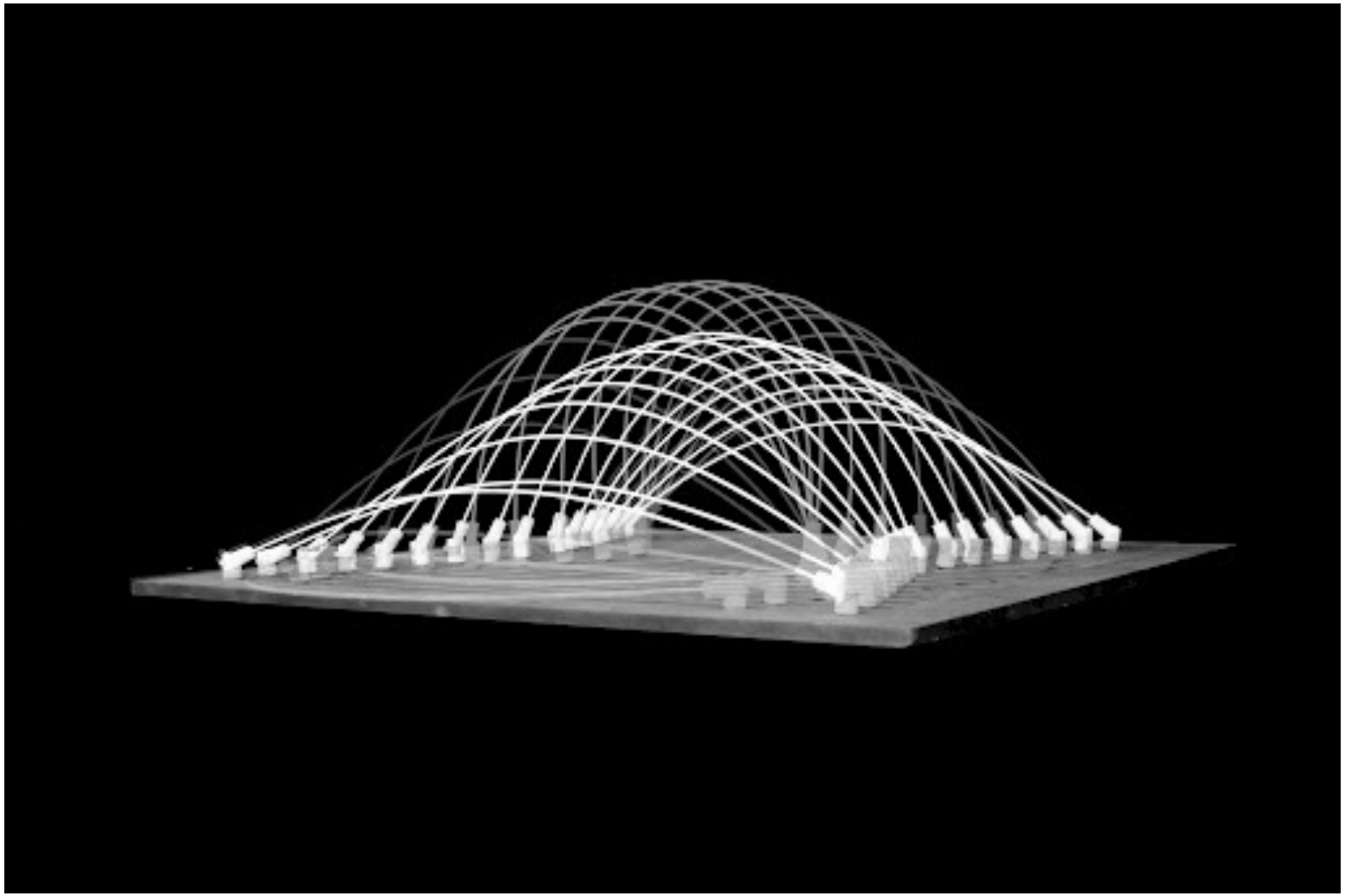






Catenary

Structural Performance



Catenary

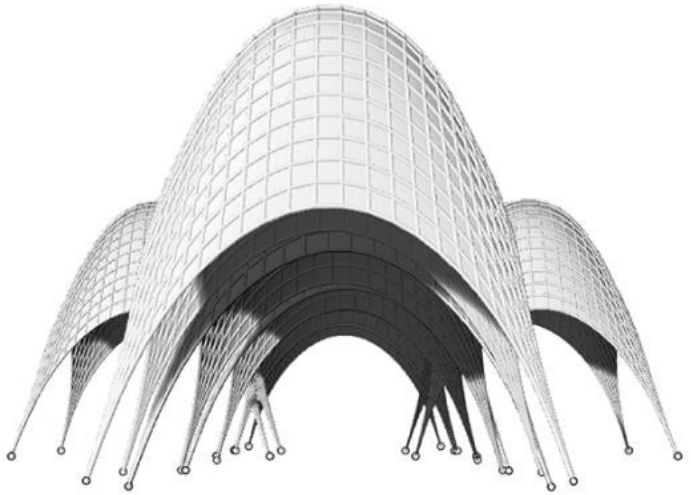
Structural Performance

Weighted strings → inverted catenaries = compression arches. Adjust one anchor → entire system propagates. The original 'parametric' model.

Weighted Catenary Model



Weighted Net Form in Rhino



Hanging Chain Model, Colònia Güell
Antoni Gaudí, 1898–1914

Structural Performance

Weighted strings → inverted catenaries = compression arches. Adjust one anchor → entire system propagates. The original 'parametric' model.

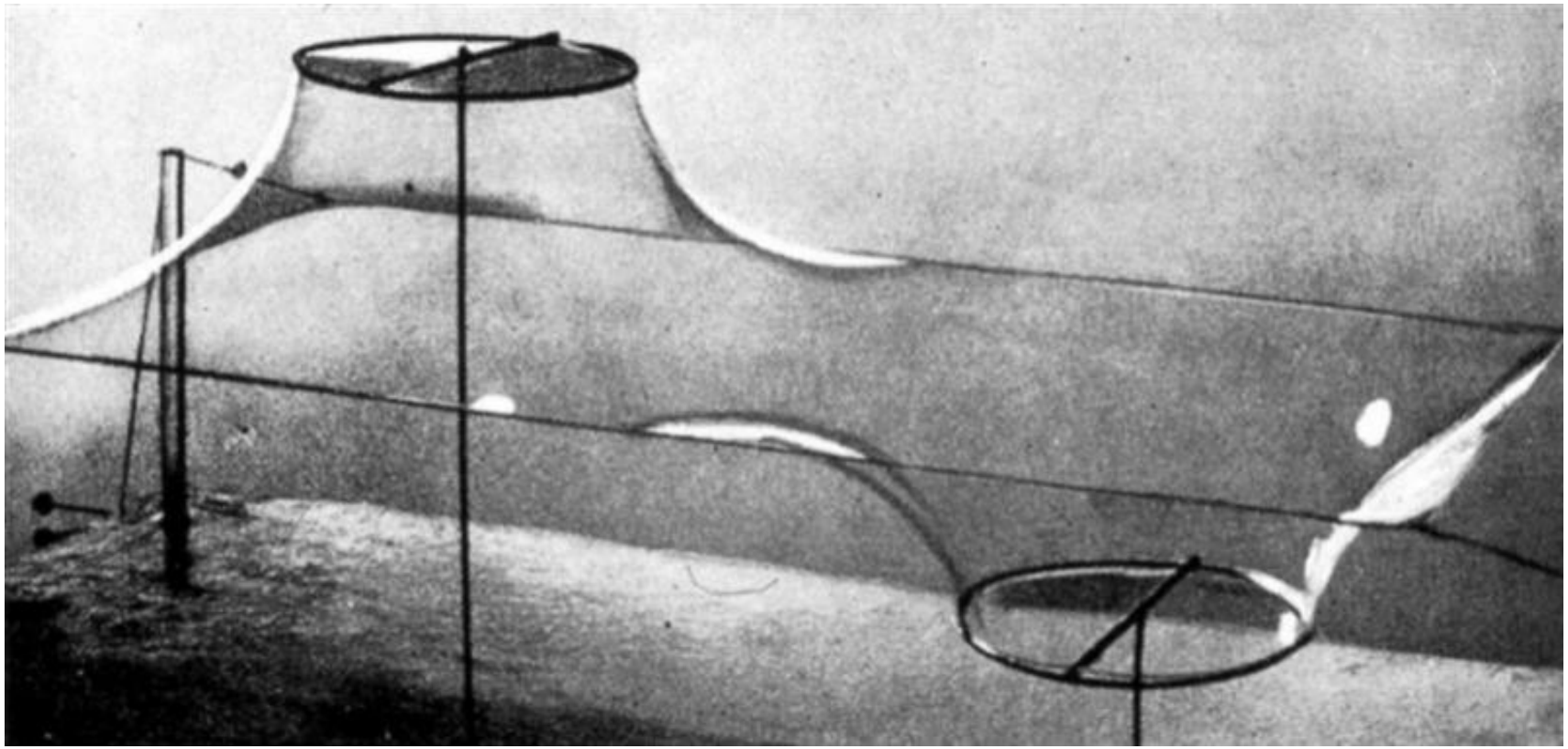




Sagrada Familia
Antoni Gaudí, 1883-

Structural Performance

Soap film stretched across boundaries
→ minimal surfaces.

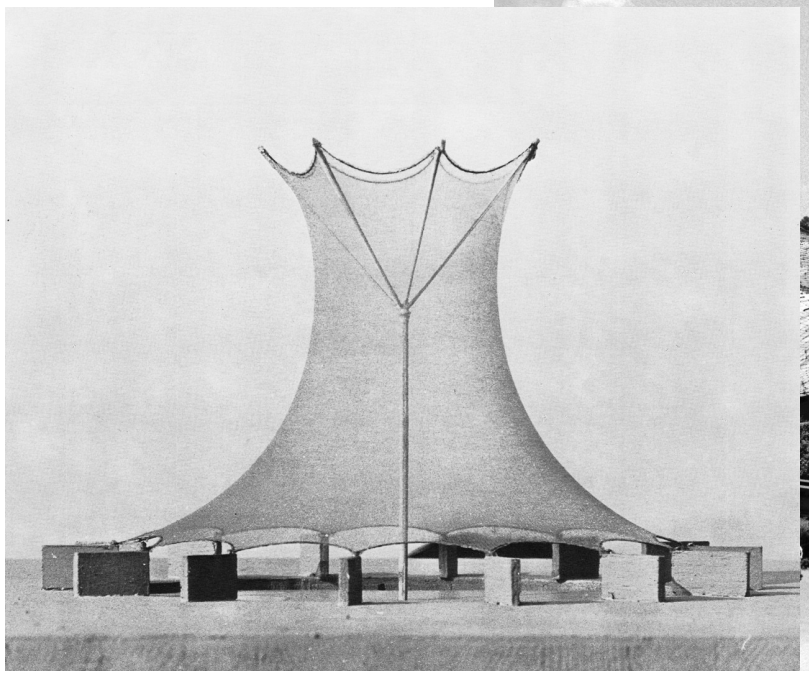


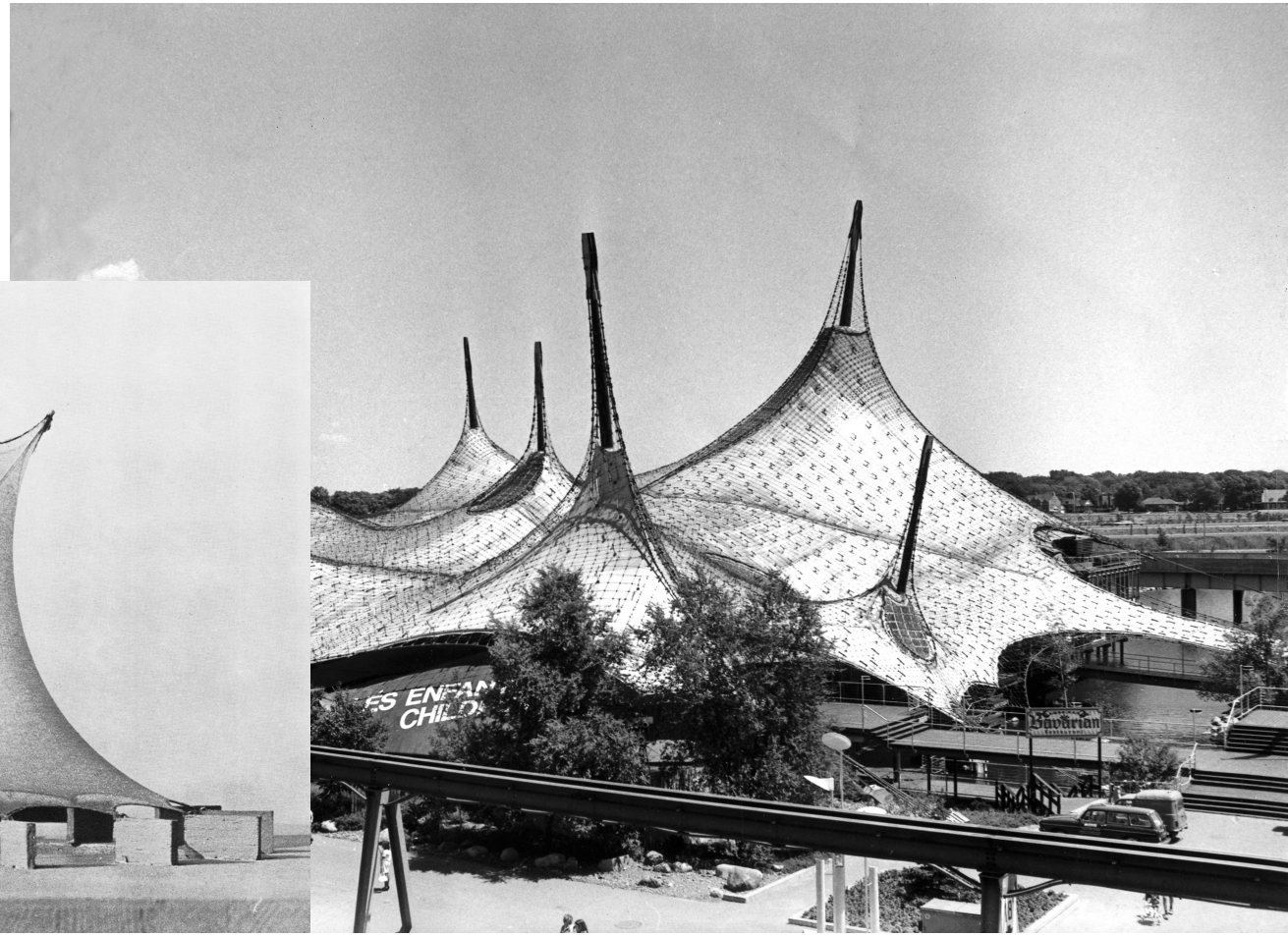
Soap Film Experiments → Munich Olympic Stadium
Frei Otto / IL Stuttgart, 1972

Resource:

Structural Performance

Form cannot be drawn, only found through material behavior.



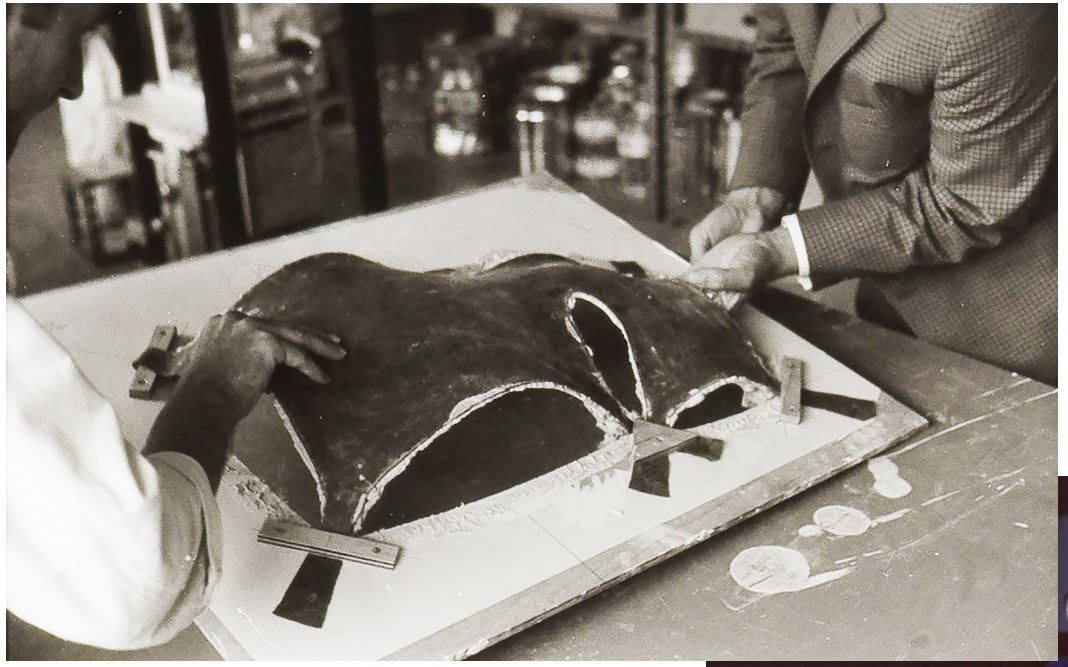


Soap Film Experiments → Munich Olympic Stadium
Frei Otto / IL Stuttgart, 1972

Resource:

Structural Performance

Hanging cloth, inflated rubber, molded earth → 1,400+ shells.
~1:500 slenderness ratio. Never used a computer.
Quantity of built work proves the method.





Thin Concrete Shells / Deitingen Service Station
Heinz Isler, 1968

Structural Performance

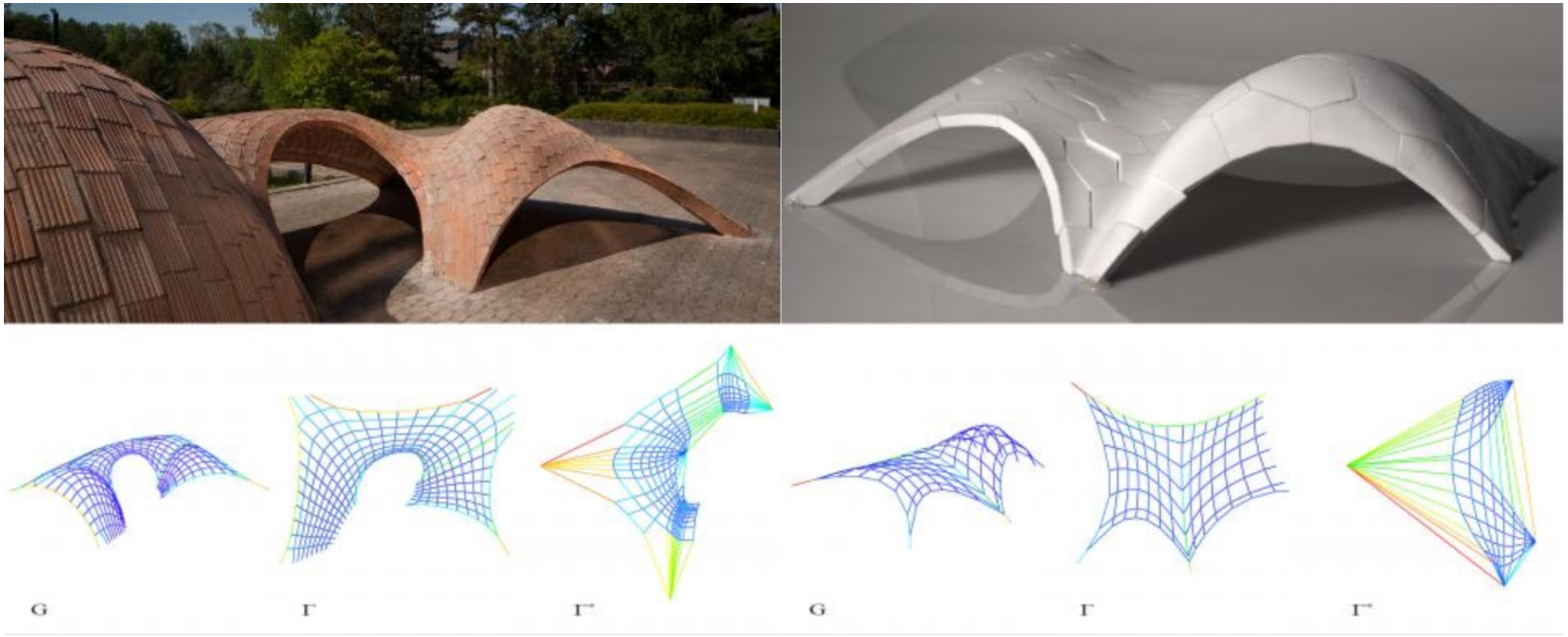
Hanging cloth, inflated rubber, molded earth → 1,400+ shells.
~1:500 slenderness ratio. Never used a computer.
Quantity of built work proves the method.





Thin Concrete Shells / Deitingen Service Station
Heinz Isler, 1968

Structural Performance



Rhino Vault

https://www.food4rhino.com/en/app/rhinovault

Structural Performance

Compression / Funicular



Armadillo Vault
Block Research Group / ETH
Zurich, 2016

Resource: https://block.arch.ethz.ch/brg/content/project/armadillo-vault-venice-italy

Structural Performance

Compression / Funicular

Mapungubwe Interpretive Centre
Block Research Group / ETH Zurich, 2009



Resource: https://block.arch.ethz.ch/brg/project/mapungubwe-national-park-interpretive-centre-mapungubwe-south-africa

Structural Performance

Compression / Funicular



Mapungubwe Interpretive Centre
Block Research Group / ETH Zurich, 2009

Resource: https://block.arch.ethz.ch/brg/project/mapungubwe-national-park-interpretive-centre-mapungubwe-south-africa

Structural Performance

Tension / Textile Hybrid

KnitCandela
BRG + ZHCODE, 2018



Resource: https://block.arch.ethz.ch/brg/project/knitcandela

Structural Performance

Tension / Textile Hybrid

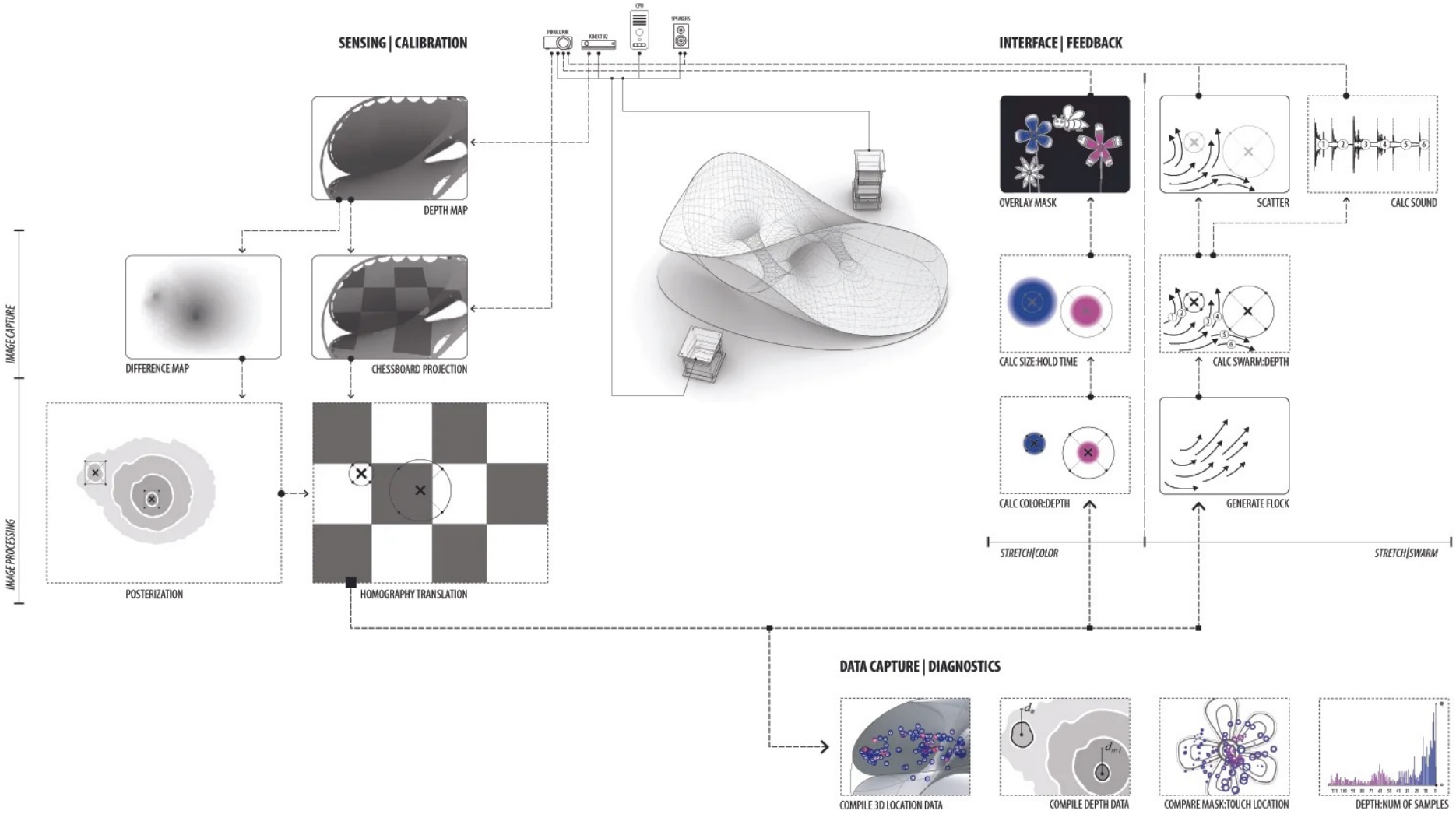


CADenary + SensoryPLAYSCAPE
Axel Kilian / Sean Ahlquist

Resource: http://www.materialarchitectures.com/social-sensory/

Structural Performance

Tension / Textile Hybrid



CADenary + SensoryPLAYS(
Axel Kilian / Sean Ahlquist

Resource: http://www.materialarchitectures.com/social-sensory/

Structural Performance

Tension / Textile Hybrid



CADenary + SensoryPLAYSCAPE
Axel Kilian / Sean Ahlquist

Resource: http://www.materialarchitectures.com/social-sensory/

Structural Performance

Shell / Optimization



Musmeci Bridge
Sergio Musmeci 1967

Structural Performance

Shell / Optimization

PS1 Afterparty
MOS



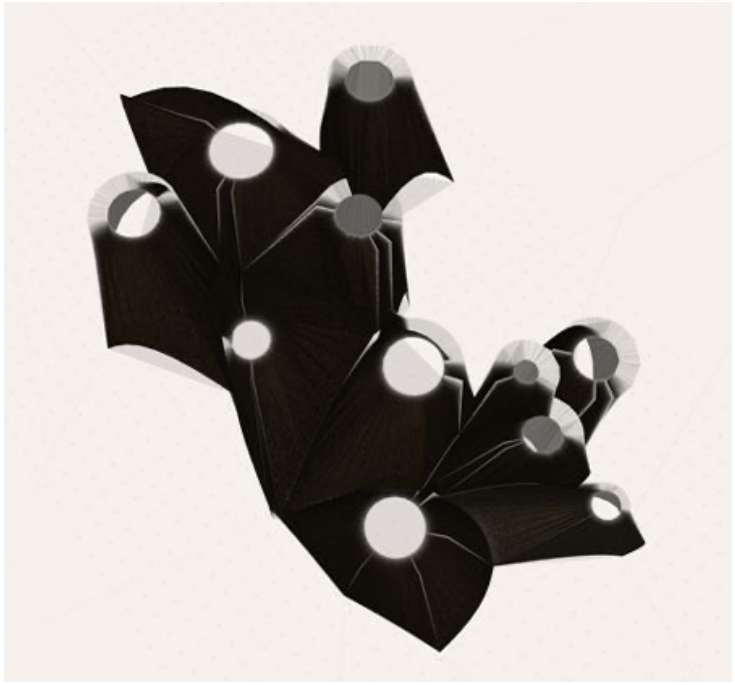




Structural Performance

Shell / Optimization





PS1 Afterparty
MOS



Structural Performance

Topology Optimization



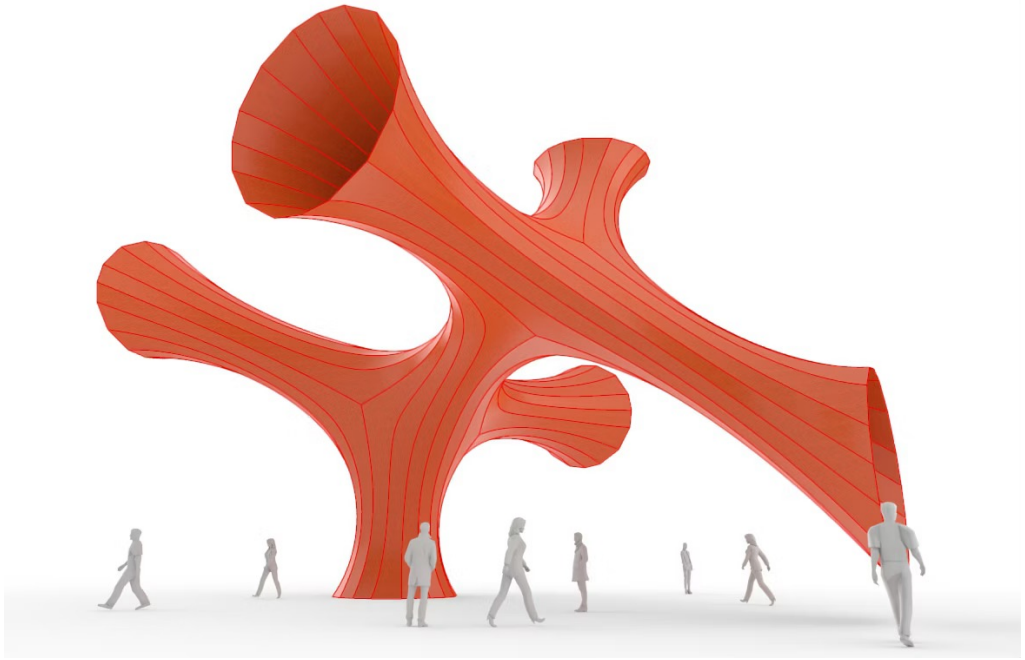
Ameba Topology Optimization
RMIT

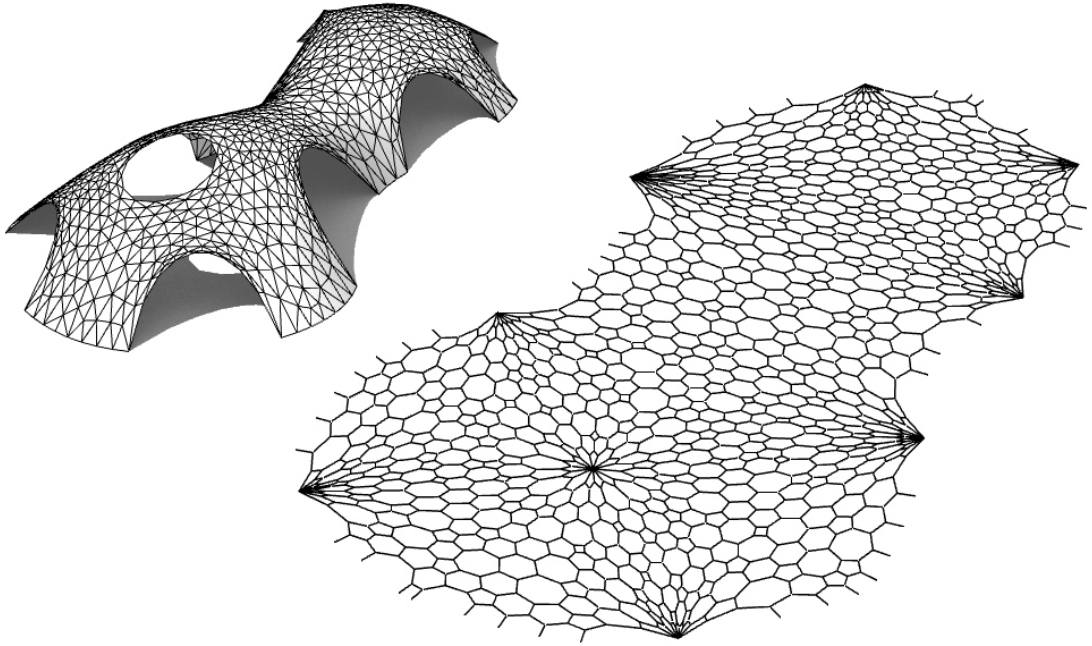
Resource: https://ameba.xieym.com/

Structural Performance: Tools

- **Kangaroo**
— live physics engine, Digital hanging chain, tension/membrane form-finding
- **Karamba3D**
— real-time FEA Structural analysis as design feedback, not post-rationalization
- Ameba
— topology optimization: Define loads + supports → algorithm finds minimum material

