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Printed Performance

Tuning heat- and mass- transfer characteristics in digitally fabricated buildings

Bharath Seshadri
PhD candidate

…to fabricate bespoke macro- and micro-scale geometry to tune the thermo-physical characteristics of DFAB buildings

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Parametric design of a 3d printed building facade for bespoke response to solar radiation

The hypothesis is to fabricate bespoke macro- and micro-scale geometry to tune the thermos physical characteristics of DFAB building element

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Content

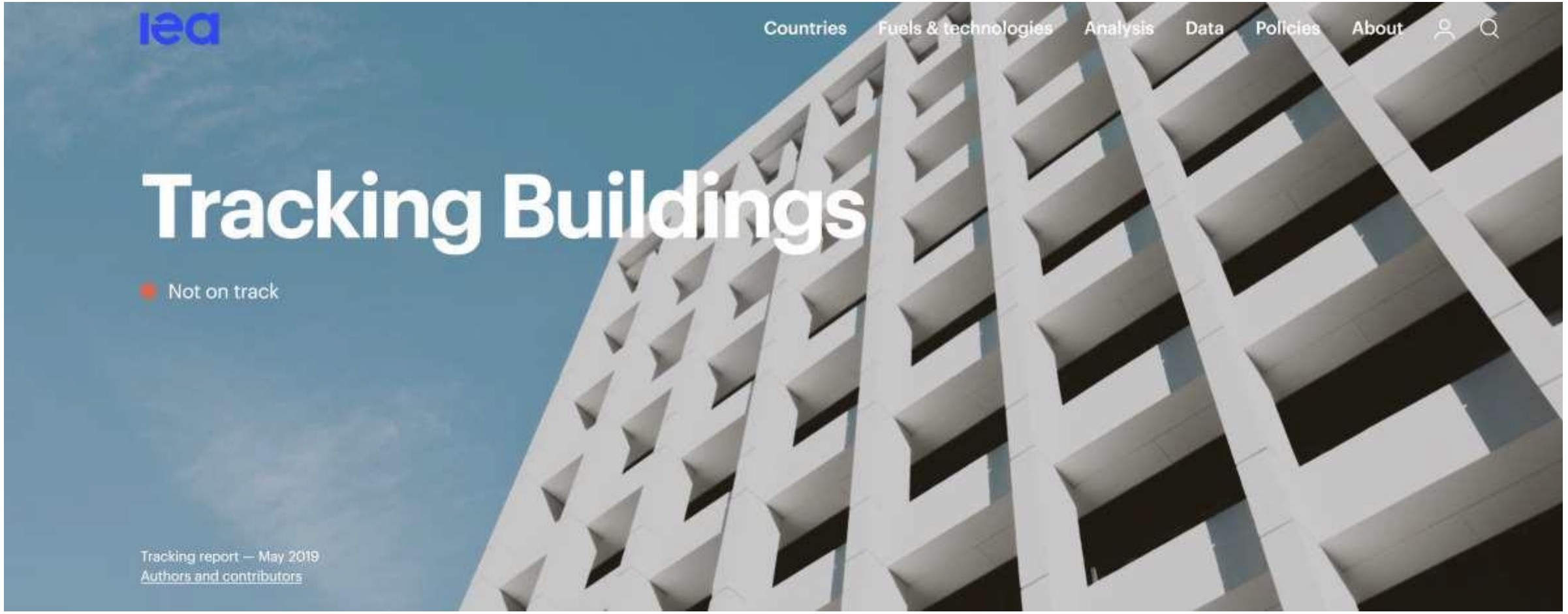
State of the Art Façade + Research Motivation

Design Logic

Topology Optimization

Additive Manufacturing Setup (AM)

Thermo-physical properties of AM plastics



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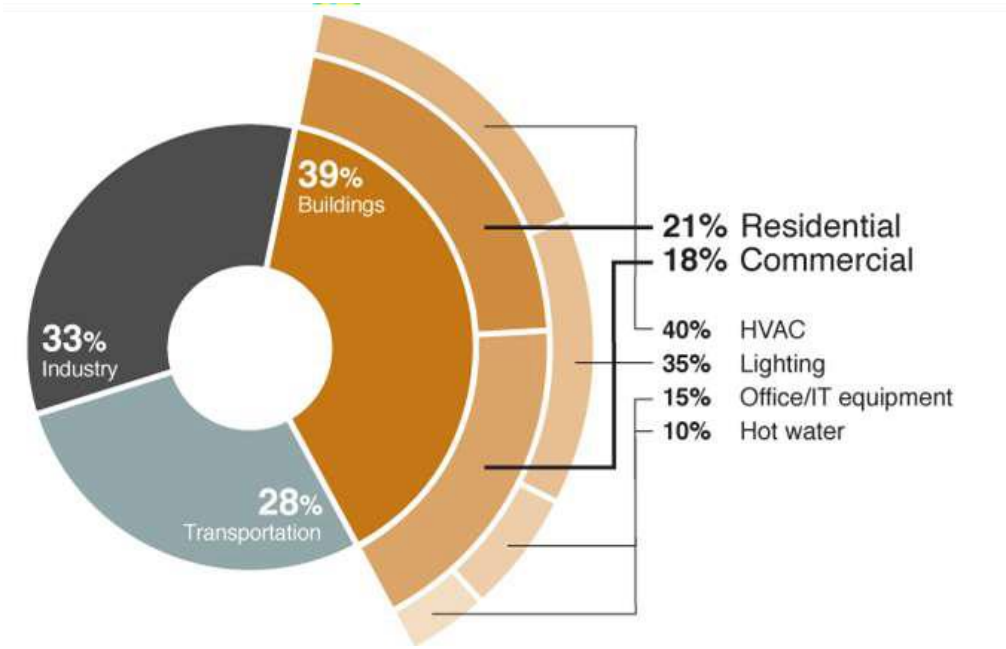
Concept

Functionalities to be demonstrated

1. Imperative facade functions (thermal + visual comfort)
   - Selective heat transfer and storage
   - Selective daylight reflection and transmission
2. Further development
   - Transparency
   - Infiltration/ventilation
   - Acoustic
   - Structure (modularity)
   - Weather (wind, rain) and fire resistance

"Buildings consume 28% (2:3 commercial:residential) of the global CO2 emissions. Global CO2 reduction target in 2050 = 50% below 2010 levels. HVAC (Heating, Ventilation and Air-Conditioning) consumes approx. 40%" [IEA, 2018]



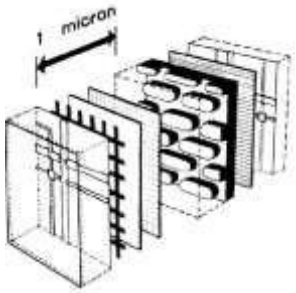
US Building sector end-use energy consumption [Sunproject, 2019]

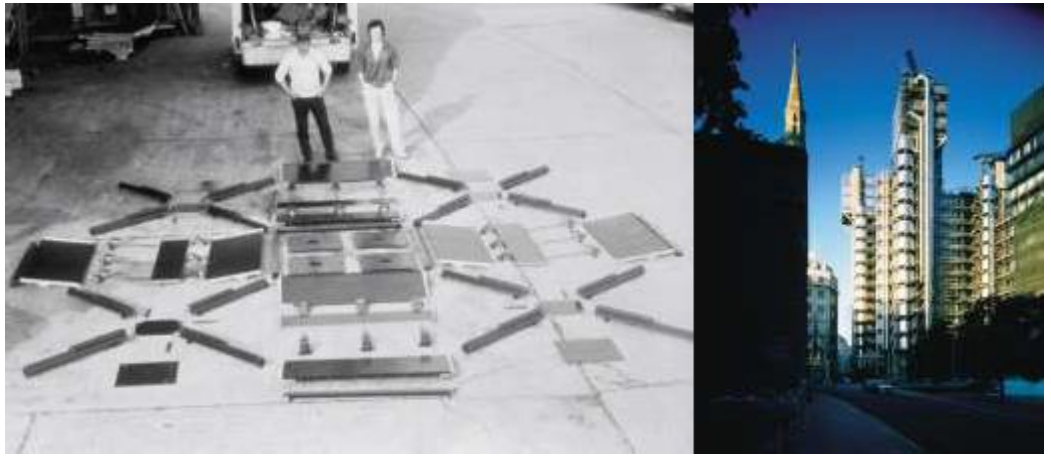
State-of-the-Art Building Facades

Active
Biomimetic
Kinetic
Intelligent
Interactive
Movable
Responsive
Switchable
Transformable

State-of-the-Art Building Facades

Polyvalent wall
Multi-functionality
Higher performance
Responsive to environment in real time
Thin membrane





Concept sketch of the *Polyvalent Wall* by Mike Davies (Davies, 1981). Building parts of the façade, and view of the Lloyd building

State-of-the-Art Building Facades

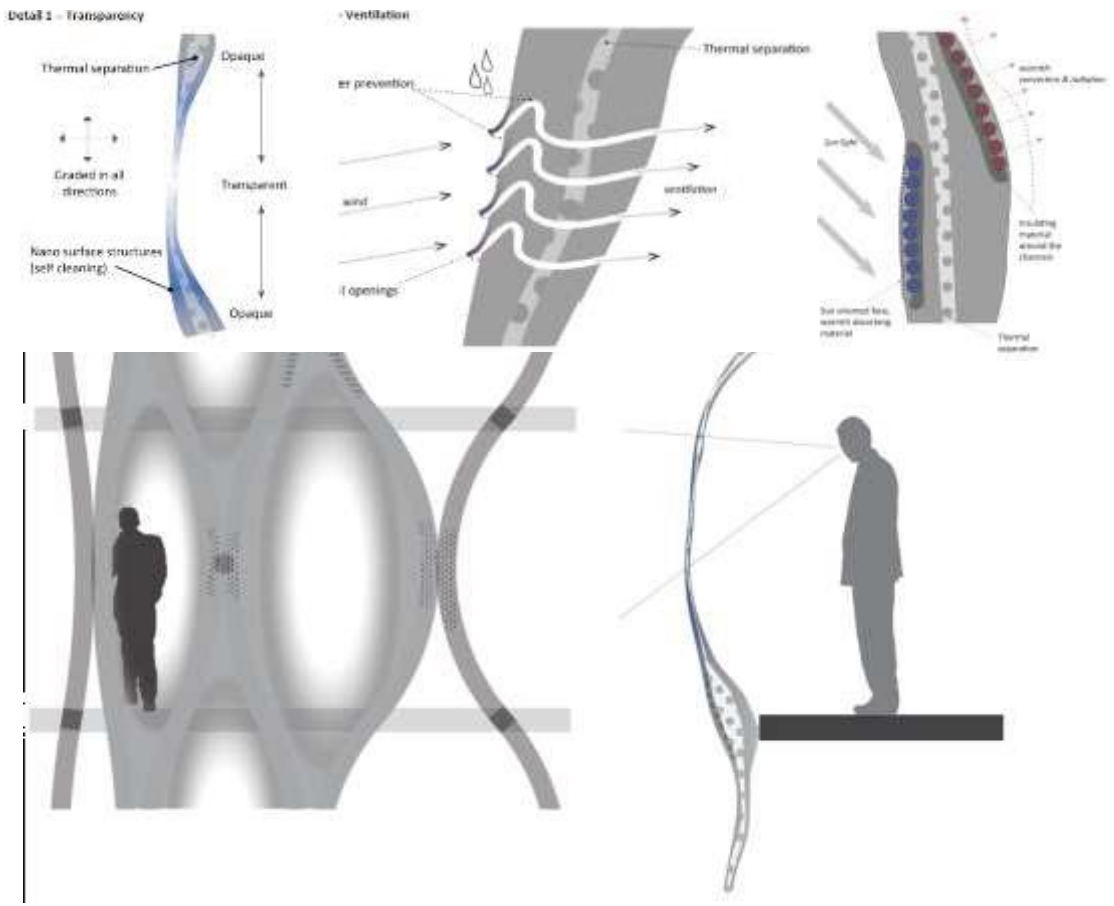
Digital Fabrication or Additive manufacturing has the potential to overcome multiple difficulties encountered in traditional fabrication methods

Multi-functional envelope

Fabrication of integrated functions

Multi-materials

Complex geometries (design freeform)



Volkers 2010

https://repository.tudelft.nl/islandora/object/uuid:6be225a6-123a-4b1a-84b6-acc1cca6a3a9?collection=education

