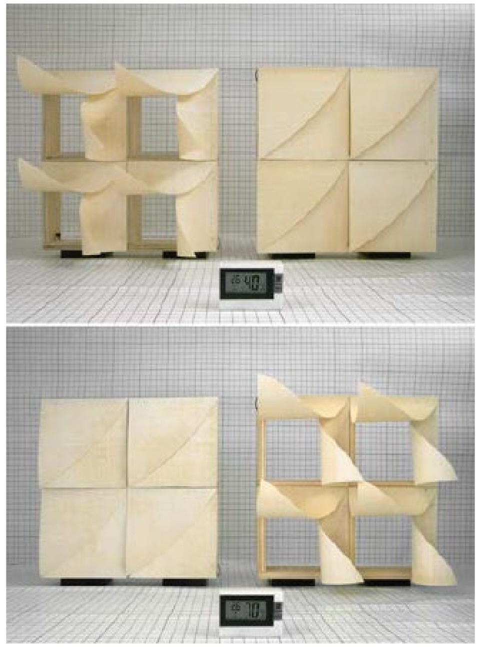
Facade Geometry Optimization with Real-time Agent-based **Light Simulation**

JICHEN WANG
VISHAL VAIDHYANATHAN



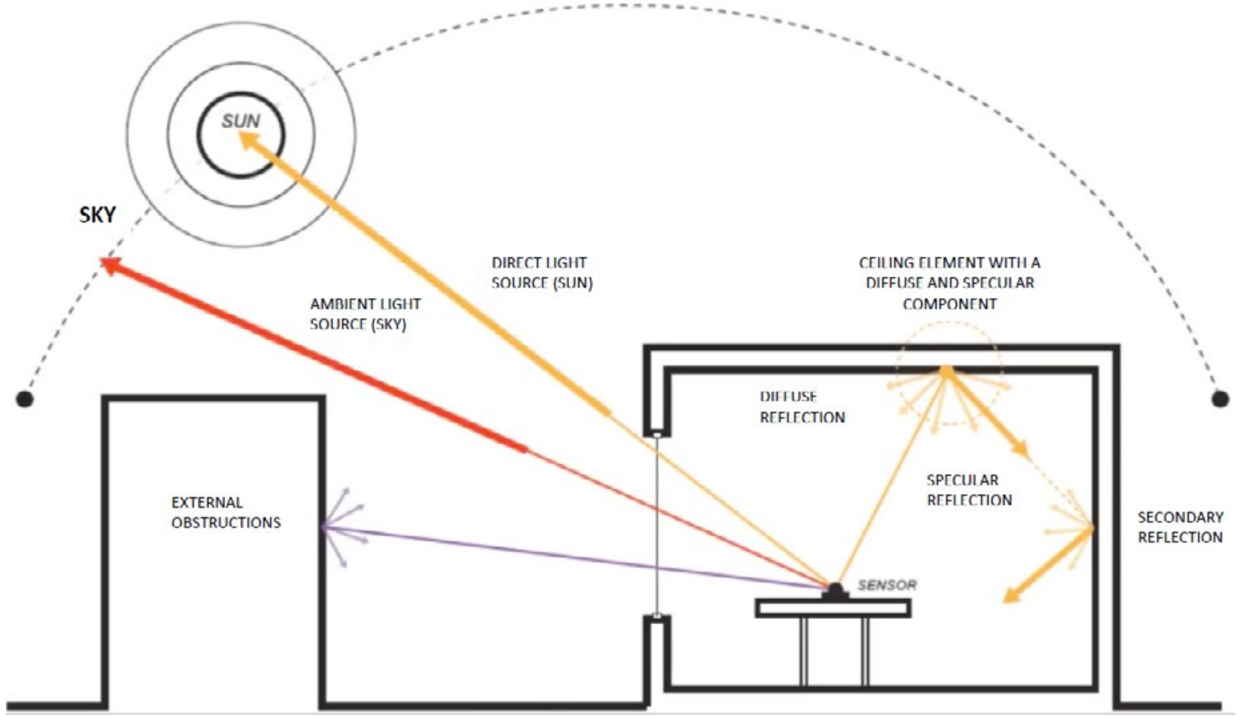
A. DESIGN PROBLEM

For **facade design responsive to light**, we want to achieve a better light condition with control of transformation of the facade units. However, during the design process, there are problems with selecting a proper tool to simulate this process and make the right choice.

B. LIGHT SIMULATION TOOL IN FIELD

Most of light simulation tools in the field are featured as **accurate** while **taking a relatively long time to calculate**, and they do not take curved surfaces as inputs. However, for early design process or for responsive facade elements, the inputs of facade unit will change fast after each iteration of simulation. Therefore the simulation tool requires **fast calculation** (almost real-time) , **input flexibility** and **does not have to be so accurate** as long as it can describe the basic behavior of light.

PROBLEM



C. EVALUATION PROPERTIES

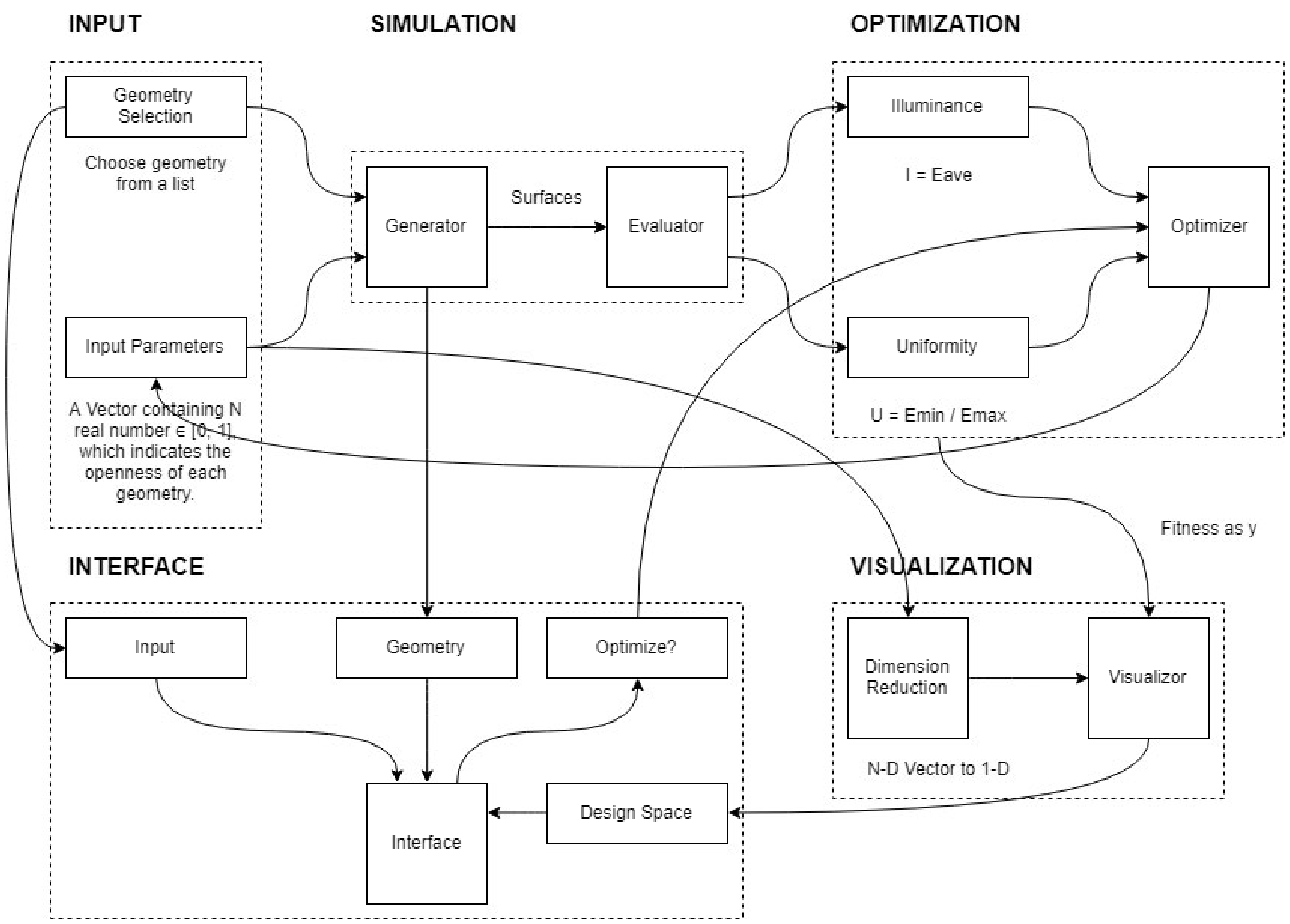
- Enough illuminance
Illuminance is the measure of the amount of light received on the surface. It is typically expressed in lux (lm/m2).