Kangaroo

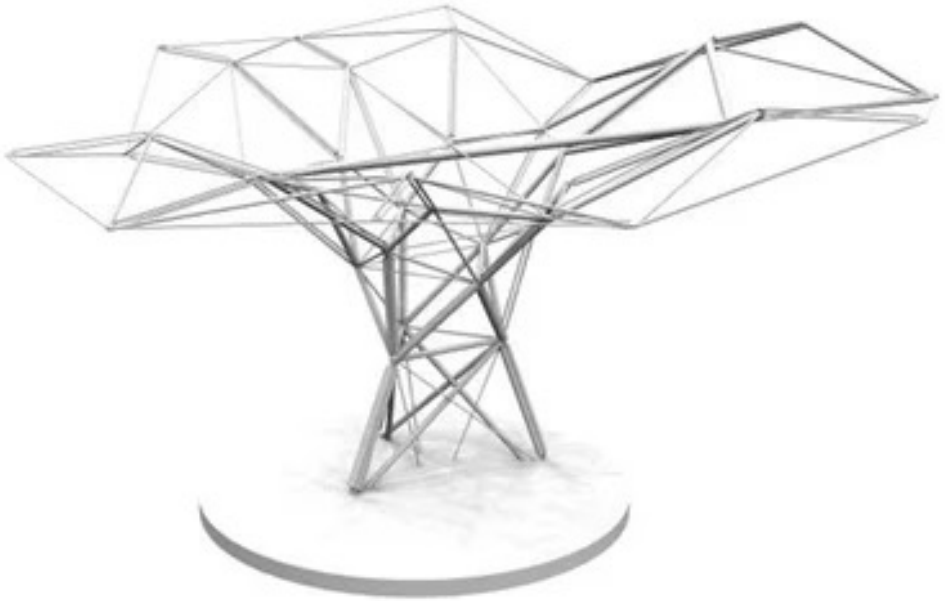


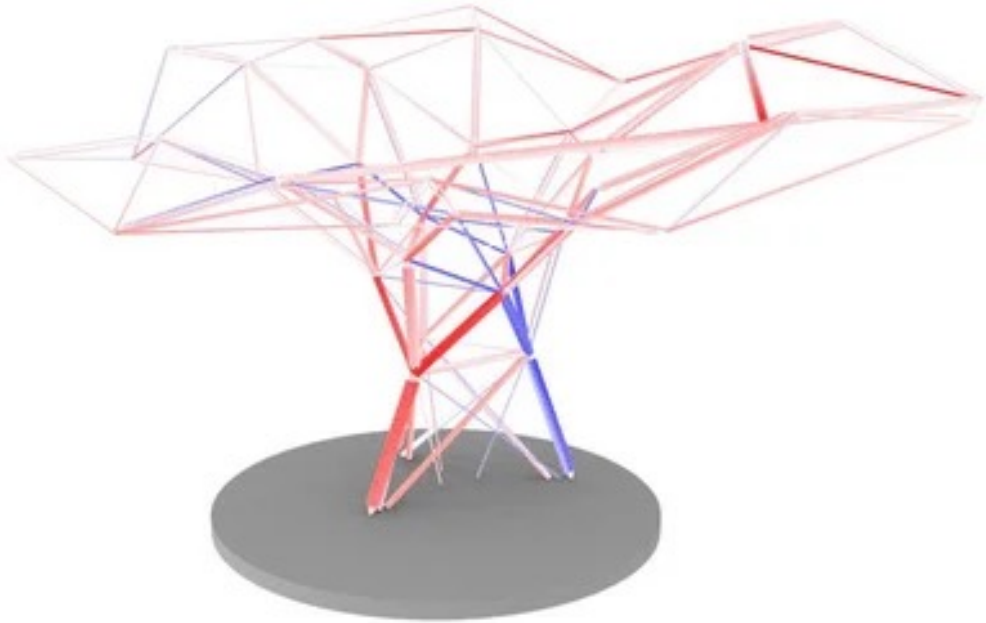


Structural Performance: Tools

- **Kangaroo**
— live physics engine, Digital hanging chain, tension/membrane form-finding
- **Karamba3D**
— real-time FEA Structural analysis as design feedback, not post-rationalization
- Ameba
— topology optimization: Define loads + supports → algorithm finds minimum material

Karamba

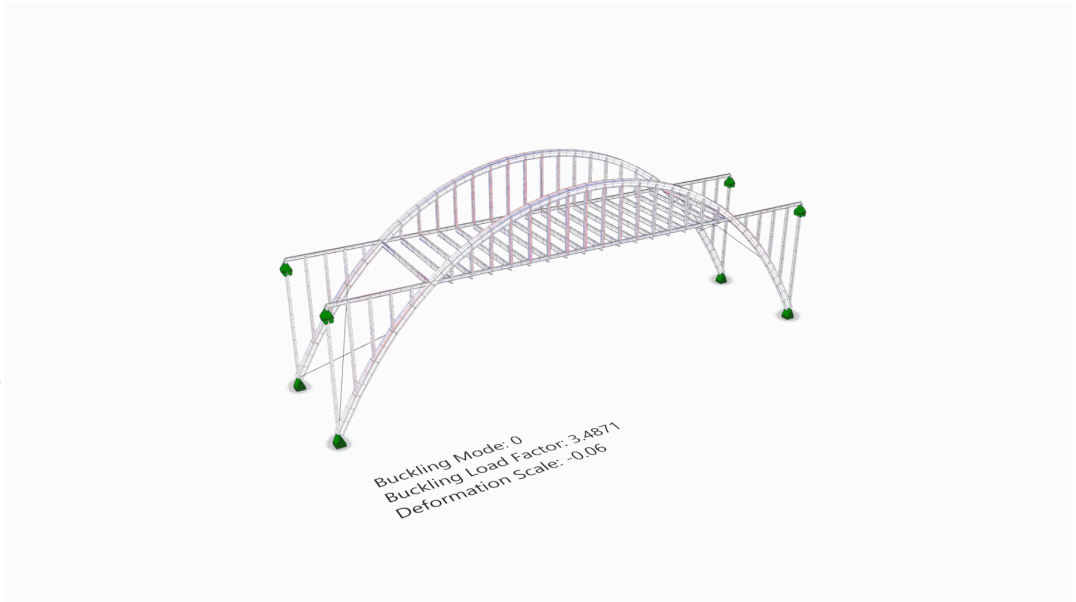


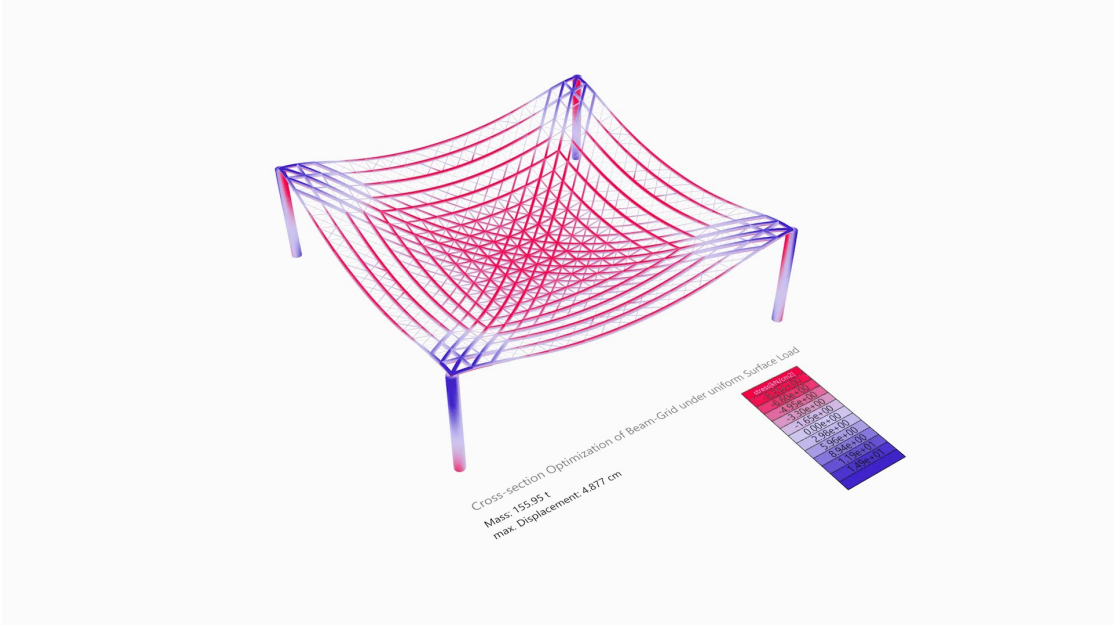


Structural Performance: Tools

- **Kangaroo**
— live physics engine, Digital hanging chain, tension/membrane form-finding
- **Karamba3D**
— real-time FEA Structural analysis as design feedback, not post-rationalization
- Ameba
— topology optimization: Define loads + supports → algorithm finds minimum material

Karamba





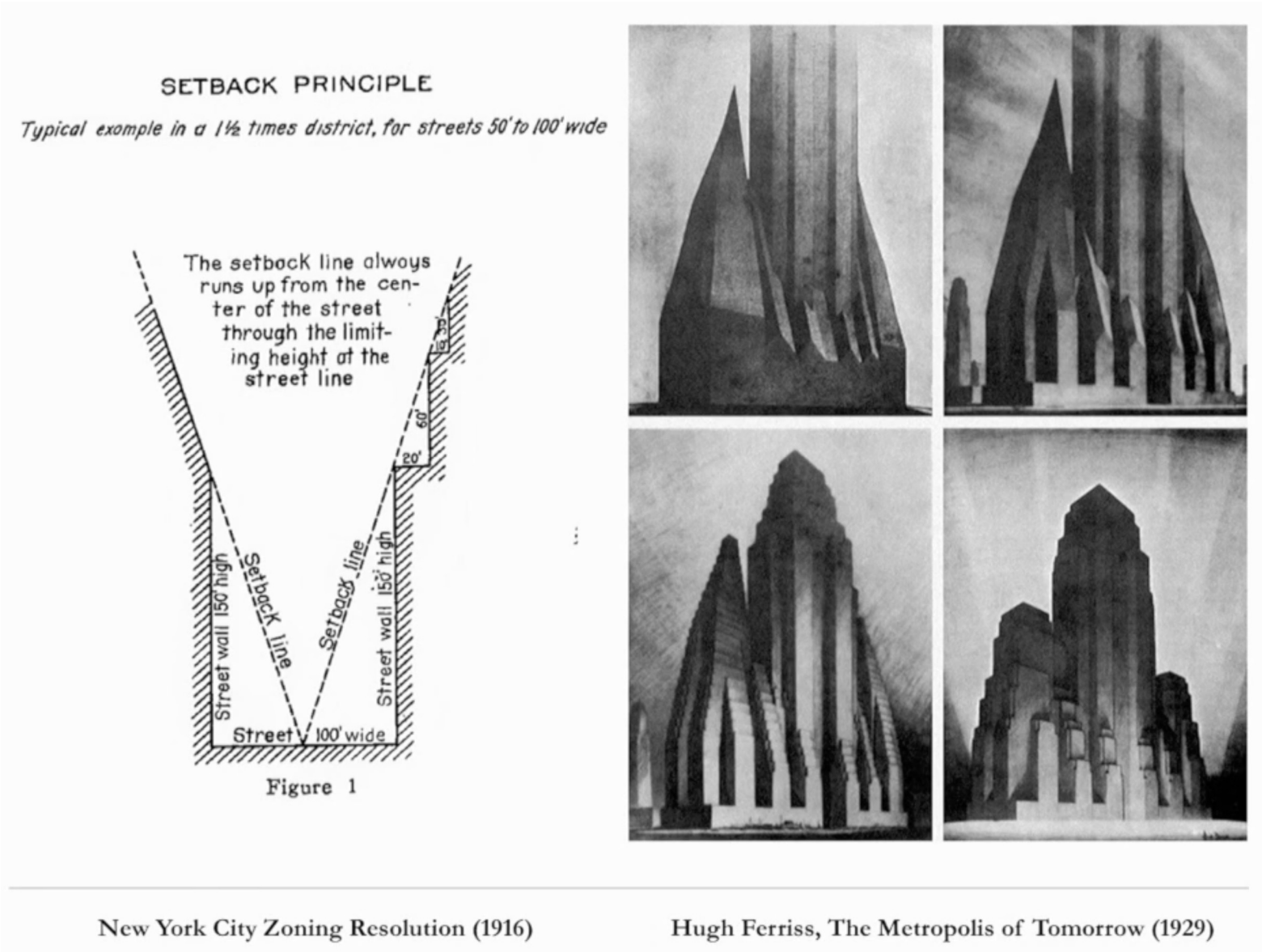
Resource: https://karamba3d.com/

Environmental Performance

Environmental Performance

Setback rules carve building form from solar access requirements.
Regulation as form generator.

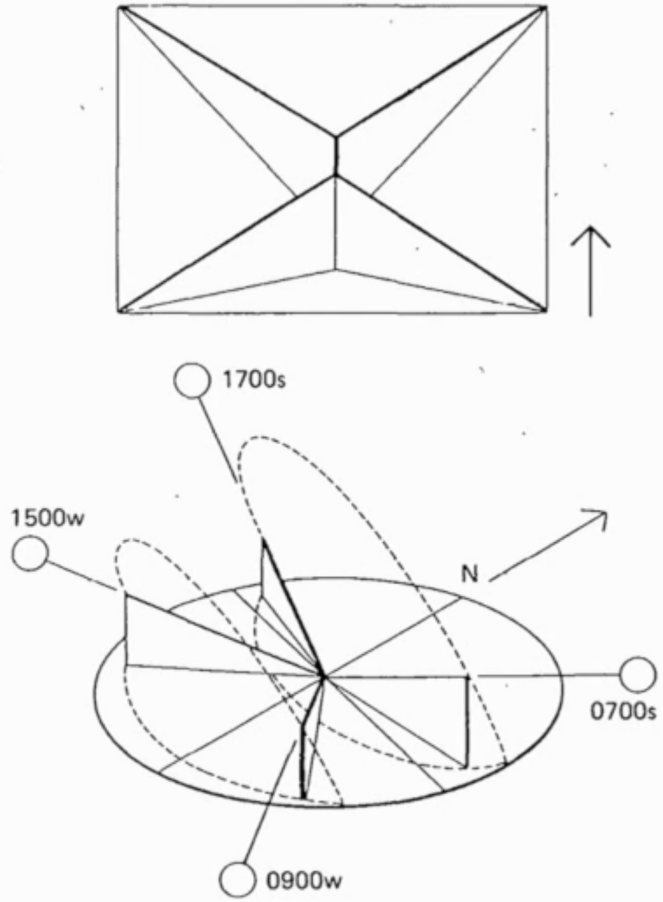
1961 Zoning Resolution
New York City, 1961



Environmental Performance

Buildable volume defined by guaranteeing solar access to neighbors.

Solar Envelope
Ralph Knowles, USC, 1974–2006



Ralph L. Knowles and Richard D. Berry,
Solar Envelope (1980)

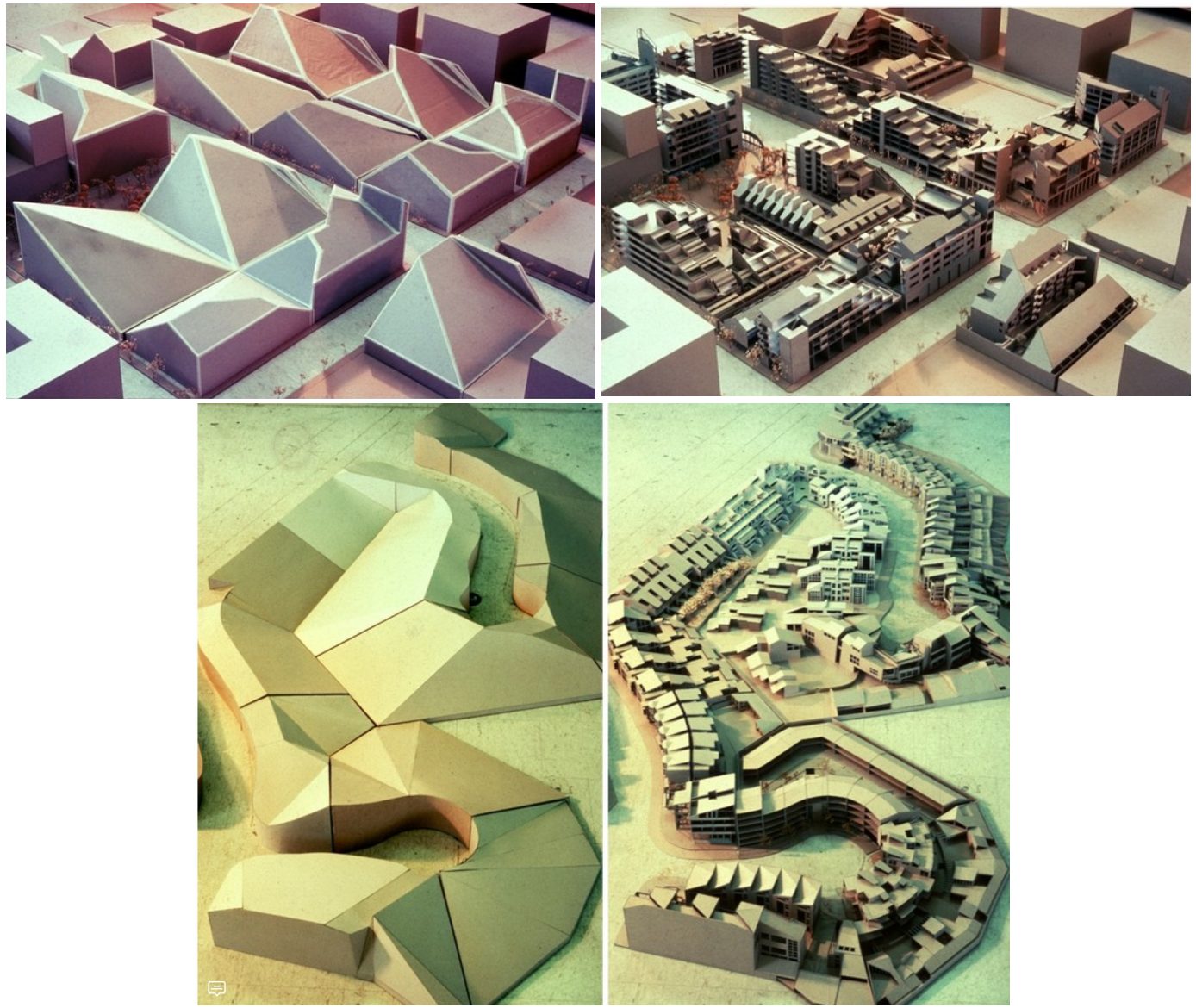


Ralph L. Knowles, Solar Envelope (1981)

Environmental Performance

Buildable volume defined by guaranteeing solar access to neighbors.

.

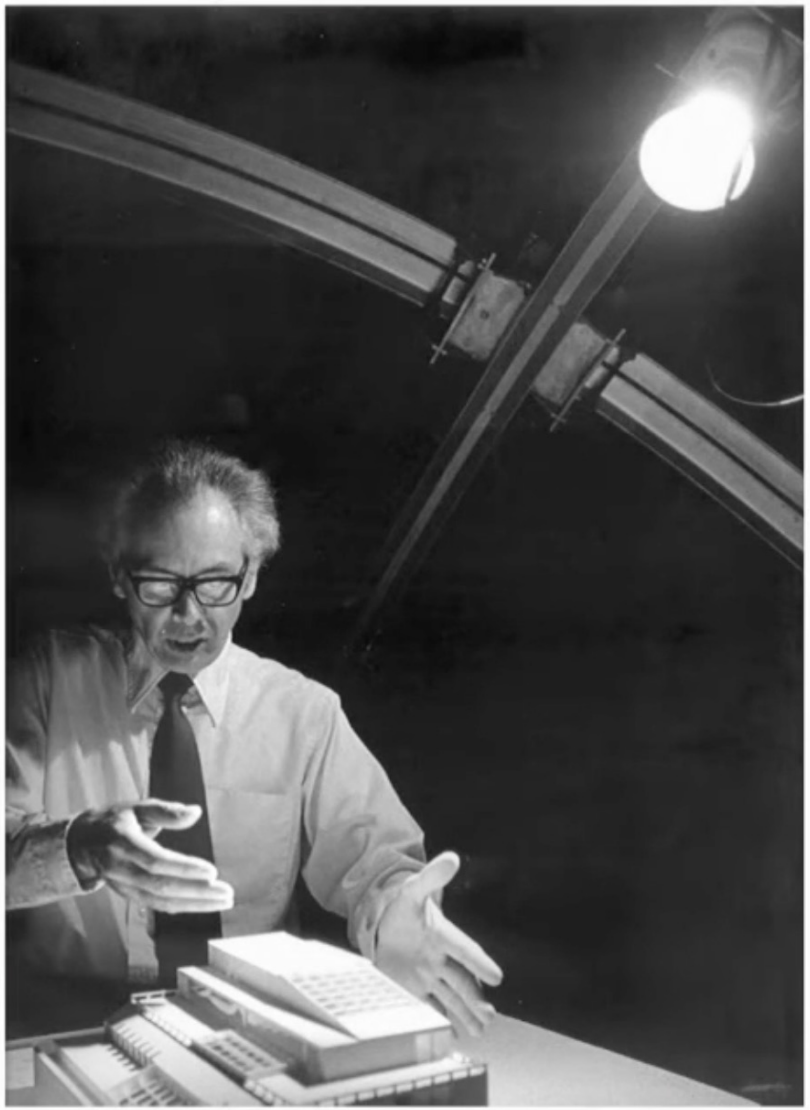


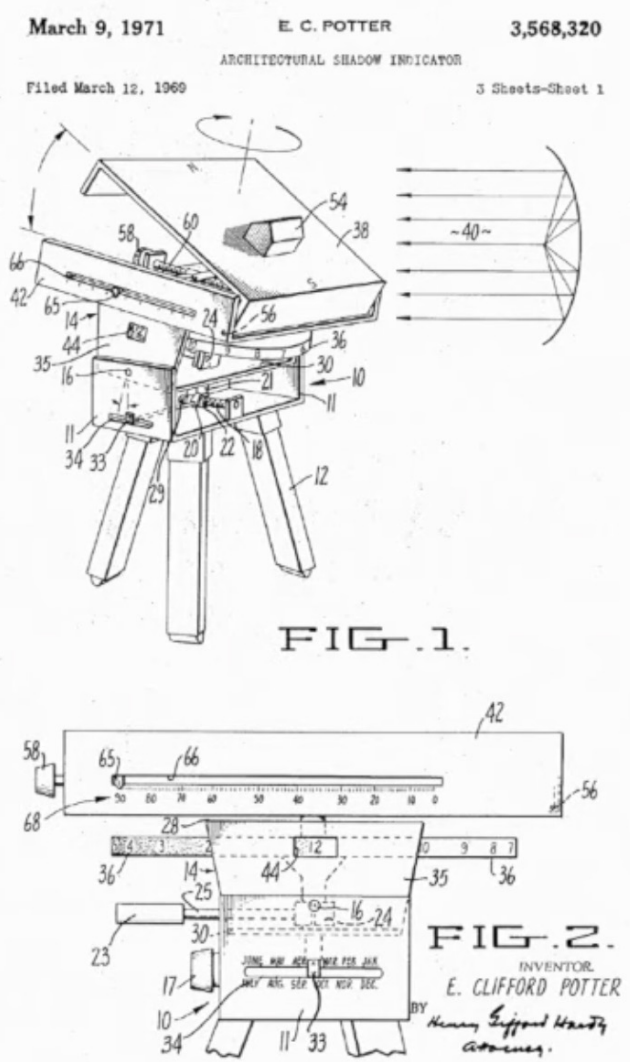
Solar Envelope
Ralph Knowles, USC, 1974–2006

Environmental Performance

Buildable volume defined by guaranteeing solar access to neighbors.

Solar Envelope
Ralph Knowles, USC, 1974–2006

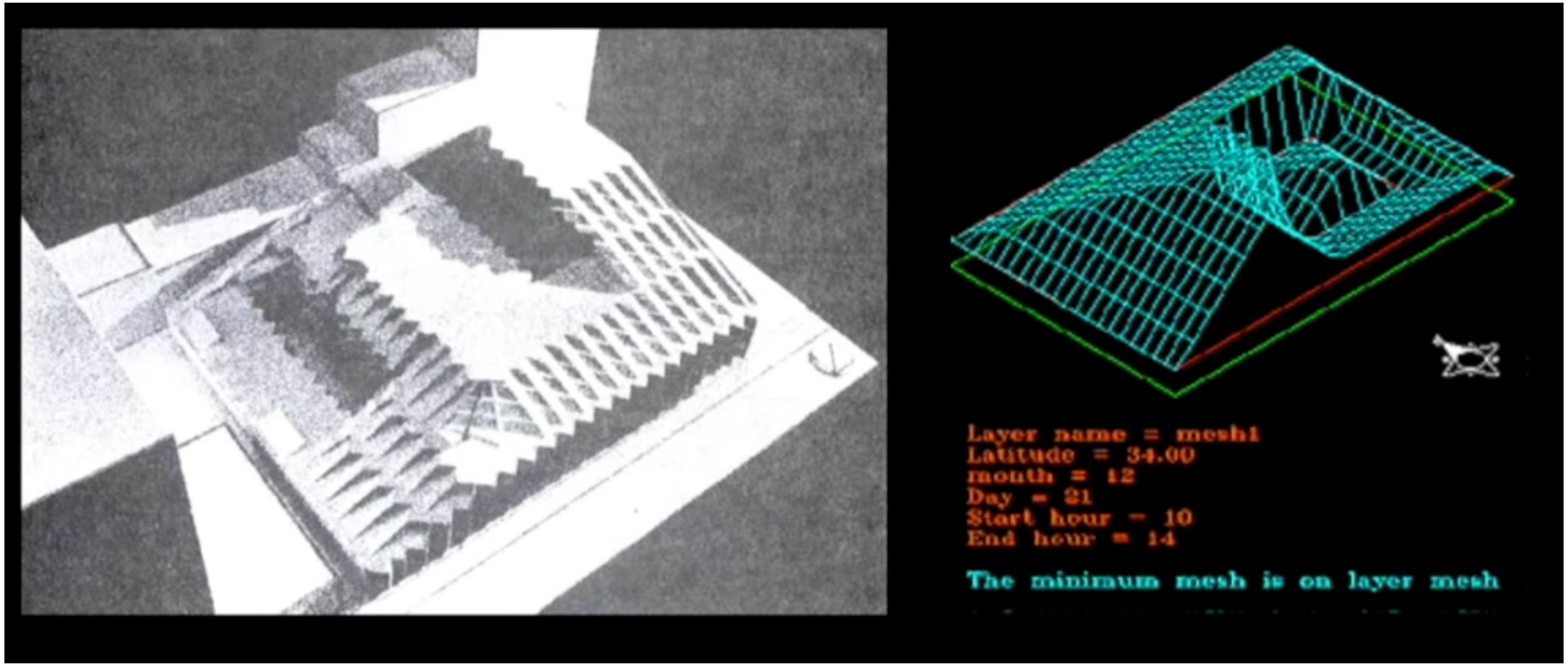




Left: Knowles with his Heliodon. Right: One of several heliodon patents by other contemporary experimentalists.

Environmental Performance

Buildable volume defined by guaranteeing solar access to neighbors.