State of the art

Additive manufactured facades

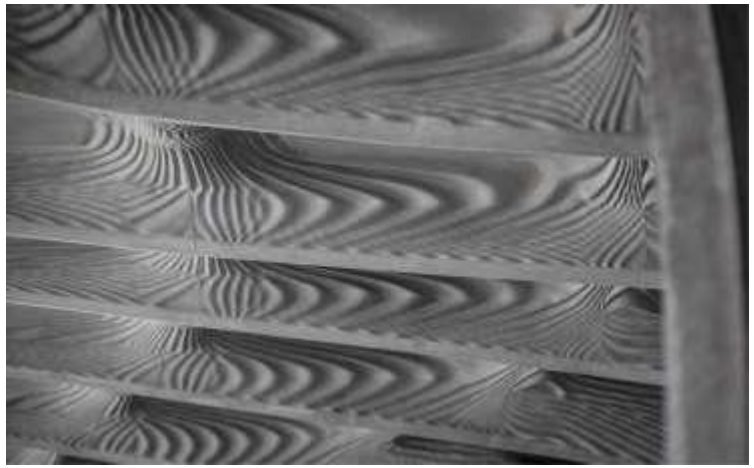
Concrete

Material extrusion, Binder Jetting

Good structural strength

Fireproof

Opaque



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UC Berkeley | Bloom

State of the art

Additive manufactured facades

Ceramic

Material extrusion, Stereolithography

Good thermal resistance (fireproof)

Requires post-production (sintering/glazing)

Opaque

Assembly system on a building facade (Mcgee and Leon, 2016)

Emerging Objects | The cabin of curiosities

State of the art

Additive manufactured facades

Metal

Wire Arc Additive Manufacturing, Powder bed fusion, Directed energy deposition, Stereolithography

Good thermal resistance (fireproof)

Structural strength

Long fabrication time

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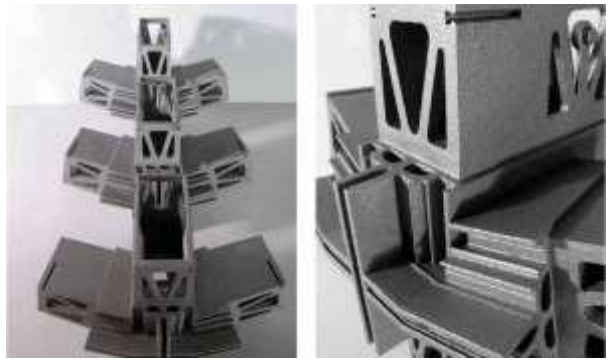


Strauss et al 2013

Bloom Do|Su Architecture

Shiva et al 2018

State of the art

Additive manufactured facades

Plastic

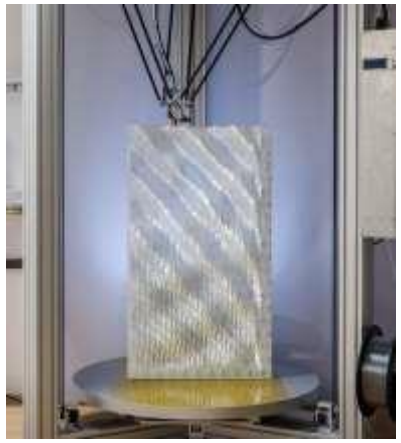
Material extrusion, Material jetting, Stereolithography

Fast fabrication time

Light materials

Non fireproof

Museum Munich

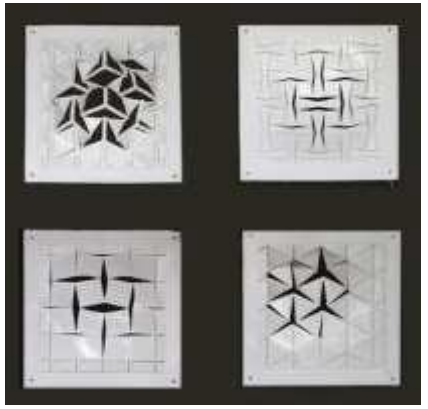


3F Studio Munich (TUM)

TU Delft

Arachne 3D Lei Yu

DUS Architects UN Building



Hiroya Tanaka MSP Auxetic

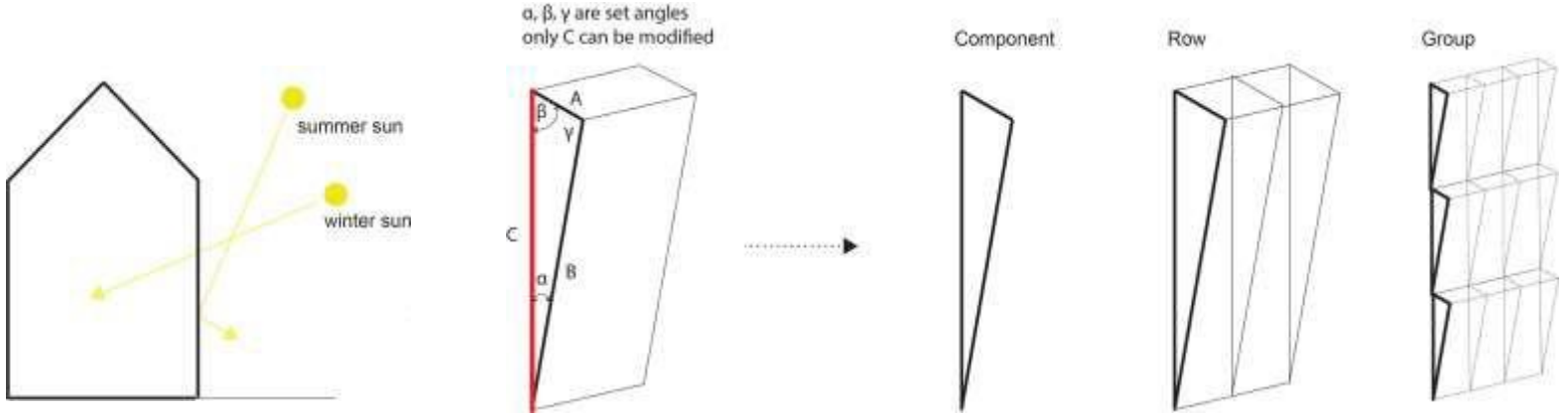
Design Logic

Solar Gain
Daylight Penetration
Air infiltration
Acoustic

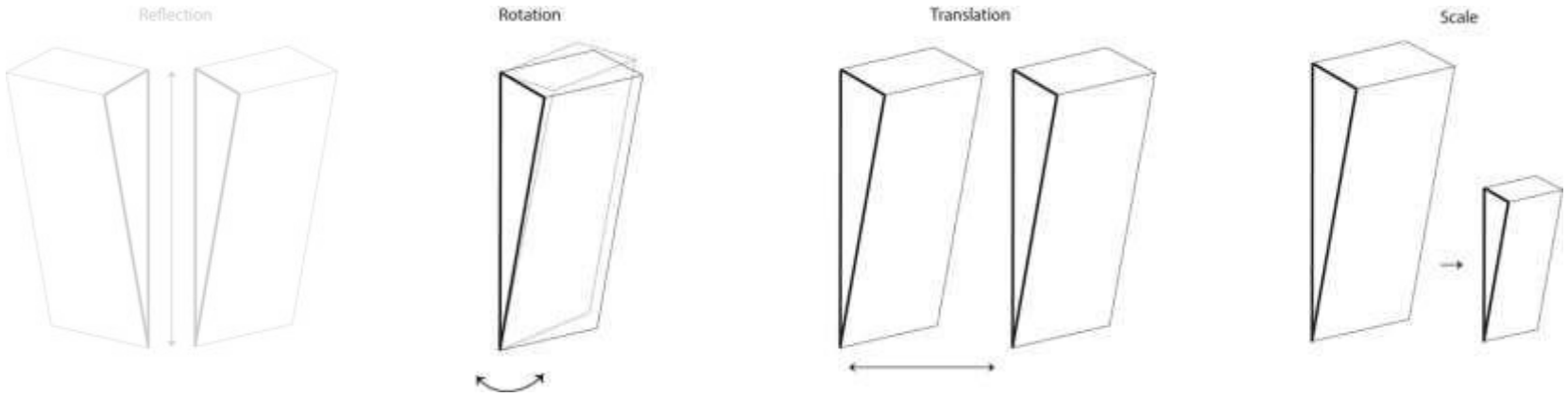
Shading and daylight transmission

Design benchmark

Component within a Row or Group



3 out of 4 types of linear **transformations** in Euclidean geometry



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Shading

Inclination adapts to solar azimuth angles

Shading

Rotation/translation adapts to solar zenith angles

Daylight

Rotation/translation affects daylight penetration

Daylight

Scale affects daylight homogeneity

Empirical testing

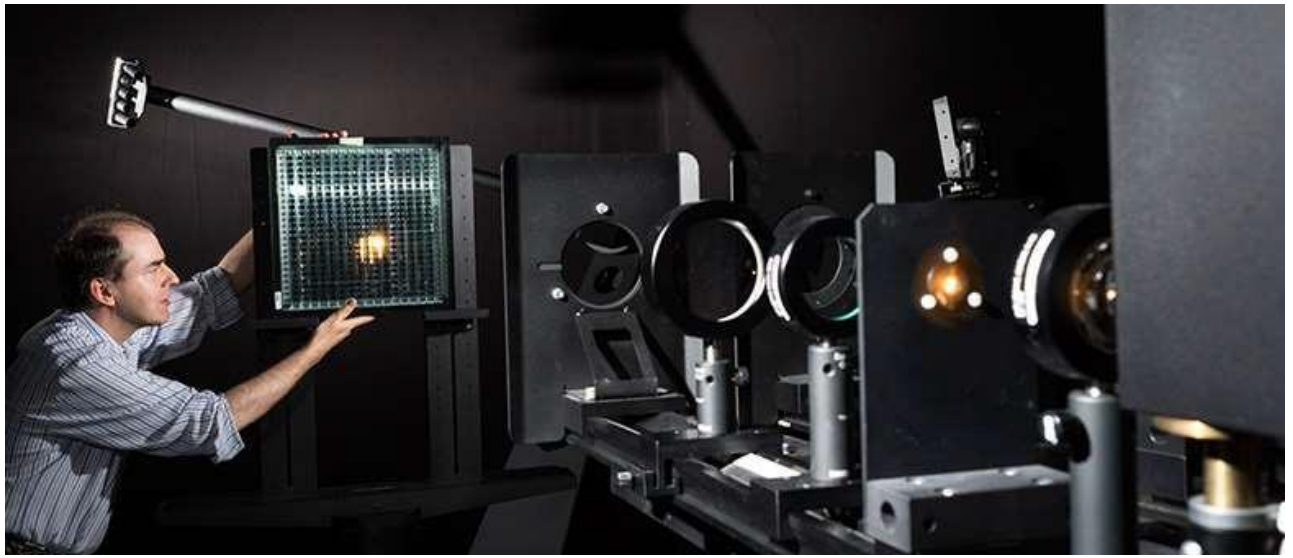
Optical Properties

Photon mapping of BSDF materials (w/HSLU)

Data-driven models replicate the irregular Bidirectional Scattering Distribution Functions (BSDFs) of optically complex facade systems in daylight simulation

BSDFs measured for translucent and reflective 3D printed plastics using a Gonio-photometer. First known measurement of light scattering properties of 3D printed structures

Using material properties and printing parameters as inputs to formulate a facade topology