E = Φ / A

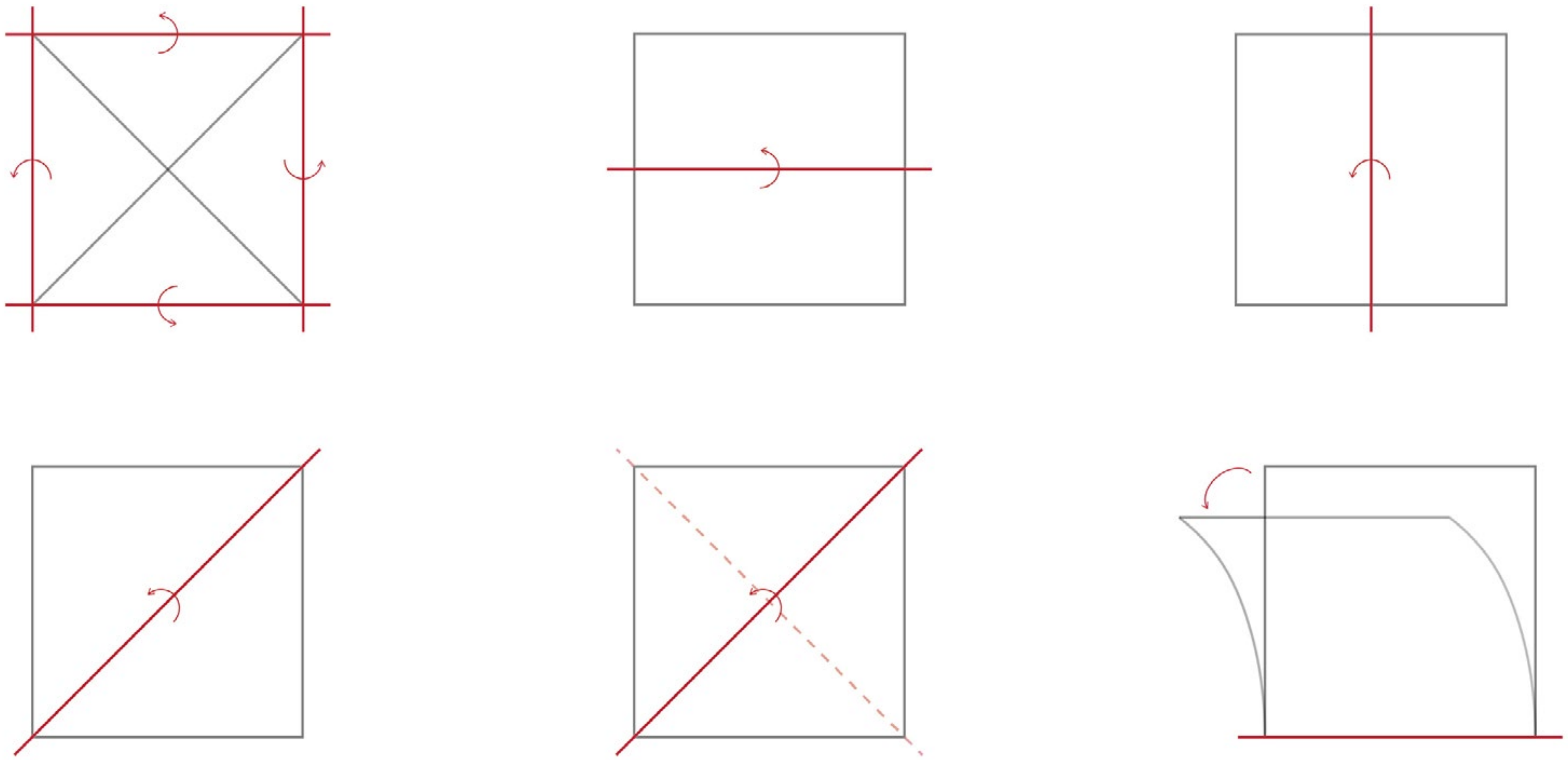
- Uniformity of illuminance
Uniform lighting allows to perceive the environment contin-uously and without sudden breaks caused by lighting level drops.

U1 = Emin / Eave, U2 = Emin / Emax

PROBLEM


INPUT
SIMULATION
OPTIMIZATION
Geometry Selection
Choose geometry from a list
Input Parameters
A Vector containing N real number ∈ [0, 1], which indicates the openness of each geometry.
Generator
Surfaces
Evaluator
Illuminance
I = Eave
Optimizer
Uniformity
U = Emin / Emax
Fitness as y
INTERFACE
VISUALIZATION
Input
Geometry
Optimize?
Interface
Design Space
Dimension Reduction
Visualizor
N-D Vector to 1-D