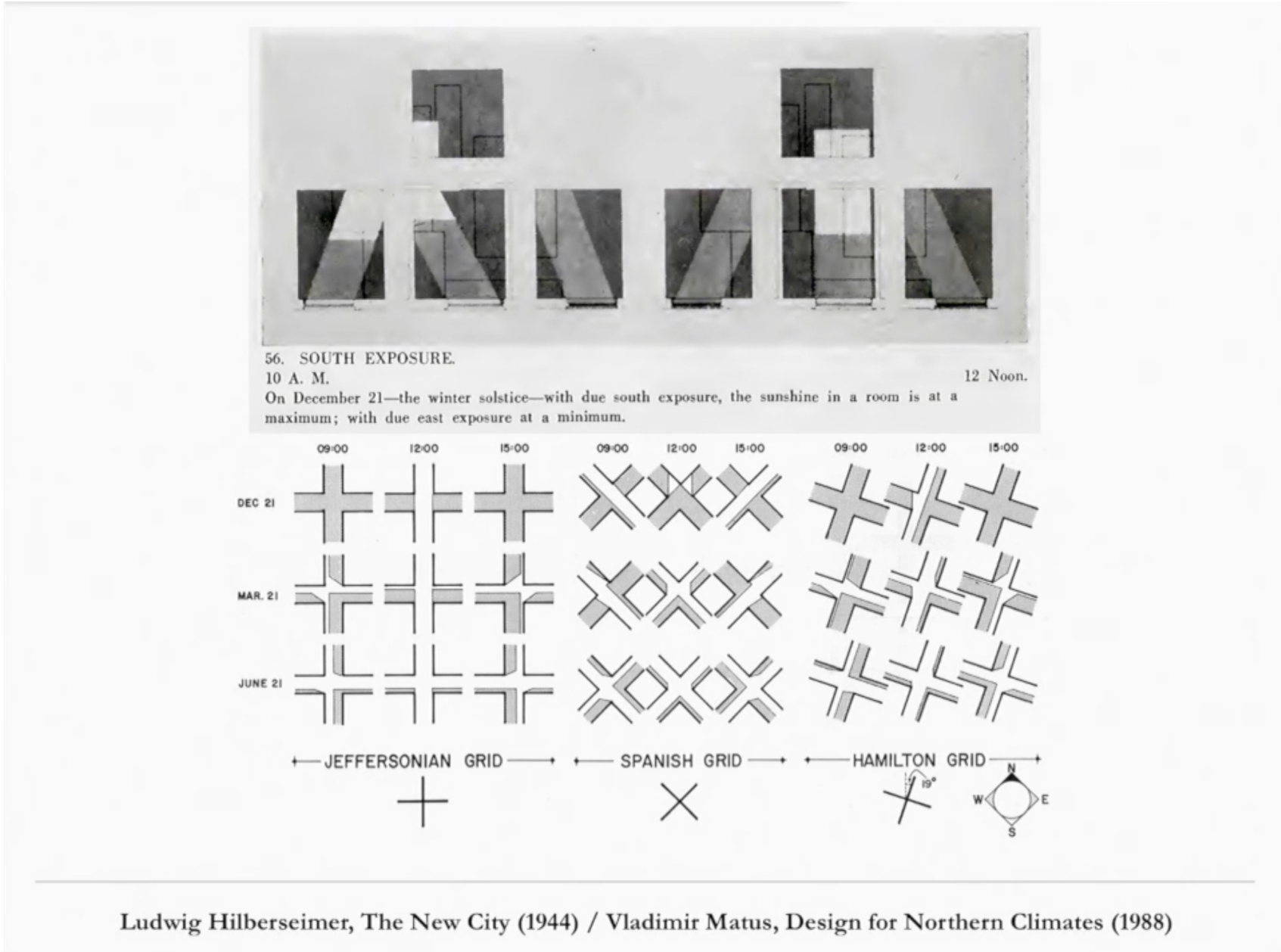


Solar Envelope
Ralph Knowles, USC, 1974–2006

Environmental Performance

Hilberseimer: urban-scale solar orientation.
Matus: Design for Northern Climates — climate as form driver.

Urban Solar Orientation Studies
Hilberseimer / Matus

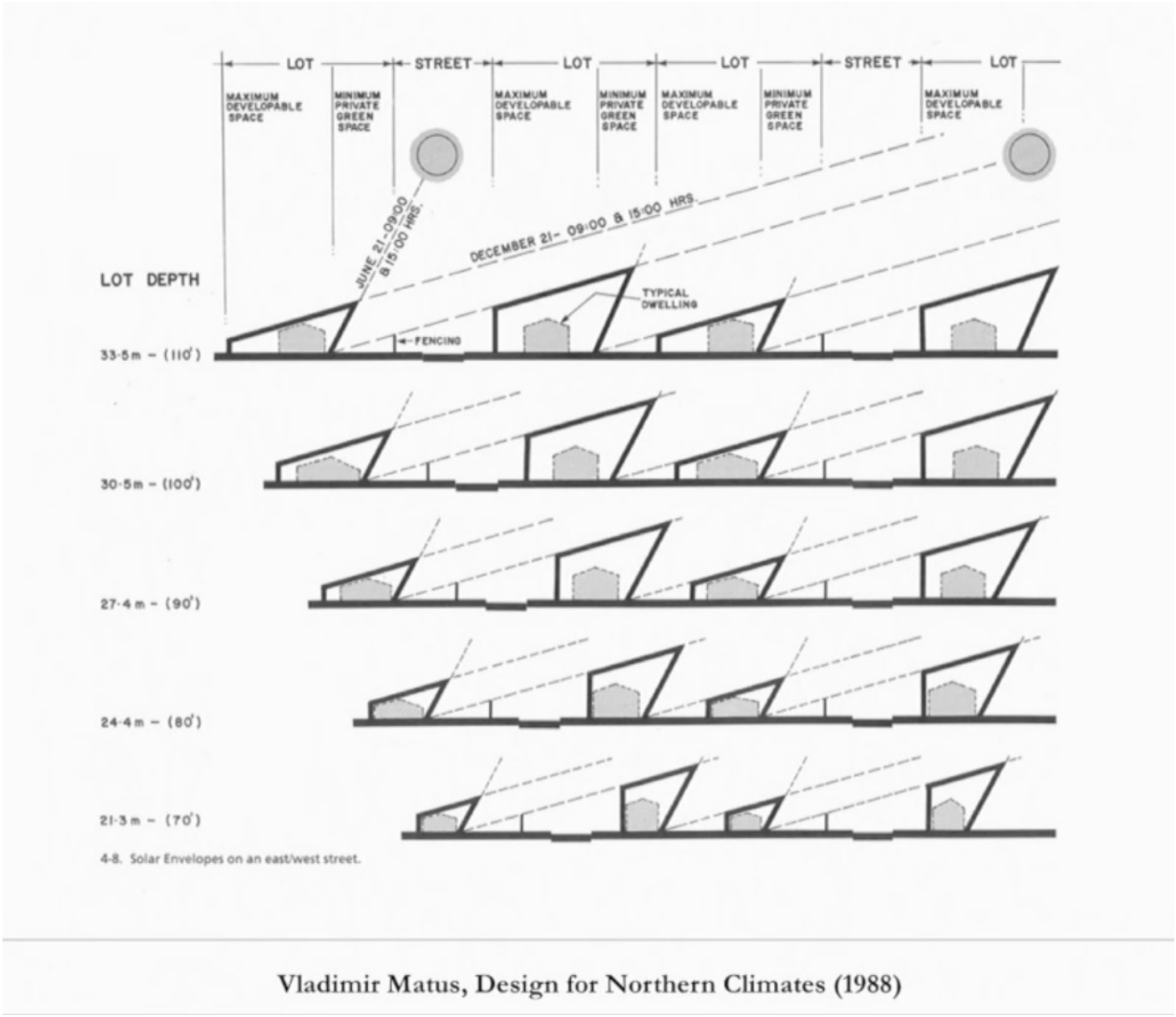


Ludwig Hilberseimer, The New City (1944) / Vladimir Matus, Design for Northern Climates (1988)

Environmental Performance

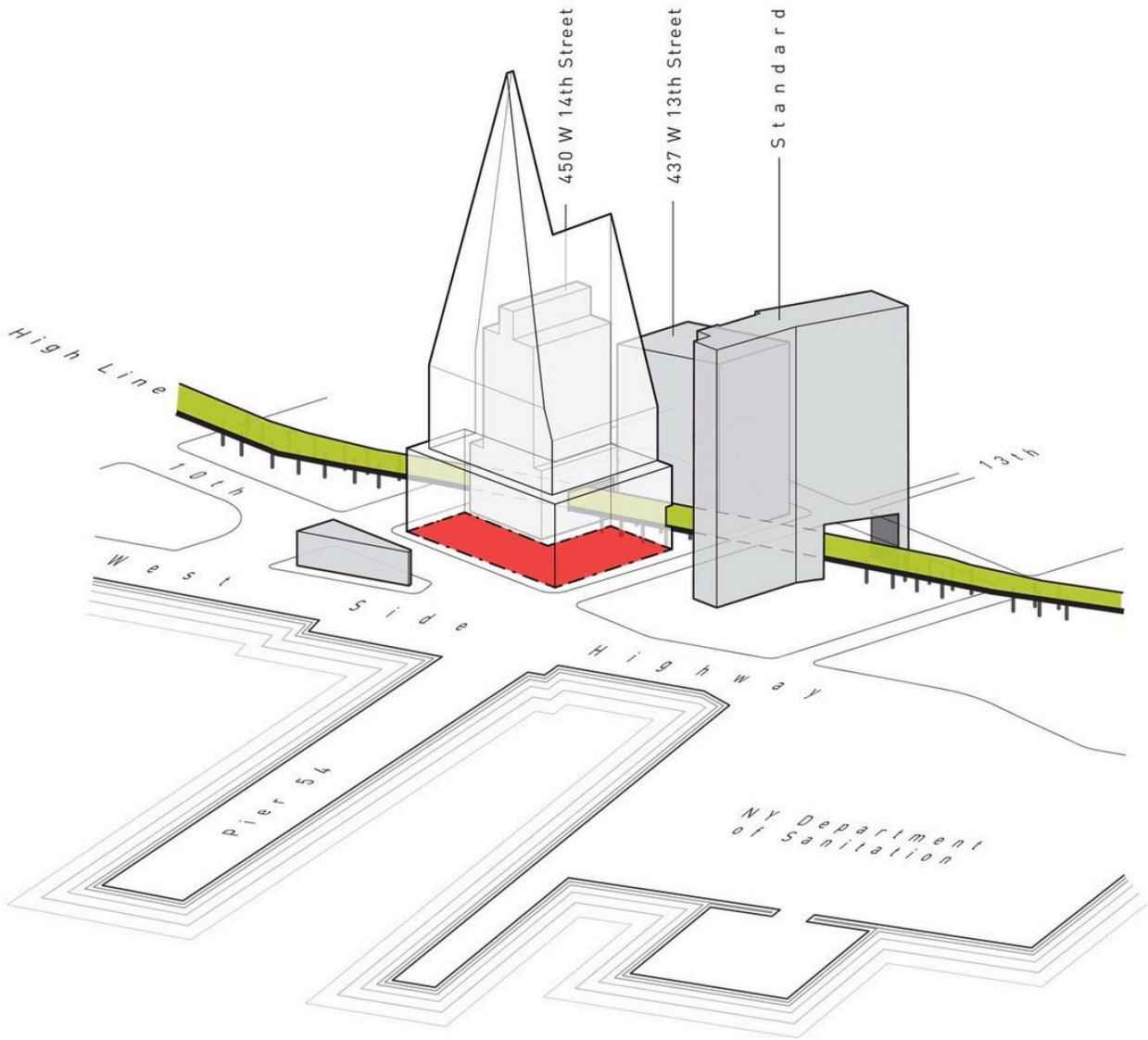
Hilberseimer: urban-scale solar orientation.
Matus: Design for Northern Climates — climate as form driver.

Urban Solar Orientation Studies
Hilberseimer / Matus



Vladimir Matus, Design for Northern Climates (1988)