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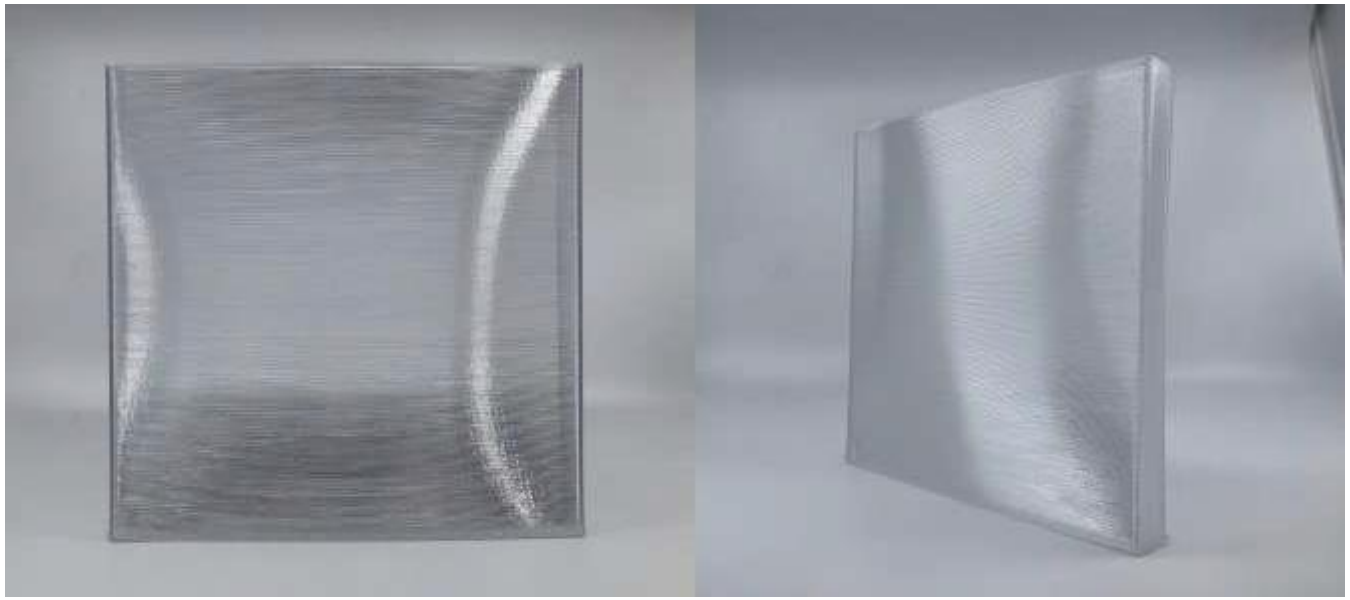
Material studies



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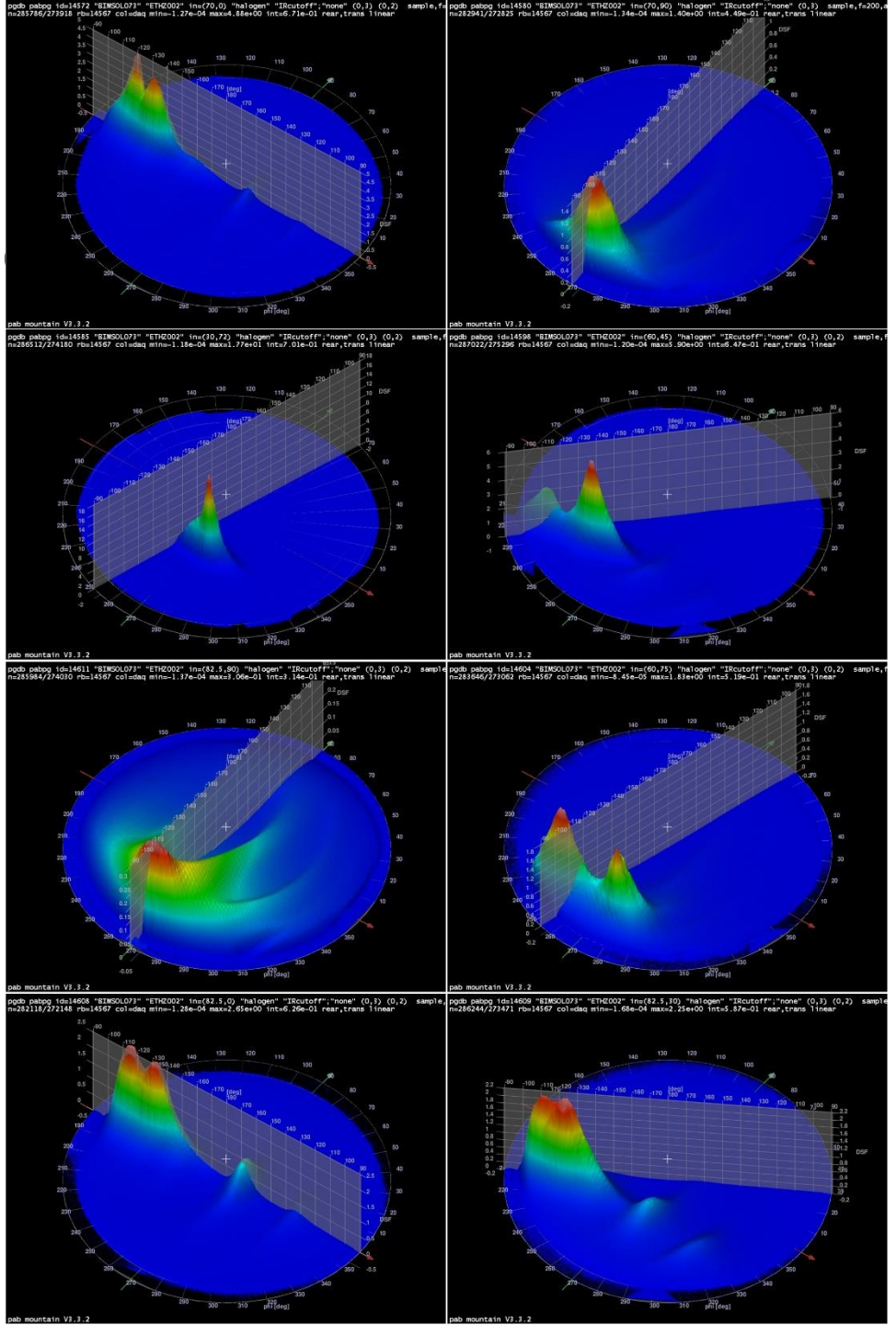
Experimental set-up

Surface spectral properties of 3d printed façade



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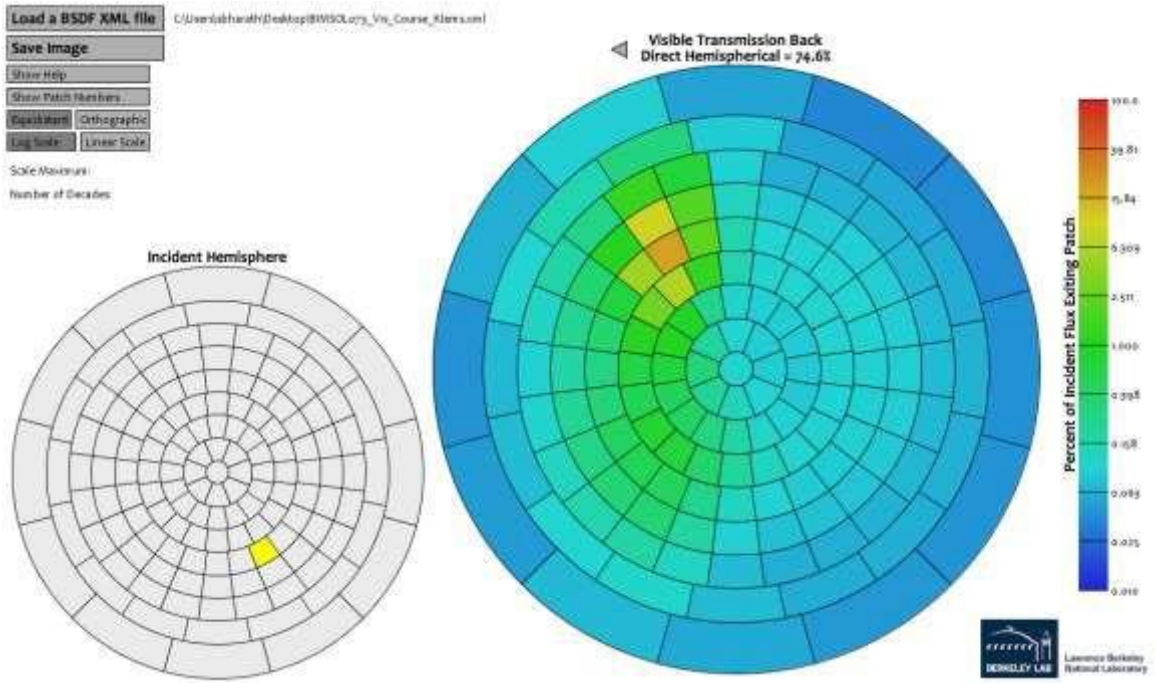
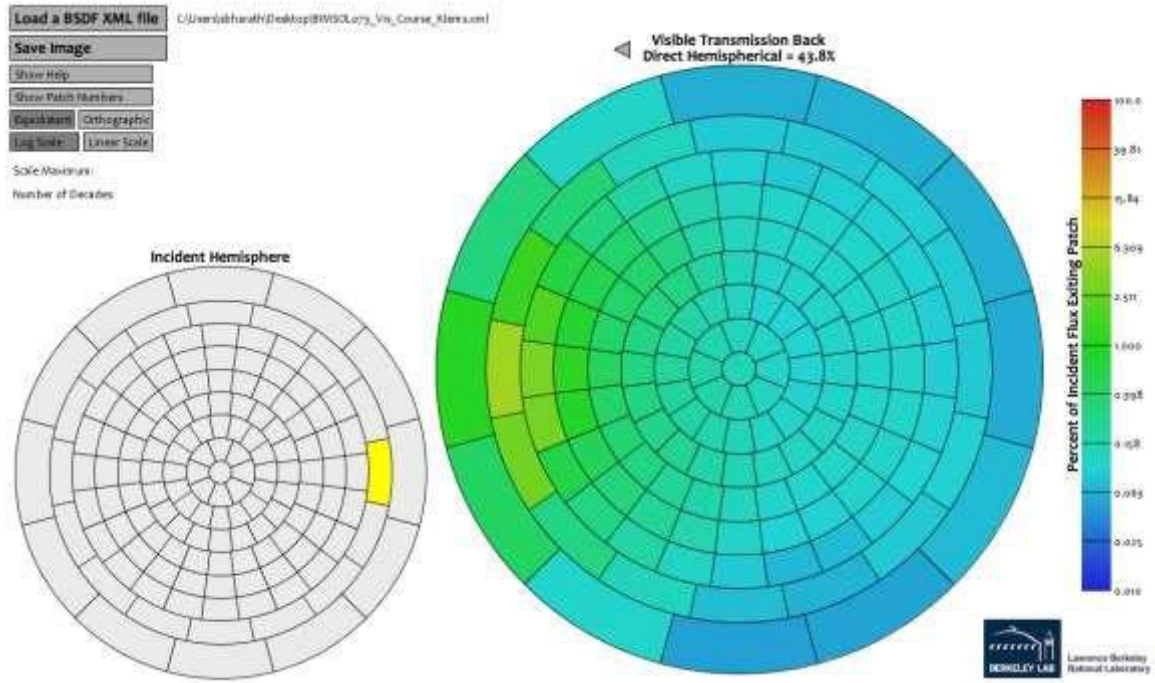
Hemispherical projections: Transmittance of translucent PLA