WORKFLOW



GEOMETRY SELECTION

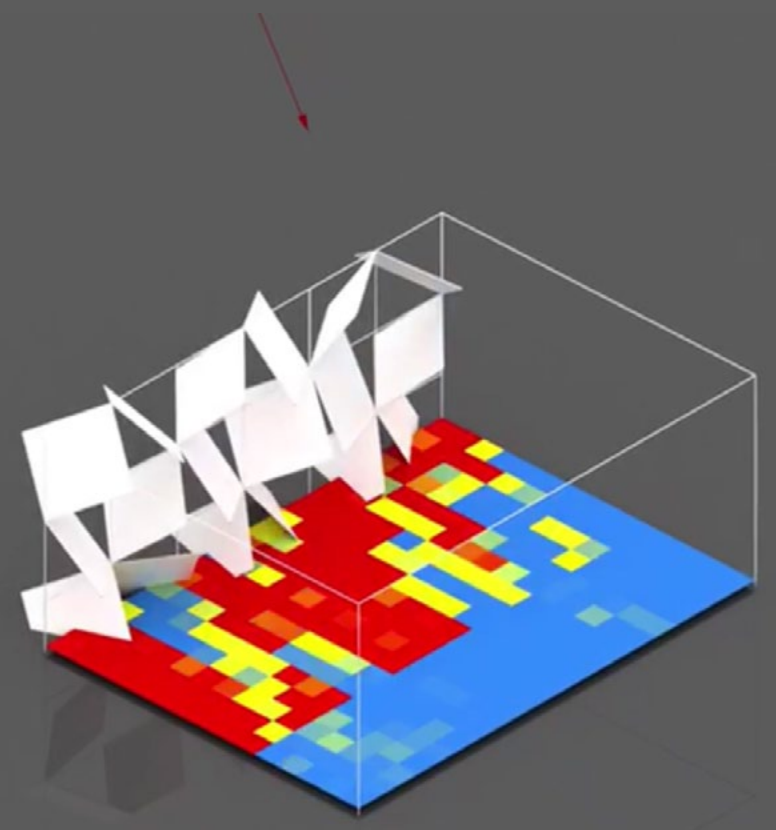
parameter = 0

parameter = 0.5

parameter = 1

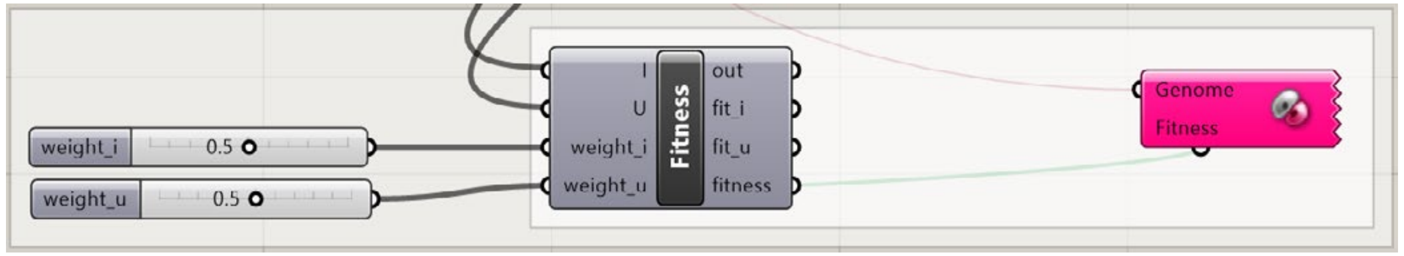
For each unit, there is a real number **range from 0 to 1** which indicates the **transformation of the unit**. It can represent rotation, bending and also other transformation methods. This representation gives a good description of features for the facade and can be further utilized in the optimization.

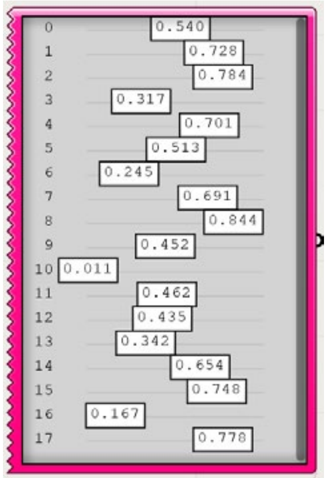
INPUT PARAMETERS

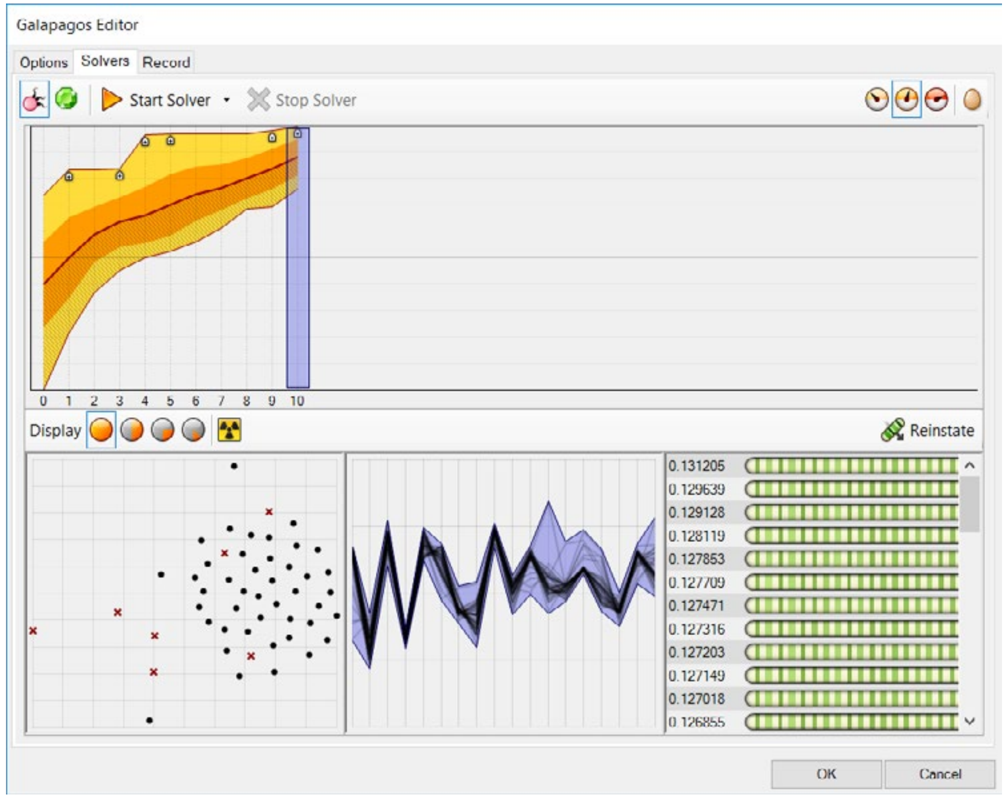


The evaluator is based on agent-based algorithm and can take any set of surfaces as input and evaluate the sunlight condition given certain sun angle. It will give both the grid analyzation and numbers of average illuminance and uniformity as output. The benefit of this tool is it simplifies the simulation process and gives immediate output which is suitable for responsive optimization.

EVALUATOR







The optimizer applies **GA(Genetic Algorithm)** and is able to adjust the transformation parameters according to the fitness generated by the evaluator.

According to the evaluation properties defined before, the objective functions are as follows:

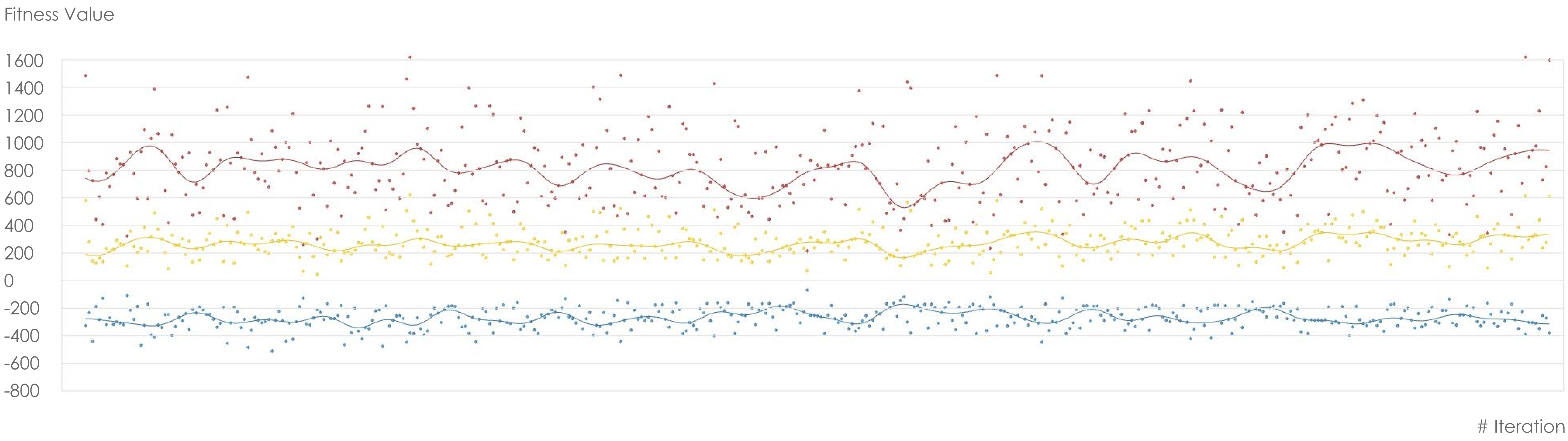
A. Illuminance: Average of cell values

$$\mu = \frac{1}{N}(x_1 + \cdots + x_N)$$

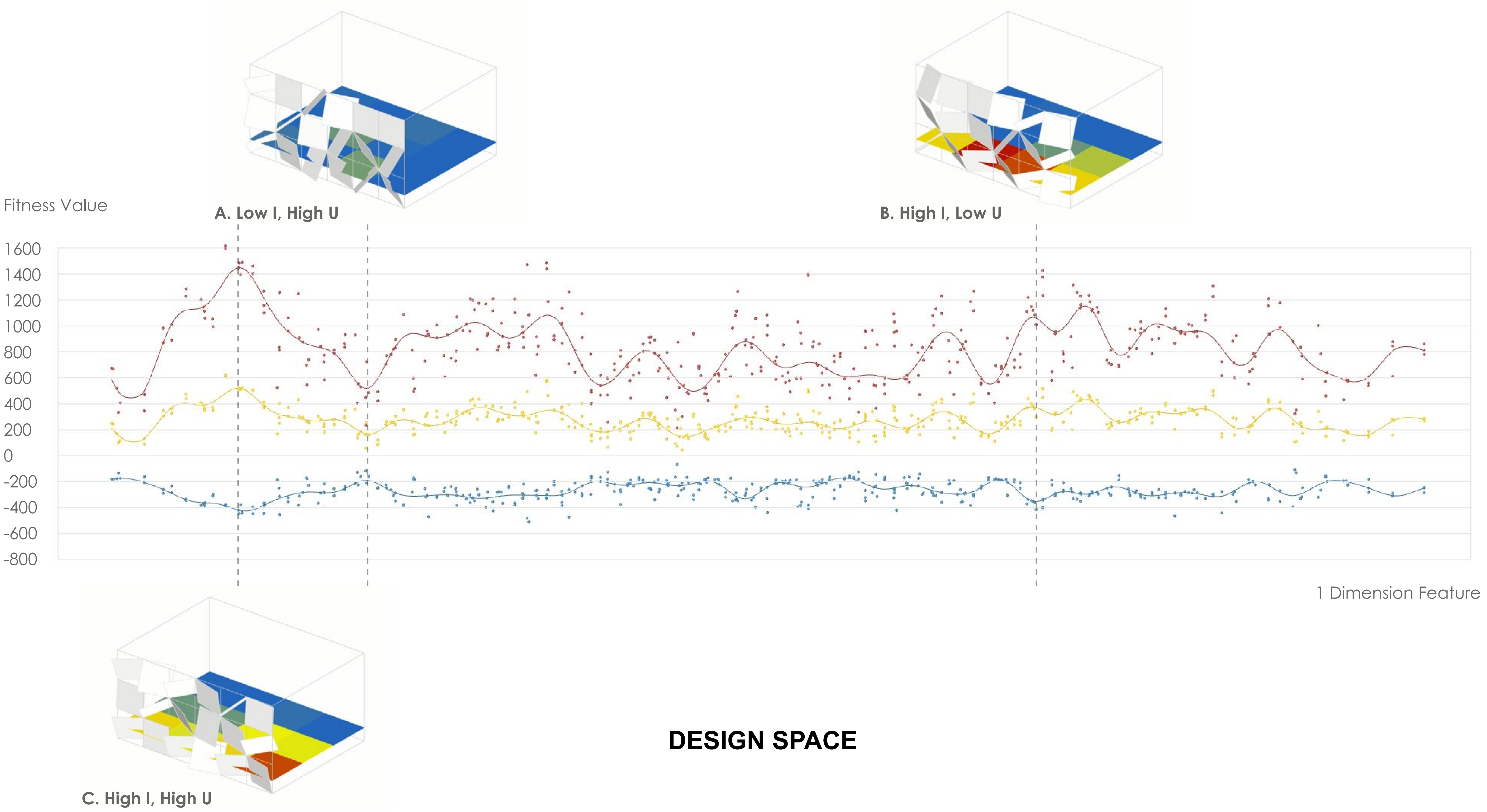
B. Uniformity: To avoid extreme small value for this objective(since Emin will sometimes become 0), we change it from Emin/Emax to negative standard deviation of the cell values.

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

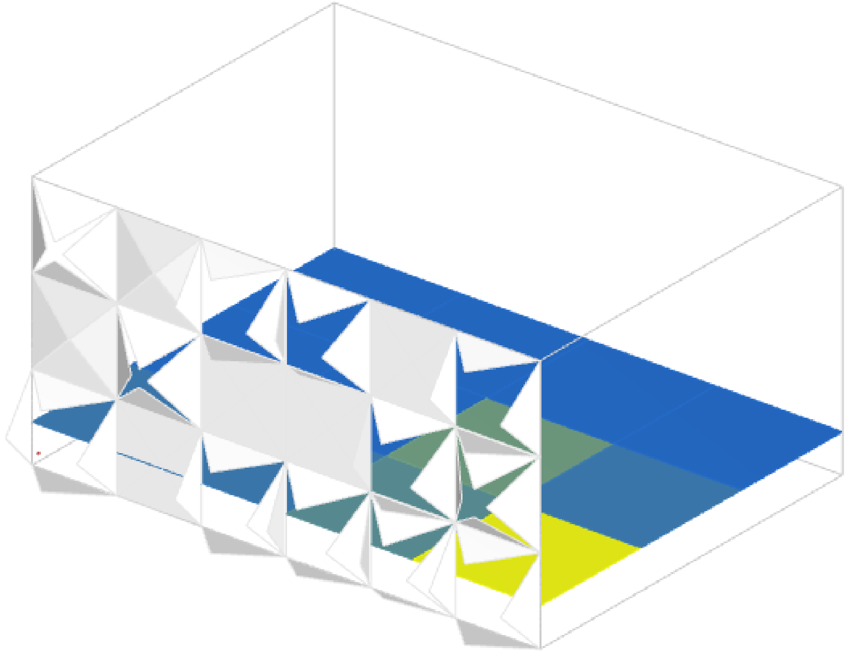
OPTIMIZER

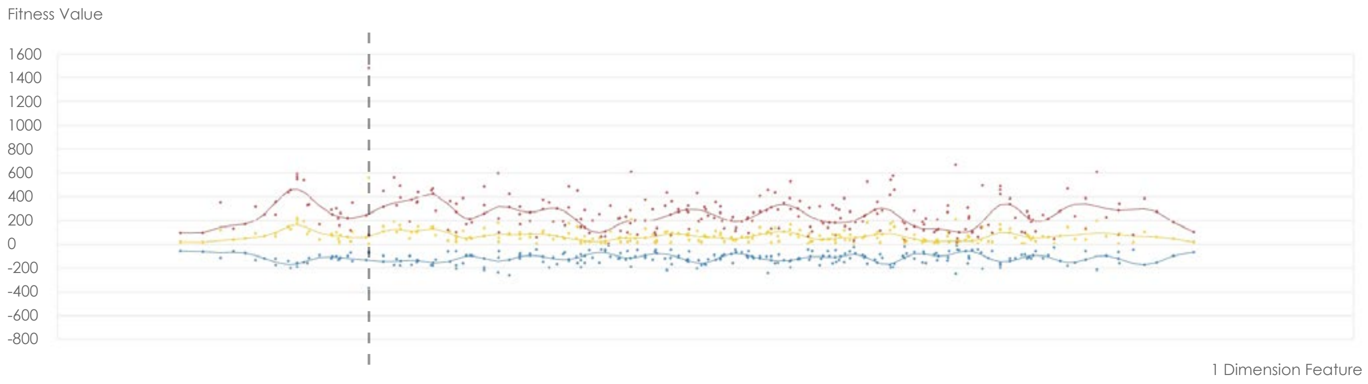

Fitness Value
1600
1400
1200
1000
800
600
400
200
0
-200
-400
-600
-800
Iteration