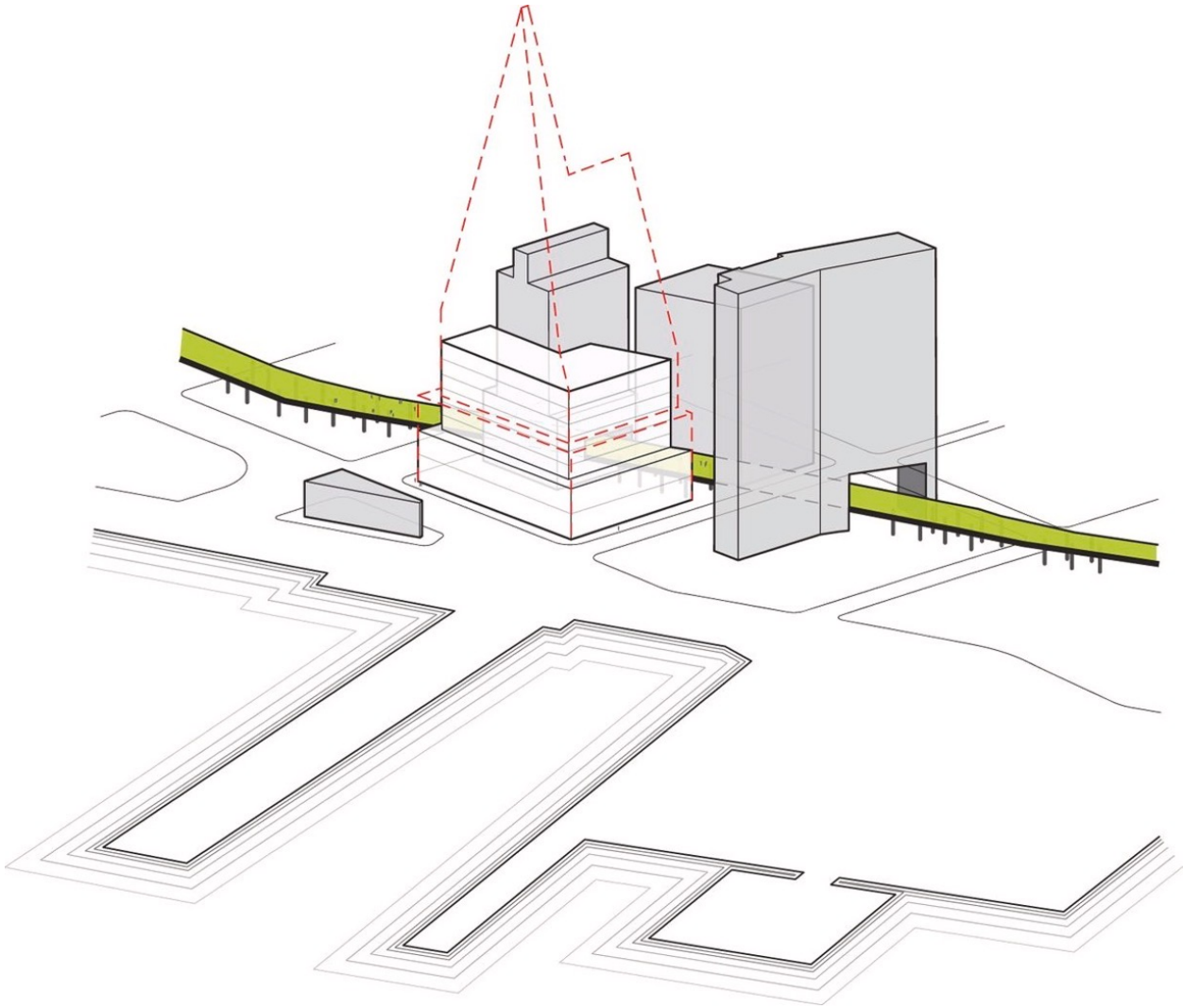
Environmental Performance



Solar Carve Tower
Studio Gang, 2019

Resource: https://studiogang.com/project/solar-carve-tower

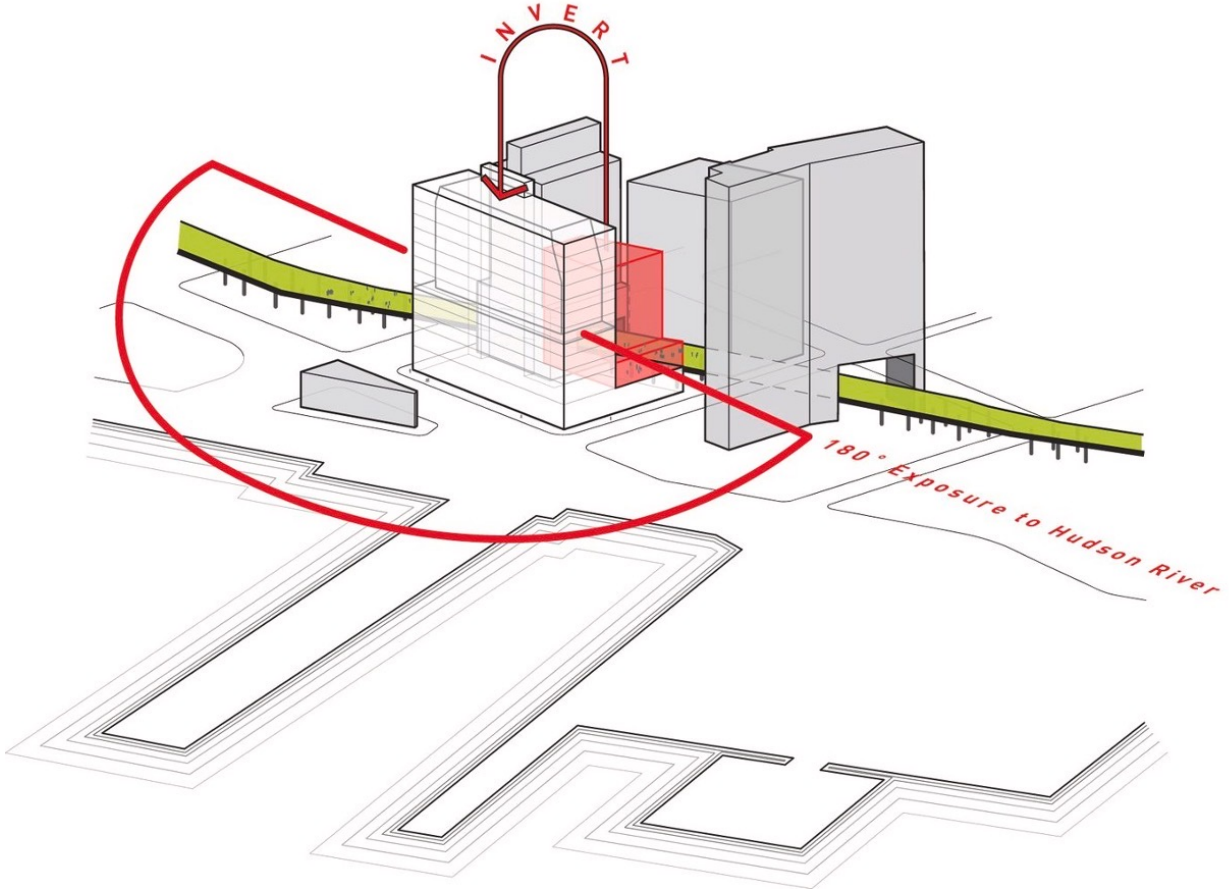
Environmental Performance



Solar Carve Tower
Studio Gang, 2019

Resource: https://studiogang.com/project/solar-carve-tower

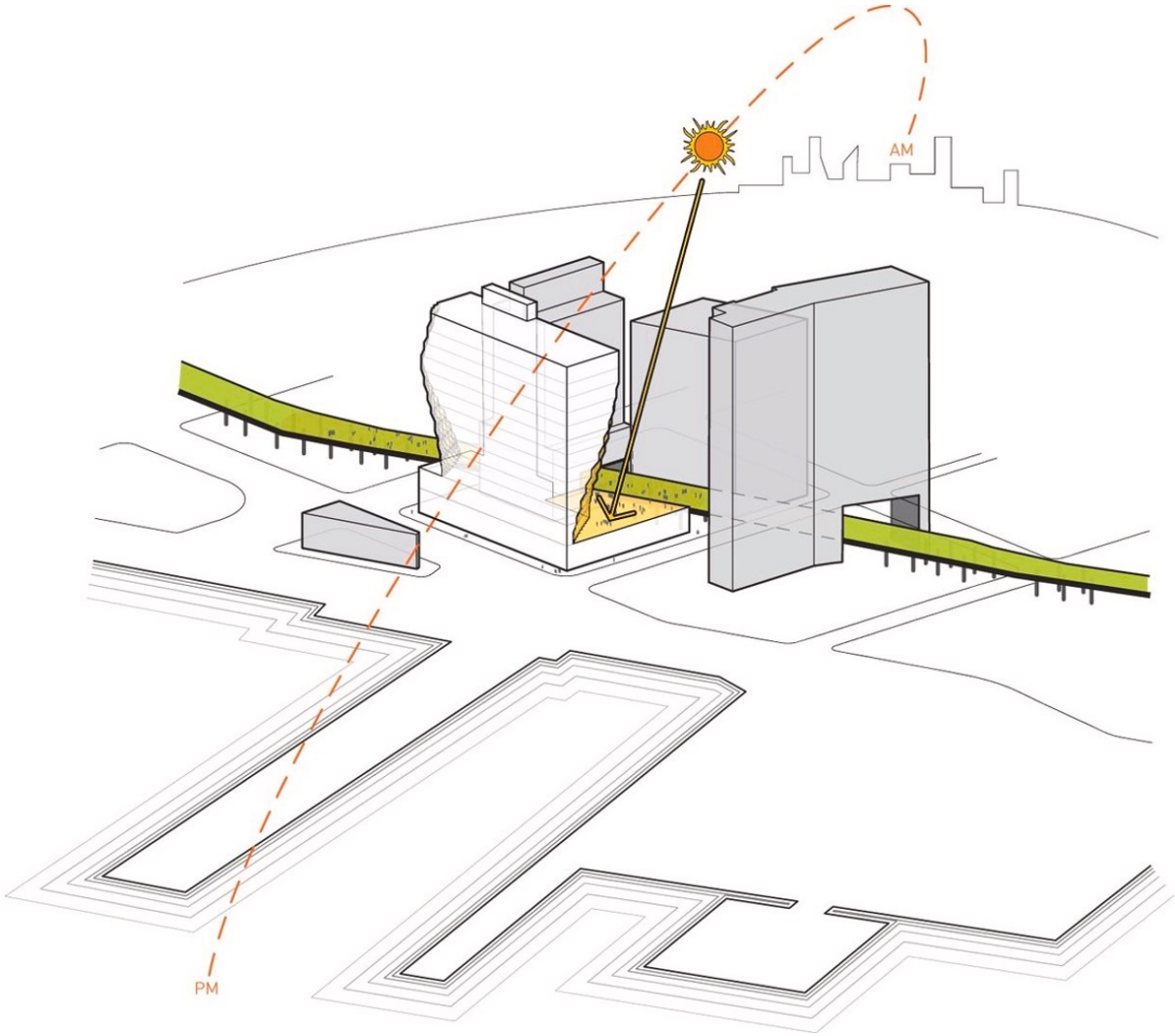
Environmental Performance



Solar Carve Tower
Studio Gang, 2019

Resource: https://studiogang.com/project/solar-carve-tower

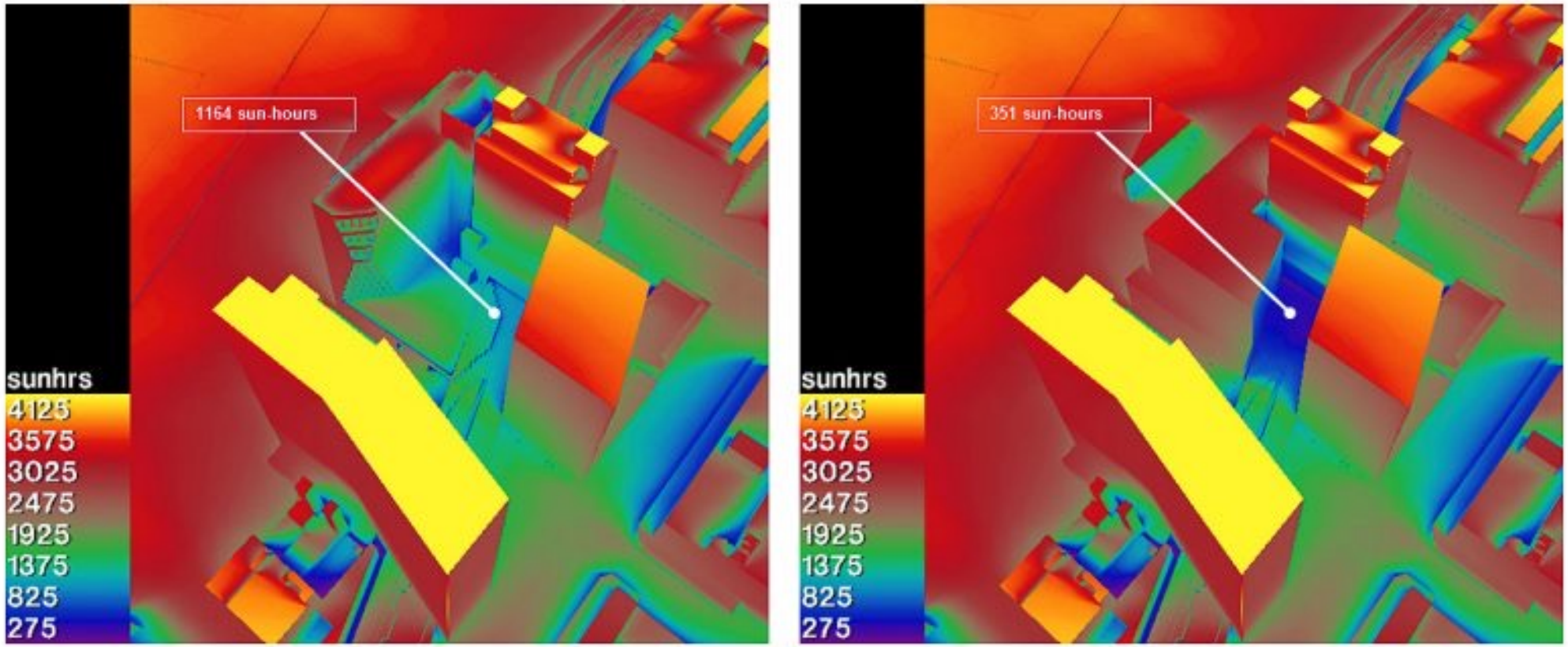
Environmental Performance



Solar Carve Tower
Studio Gang, 2019

Resource: https://studiogang.com/project/solar-carve-tower

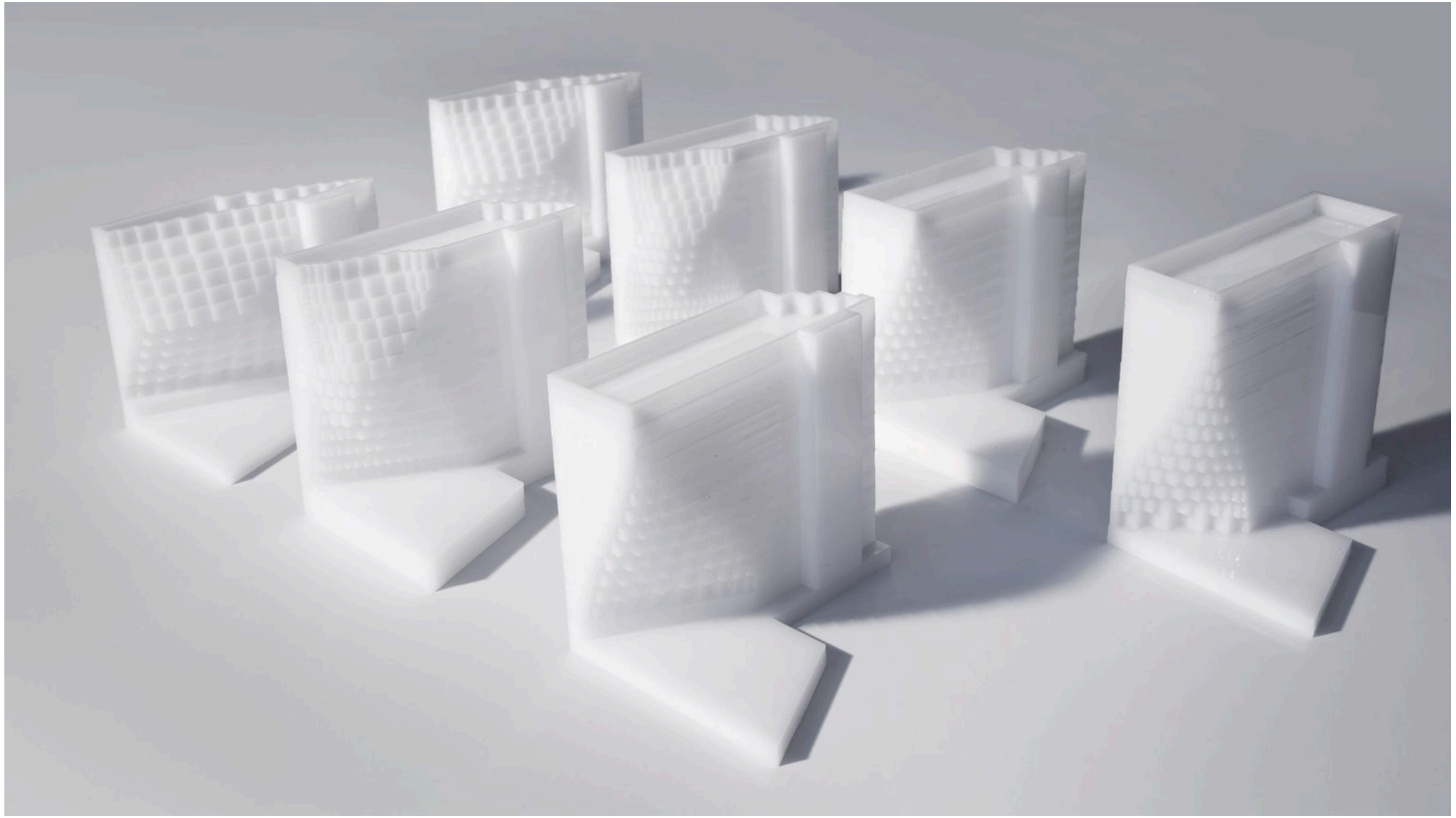
Environmental Performance



Solar Carve Tower
Studio Gang, 2019

Resource: https://studiogang.com/project/solar-carve-tower

Environmental Performance



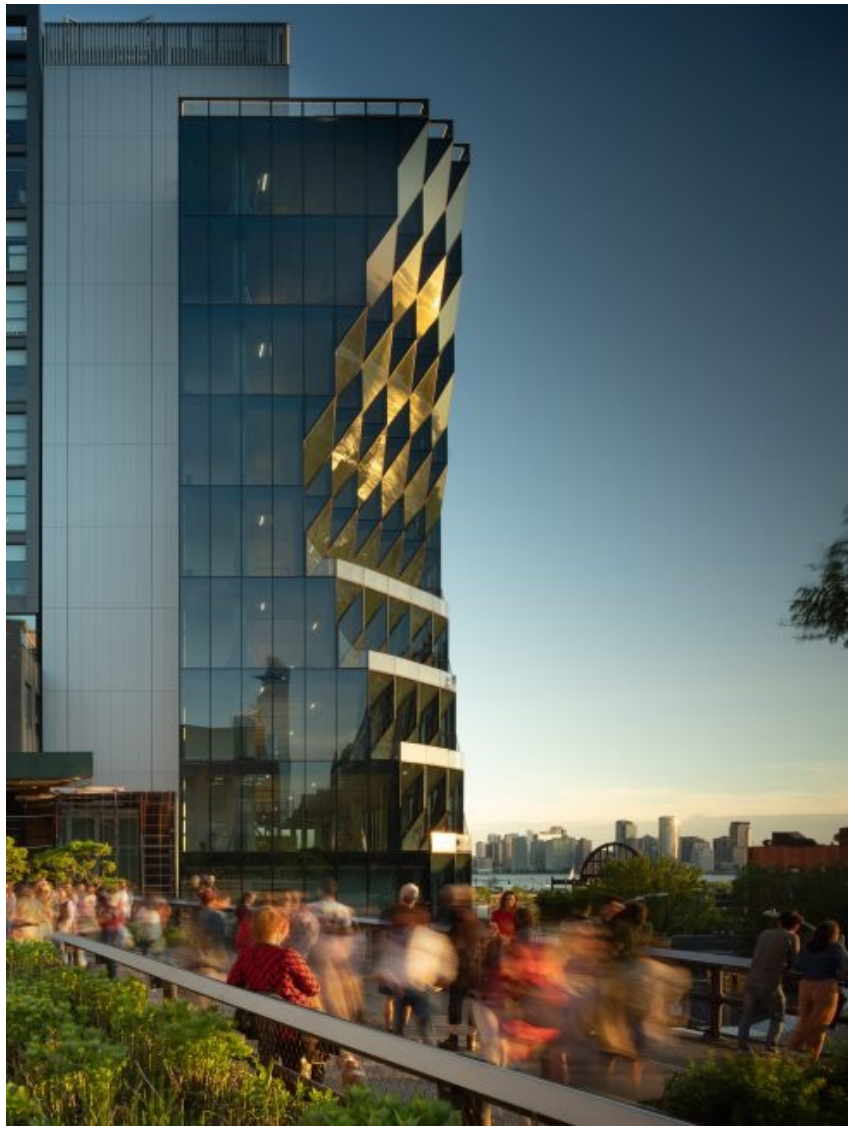
Solar Carve Tower
Studio Gang, 2019

Resource: https://studiogang.com/project/solar-carve-tower

Environmental Performance

Solar Carve Tower
Studio Gang, 2019





Resource: https://studiogang.com/projects/40-tenth-ave/

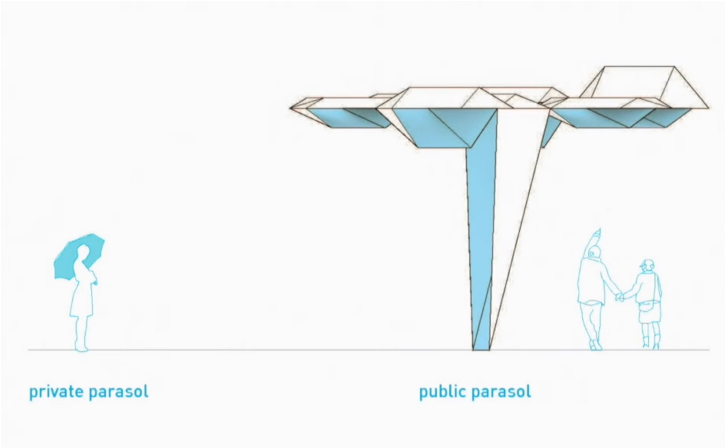
Environmental Performance

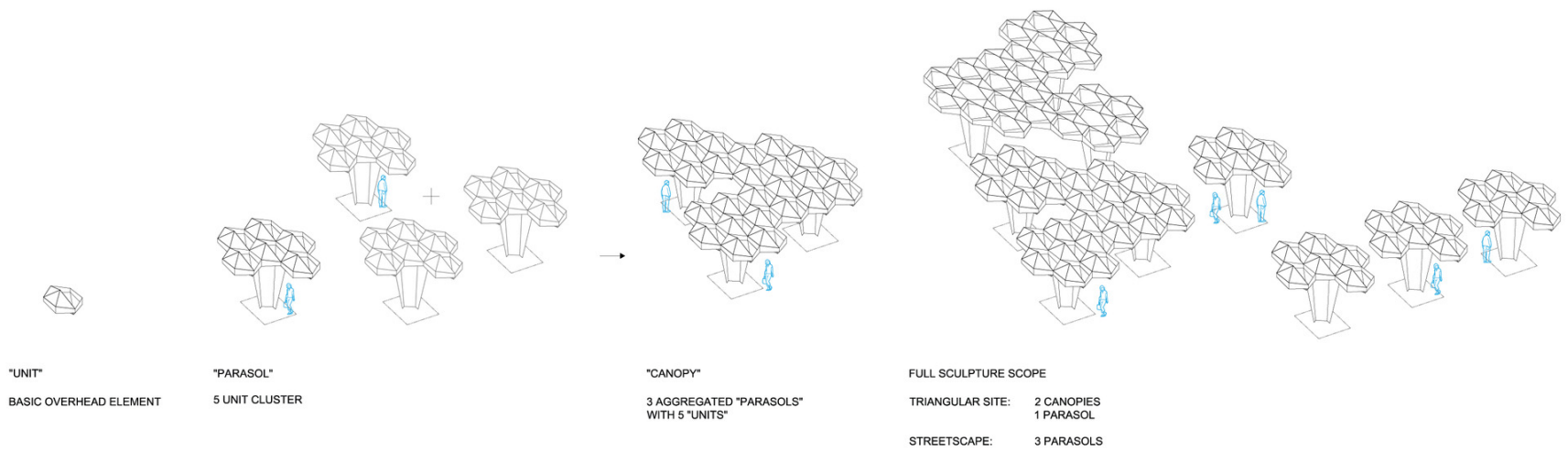


Roosevelt Row Parasol — Shadow Play
Höweler+Yoon, Phoenix AZ

Resource: https://www.howeleryoon.com/

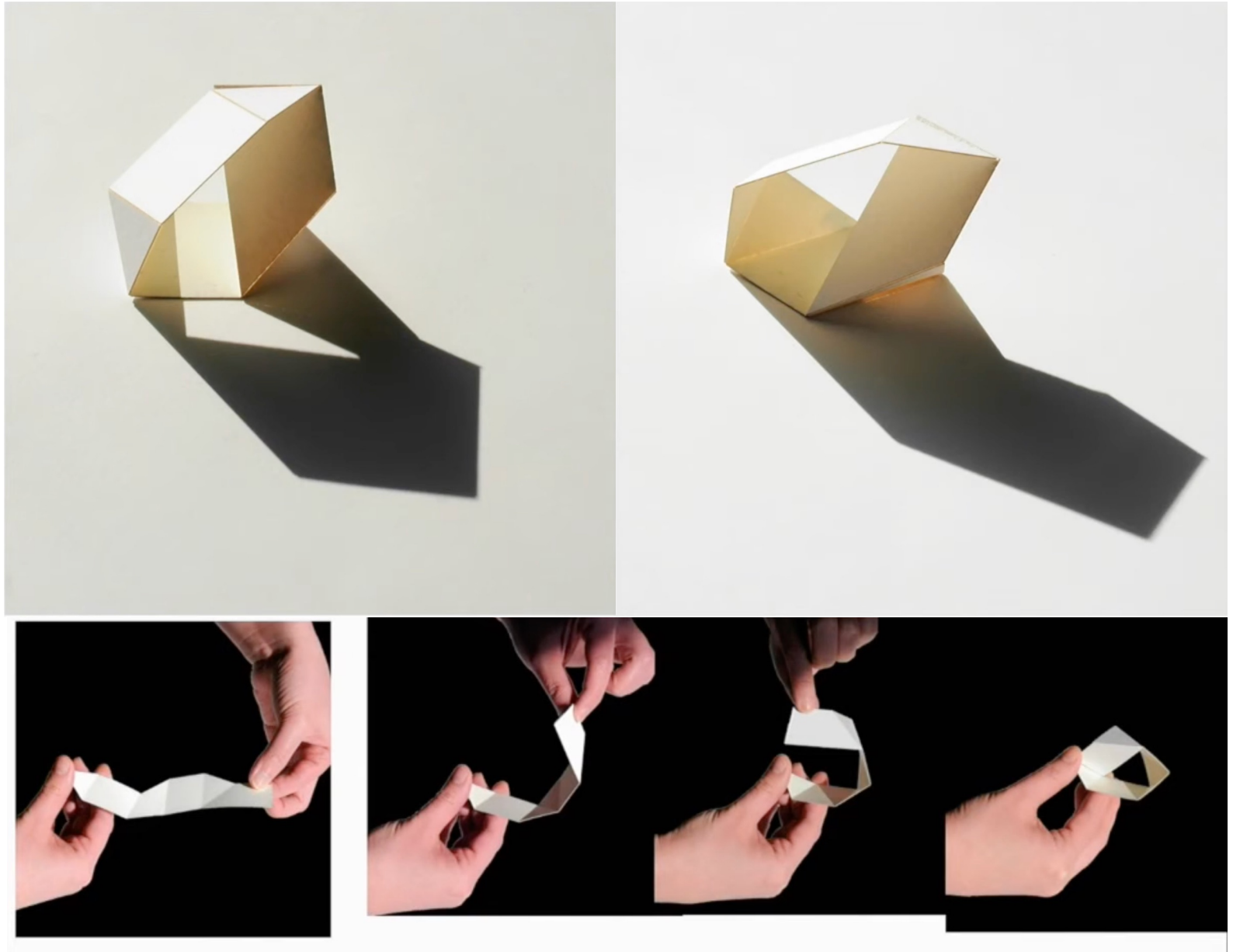
Environmental Perform





Roosevelt Row Parasol — Shadow Play
Höweler+Yoon, Phoenix AZ

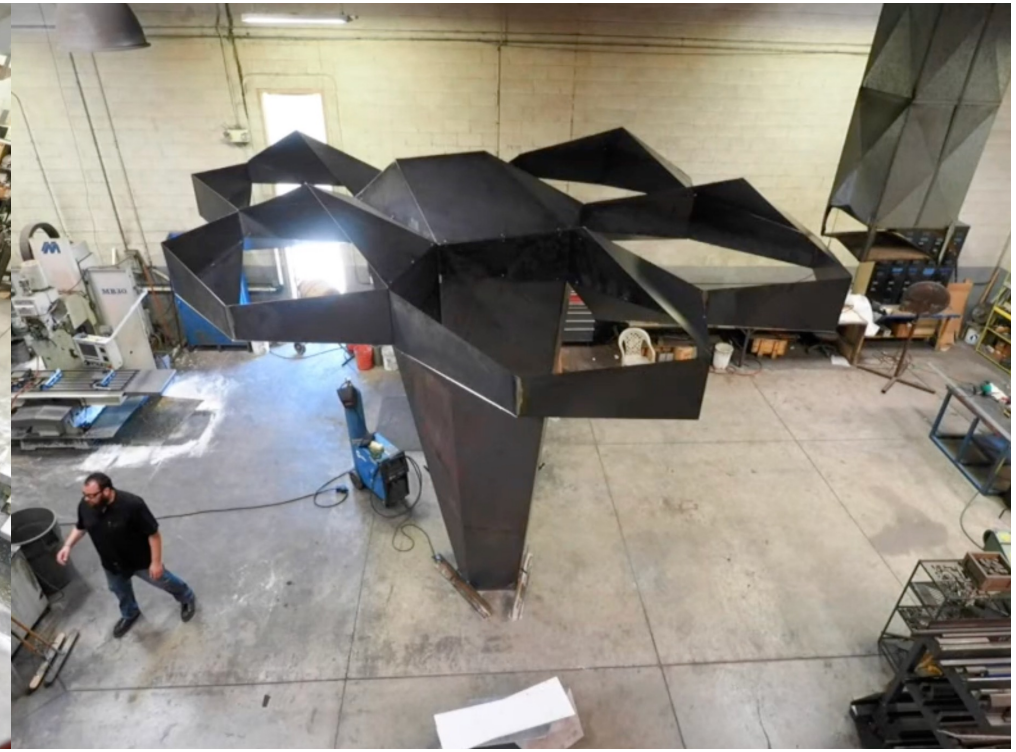
Environmental Performance



Roosevelt Row Parasol — Shadow Play
Höweler+Yoon, Phoenix AZ

Environmental Performance

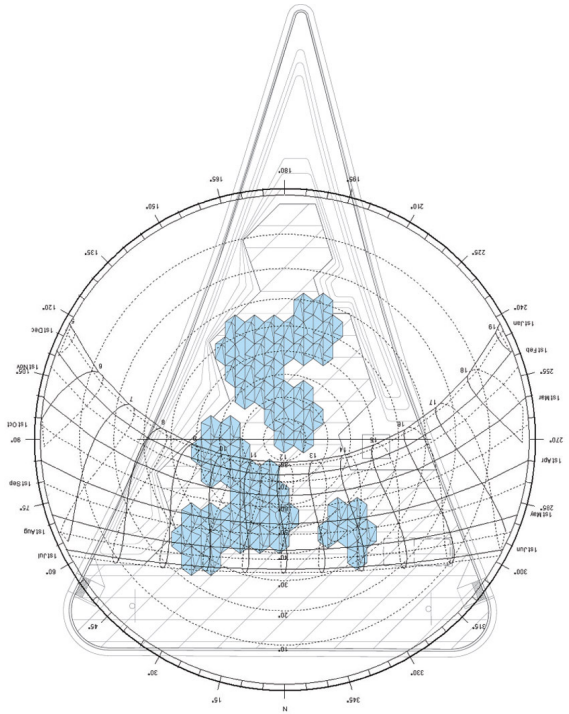


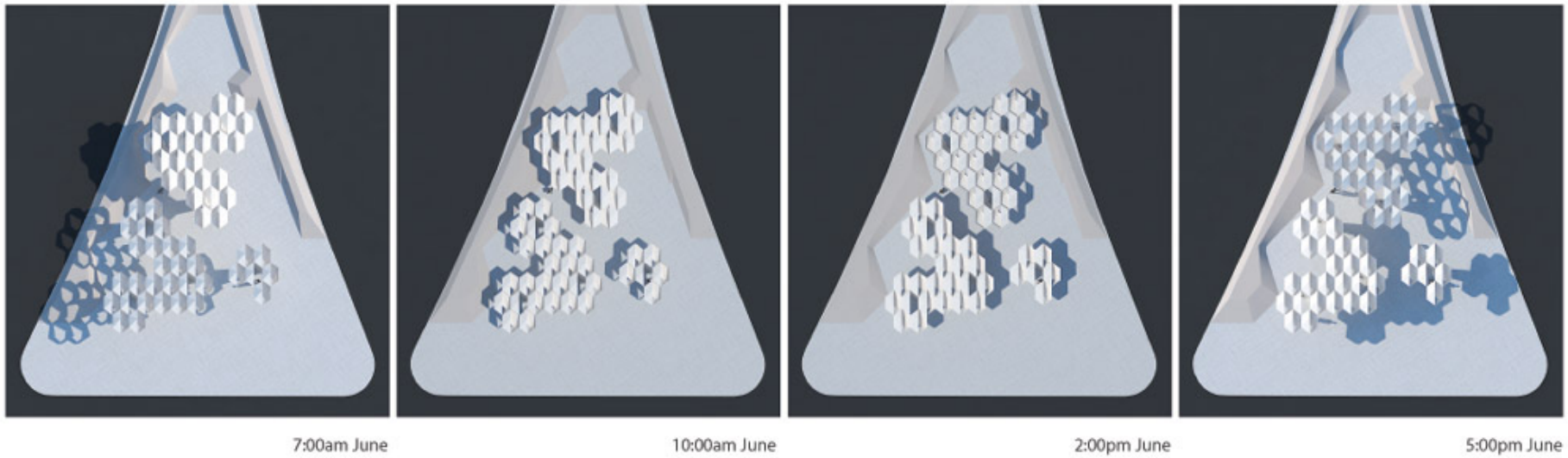


Roosevelt Row Parasol — Shadow Play
Höweler+Yoon, Phoenix AZ

Resource: https://www.howeleryoon.com/

Environmental Performance

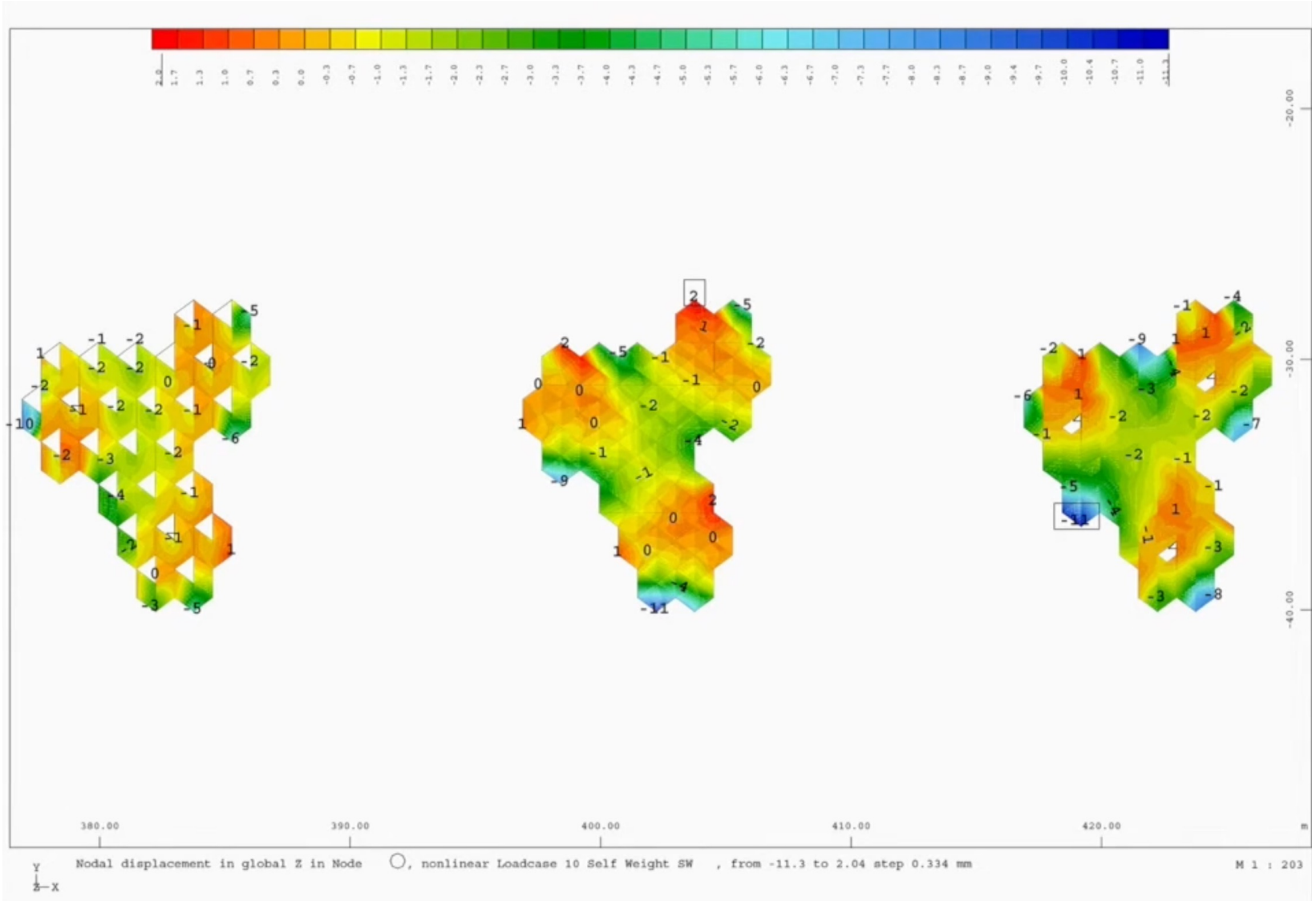




Roosevelt Row Parasol — Shadow Play
Höweler+Yoon, Phoenix AZ

Resource: https://www.howeleryoon.com/

Environmental Performance