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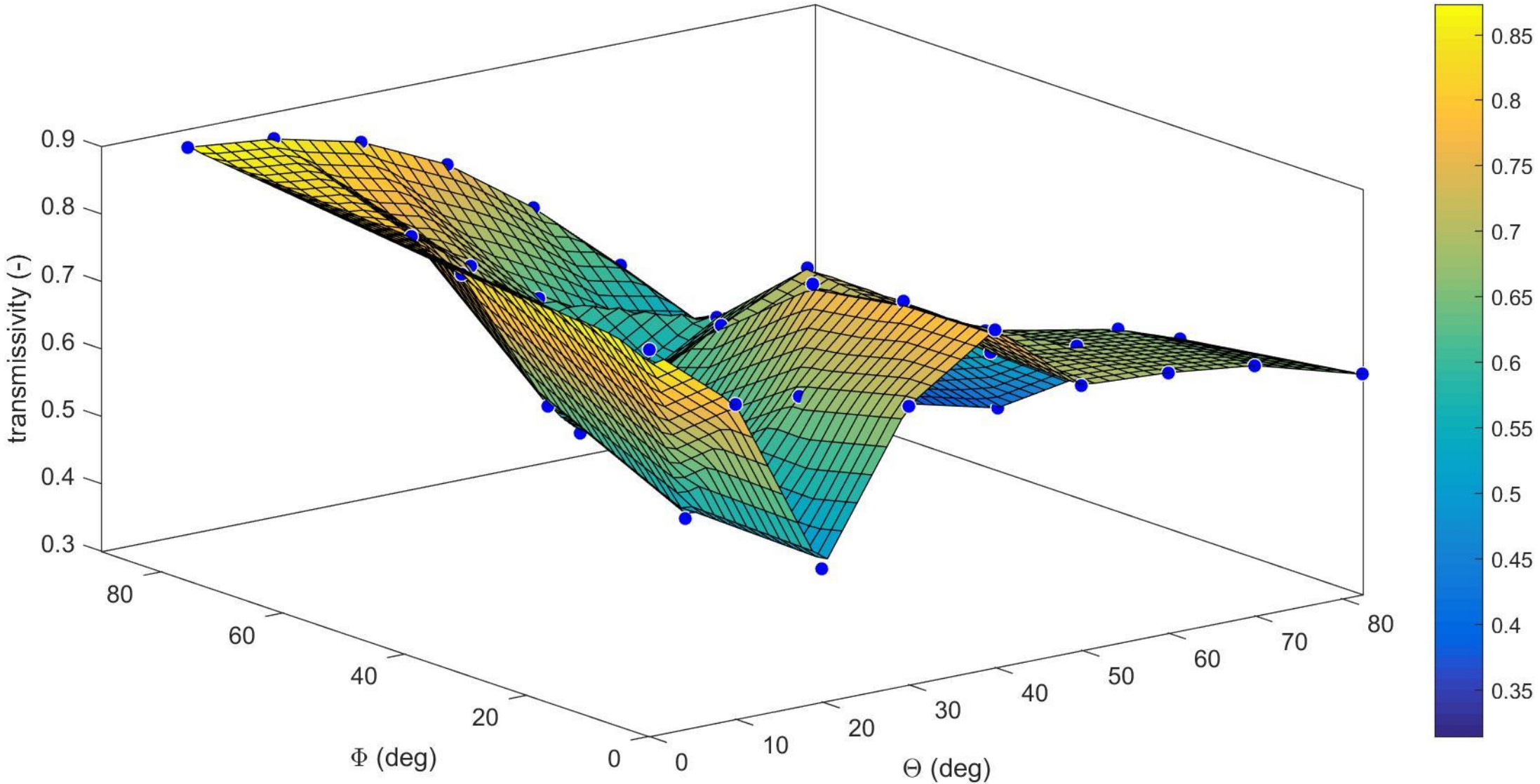
Hemispherical Integrals



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Daylight images using BSDF data

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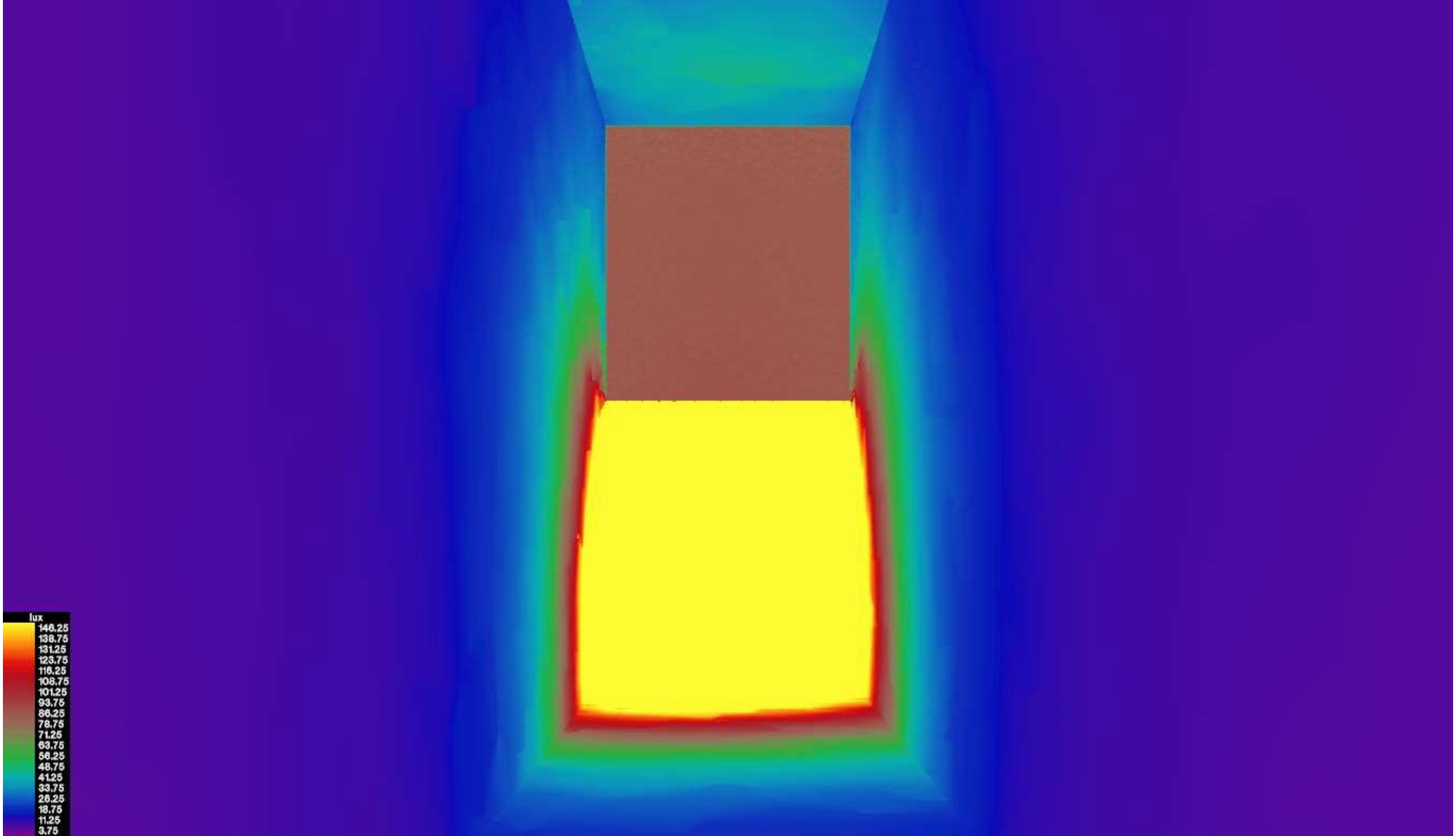
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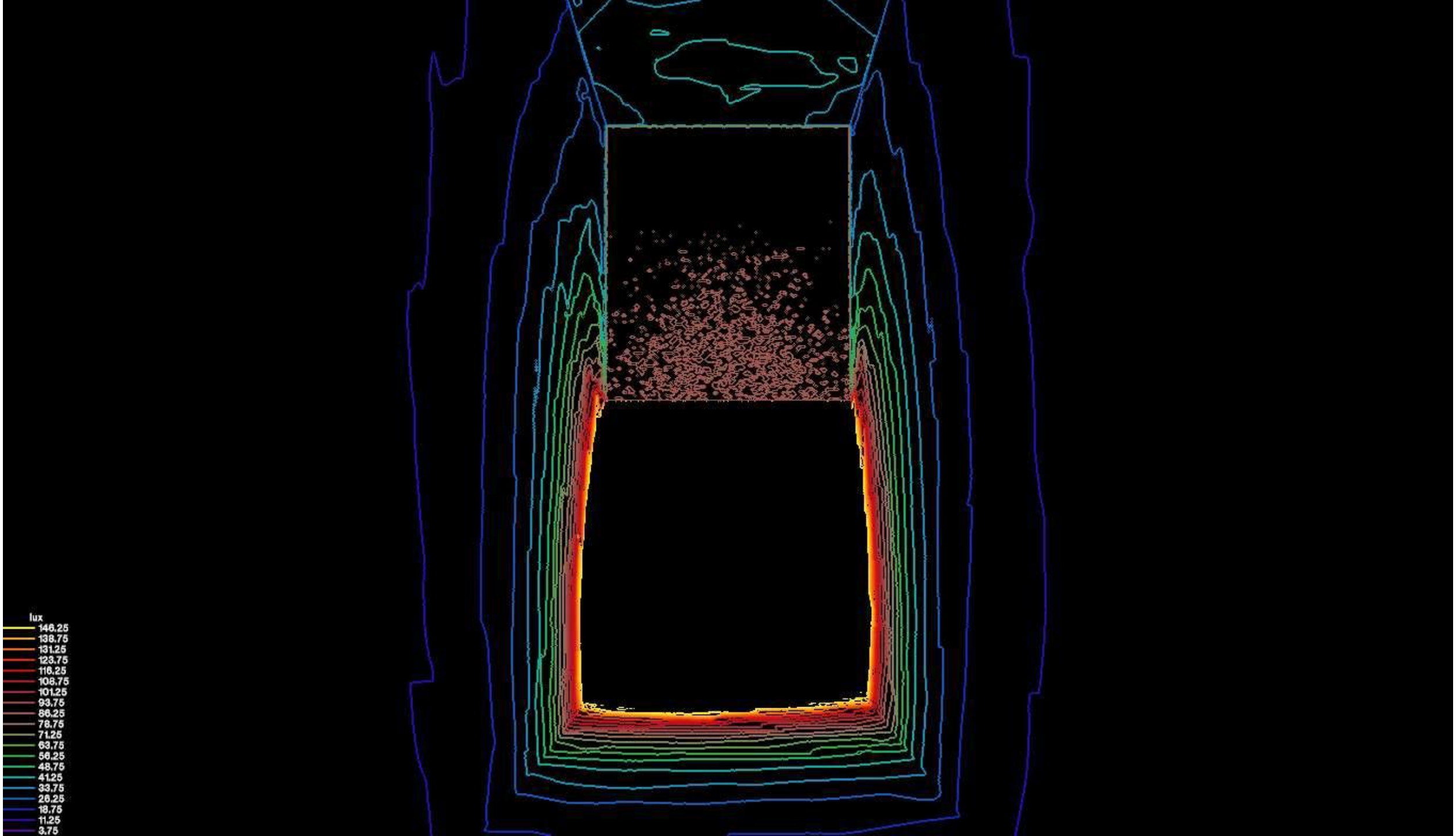
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Topology Optimization

Solar Gain
Daylight Penetration
Air infiltration
Acoustic

→ iterations through a genetic algorithm

Genetic Optimizer

Façade performance objectives (Fitness)

01 Minimize solar heat gain in the summer

02 Maximize solar heat gain in the winter

03 Maximize daylight quality in the winter

04 Maximize daylight homogeneity in the winter

Selected façade geometry variables (Genetic Input)

1. Inclination angles

2.Rotation/translation (pro-/intrusion)

03 Scale (Material distribution)

Selected façade material properties*

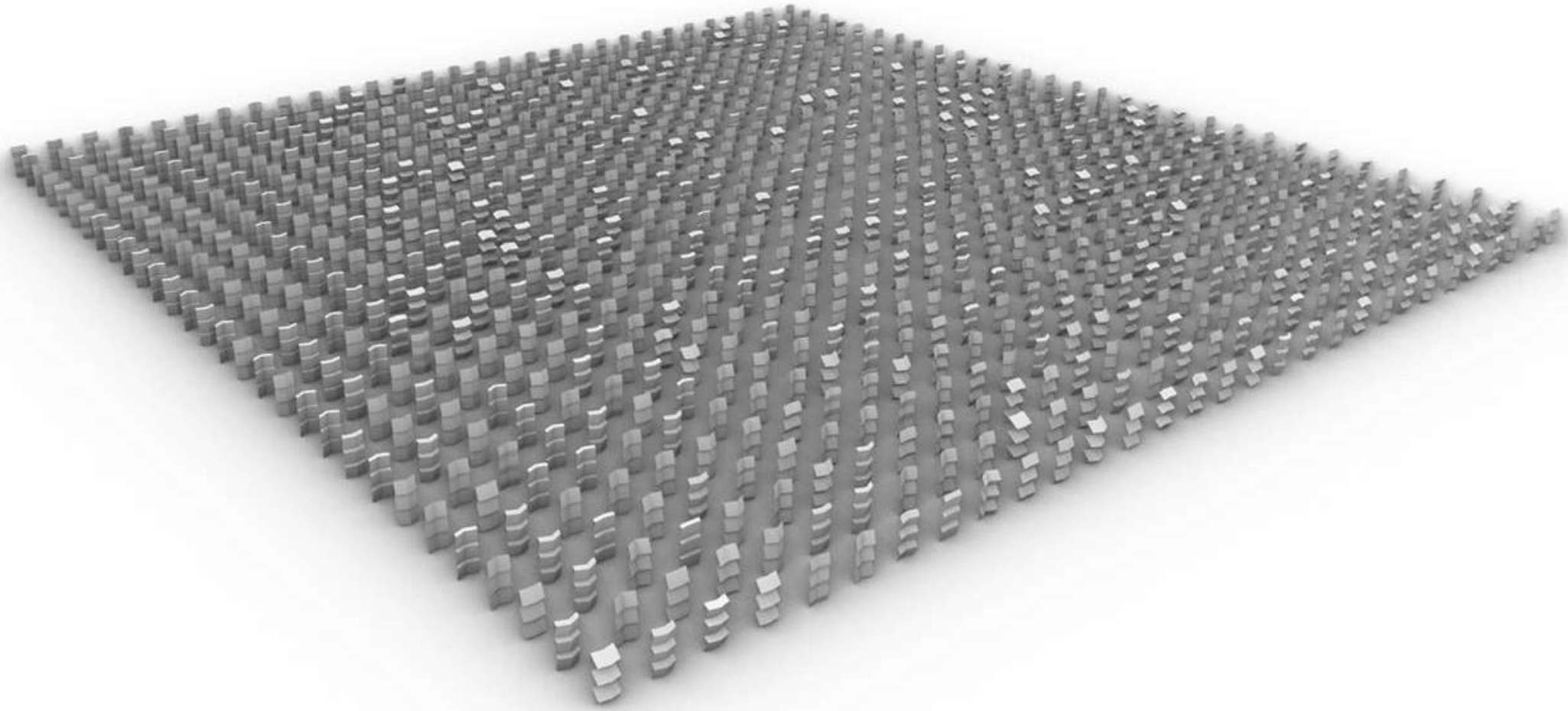
Reflection and transmission (derived from BSDF measurements)