OPTIMIZER



DESIGN SPACE



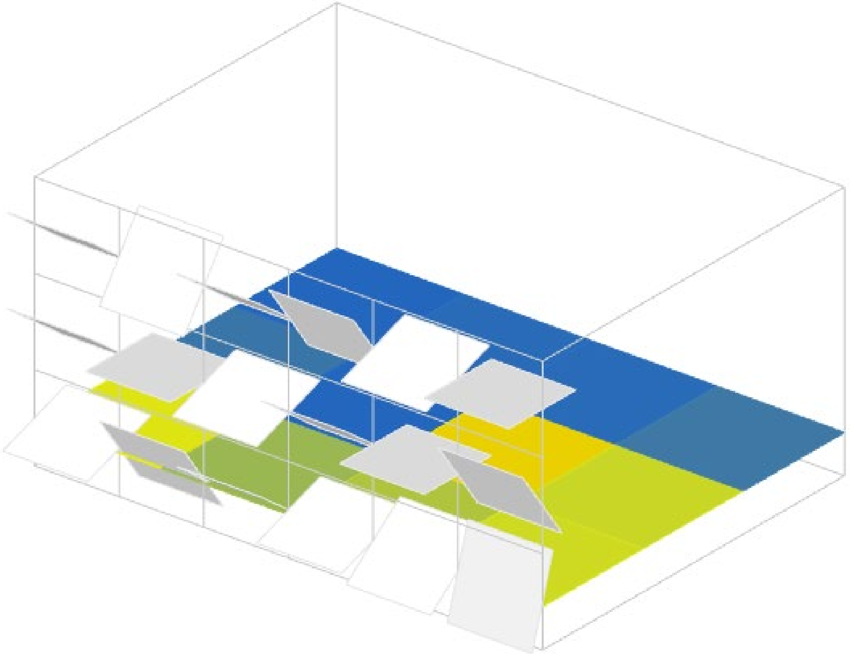


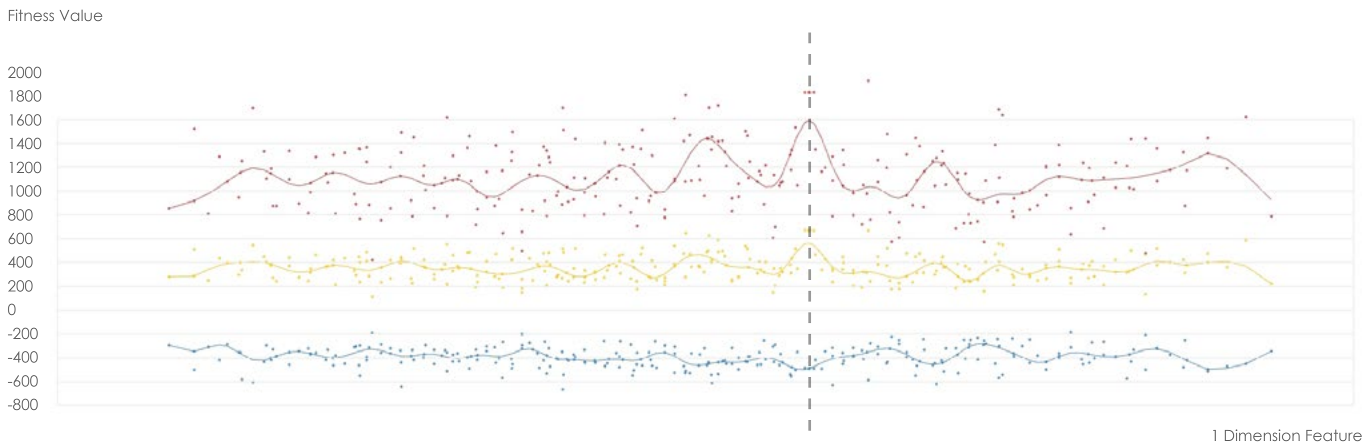
Type 0

Illuminance: 1482

Uniformity: 366

ANALYSIS



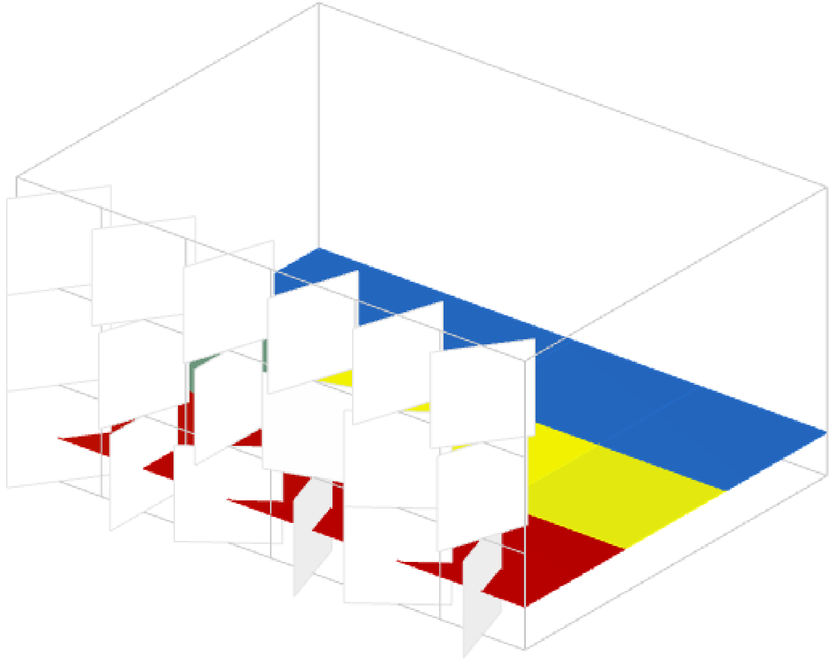


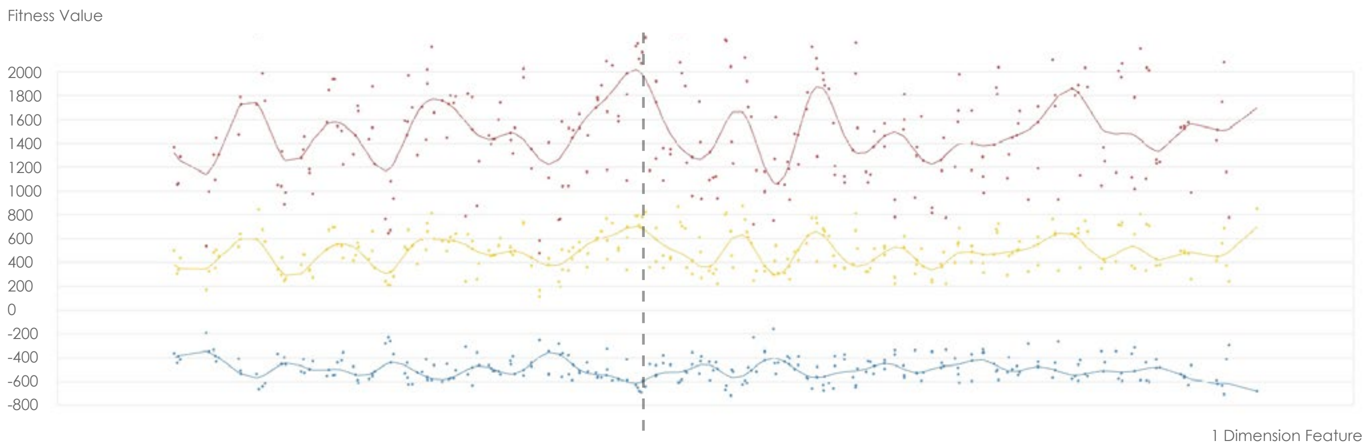
Type 1

Illuminance: 1826

Uniformity: -487

ANALYSIS



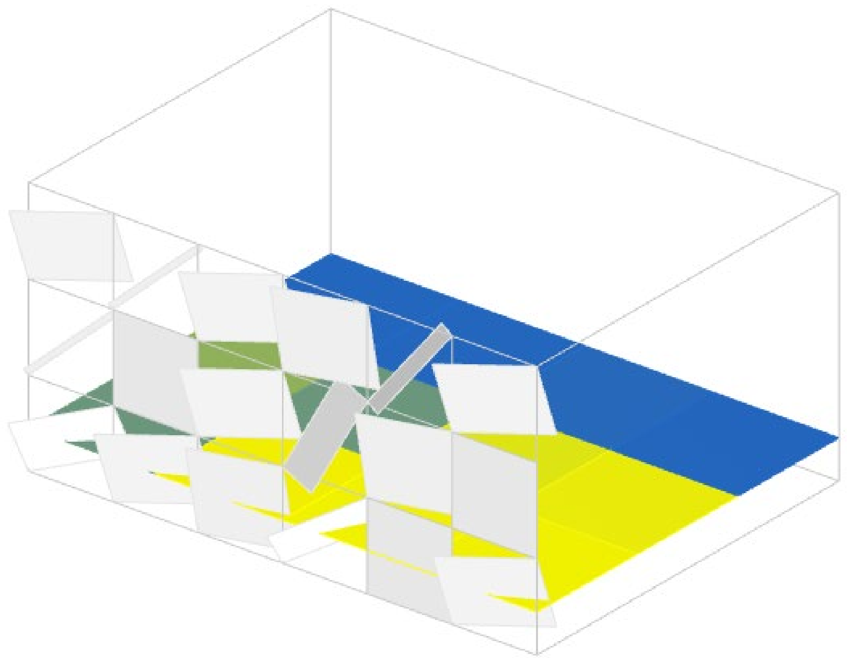


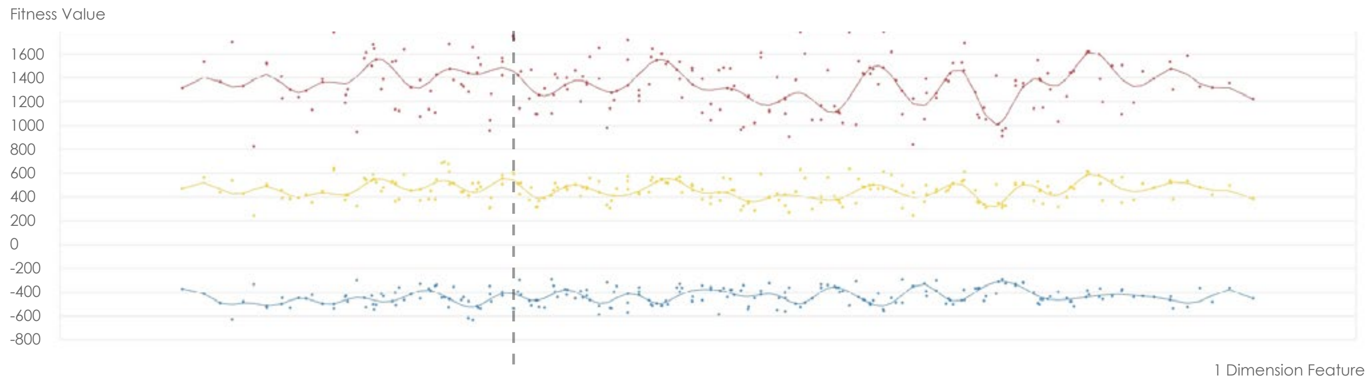
Type 2

Illuminance: 2345

Uniformity: -603

ANALYSIS



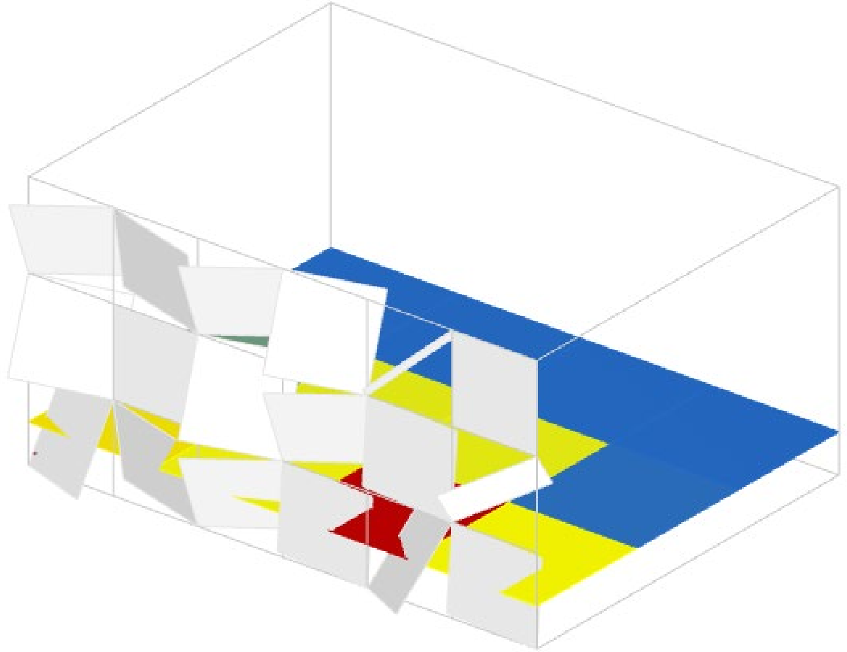


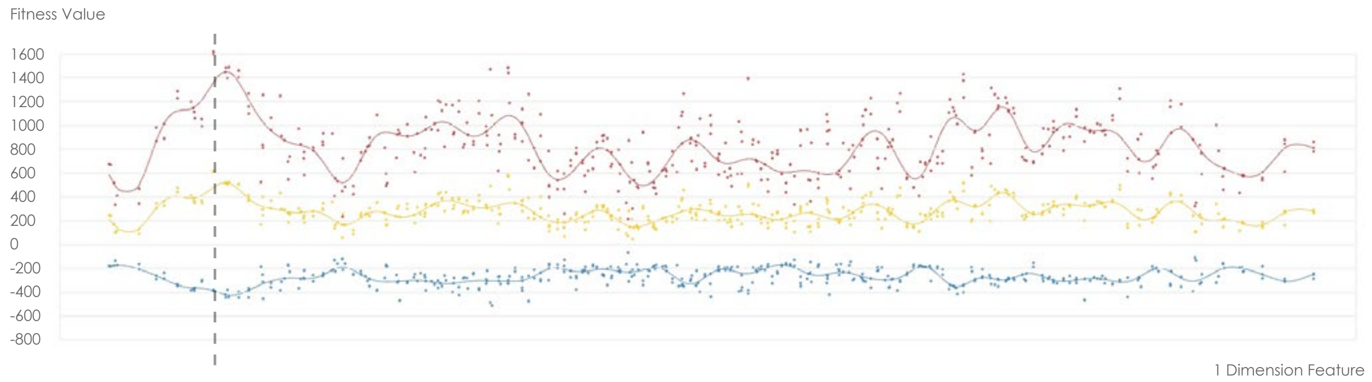
Type 3

Illuminance: 1827

Uniformity: -440

ANALYSIS



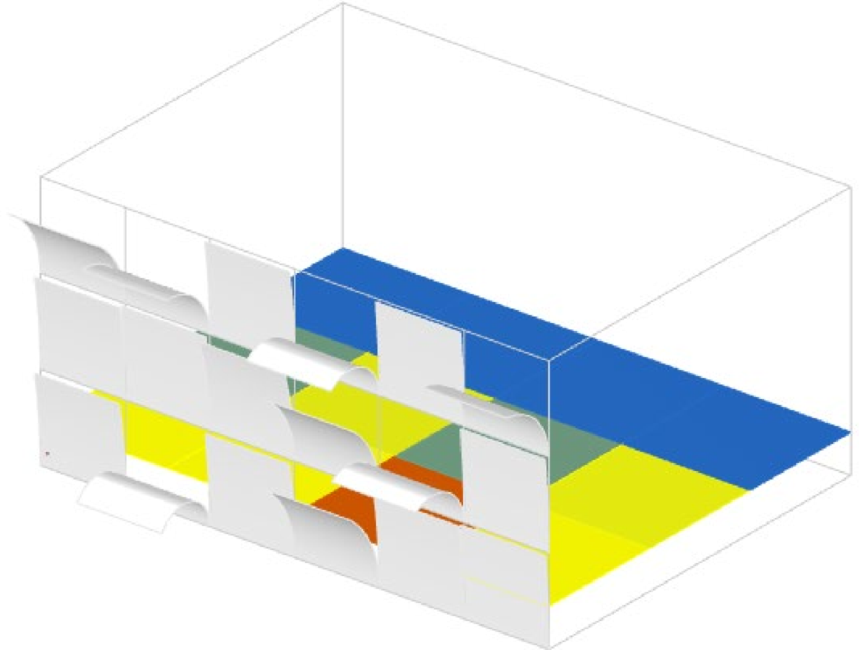


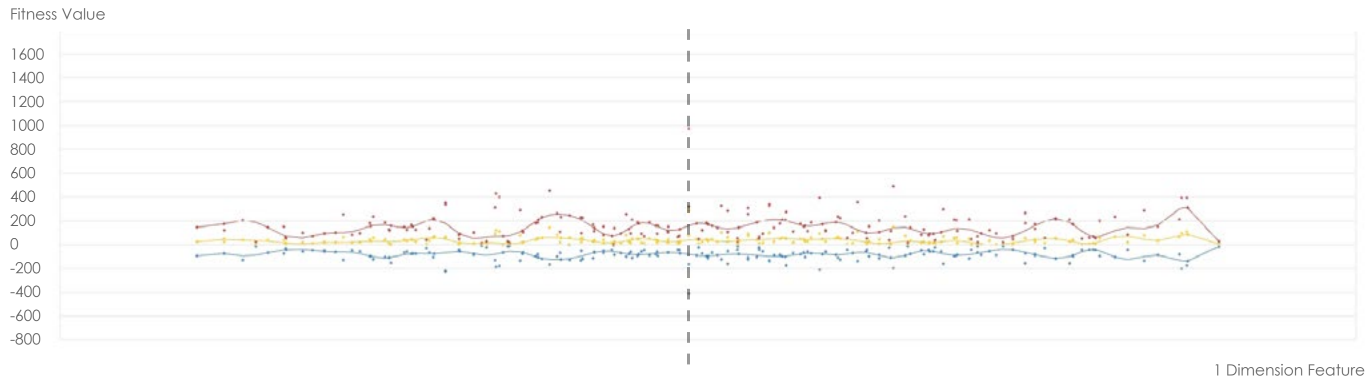
Type 4

Illuminance: 1568

Uniformity: -356

ANALYSIS



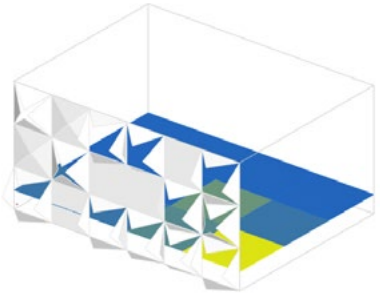


Type 5

Illuminance: 973

Uniformity: -406

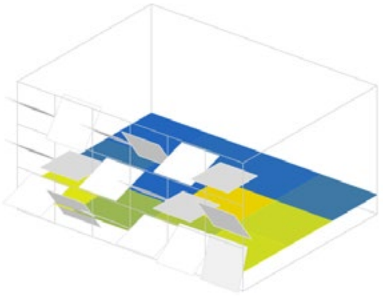
ANALYSIS



Type 0

Illuminance: 1482