Roosevelt Row Parasol — Shadow Play
Höweler+Yoon, Phoenix AZ

Resource: https://www.howeleryoon.com/

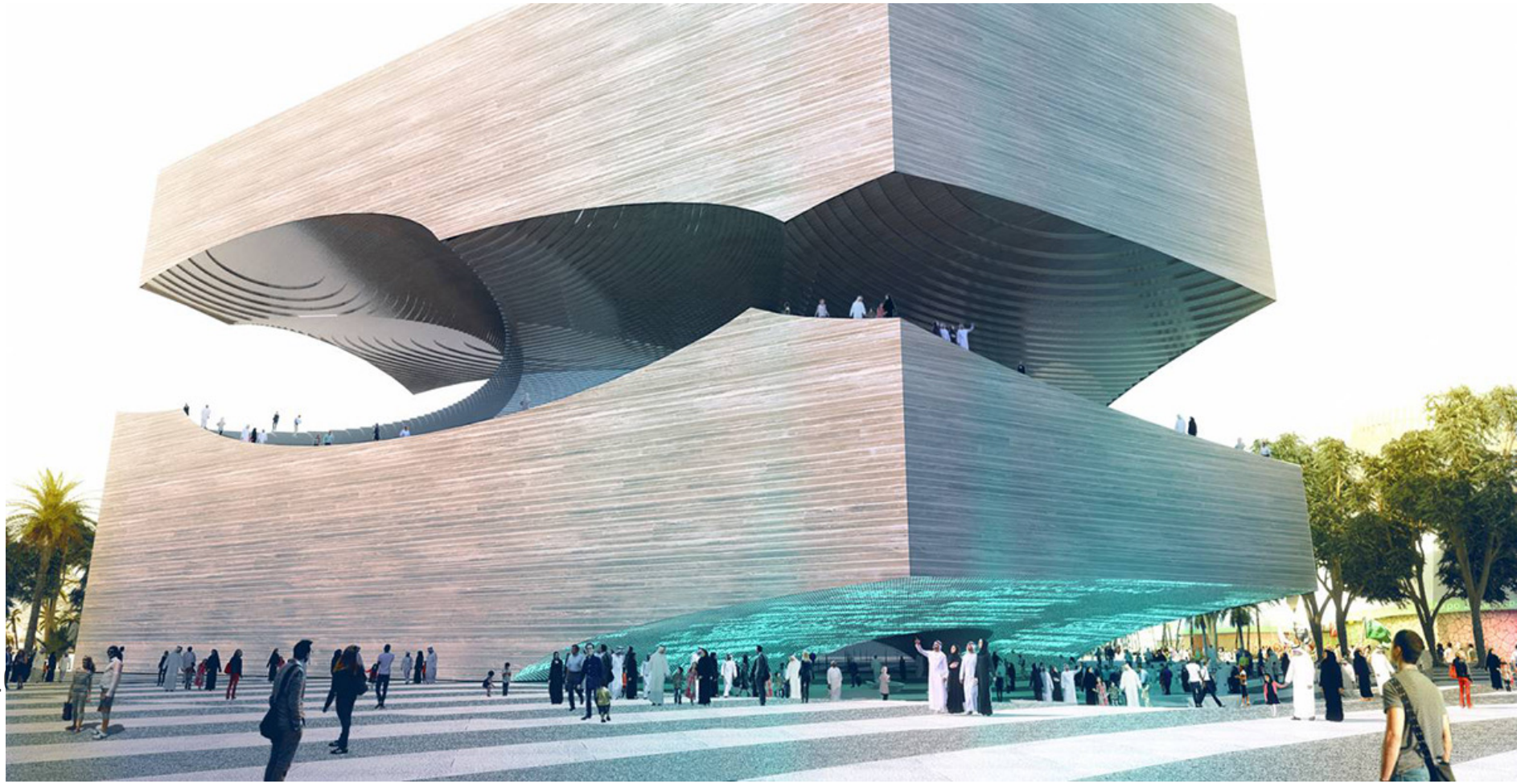
Environmental Performance



Roosevelt Row Parasol — Shadow Play
Höweler+Yoon, Phoenix AZ

Resource: https://www.howeleryoon.com/

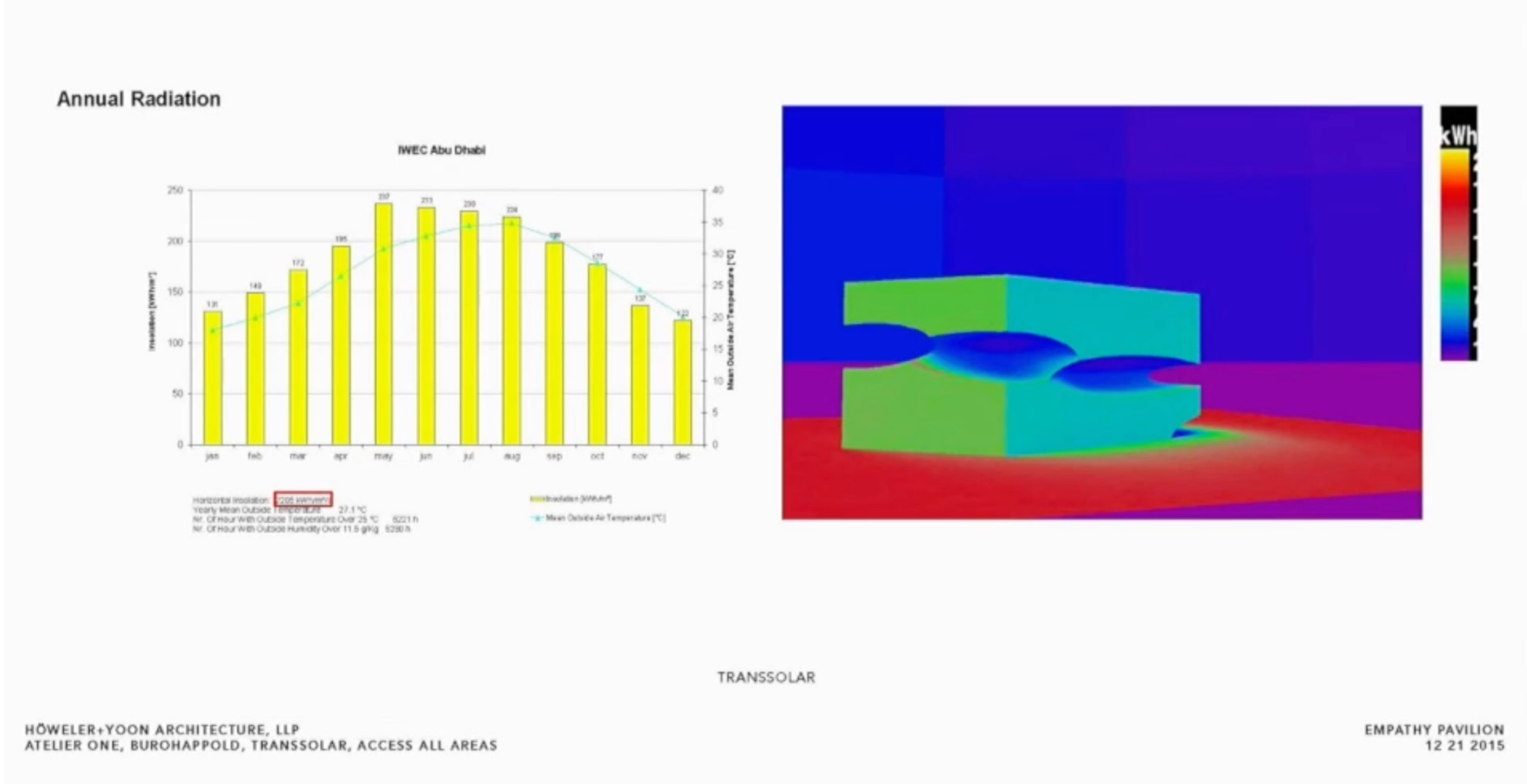
Environmental Performance



Empathy Pavilion
Höweler+Yoon + Transsolar, 2

Resource: https://www.howeleryoon.com/

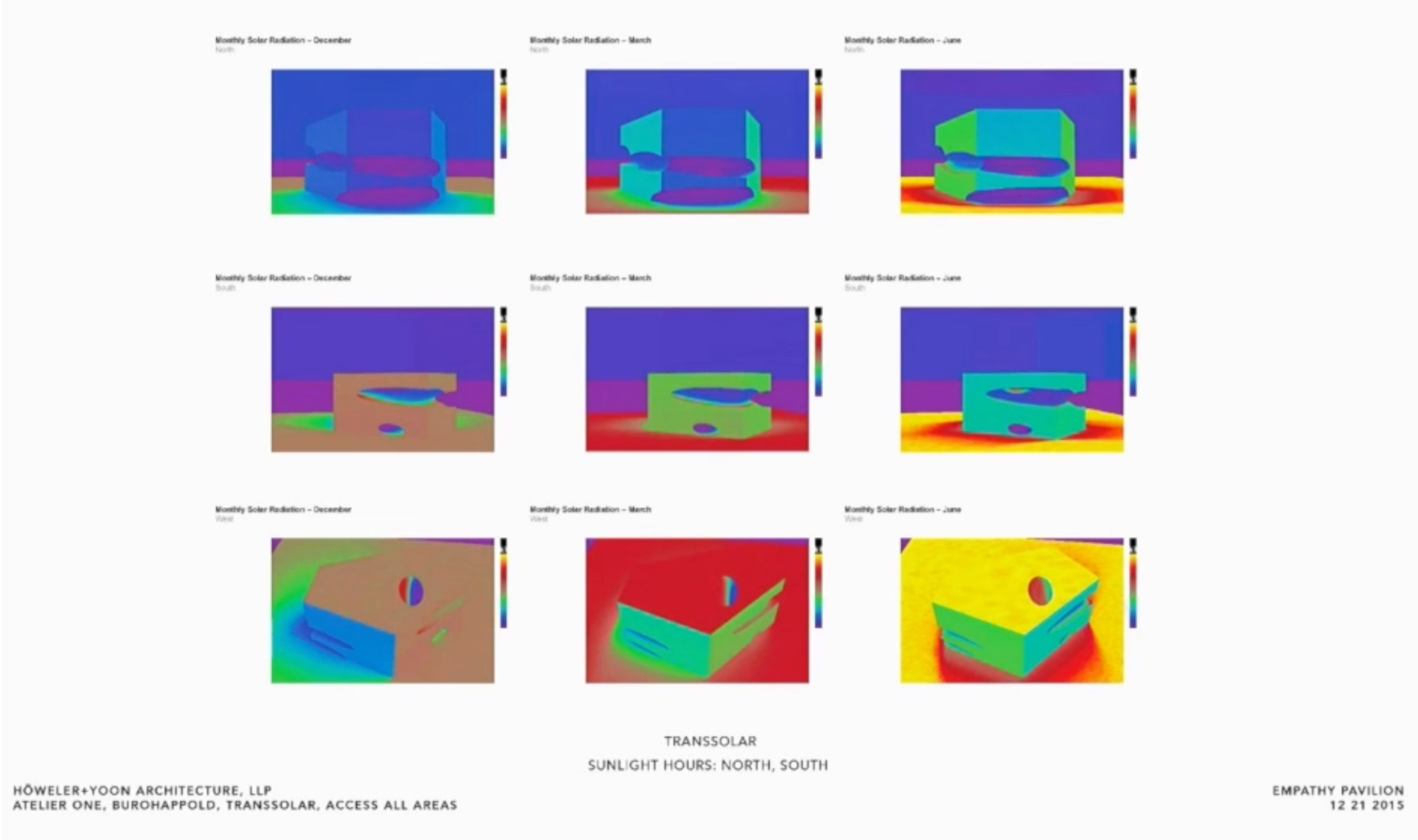
Environmental Performance



Empathy Pavilion
Höweler+Yoon + Transsolar, 2020

Resource: https://www.howeleryoon.com/

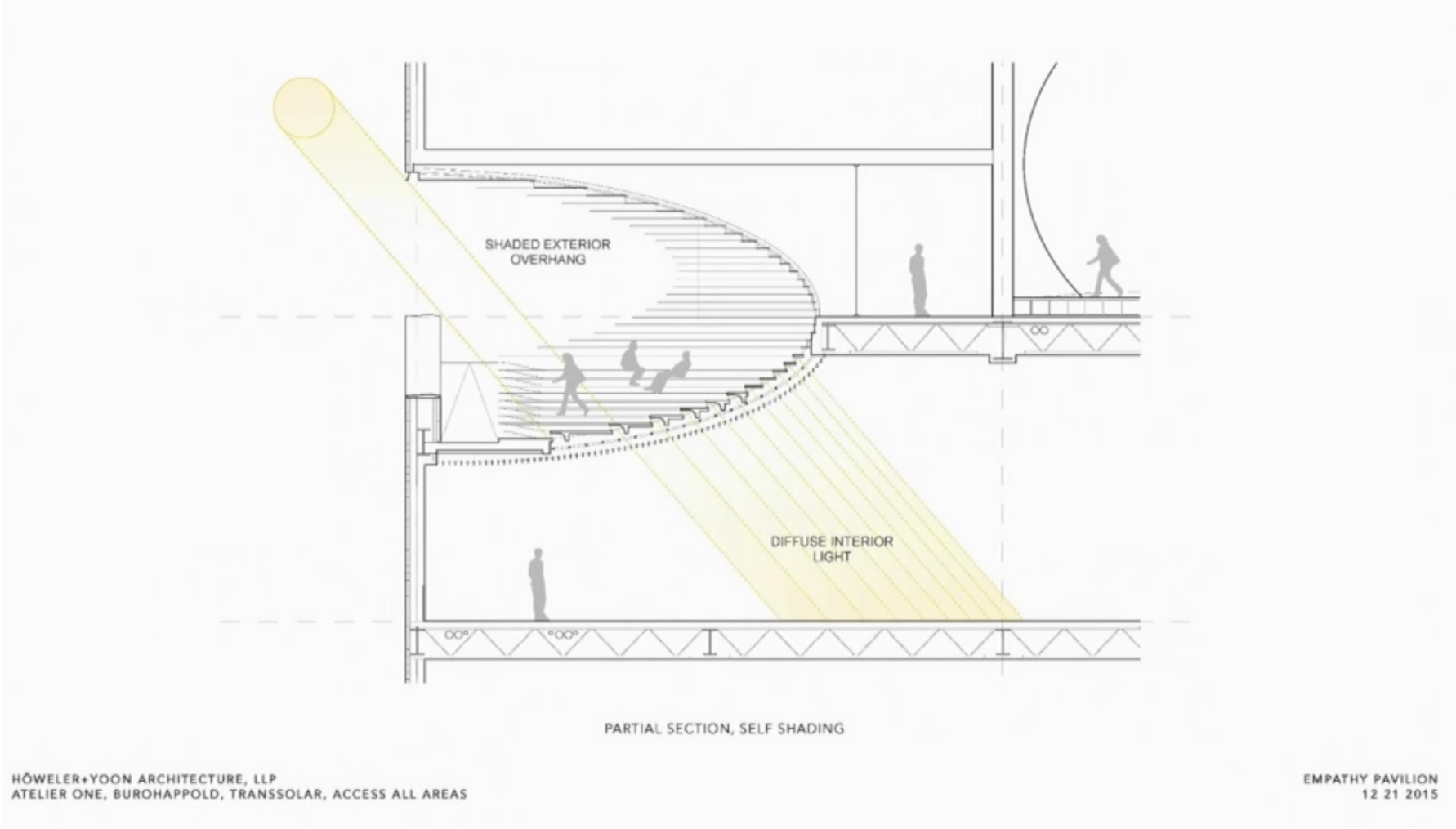
Environmental Performance



Empathy Pavilion
Höweler+Yoon + Transsolar, 2020

Resource: https://www.howeleryoon.com/

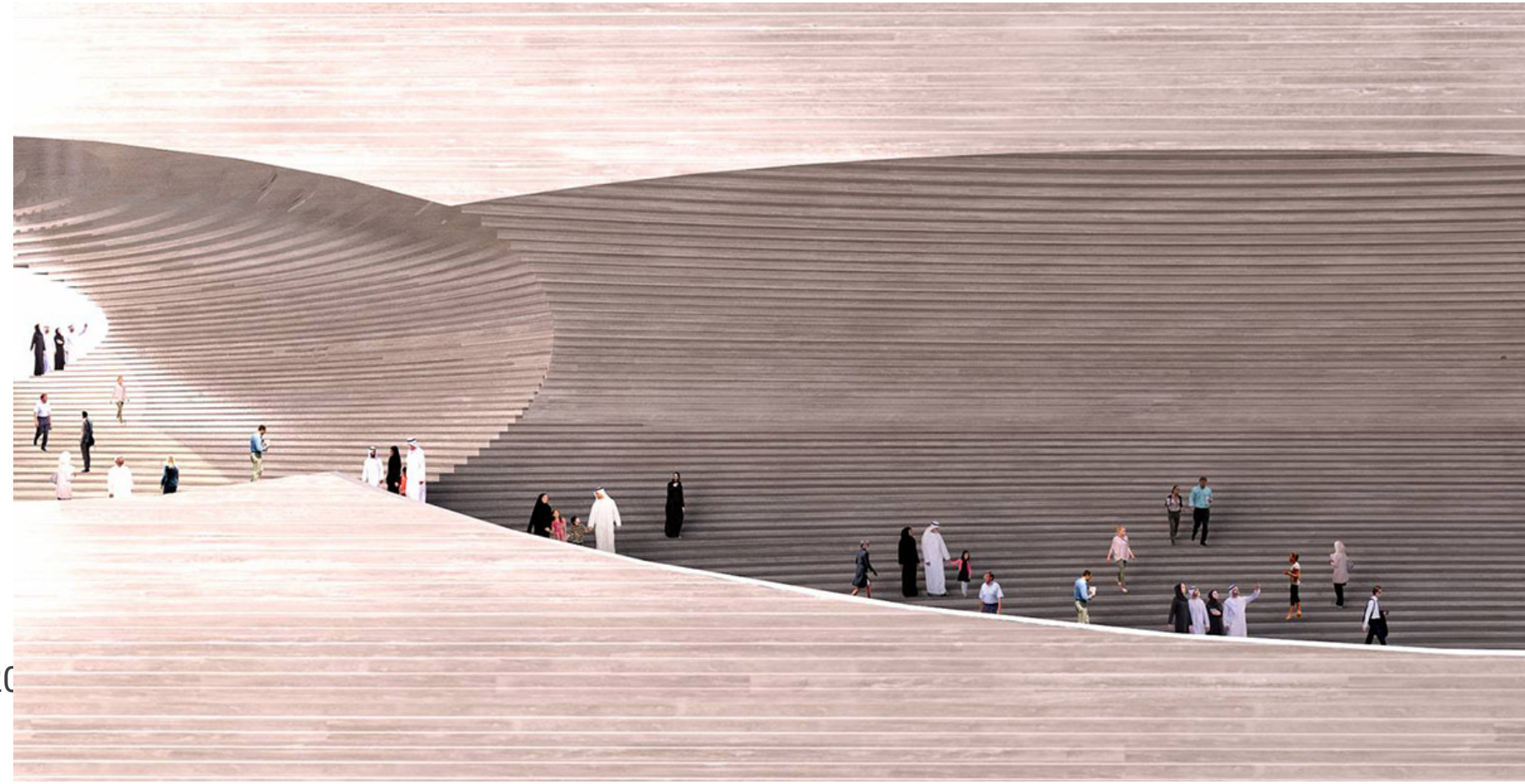
Environmental Performance



Empathy Pavilion
Höweler+Yoon + Transsolar, 2020

Resource: https://www.howeleryoon.com/

Environmental Performance

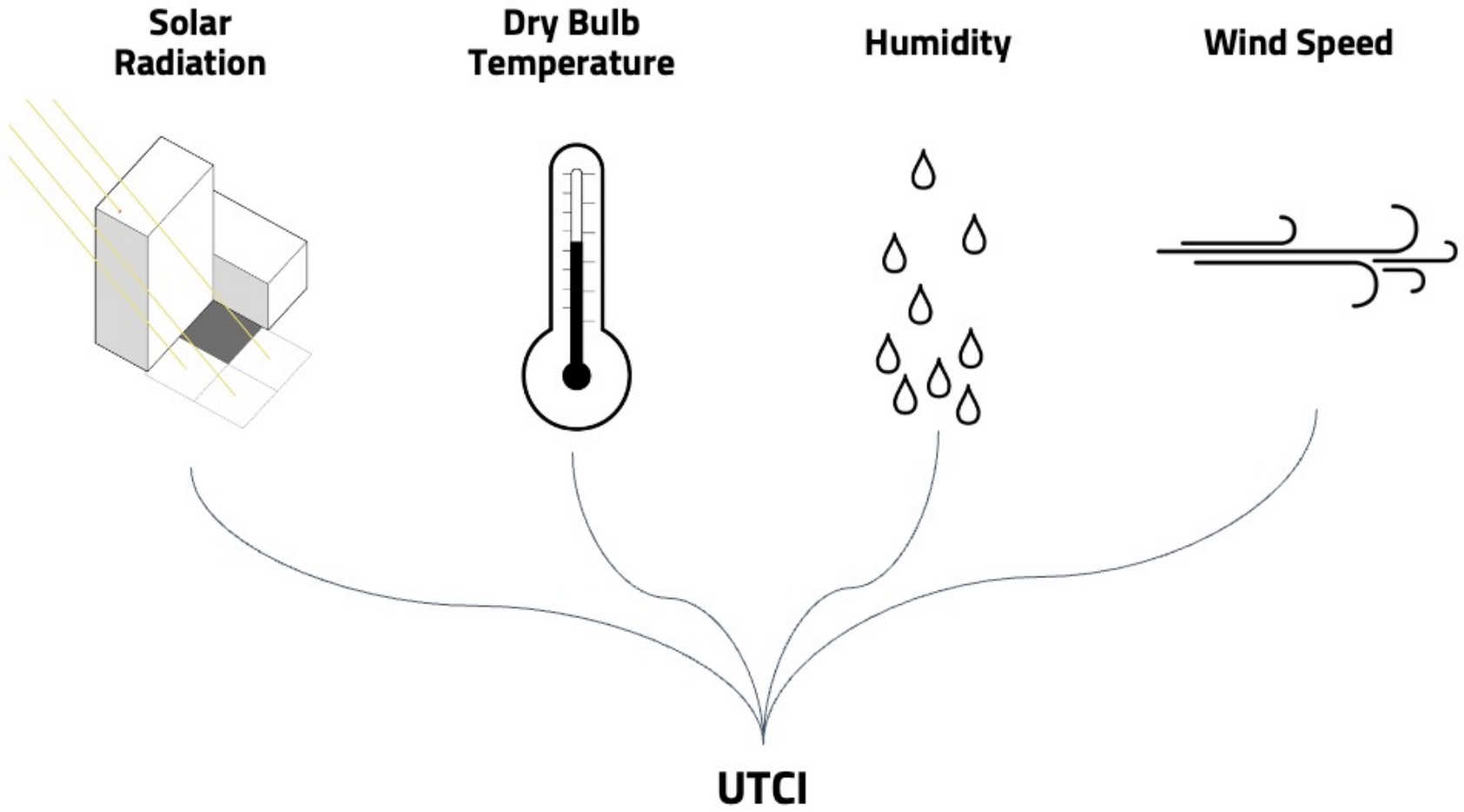


Empathy Pavilion
Höweler+Yoon + Transsolar, 2020

Resource: https://www.howeleryoon.com/

Environmental Performance

Parametric urban massing driven by solar/wind performance metrics. Urban-scale environmental optimization.

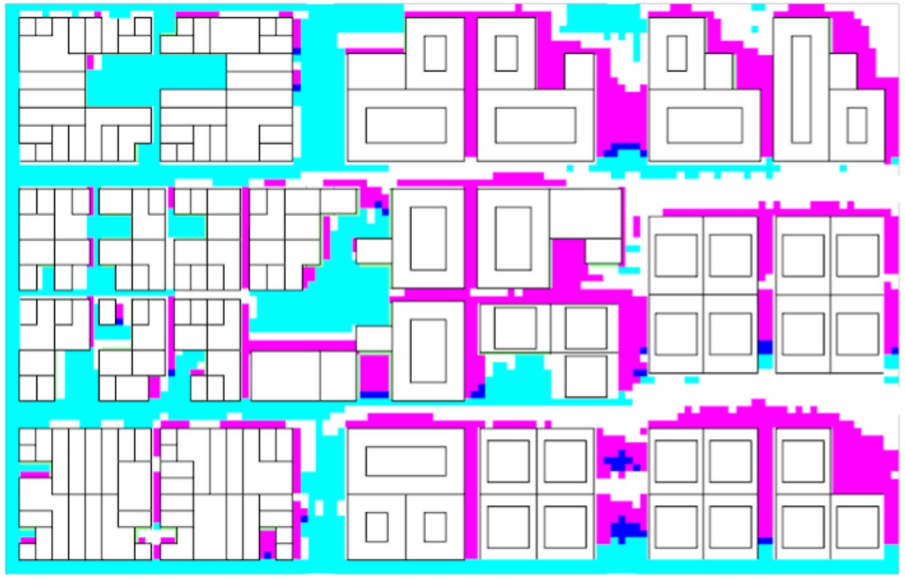


How to Generate a Thousand Master Plans
KPF Urban Interface, SimAUD 2019

Resource: https://ui.kpf.com/simaud-2019

Spatial and Temporal Distribution

Low density ⟷ High density



% Passing Warm Months: 0.63
% Passing: 0.61
% Passing Cold Months: 0.64
Improvement Over Dry Bulb: 1.11
MAX BUILDING HEIGHT: 98 m
% above 65% summer comfort: 0.32
AVERAGE FAR: 7.0
% above 65% winter comfort: 0.43

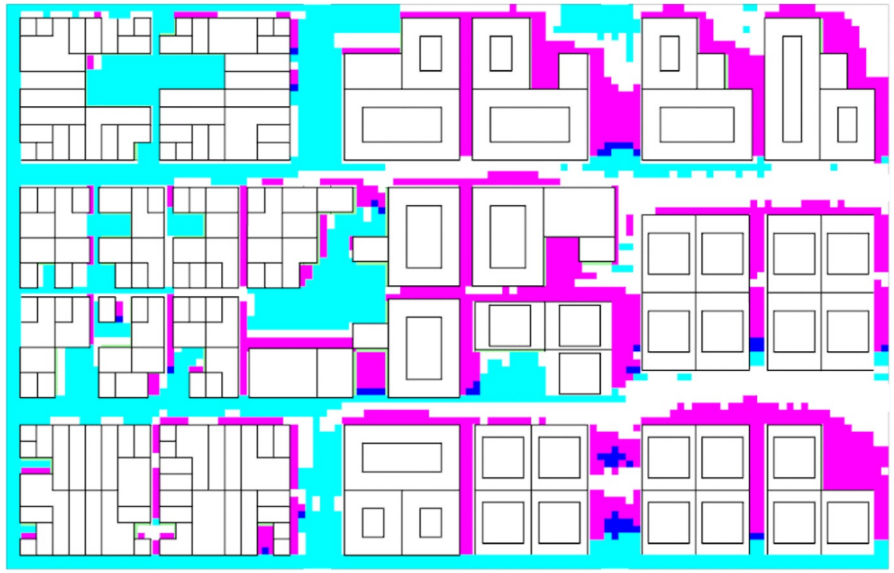
Winter Comfort

Summer Comfort

Annual Comfort

Spatial and Temporal Distribution

Low density ⟷ High density

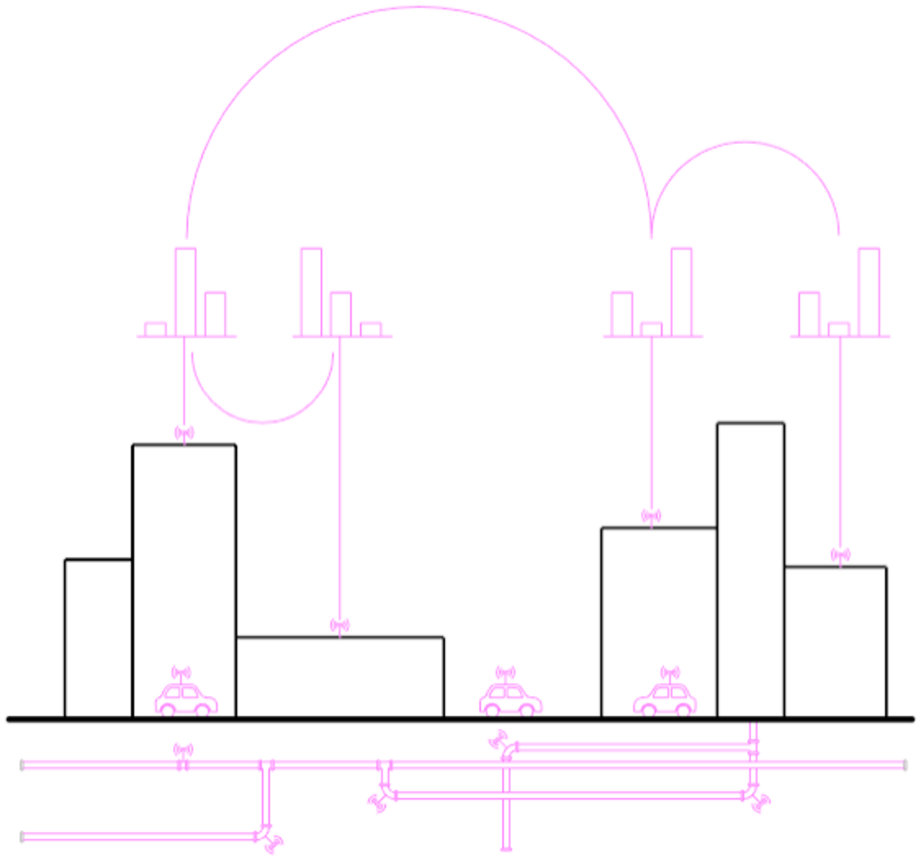


% Passing Warm Months: 0.63
% Passing: 0.61
% Passing Cold Months: 0.64
Improvement Over Dry Bulb: 1.11
MAX BUILDING HEIGHT: 98 m
% above 65% summer comfort: 0.32
AVERAGE FAR: 7.0
% above 65% winter comfort: 0.43