Selection methodology

Individual and average fitness rankings

Pareto front

UML (K-Means, Hierarchical)



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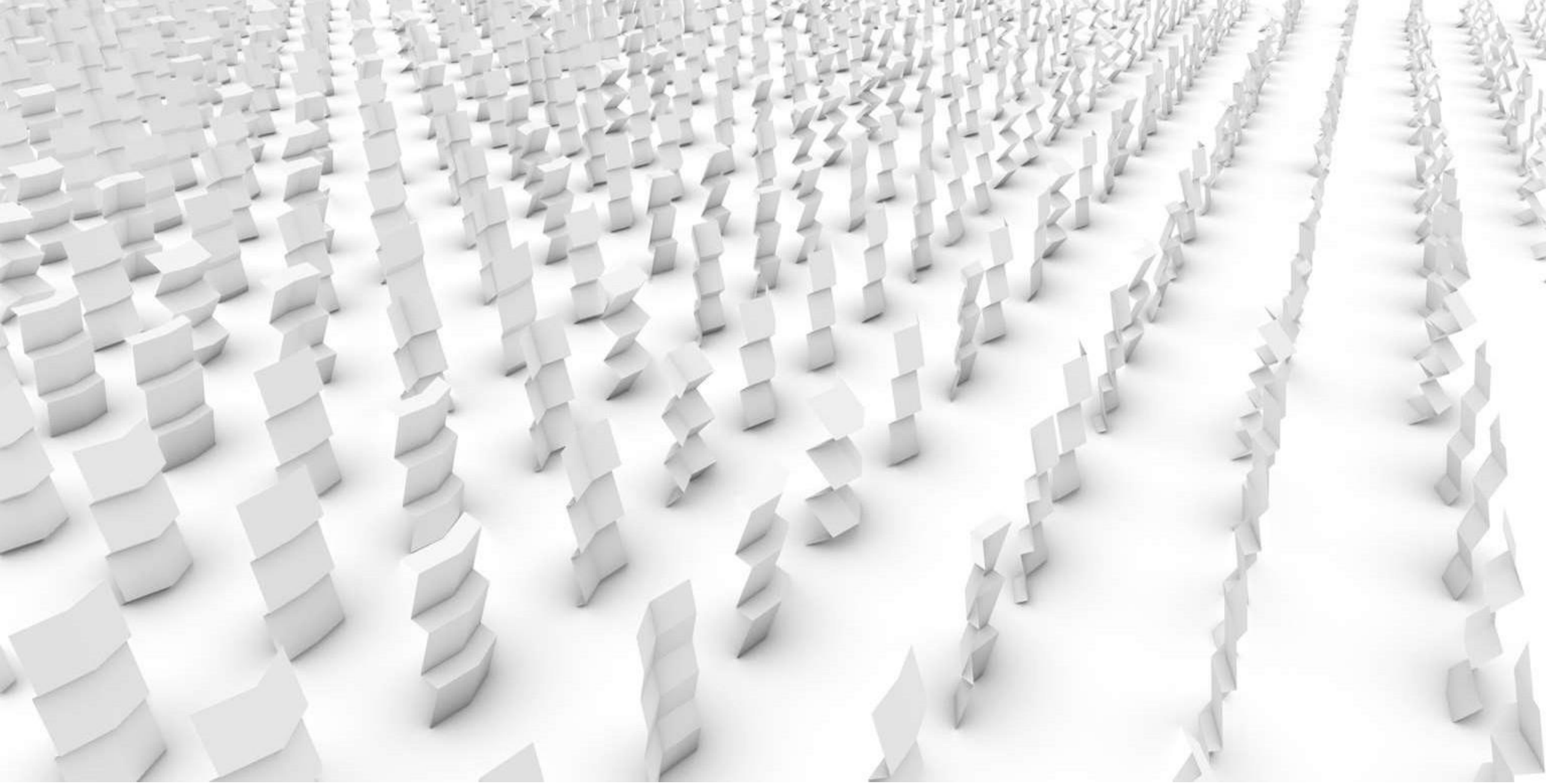

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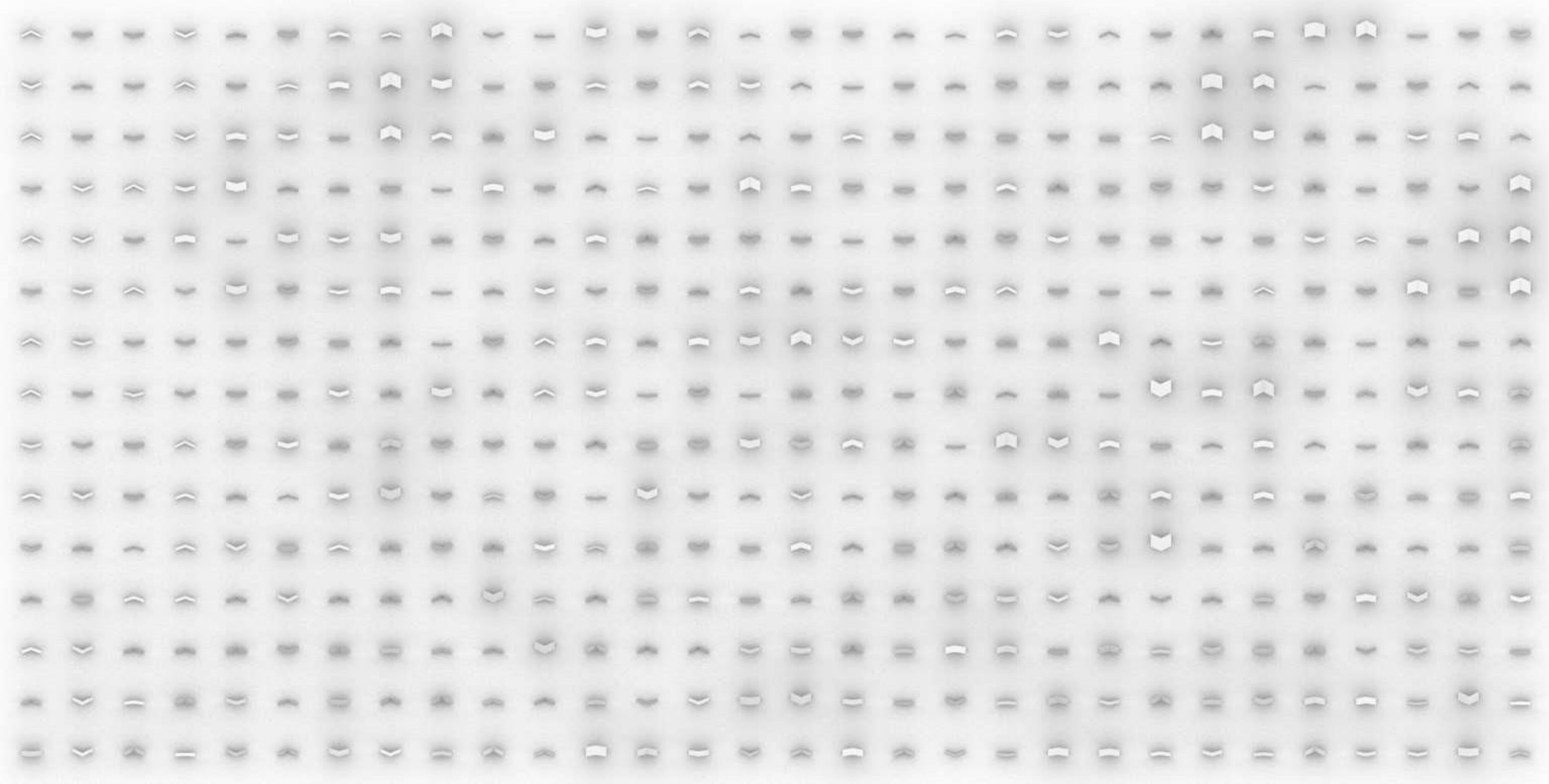

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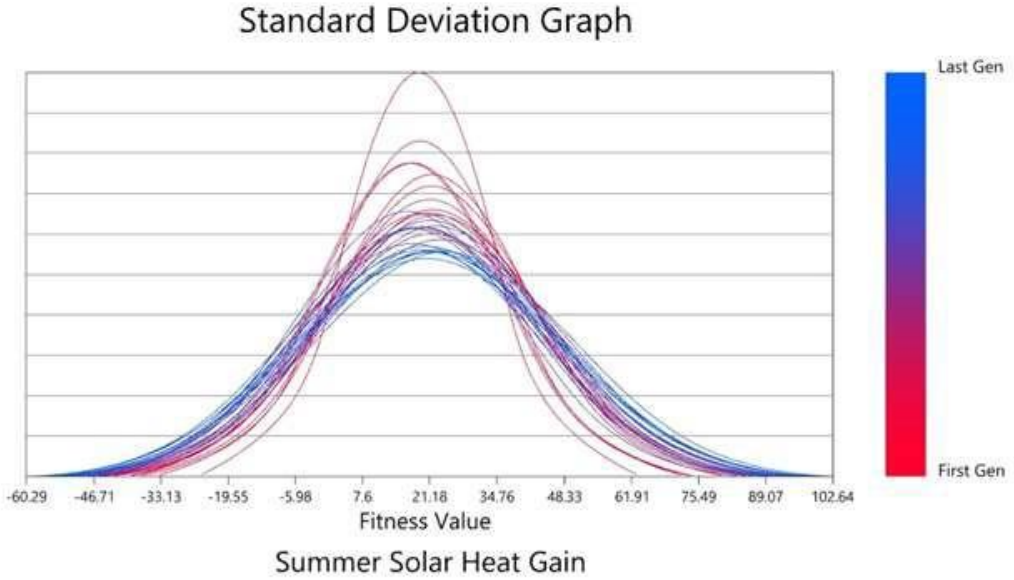