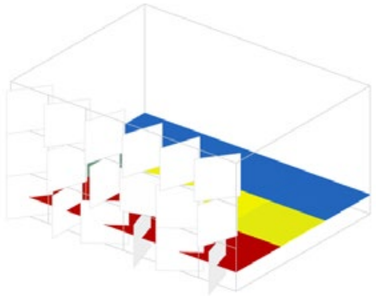
Uniformity: 366



Type 1

Illuminance: 1826

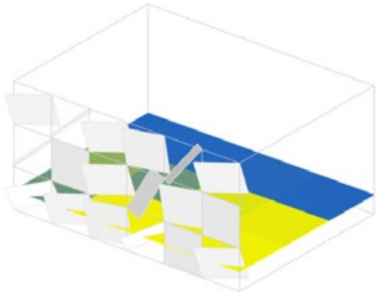
Uniformity: -487



Type 2

Illuminance: 2345

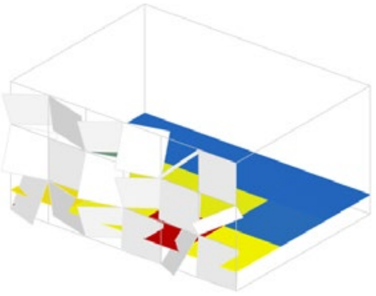
Uniformity: -603



Type 3

Illuminance: 1827

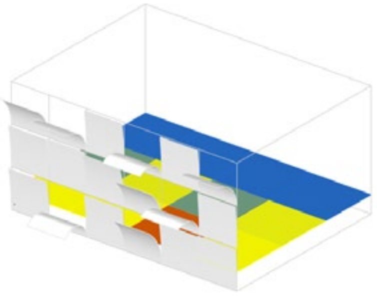
Uniformity: -440



Type 4

Illuminance: 1568

Uniformity: -356

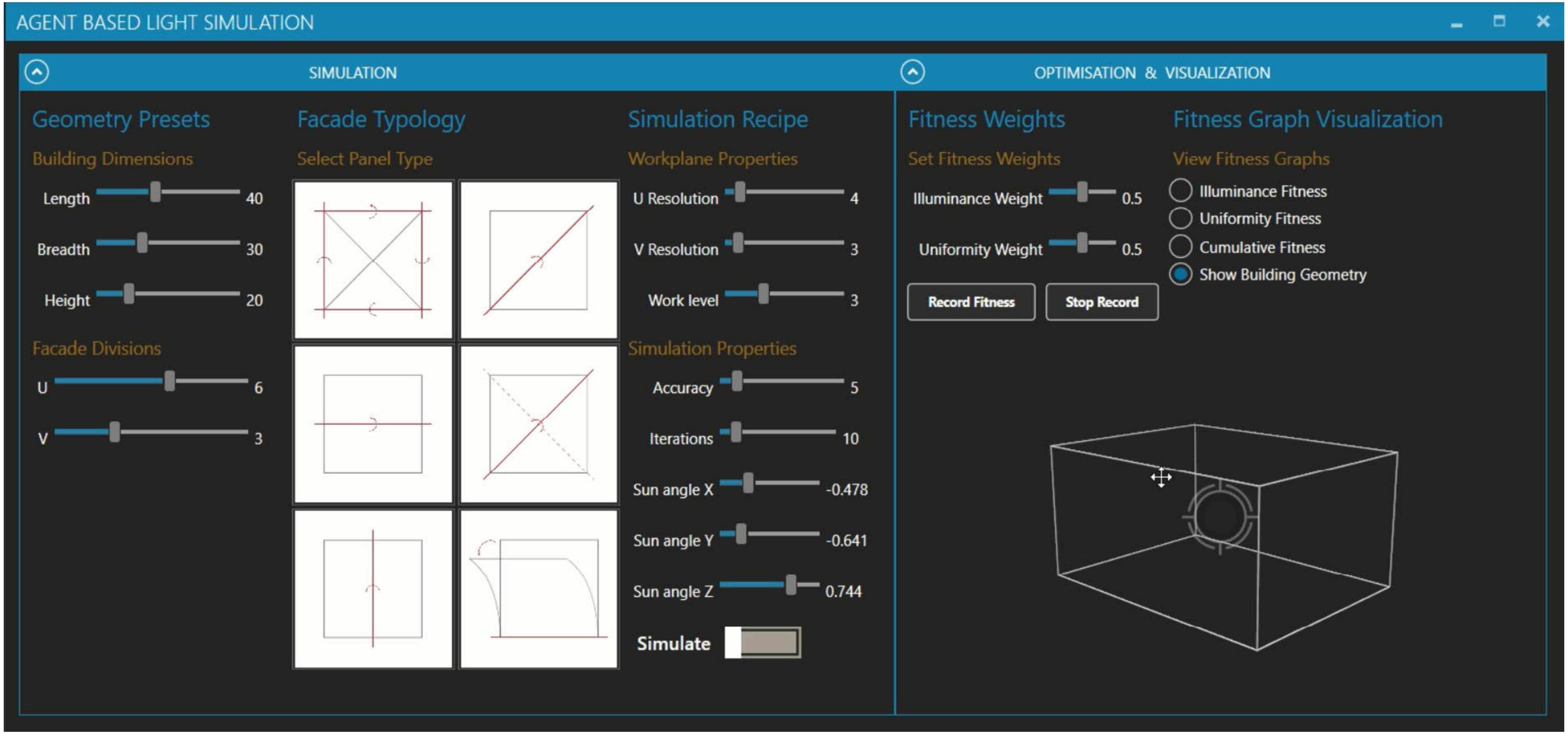


Type 5

Illuminance: 973

Uniformity: -406

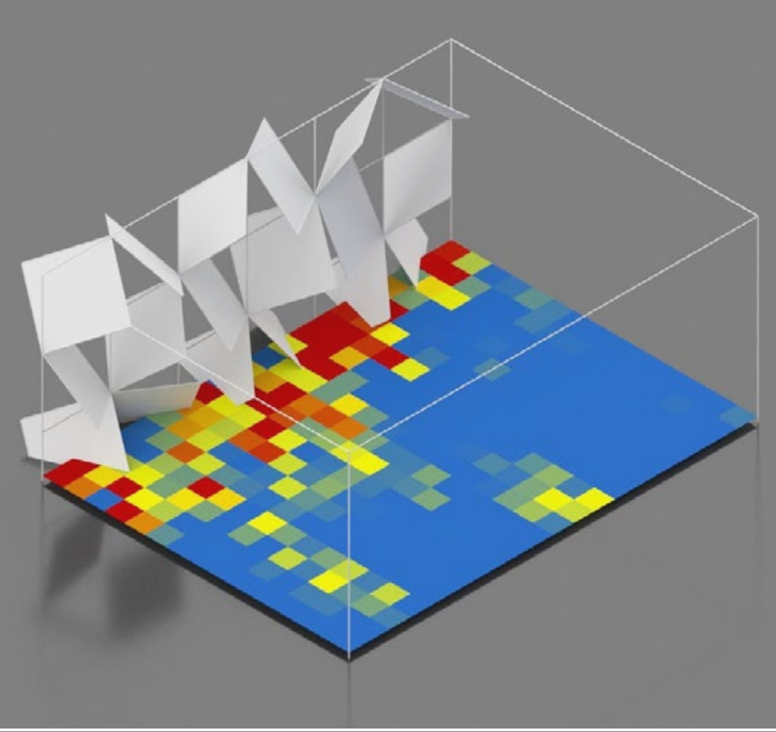
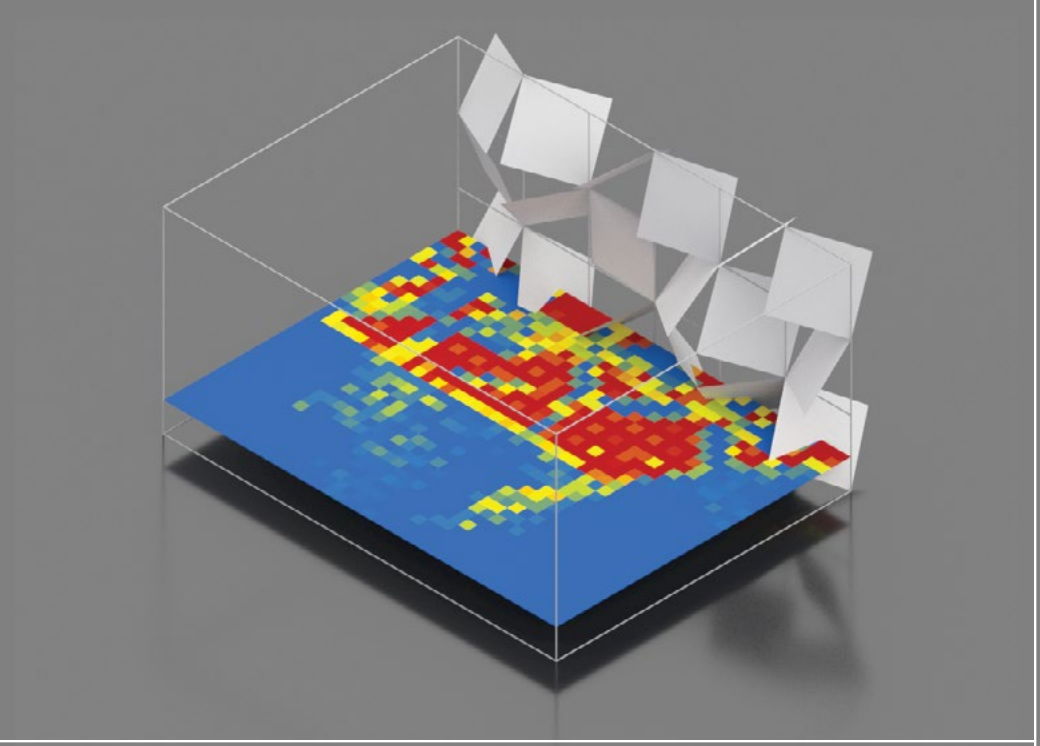
ANALYSIS


AGENT BASED LIGHT SIMULATION
SIMULATION
OPTIMISATION & VISUALIZATION
Geometry Presets
Building Dimensions
Length 40
Breadth 30
Height 20
Facade Divisions
U 6
V 3
Facade Typology
Select Panel Type
Simulation Recipe
Workplane Properties
U Resolution 4
V Resolution 3
Work level 3
Simulation Properties
Accuracy 5
Iterations 10
Sun angle X -0.478
Sun angle Y -0.641