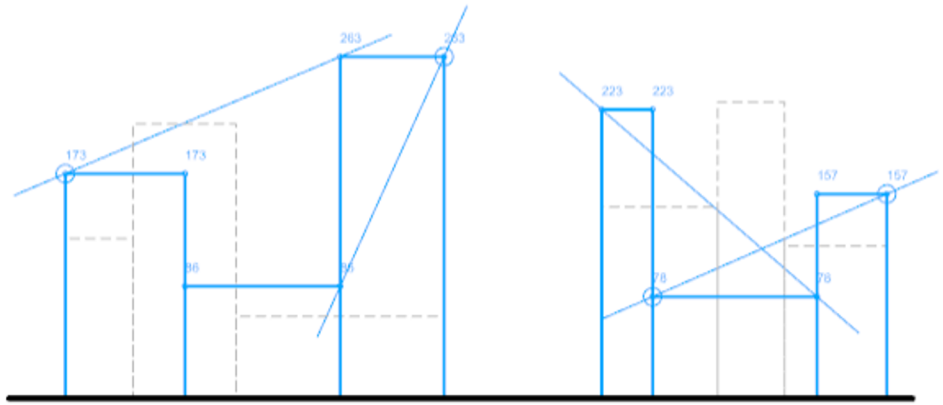
Winter Comfort

Summer Comfort

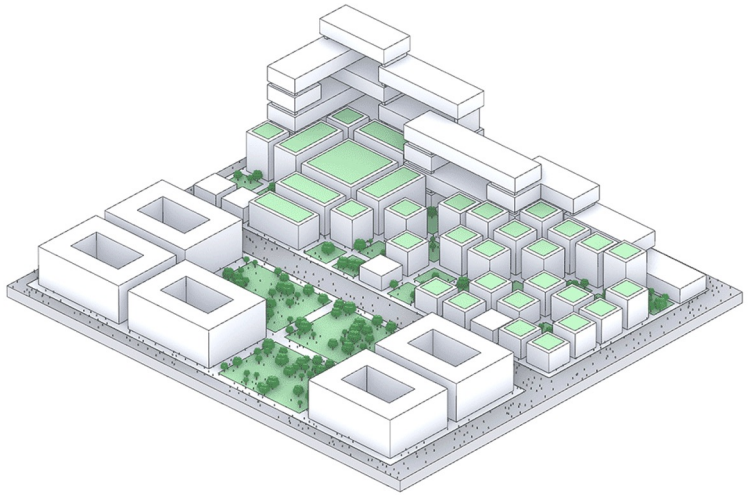
Annual Comfort



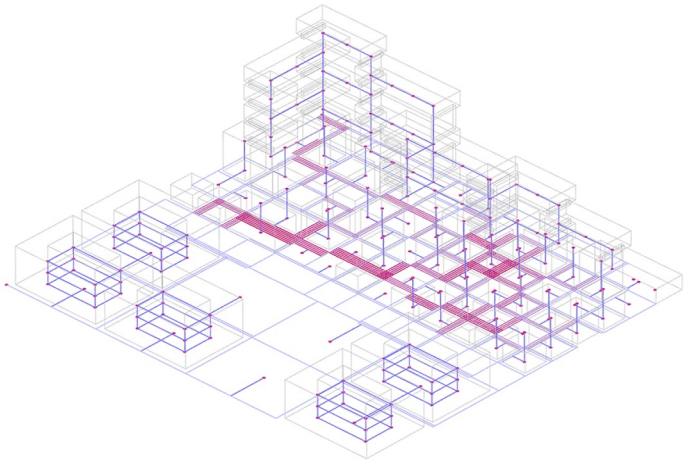
Smart City



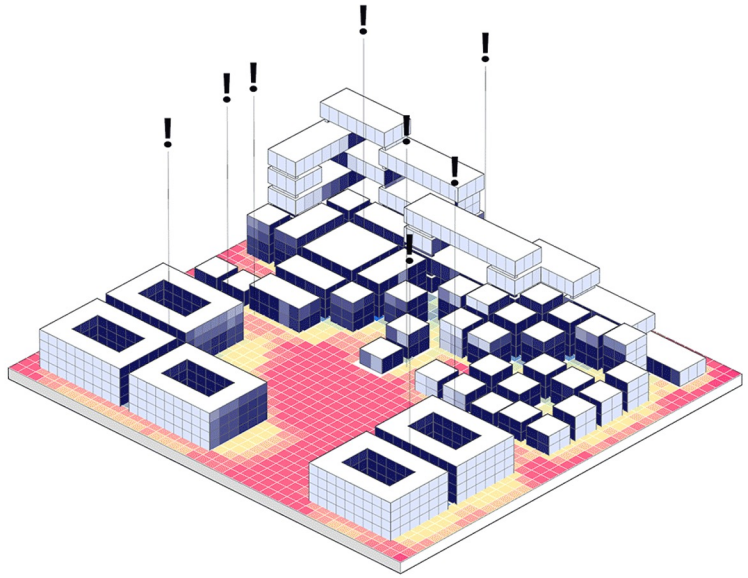
Smart(er) City



Buildings

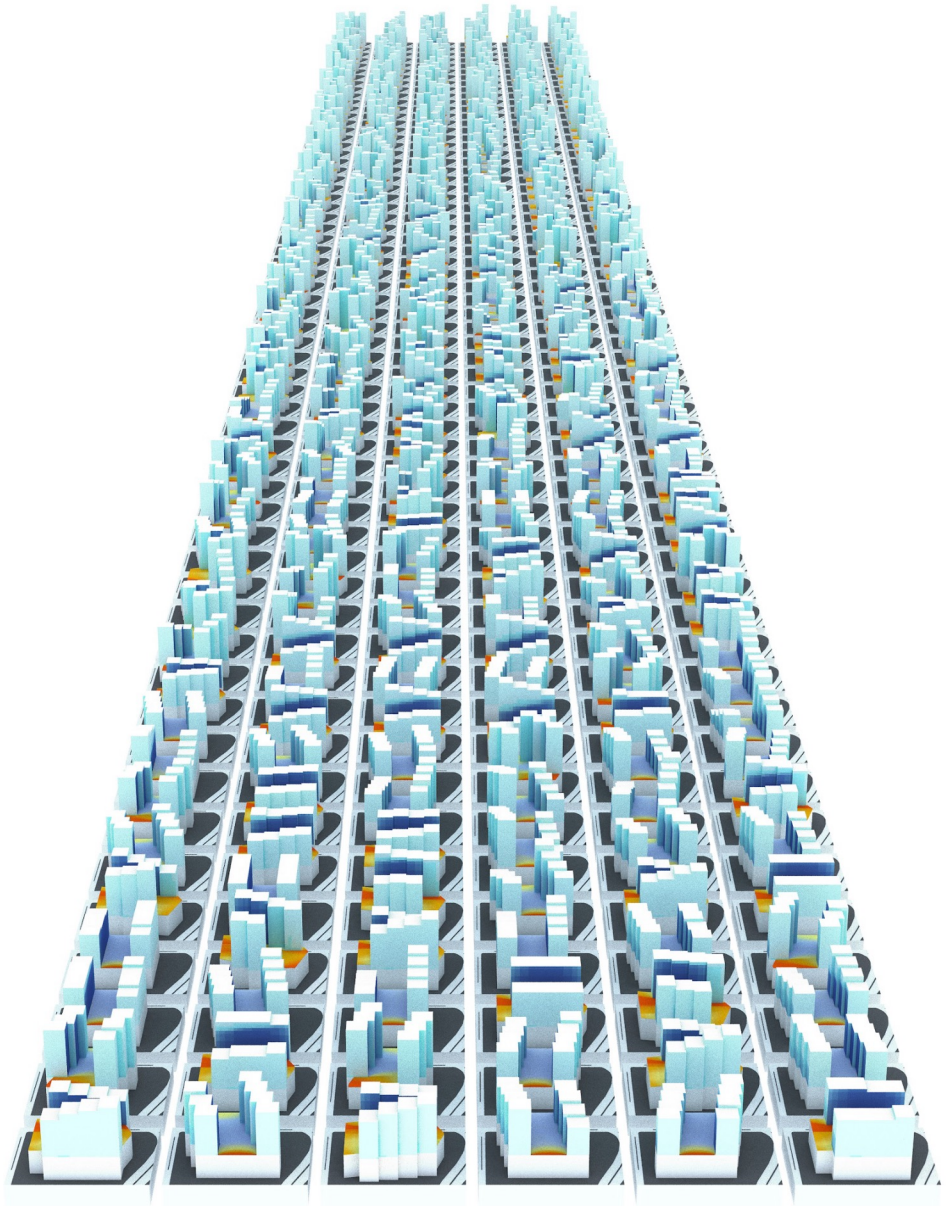


Networks

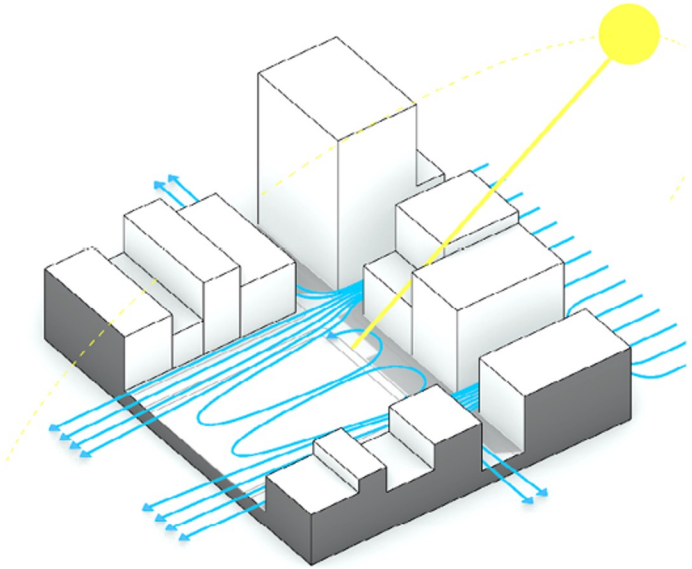


Performance

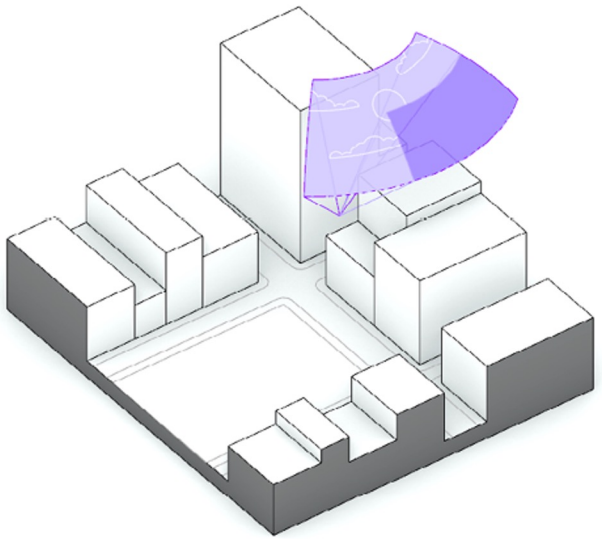
Prototyping



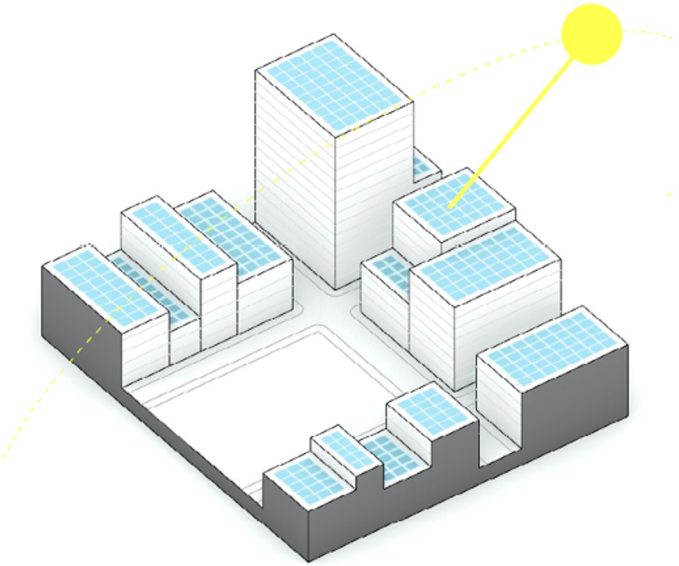
Metrics



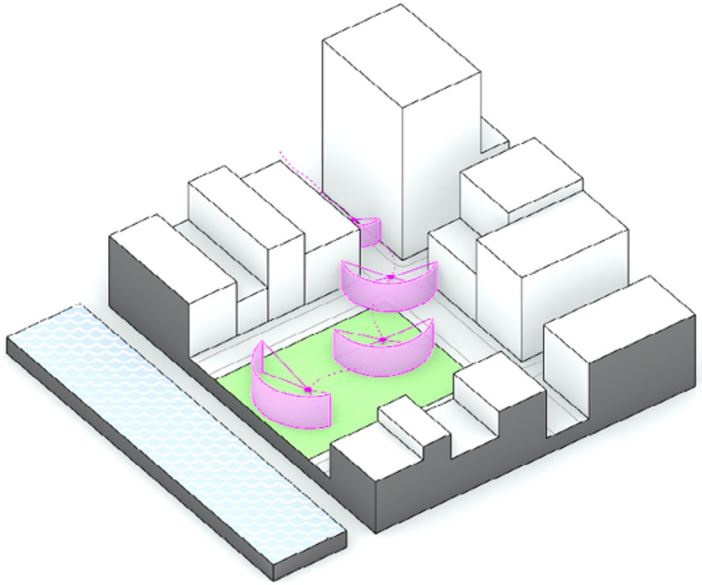
Outdoor Comfort



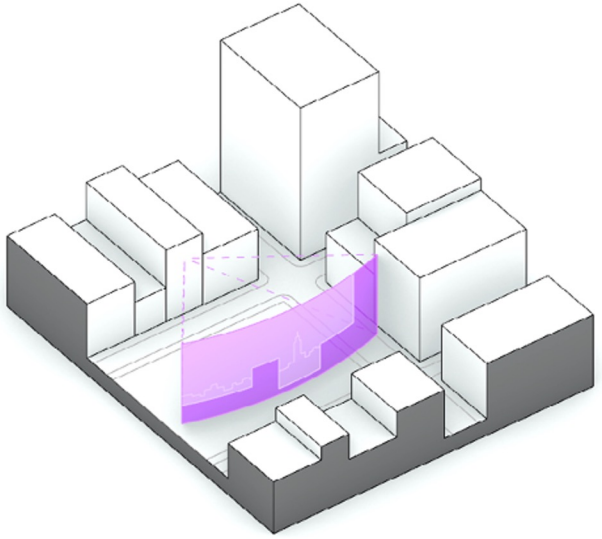
Daylight



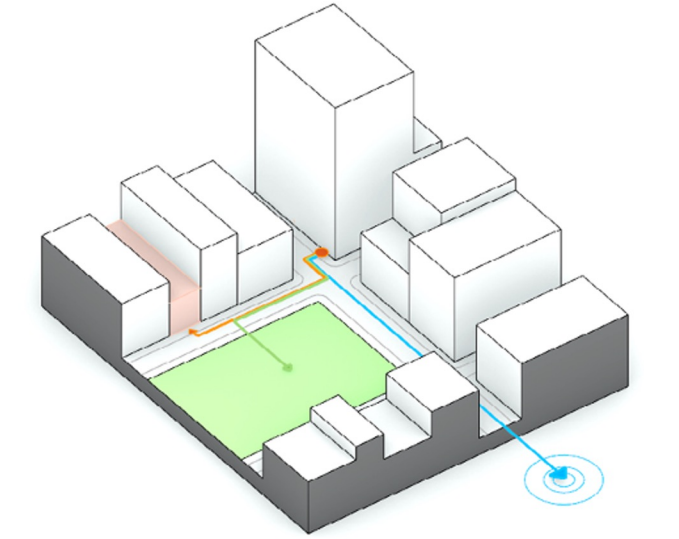
Energy Generation



Visual Interest

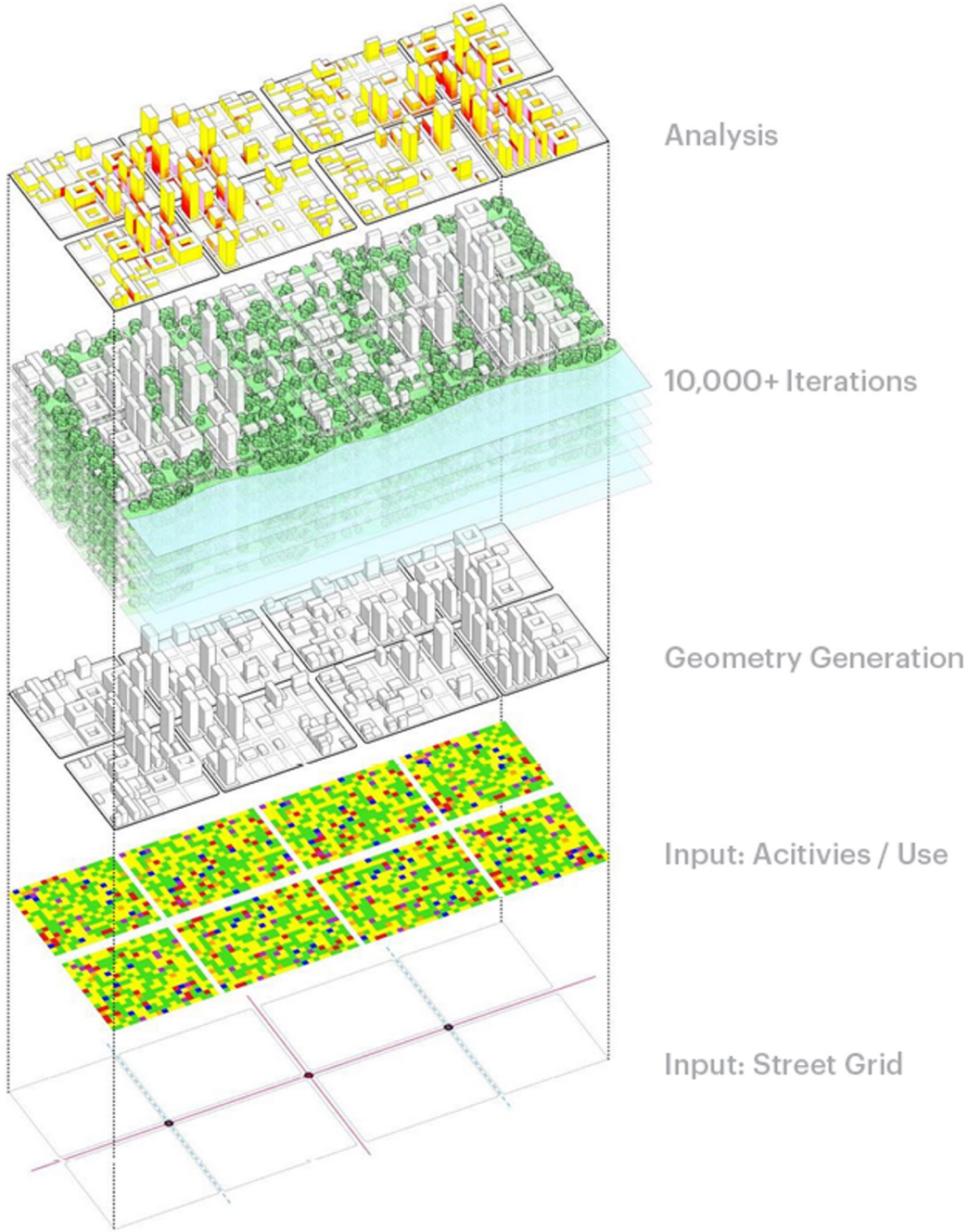


Views

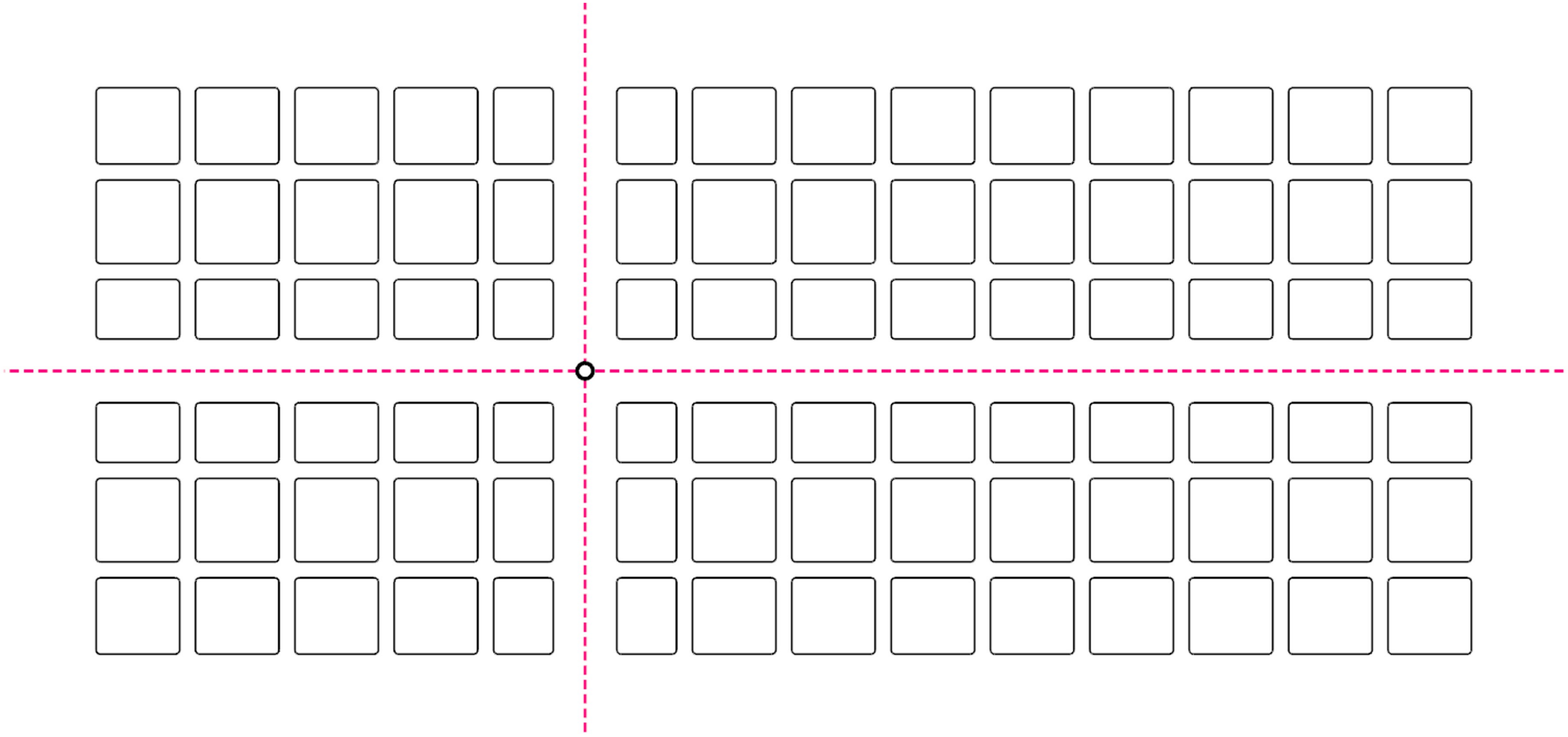


Mobility

Computational Urban model

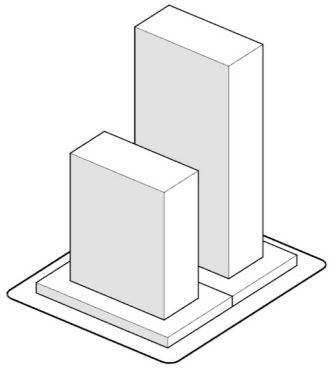


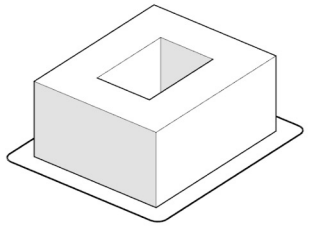
Mobility Network

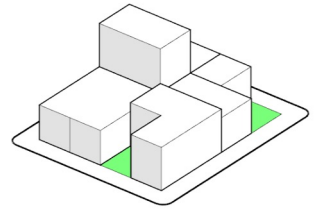


Click to edit Master title style

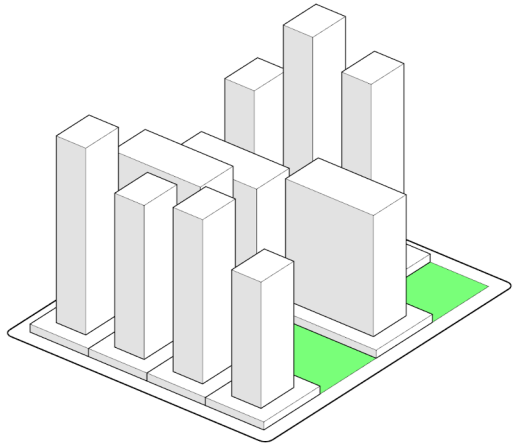
Building Types

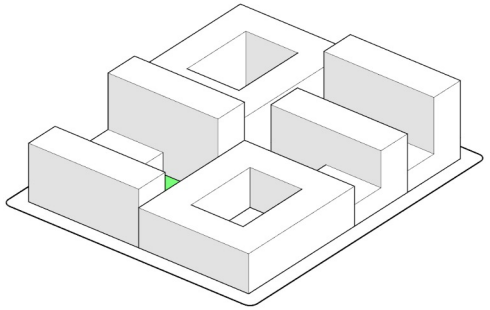


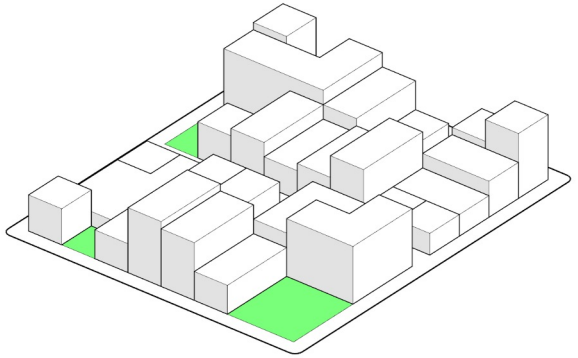


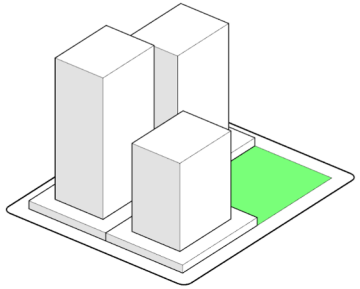


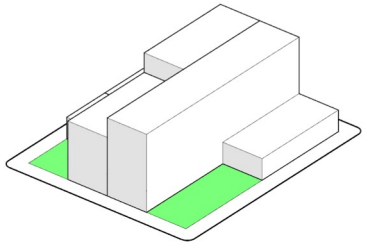
Building Types

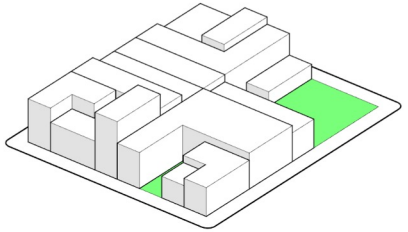


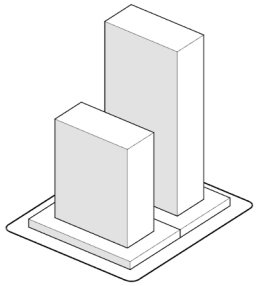


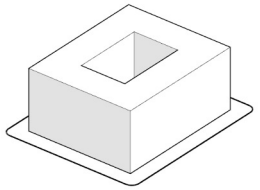


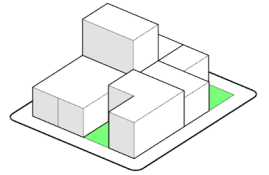




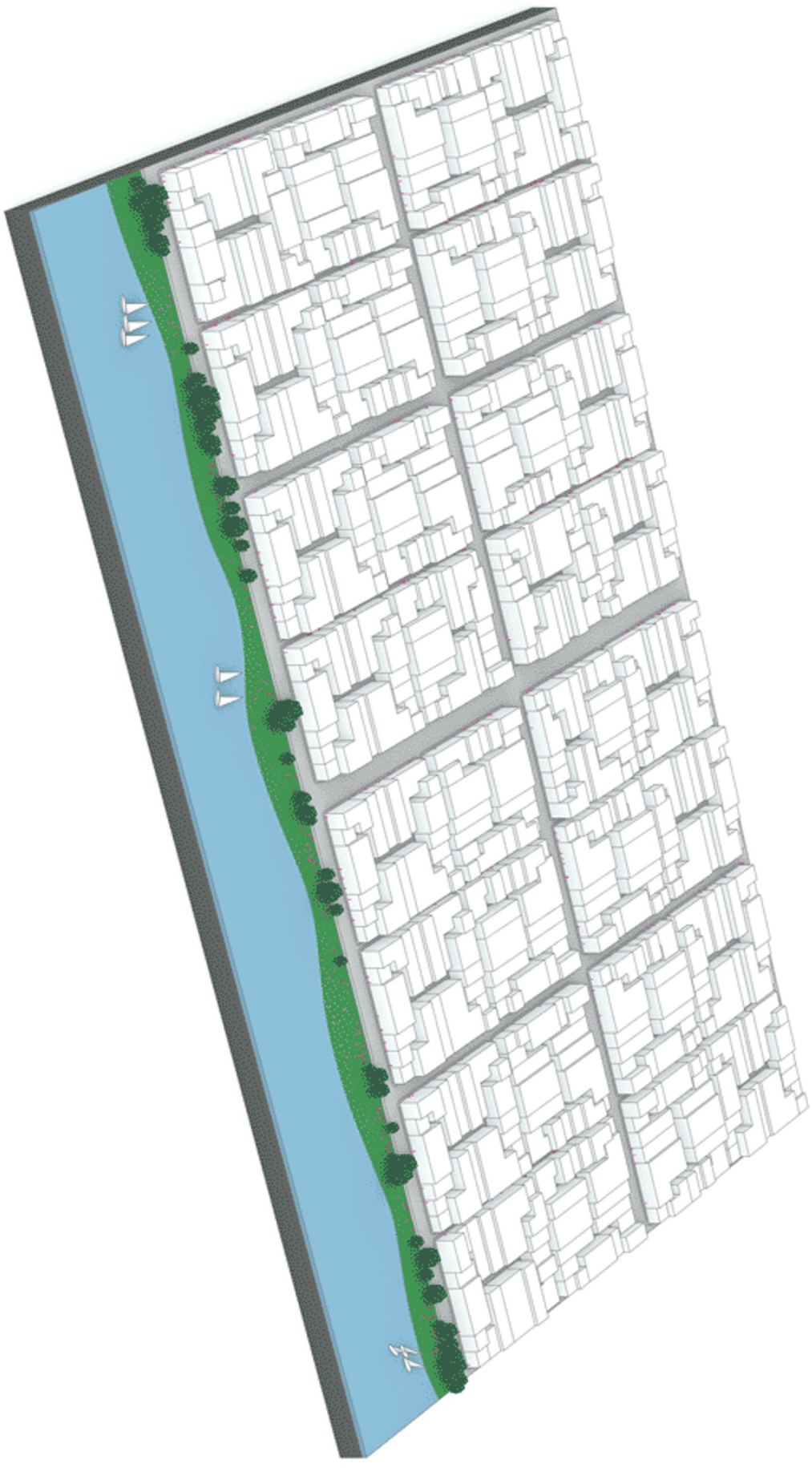




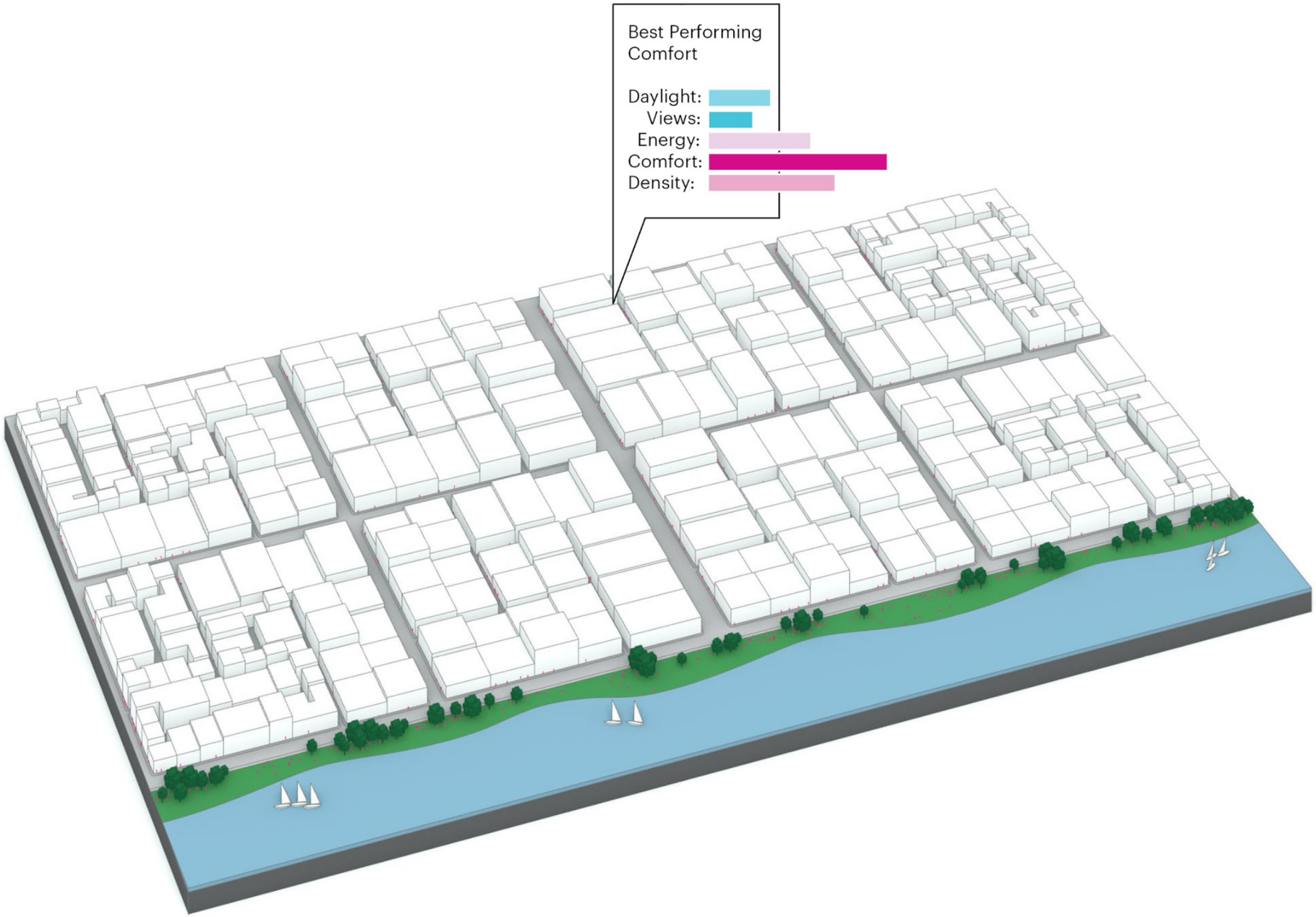




Testing Thousands of Options



If you prioritize Comfort



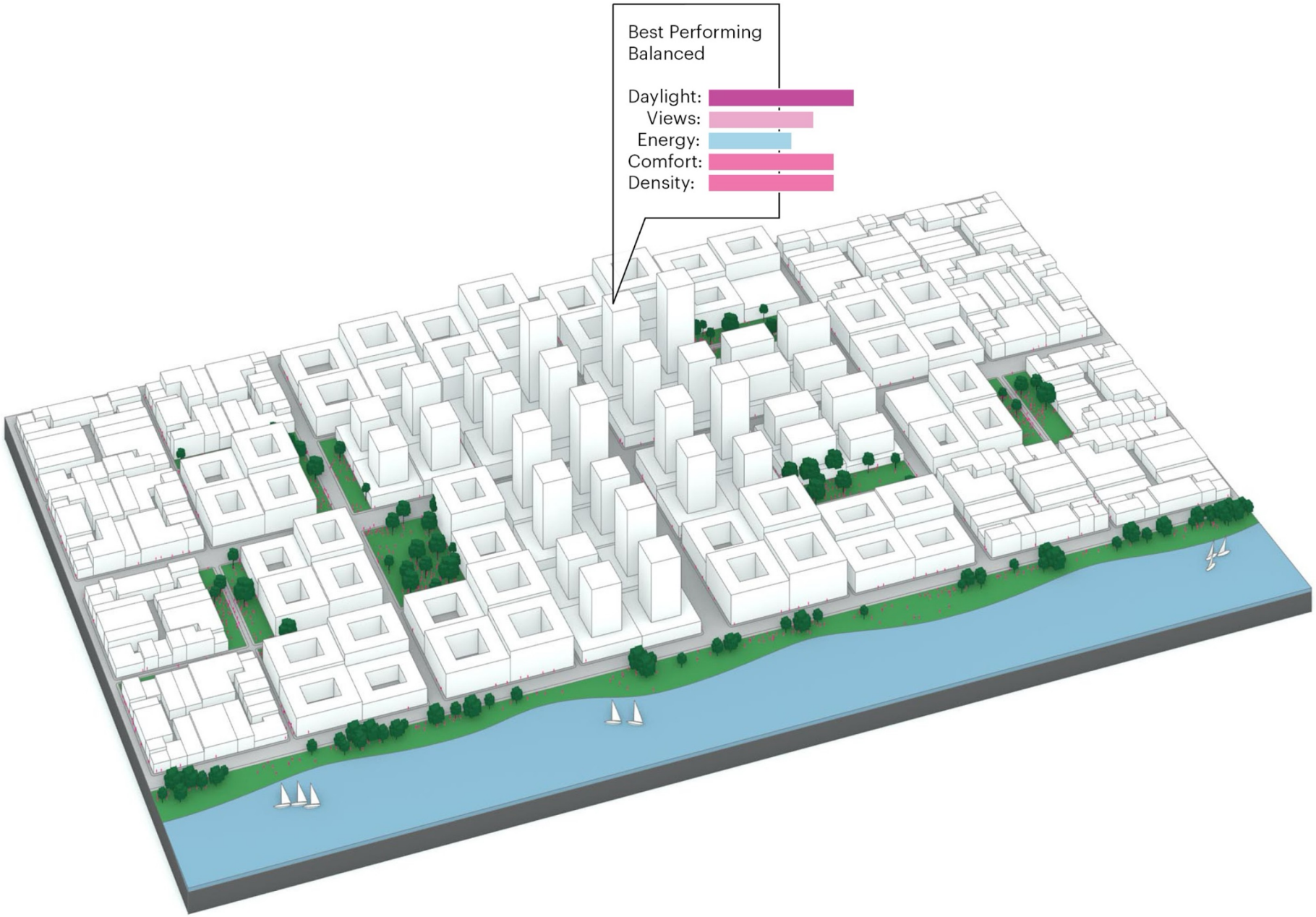