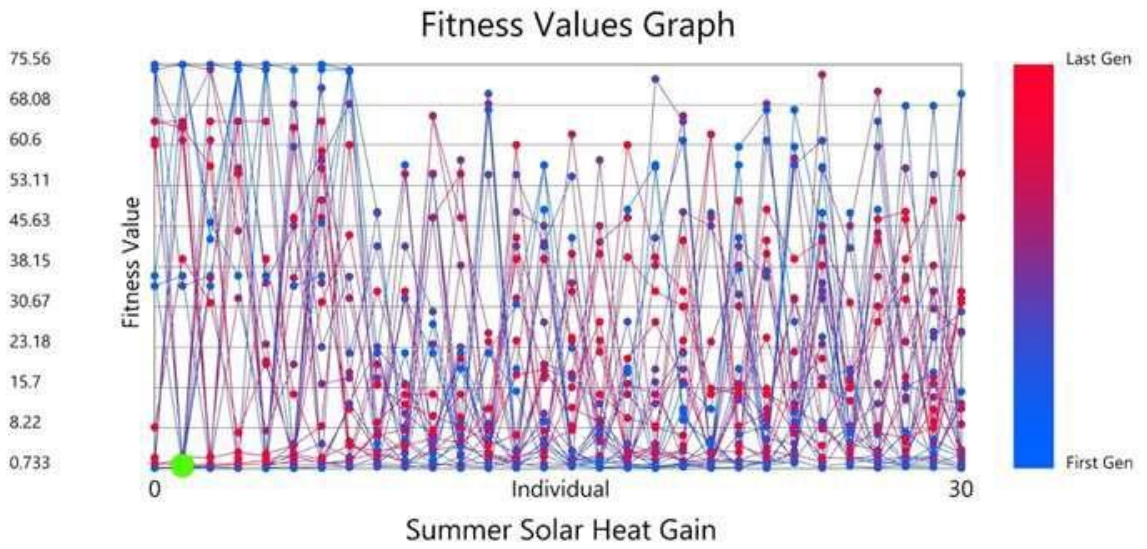

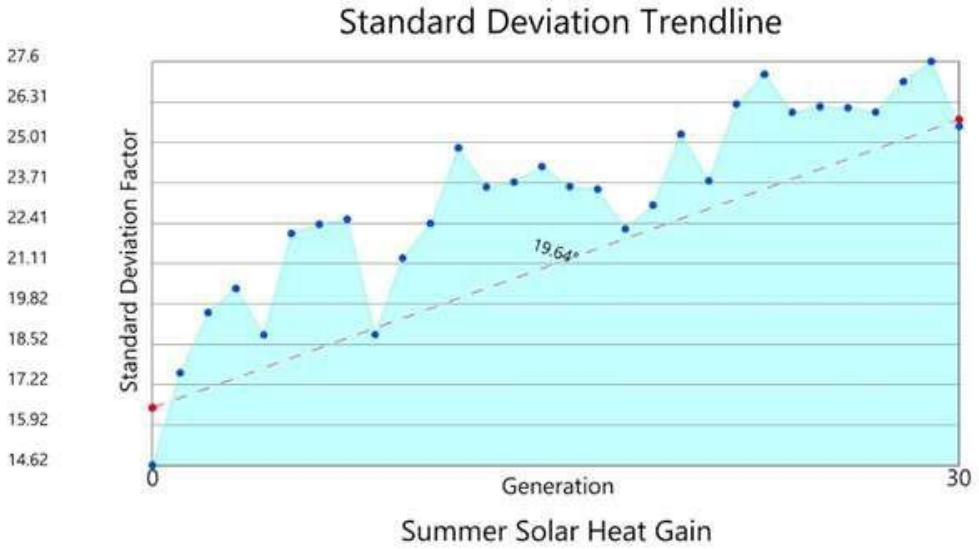

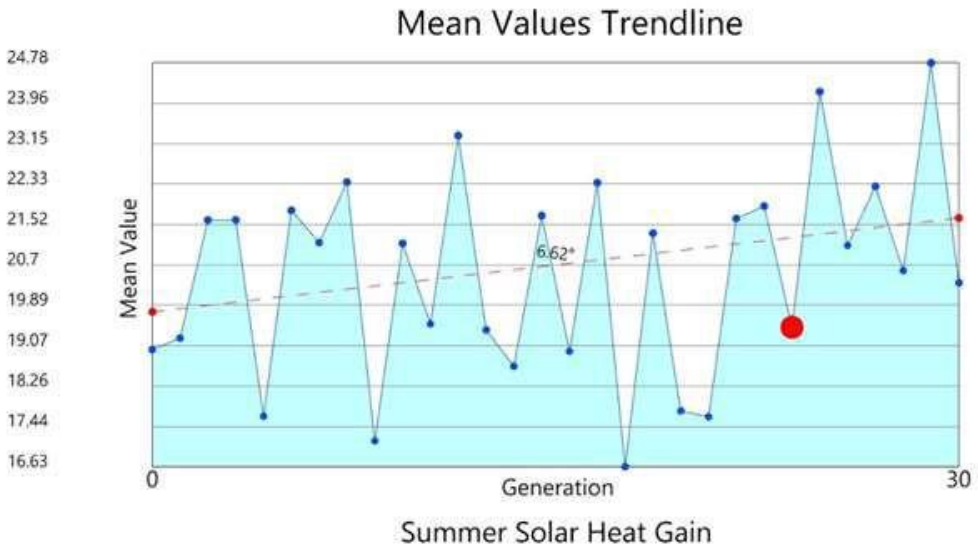

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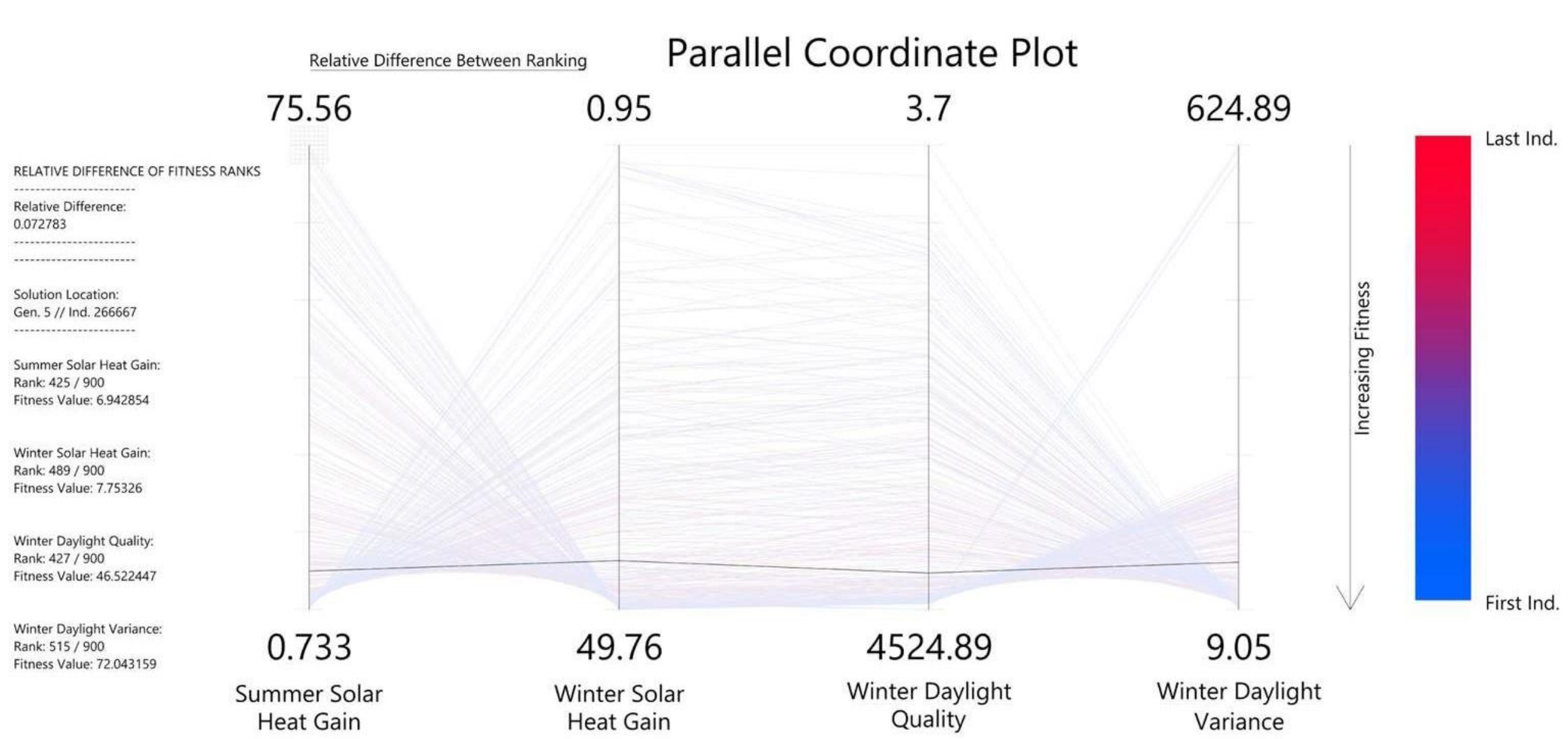
Parallel Coordinate Plot



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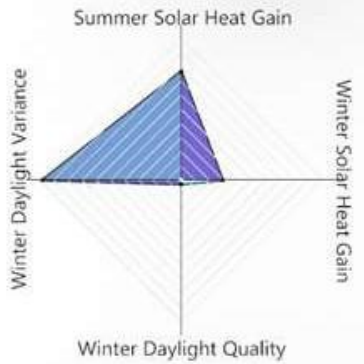

Generation 21 // Ind. 2

Summer Solar Heat Gain
Rank: 686 / 900
Fitness Value: 36.414477

Winter Solar Heat Gain
Rank: 251 / 900
Fitness Value: 28.140477

Winter Daylight Quality
Rank: 8 / 900
Fitness Value: 4524.886878

Winter Daylight Variance
Rank: 882 / 900
Fitness Value: 604.587167

Generation 28 // Ind. 1

Summer Solar Heat Gain
Rank: 1 / 900
Fitness Value: 0.733259

Winter Solar Heat Gain
Rank: 898 / 900
Fitness Value: 0.950028

Winter Daylight Quality
Rank: 898 / 900
Fitness Value: 3.697022

Winter Daylight Variance
Rank: 0 / 900
Fitness Value: 9.050157

Generation 0 // Ind. 16

Summer Solar Heat Gain
Rank: 472 / 900
Fitness Value: 9.269868

Winter Solar Heat Gain
Rank: 405 / 900
Fitness Value: 13.495823

Winter Daylight Quality
Rank: 456 / 900
Fitness Value: 34.927177

Winter Daylight Variance
Rank: 391 / 900
Fitness Value: 36.781167

Generation 3 // Ind. 10

Summer Solar Heat Gain
Rank: 422 / 900
Fitness Value: 6.942854

Winter Solar Heat Gain
Rank: 490 / 900
Fitness Value: 7.75326

Winter Daylight Quality
Rank: 426 / 900
Fitness Value: 46.522447

Winter Daylight Variance
Rank: 514 / 900
Fitness Value: 72.043159

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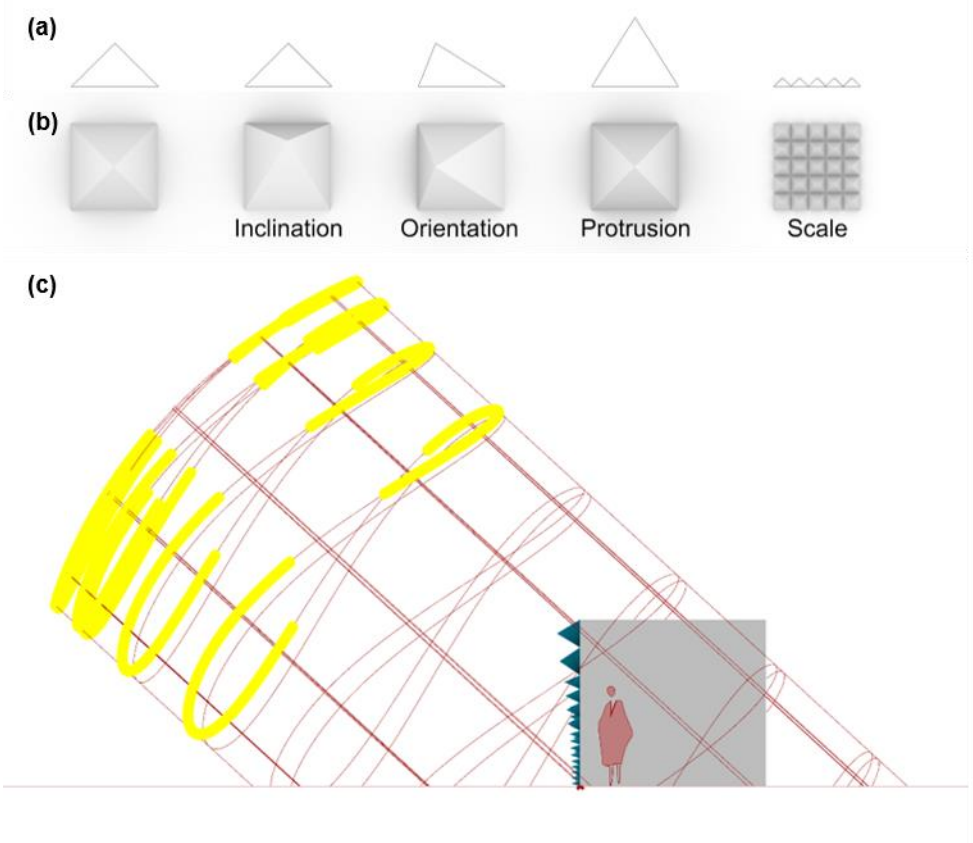