Sun angle Z 0.744
Simulate
Fitness Weights
Set Fitness Weights
Illuminance Weight 0.5
Uniformity Weight 0.5
Record Fitness
Stop Record
Fitness Graph Visualization
View Fitness Graphs
Illuminance Fitness
Uniformity Fitness
Cumulative Fitness
Show Building Geometry

INTERFACE

Agent-based Simulation vs **Ladybug Tools (Point in time)**

low quality, colour scheme matched

Simulation		
Run - time	< 1 second	~26 seconds
Reqd. Inputs / Depends	Rhino (CAD) Geo, Accuracy, Resolution, Sun Angle	Honeybee zones, Radiance/Daysim engine
USPs	Real time, Geometry based simulation, No external engine dependency, Works with curved and complex surfaces as well, Allows expedited optimisation workflows.	

COMPARISON

Task	Jichen Wang	Vishal Vaidhyanathan
Input Design	√	
Simulation Algorithm	√	
Optimization	√	
Result Visualization	√	
Interface Development		√
Software Comparison		√
Diagram	√	
Video	√	√

Final Task Assignment

VIDEO LINK: https://youtu.be/i_RVaW5gclw

A. AGENT-BASED METHOD

There are doubts considering whether agent-based method is the best way for this simulation problem. Certainly there are more efficient ways to calculate light. However, the concept of treating light in a behavioral way is still intriguing. In this project, we simplified the behavior to only reflection and use deterministic method to make the algorithm more efficient. For further improvement we might apply threads in calculation as well as think of other method to represent the problem.

B. USER EXPERIENCE

As a tool for designers to make better design choice, the input part still needs to be improved. Right now, it only allows users to choose from different options and is really difficult to understand the workflow. There is a chance to make a more straight-forward and input flexible user interface.

CONCLUSION