If you prioritize Daylight



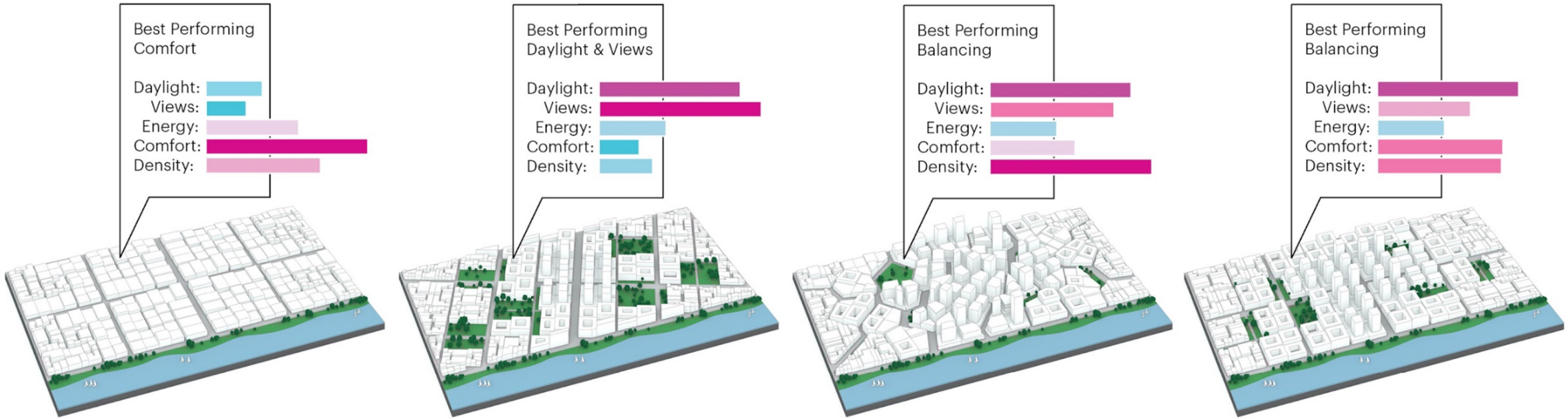
If you Balance

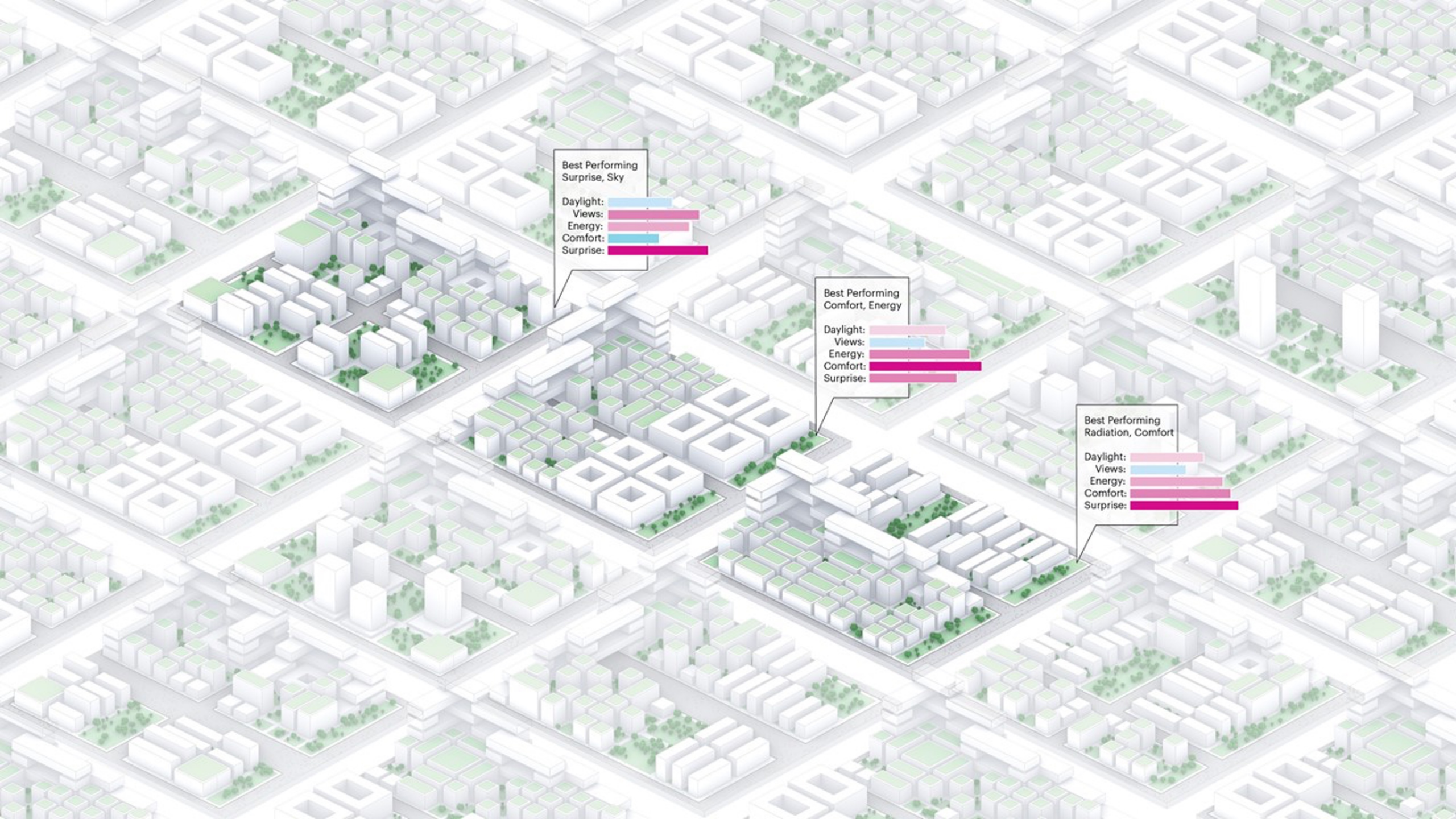


If you Balance

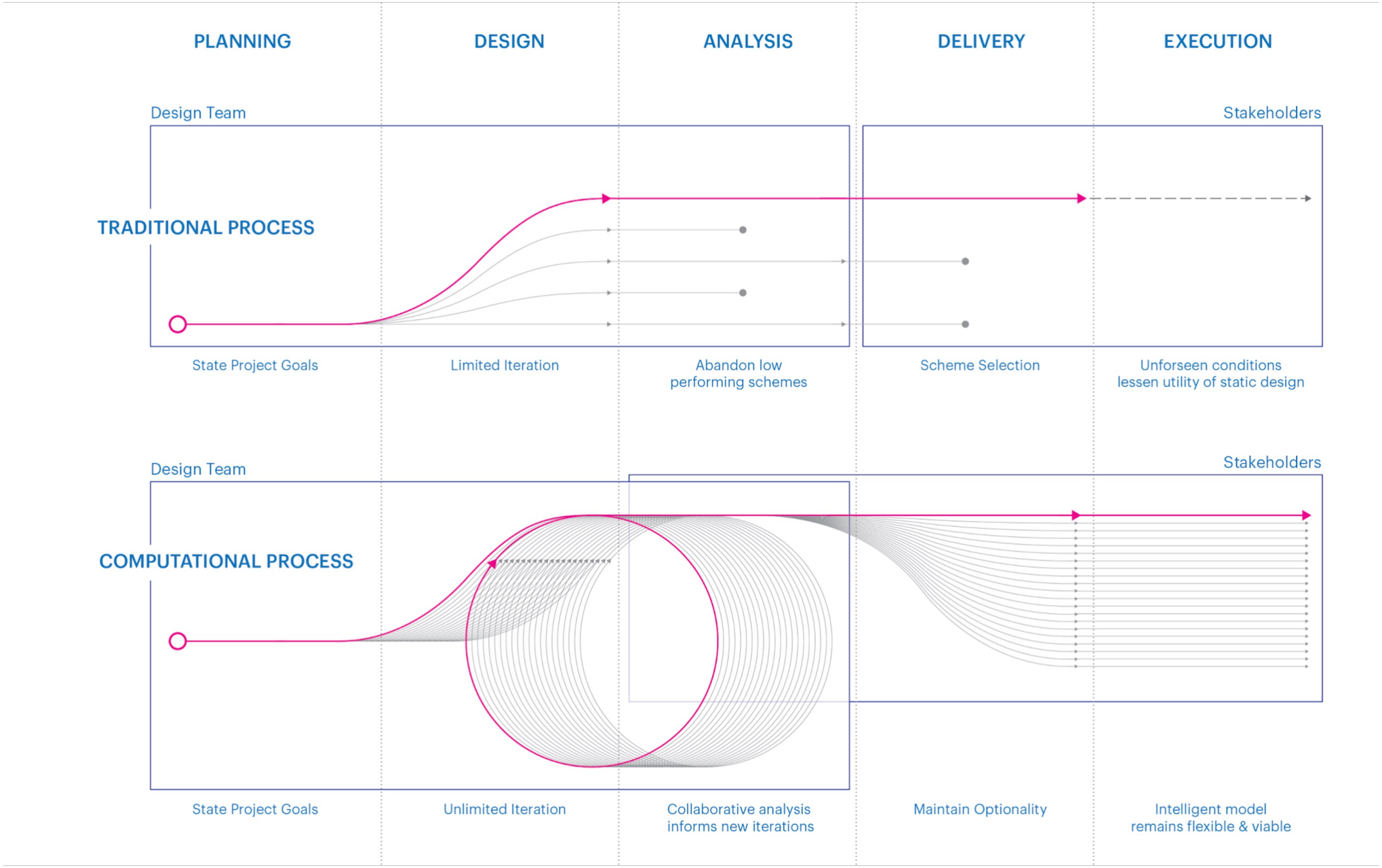


Trade-Offs


Best Performing
Comfort
Daylight:
Views:
Energy:
Comfort:
Density:
Best Performing
Daylight & Views
Daylight:
Views:
Energy:
Comfort:
Density:
Best Performing
Balancing
Daylight:
Views:
Energy:
Comfort:
Density:
Best Performing
Balancing
Daylight:
Views:
Energy:
Comfort:
Density:


Best Performing
Surprise, Sky
Daylight:
Views:
Energy:
Comfort:
Surprise:
Best Performing
Comfort, Energy
Daylight:
Views:
Energy:
Comfort:
Surprise:
Best Performing
Radiation, Comfort
Daylight:
Views:
Energy:
Comfort:
Surprise:

Typical Planning



Design Your Neighbourhood



Design Your Neighbourhood

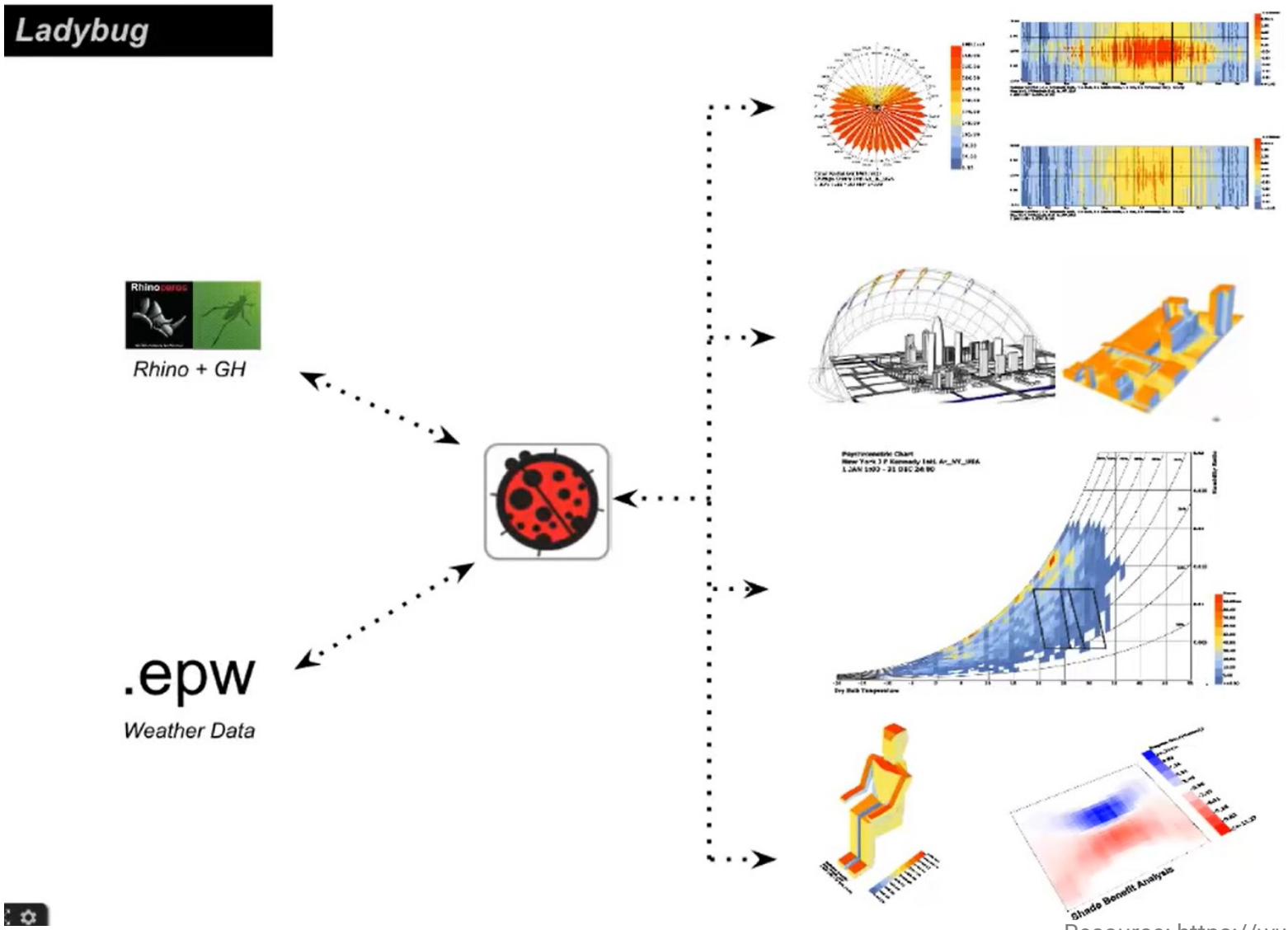



riation
Feedback
Street Grid
Green Space

Stakeholder Engagement



Environmental Performance: Tools

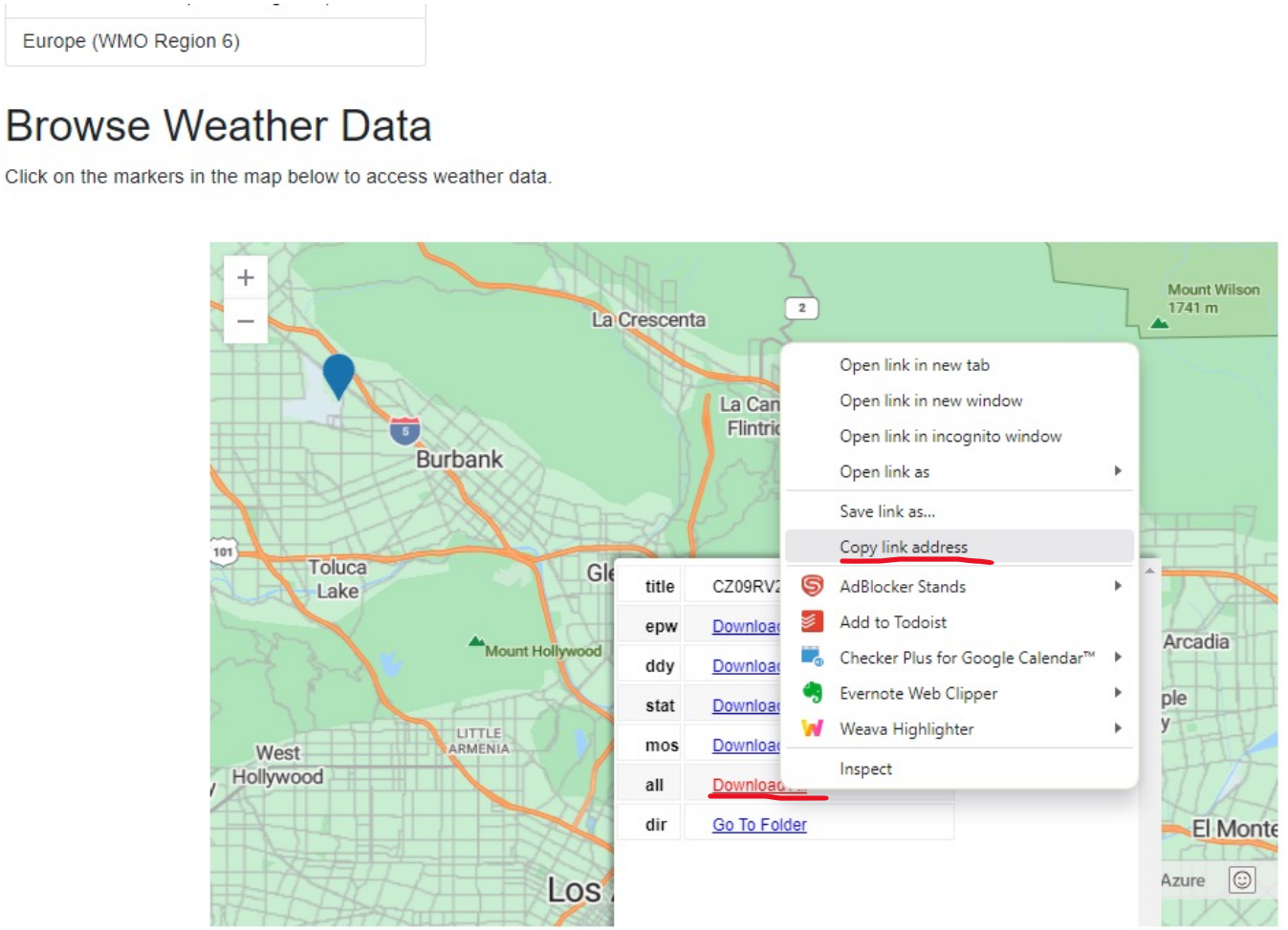


Resource: https://www.ladybug.tools/ladybug.html

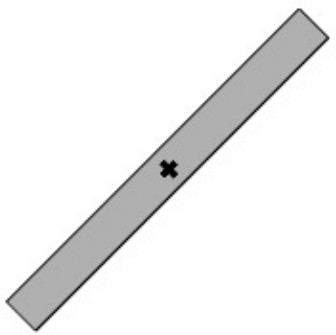
Go to https://energyplus.net/weather
Find the location closest to your site,
Click the location icon – Right click “Download All” – select “Copy link address”.

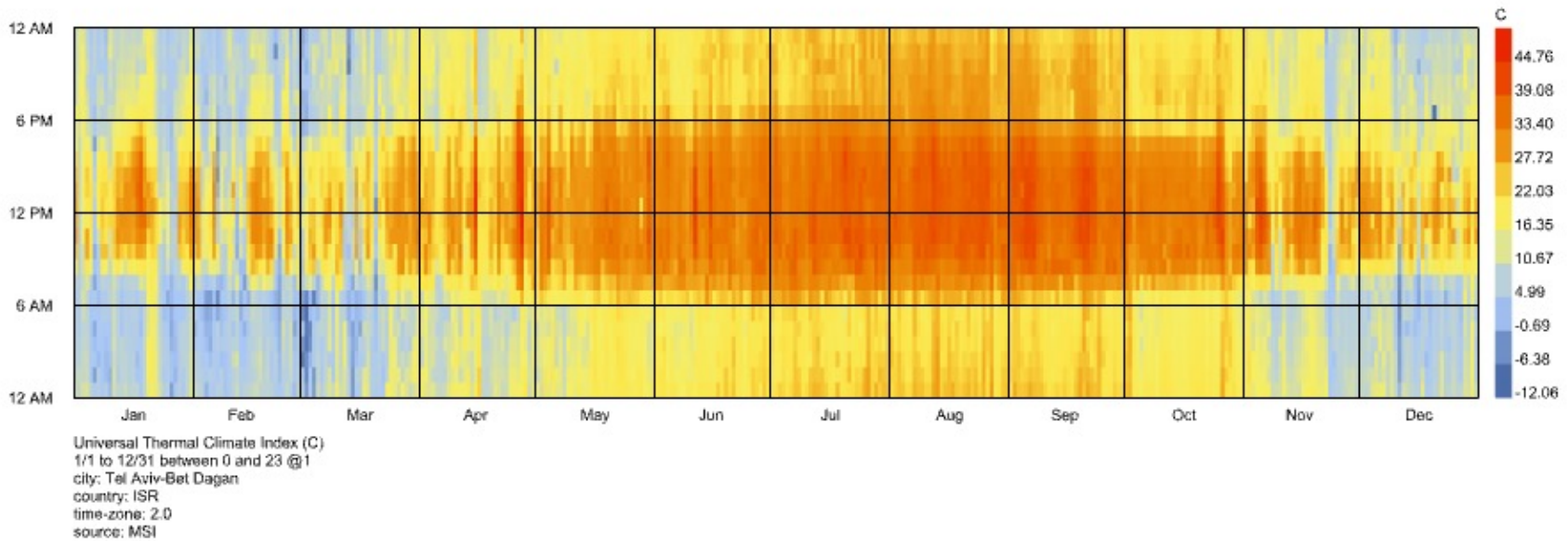
You can also find at https://www.ladybug.tools/epwmap/#close.

The copied link should look like this (Los Angeles):
https://energyplus-weather.s3.amazonaws.com/north_and_central_america_wmo_region_4/USA/CA/USA_CA_Santa.Monica.Muni.AP.722885_TMY3/USA_CA_Santa.Monica.Muni.AP.722885_TMY3.zip