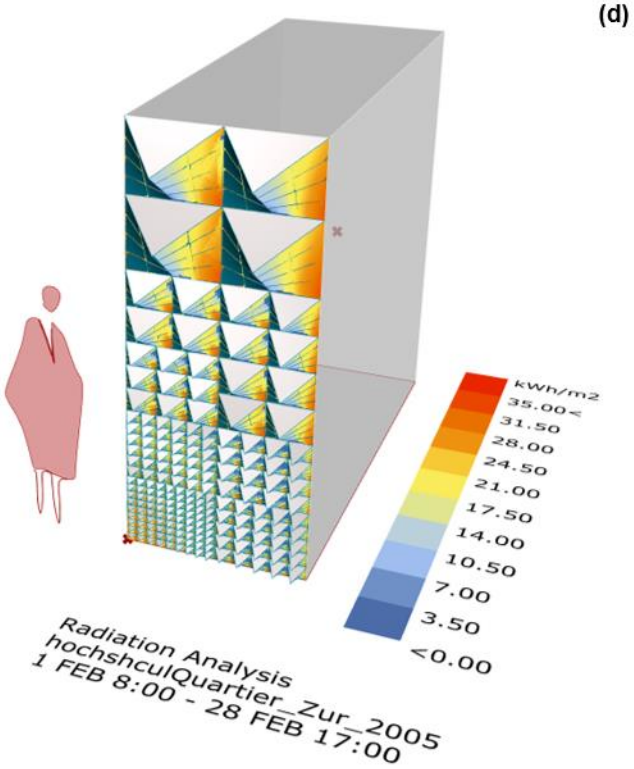

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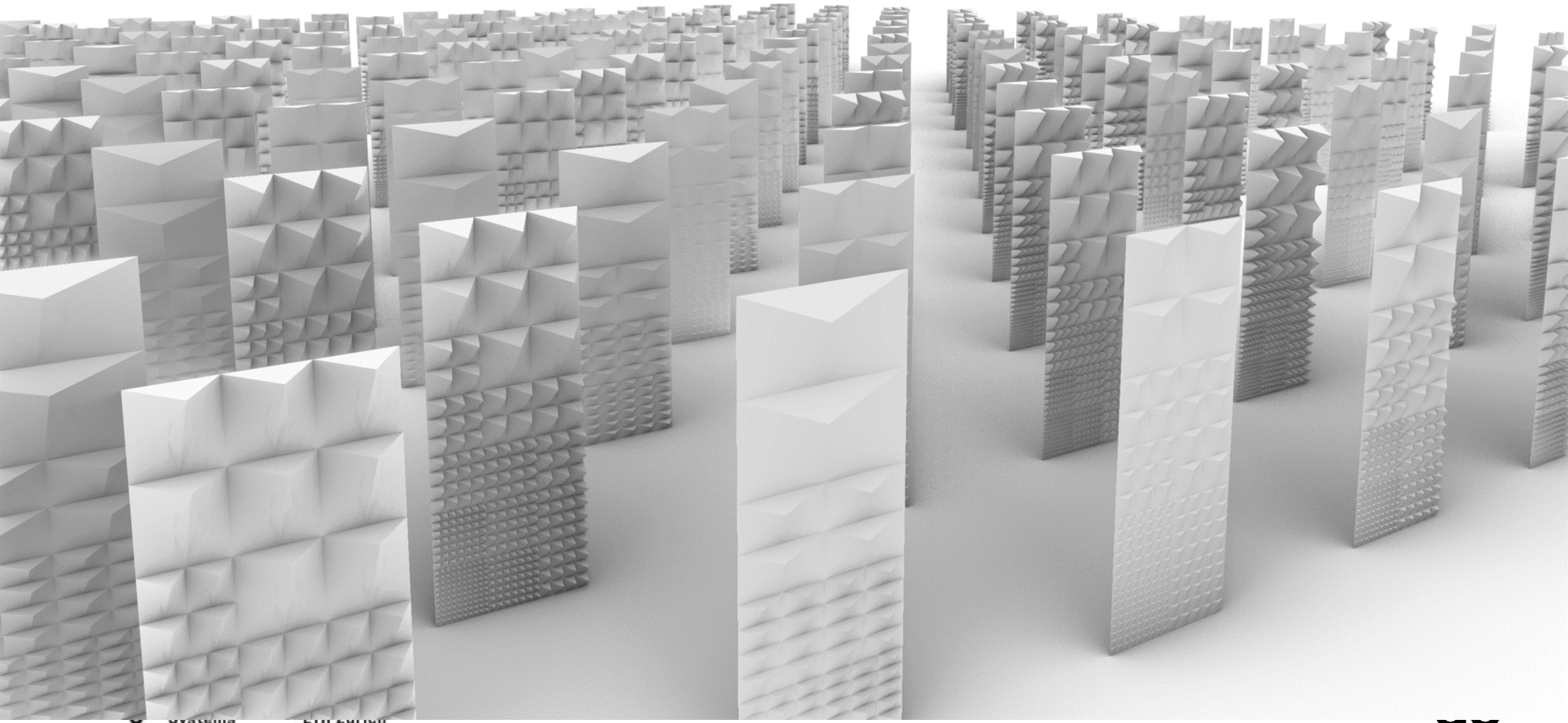

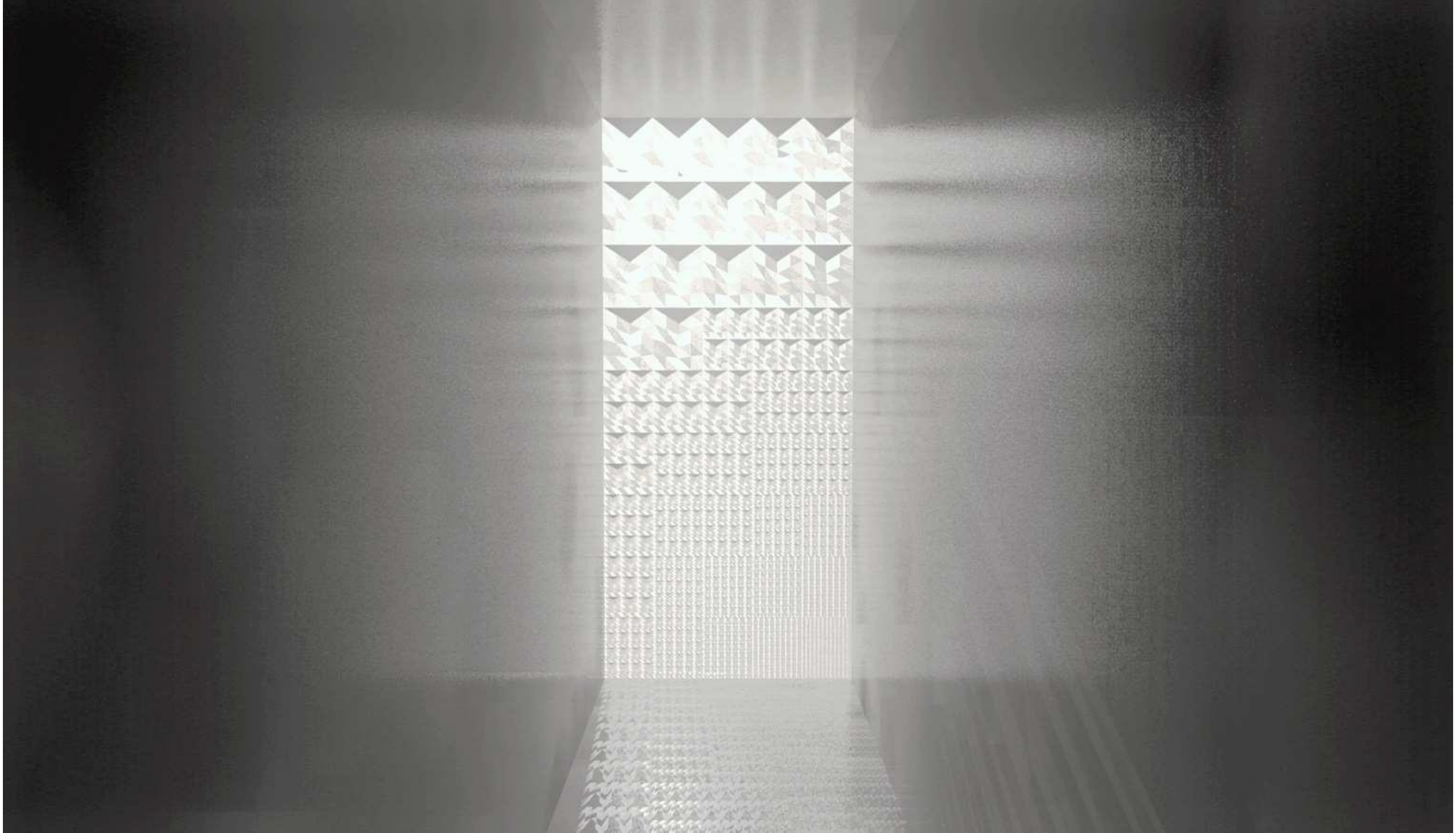

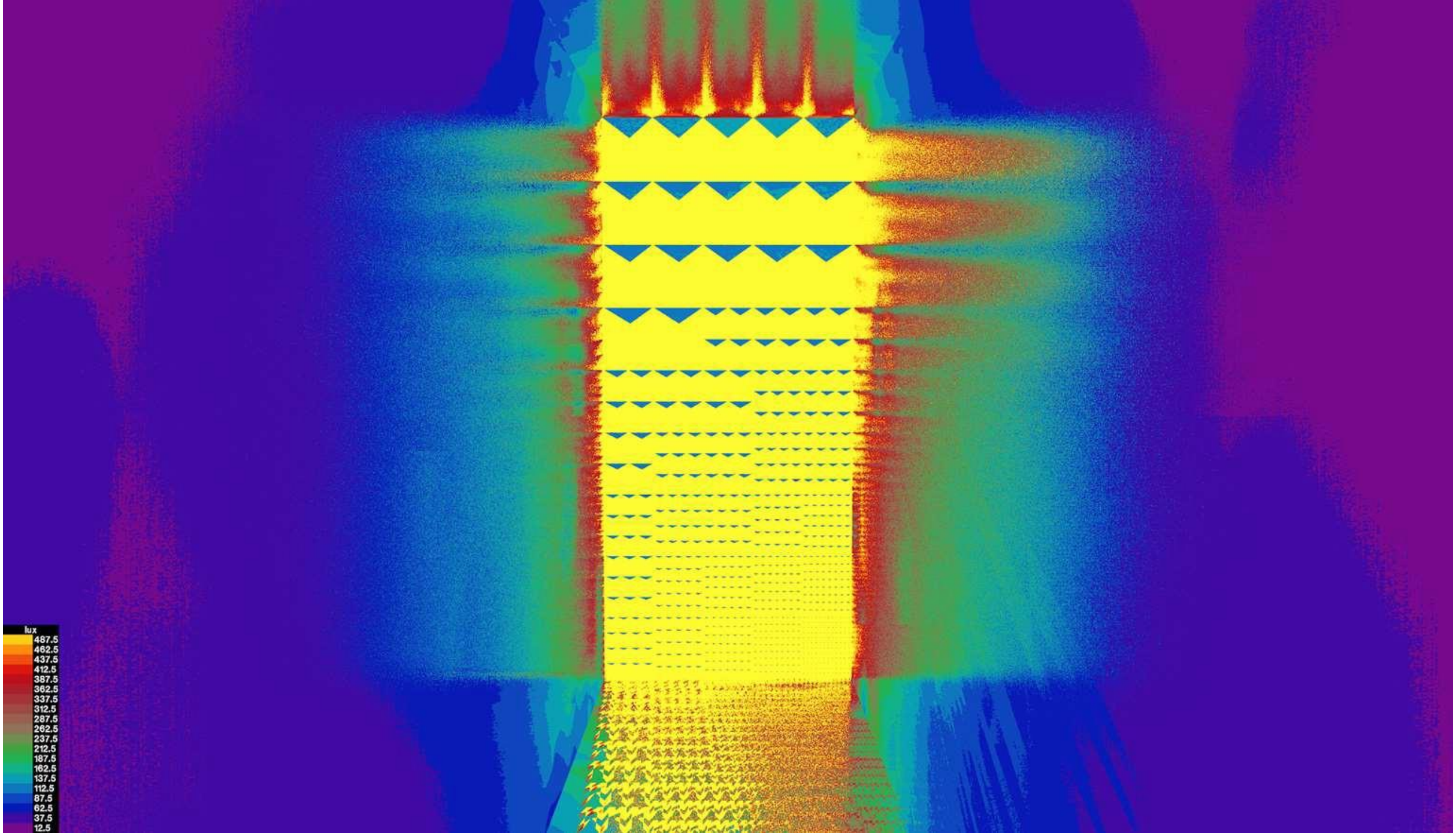
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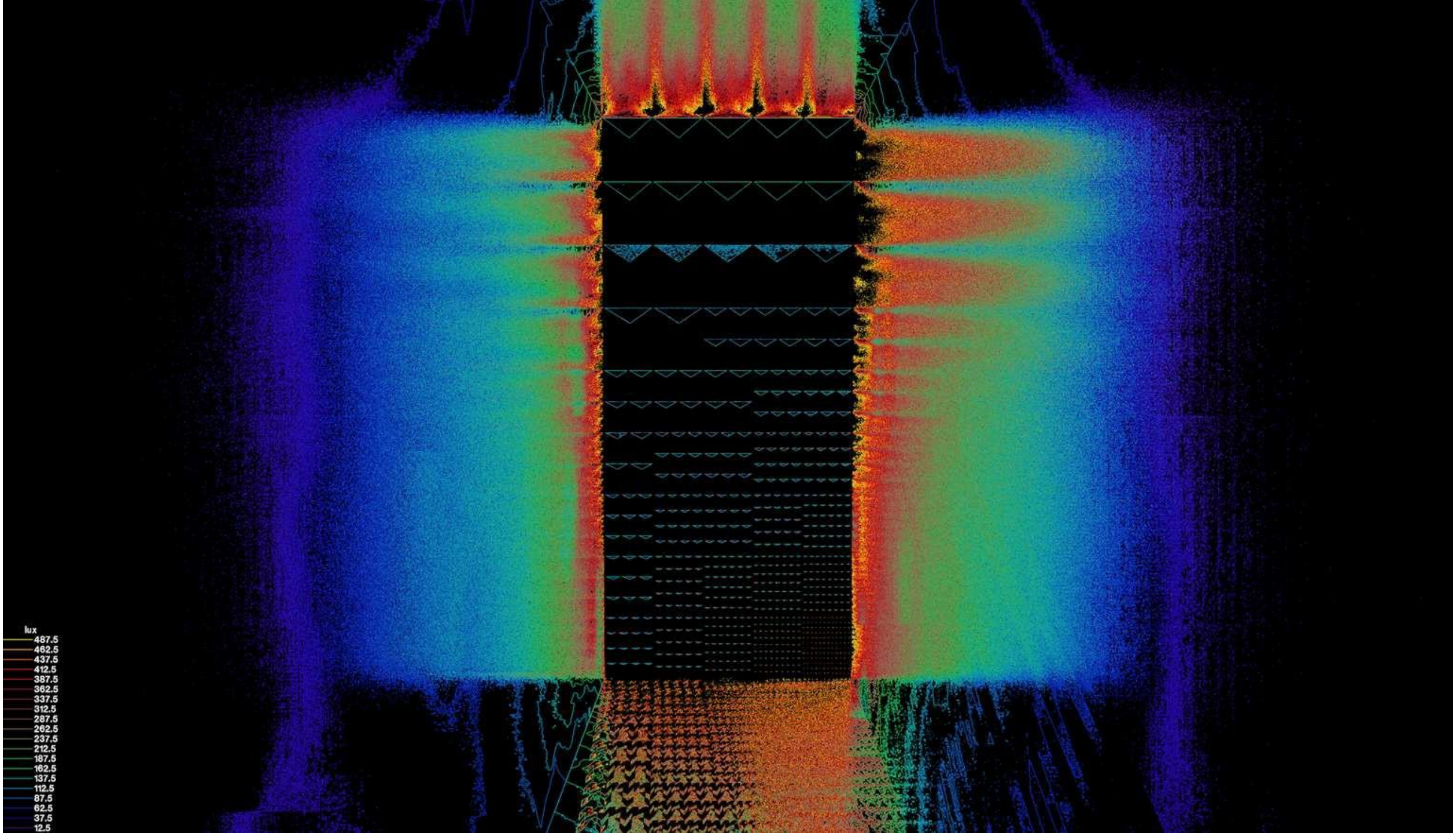
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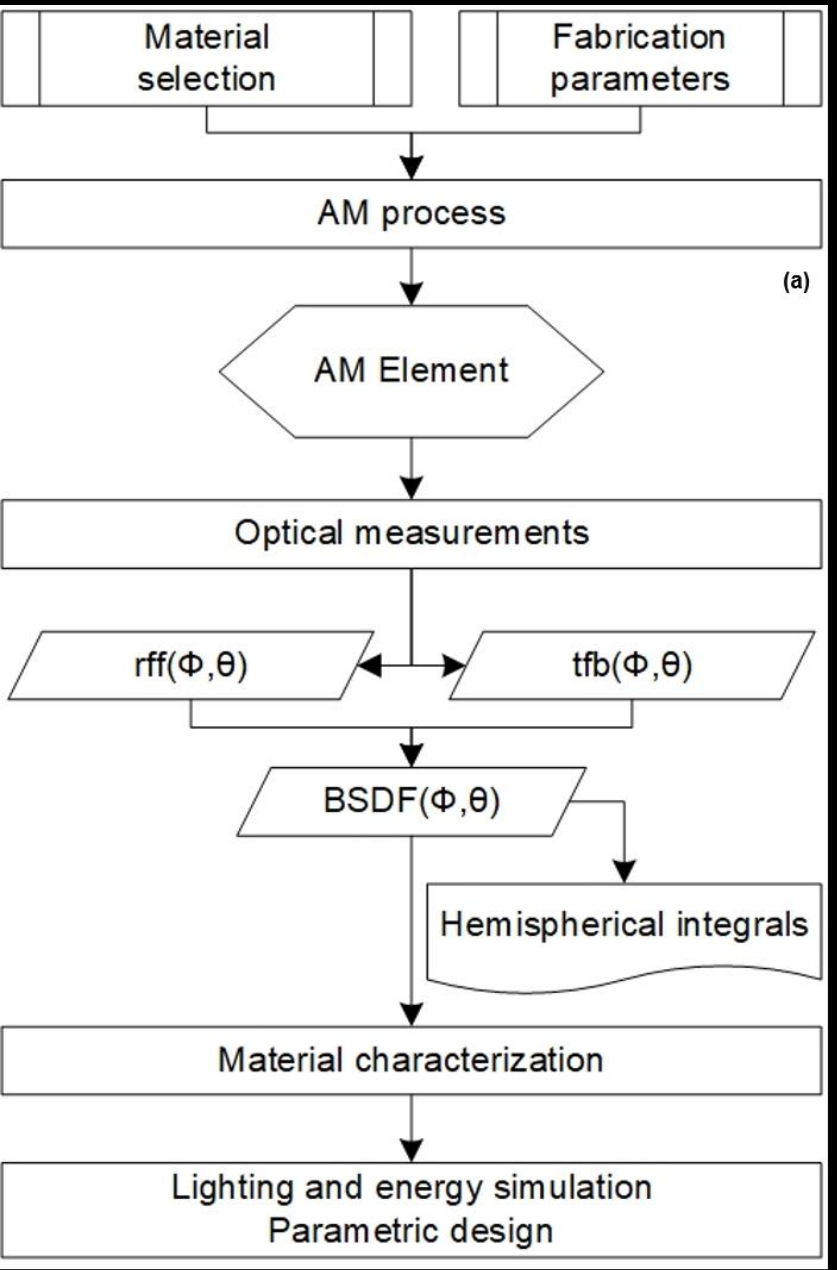
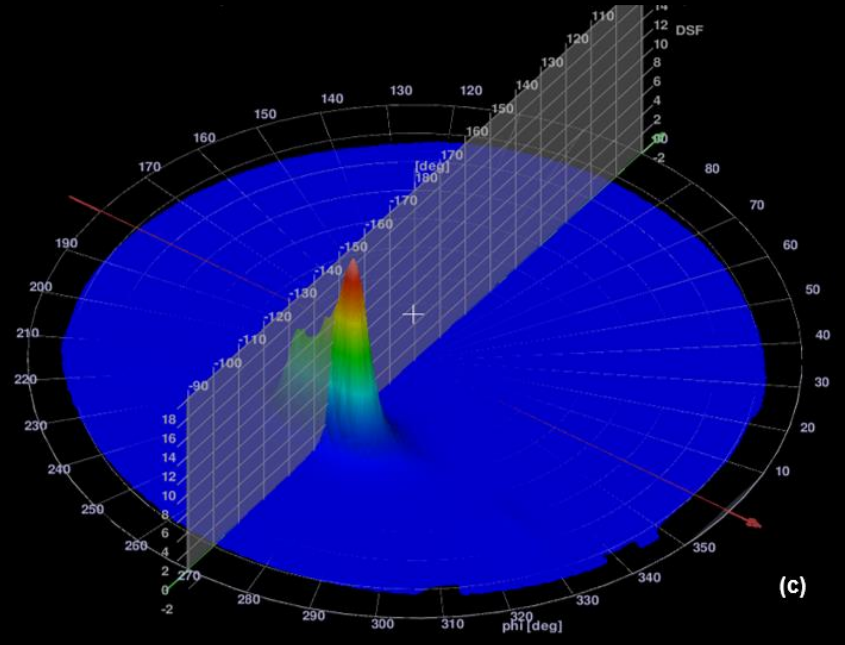
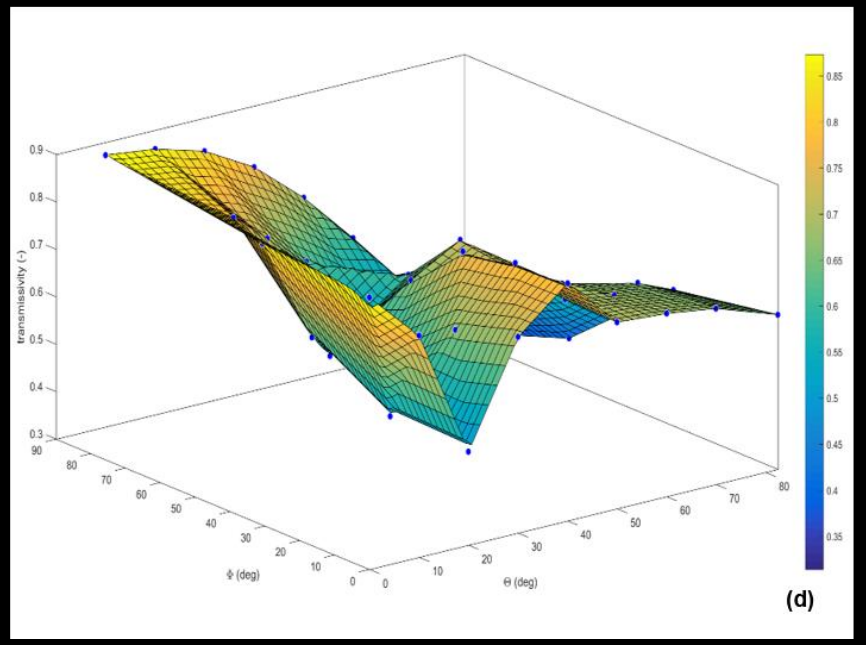

Material selection
Fabrication parameters
AM process
(a)
AM Element
Optical measurements
rff(Φ,θ)
tfb(Φ,θ)
BSDF(Φ,θ)
Hemispherical integrals
Material characterization
Lighting and energy simulation
Parametric design


(b)


DSF
[deg]
phi [deg]
(c)


transmissivity (-)
Φ (deg)
Θ (deg)
(d)


(e)