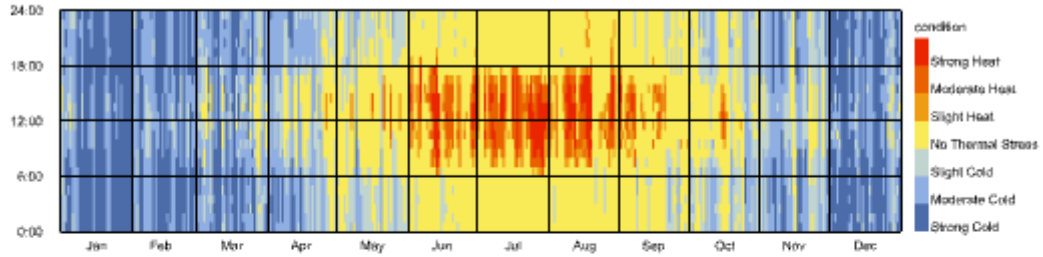


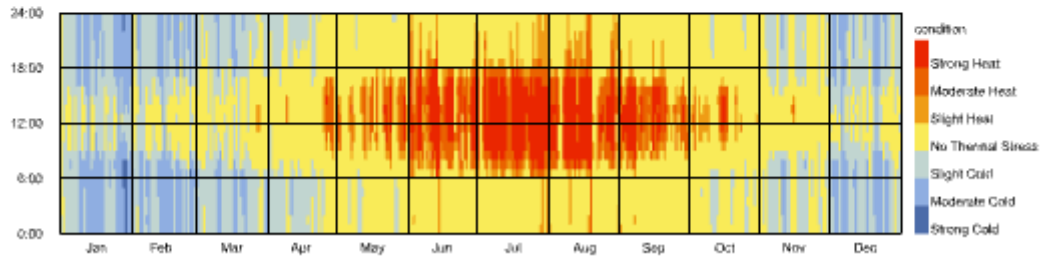
Data imported to Ladybug

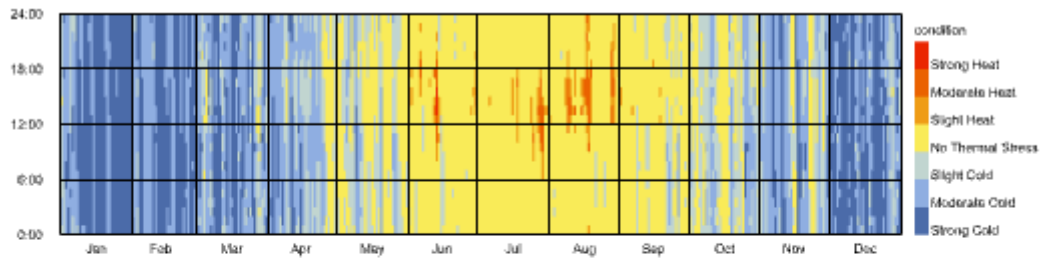


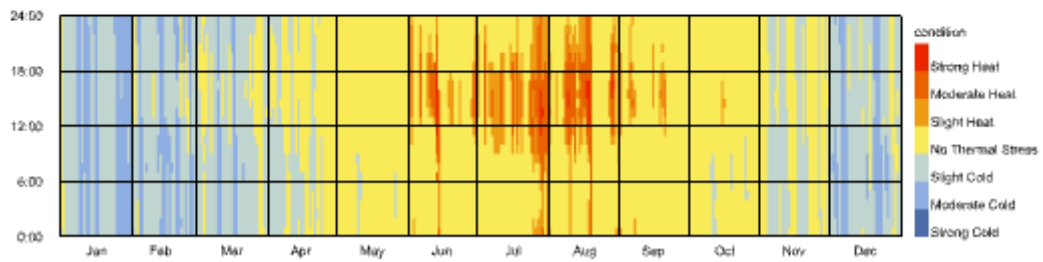


Street Canyon Comfort: Ladybug

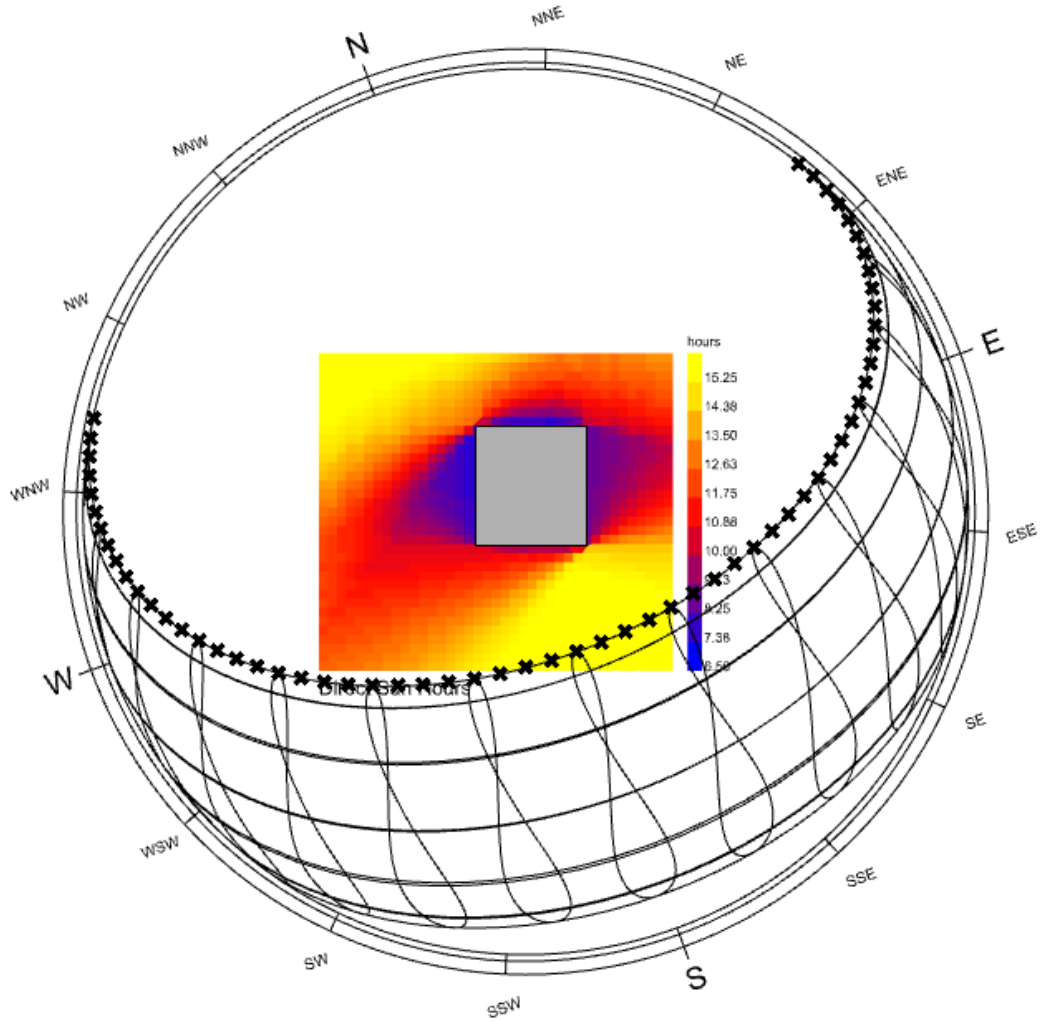






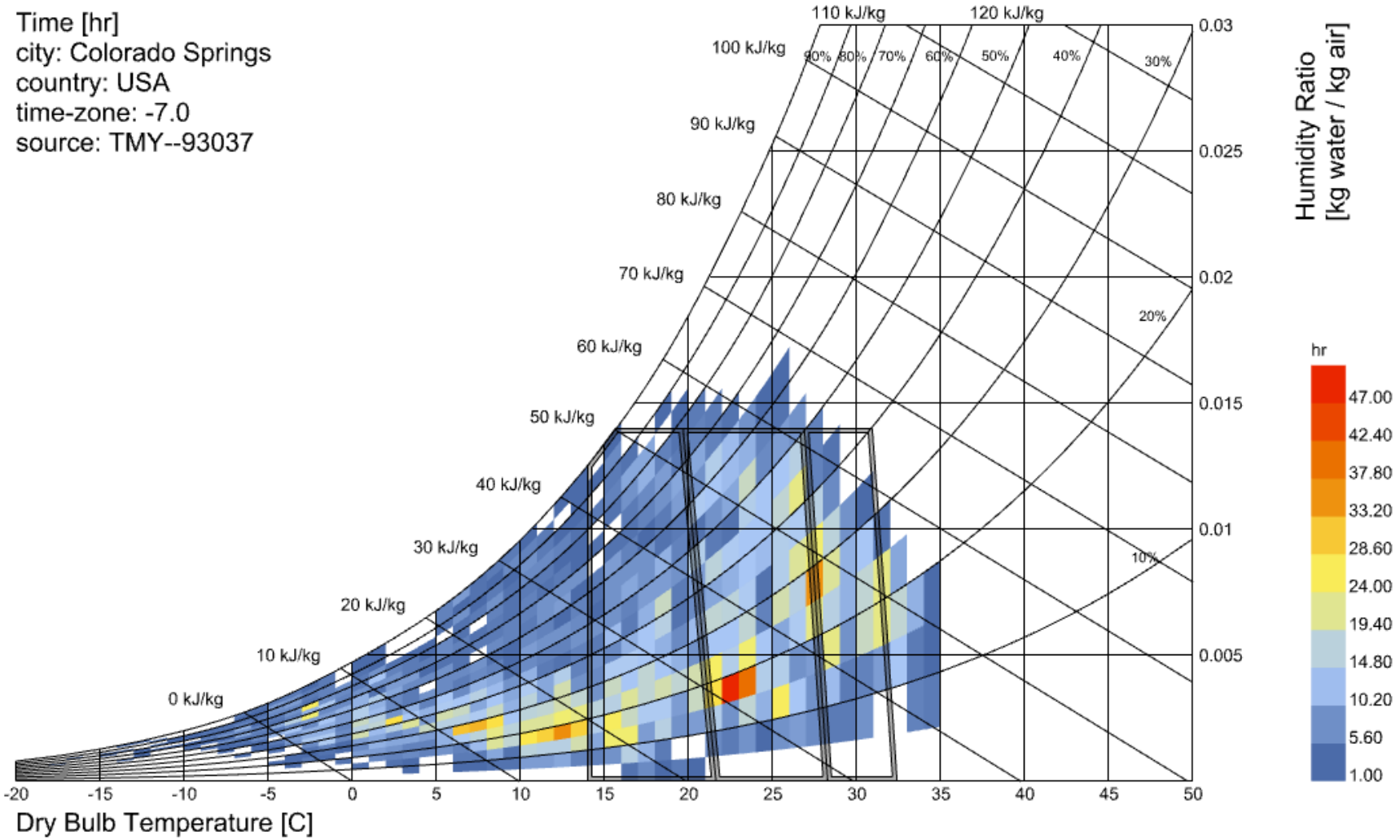


Outdoor Comfort

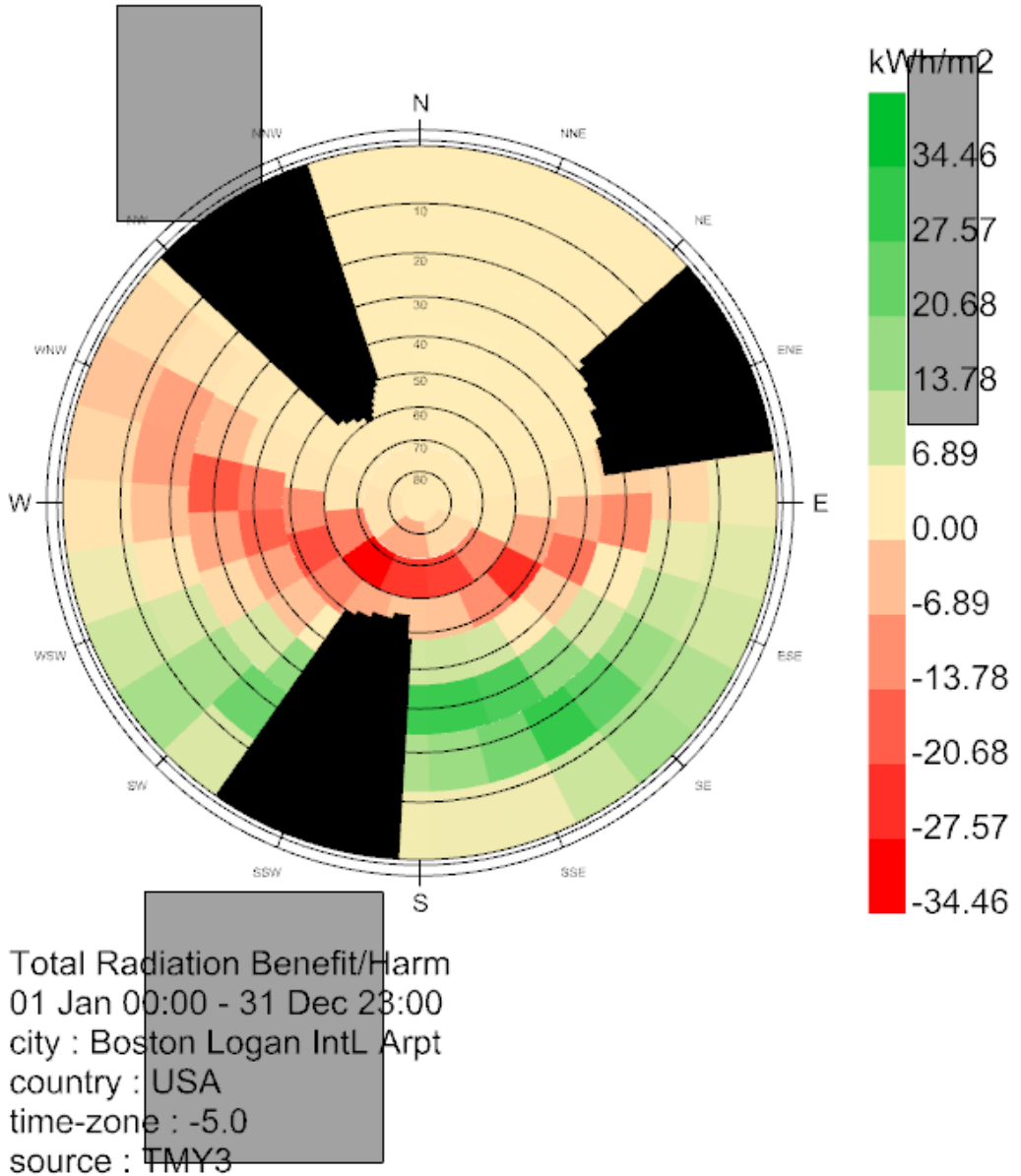


city: Madison-Dane County Rgnl AP-Truax Field

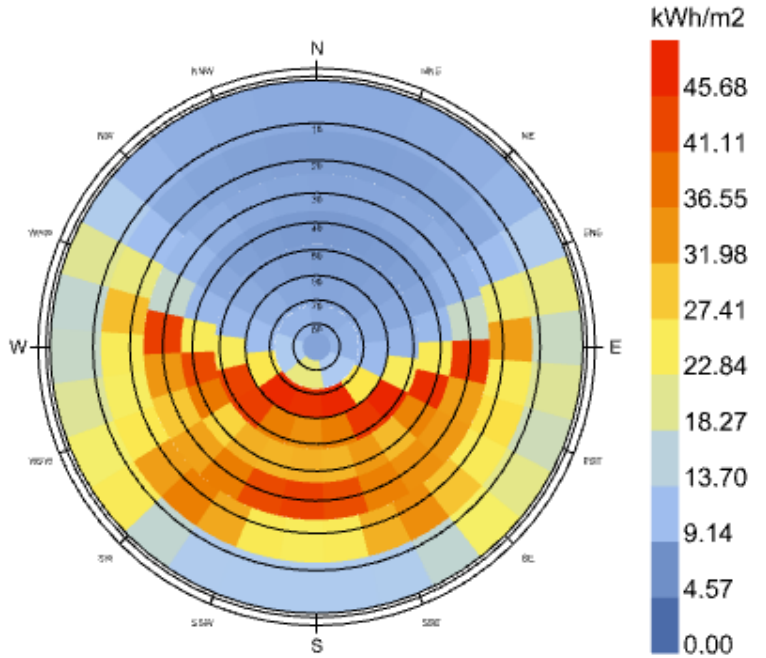
Direct Sun Study: Ladybug



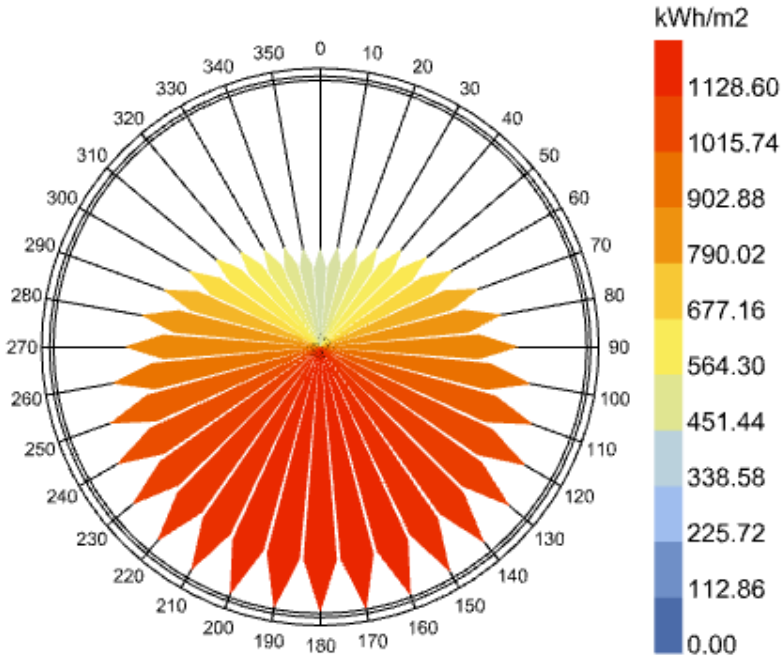
Psychrometric chart: Ladybug



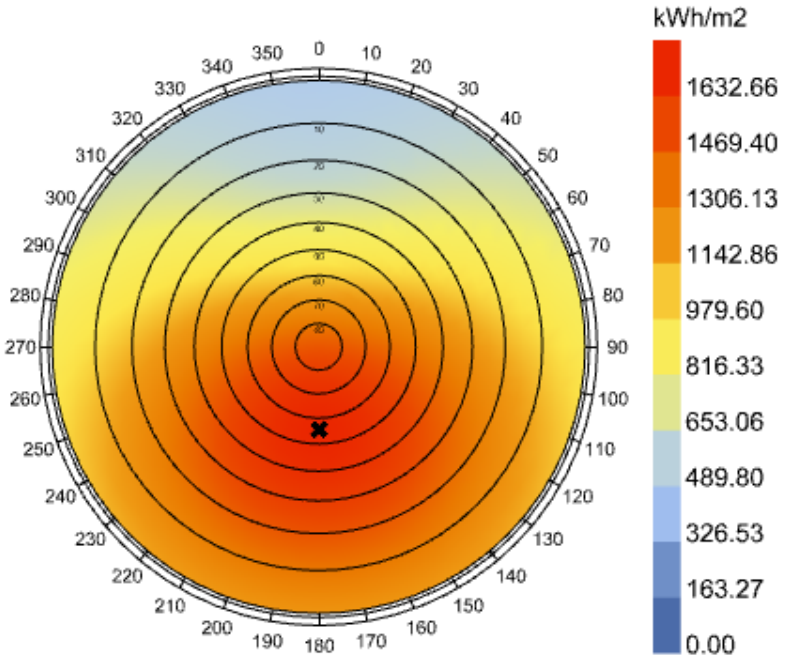
Radiation Benefit: Ladybug



Total Radiation
01 Jan 00:00 - 31 Dec 23:00
city : Madison-Dane County Rgnl AP-Truax Field
country : USA
time-zone : -6.0
source : TMY3

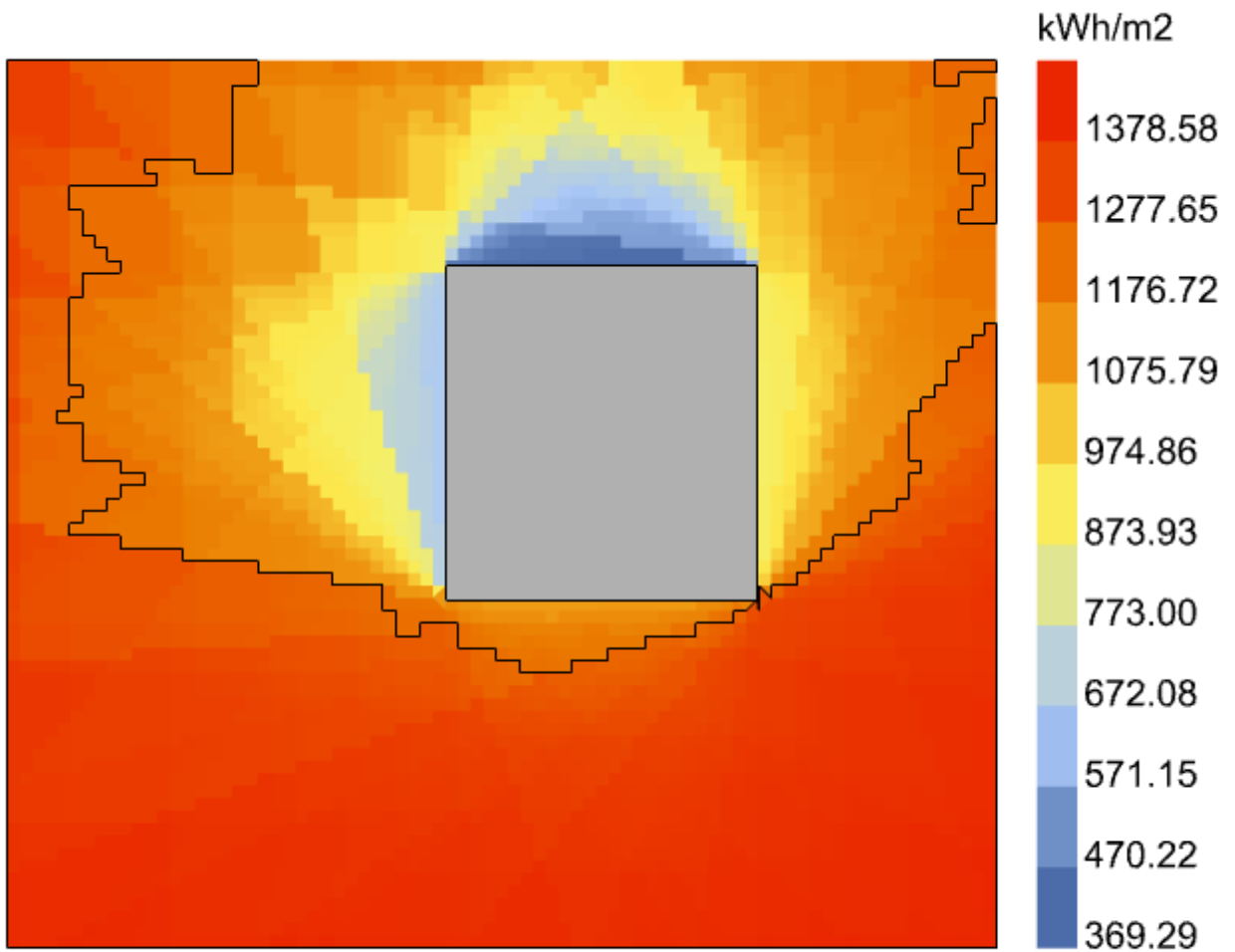


Total Radiation
01 Jan 00:00 - 31 Dec 23:00
city : Madison-Dane County Rgnl AP-Truax Field
country : USA
time-zone : -6.0
source : TMY3



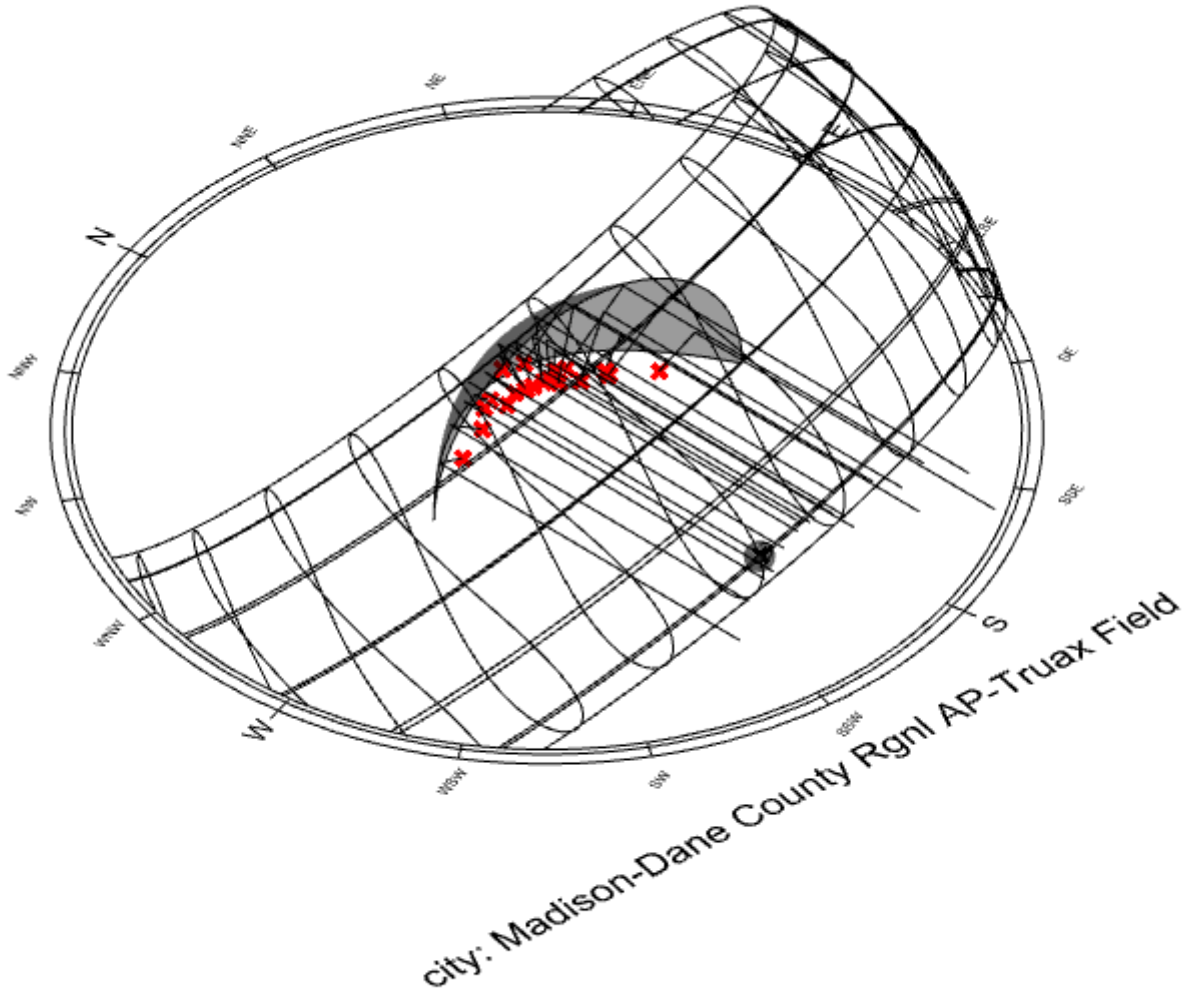
Total Radiation
01 Jan 00:00 - 31 Dec 23:00
city : Madison-Dane County Rgnl AP-Truax Field
country : USA
time-zone : -6.0
source : TMY3

Radiation Graphics: Ladybug

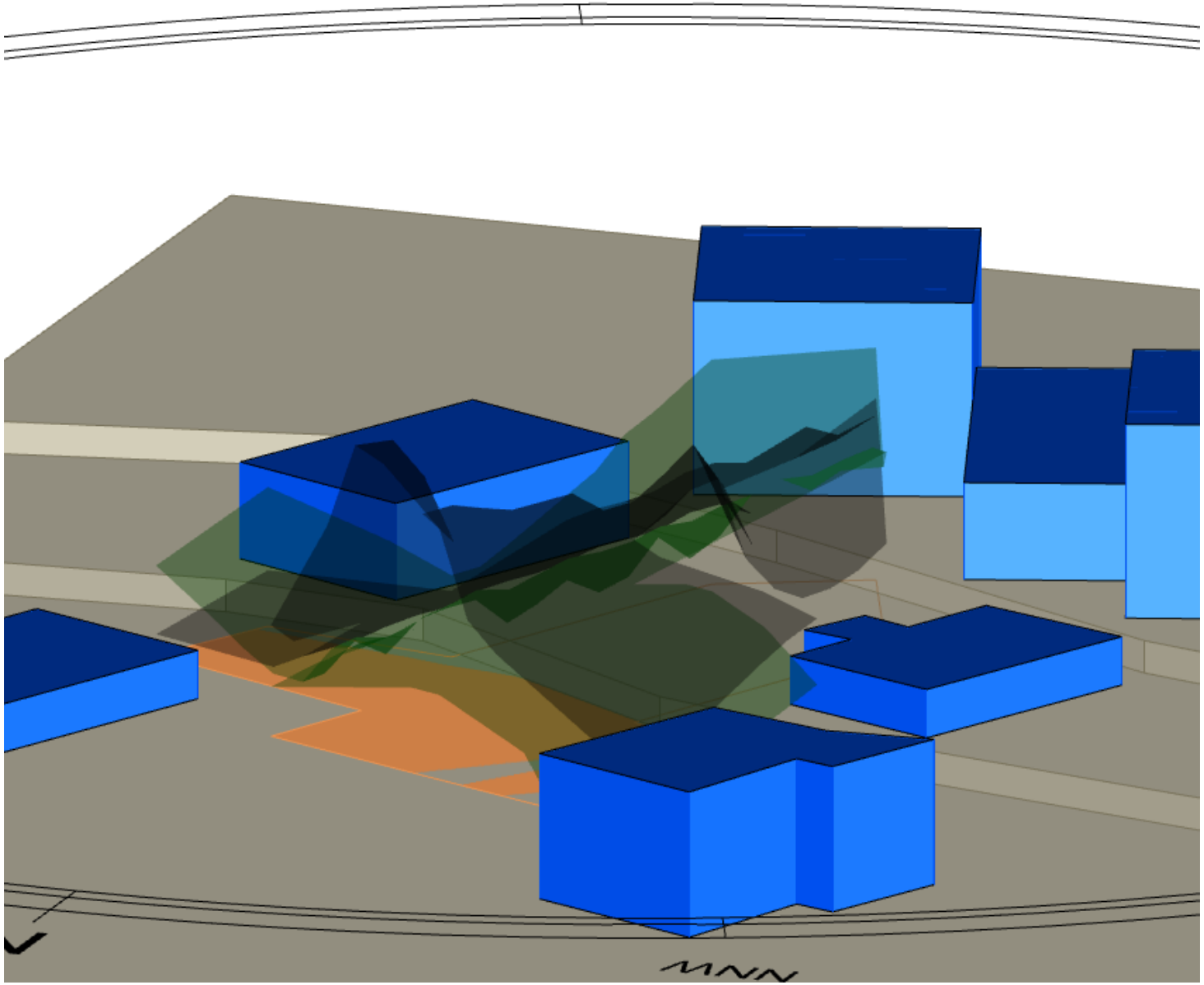


Incident Radiation

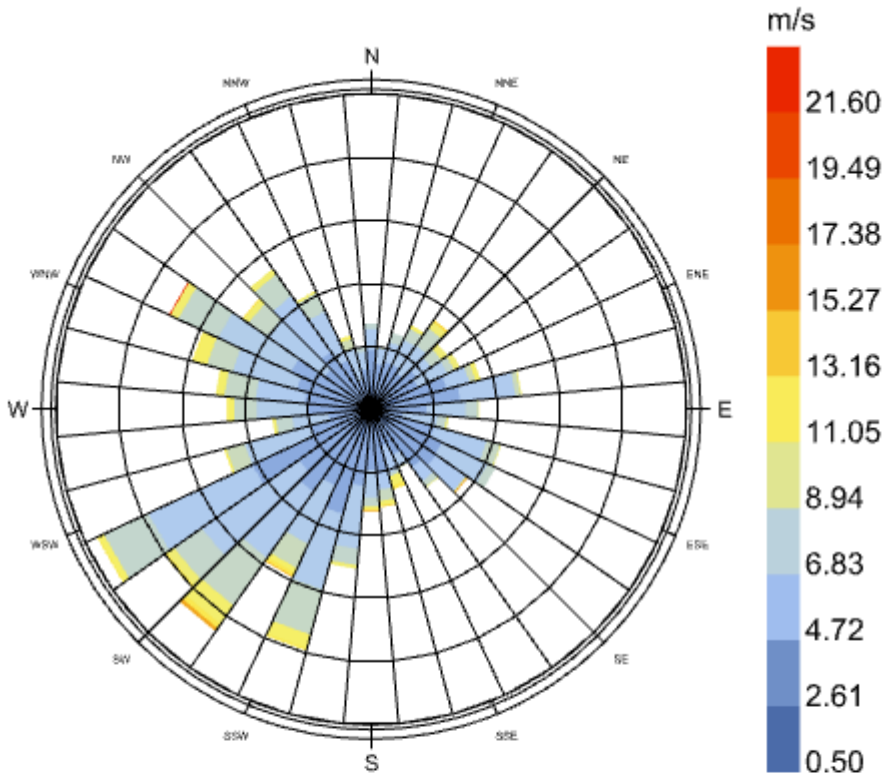
Radiation study: Ladybug



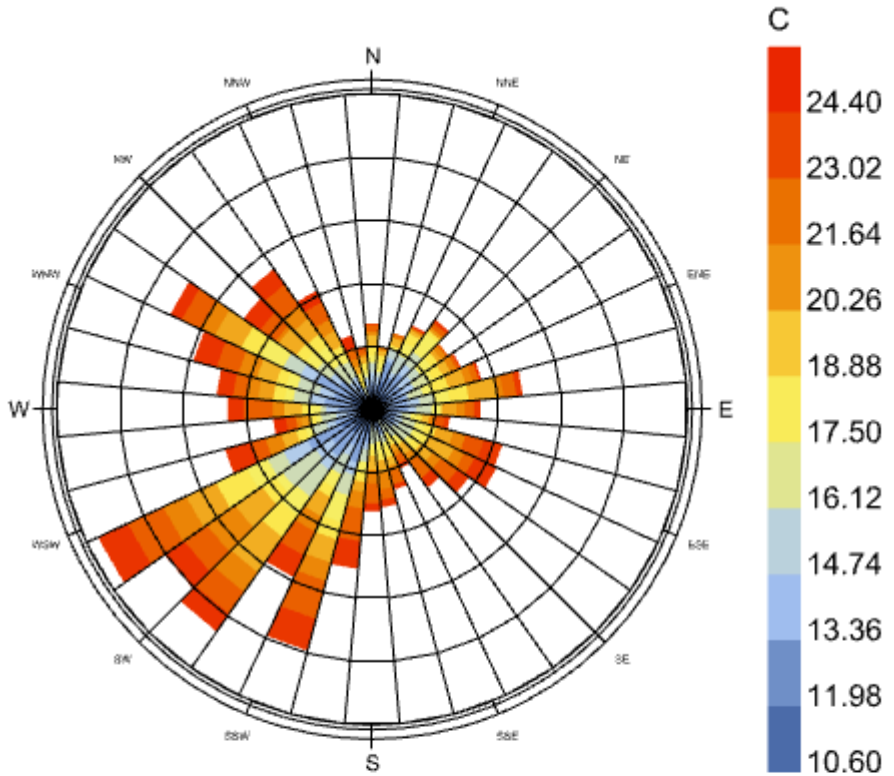
Raytrace: Ladybug



Solar Envelope: Ladybug



Wind Speed (m/s)
city: Boston Logan IntL Arpt
country: USA
time-zone: -5.0
source: TMY3
period: 1/1 to 12/31 between 0 and 23 @1
Calm for 0.44% of the time = 17 hours.
Each closed polyline shows frequency of 1.3% = 50 hours.



Dry Bulb Temperature (C)
city: Boston Logan IntL Arpt
country: USA
time-zone: -5.0
source: TMY3
period: 1/1 to 12/31 between 0 and 23 @1
Each closed polyline shows frequency of 1.3% = 50 hours.

Wind rose: Ladybug

3. Simulation as Design Syntax

URBAN SPACE ANALYSIS

- Urban Layout
  - DecodingSpaces
  - UrbanXTools
  - Urban Network analysis Toolbox
  - Grasshopper Reach Analysis Toolkit
  - Chameleon.tools
  - Numeric Network Analysis
- Space Syntax
  - SmartSpace Analyser
  - SpaceChase
  - Syntactic
- Traffic/Road
  - Dog
  - Mouse
  - Pedsim
  - ShortestWalk
  - LeafVein
  - Geodesic lines on mesh

ENVIRONMENTAL ANALYSIS

- Topo
  - Bison
  - Docofossor
  - Groundhog
- Solar
  - Ladybug
  - Heliotrope
  - Nigthingale
  - Solar Toolbox
  - Sunflower
- Wind
  - Butterfly
  - Eddy
  - Swift
  - ixCube CFD
- Plants
  - AiPlantCare
  - Nero
  - Pando
- Water/Runoff
  - Nudibranch

OTHERS

- Behaviours/Flocking
  - Quelea
  - Stella 3D
- Physics
  - Kangaroo
  - FlexHopper
  - Linketix
- Light
  - Reflector
  - Lark Spectral Lighting
- Sound
  - Pachyderm Acoustical Simulation
  - Snail
- Interior
  - Eabbit
  - PlanBee
  - Jerboa

- Model → Simulate → Evaluate → Adjust → Re-simulate

- Key distinction:

  DURING design = generative (early stage)

  AFTER design = evaluative / compliance

- What if we automate the feedback loop?
  - Human steps out of the 'adjust' step
  - Solver searches the design space for optimal solutions
  - → Galapagos (evolutionary solver in Grasshopper)
  - Next lecture: L3.3 Evolutionary Design

Suggestions for Learning Grasshopper:

- Module 1 (covered): basics — data trees, attractors, fields

- Moving forward: the plugin ecosystem
    - Geometry plugins
    - Simulation (physical, environmental, etc)
    - Workflow / data communication
    - Interface / robotic / fabrication

- Self-learning path:
    - Check demo videos → choose the right plugin
    - Search for example files / documentation
    - Learn core components + logic of each plugin
    - Adapt and apply