Useful Daylight Illuminance (UDI) performance analysis with 5 Stage of the Building options in Barcelona, to perform the Building façade design Optimization by Integrating individual's Aesthetic sensibility and Environment based Daylighting performance

FINAL RESEARCH PROJECT PROCESS SUBMISSION
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UNIVERSITY OF PENNSYLVANIA
ARCH-754 - BUILDING PERFORMANCE WORKSHOP SPRING 2017

Building façade design Optimization by Integrating individual's Aesthetic sensibility and Environment based Daylighting performance

Useful Daylight Illuminance (UDI) performance analysis with 5 stage of the building options in Barcelona:

Current Toyo Ito's facade with single story building,

Single story building with no sea wave facade,

Single story building with Genetic Algorithm (GA) produced facade,

Full story building with Genetic Algorithm (GA) produced facade,

Full story building with optimized facade that integrating individual's aesthetic sensibility and environment based daylighting performance

Each steps are performed throught out the research, to compare and also to take steps toward the goal, "Full story building with optimized facade that integrating individual's aesthetic sensibility and environment based daylighting performance".

Introduction and Background

DESIGN PROBLEM

The research began from the attempt to narrow the gap between performance oriented buildings and design centric buildings. The research and experiments are founded from prevalent views that many modern buildings with appealing designs are not satisfactory in regards to performance aspects. And many times, vise- versa. With current technology, however, performance can be quantified. If design aesthetics can also be simultaneously quantified, buildings would be able to satisfy both performance goals as well as aspects related to elaborate design.

The purpose of the research is thus to propose a method to integrate two different performances, quality and quantity, into one measurable goal. In detail, the goal is to develop automated optimization workflows based on combination of qualitative and quantitative design criteria for a building skin. The intention is to make a system that is not only flexible but also subject to optimization by the building façade shape according to different personal aesthetics and different environmental locations.

WHY IS IT INTERESTING PROBLEM?

Building envelope design using parametric design methodology has recently become great interest to major architects. The design of building form with parametric envelopes or façades takes method of continuous deformation of façade till the architect finds interesting patterns or shapes that satisfy the architect's aesthetics. However, those new design methods used by major architects pose a question in regards to reasoning behind them. Endless process of finding patterns and shapes is difficult to justify and mostly depends on designer's subjective views. Since we are hardly able to find any cases that integrate the quality with the quantitative performance goals, this research stems from motivation to contribute to such morphological process. Quantitative goals, in this aspect, can be objectives that are adoptable for its surrounding environment to save energy or can be the objectives that control the daylight according to human dynamics inside the building.

It is said that people spend 80% of their life time indoors. Thus, buildings have to be occupant centric. This research aims to, as a byproduct, generate the best building designs that are occupant centric, as each location possesses appropriate or optimal building shapes that gives people inside the best quality of appropriate daylighting to keep healthy life and save energy, as defined by its environmental location as well as its surroundings.

The research possesses significant meaning because the program made with the Multi-Objective Evolutionary Algorithms will provide the screen wall façade shape and numerous variations of building forms that allow the best daylighting performance in different environments and urban locations. Most importantly, it will allow users to match their aesthetic sensibilities as well.

Background

METHODOLOGY

The research will use an existing building's screen wall as a case study. The case building's screen will be analyzed to understand architect's intent on screen wall's form logics. The founded logic will be manipulated in existing NURBS Geometry tool which will allow one to utilize simulation tool to achieve optimization and find performance of the screen.
For optimization, the paper considers subjective matter as one of objective functions in Multi-Objective Evolutionary Algorithms. This method would allow the architect to find his or her design preference and would satisfy quantitative performance goals as well.

Fallowings are each steps are performed throught out the research, to compare and also to take steps toward the goal, "Full story building with optimized facade that integrating individual's aesthetic sensibility and environment based daylighting performance".

Current Toyo Ito's facade with single story building,

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OVER ALL ALGORITHM WORK FLOW

1. To quantify aesthetic value screen wall facade form categorized forms

2. Categorize form into 4 options, with two subcategories under each option that has opposite characteristics. Therefore, in total, 8 options. Among those, the architect picks 4 design characteristics.

3. Each characteristic is formulated and its algorithm is made in Grasshopper.

4. Multiple choices have slide bars so that they can be controlled. (In Grasshopper)

5. Environment analysis added in algorithm with proper material embedded to computer architecture model (Using Radiance, I used Diva daylighting)

6. Various forms that satisfy all 4 options of aethetic values are fallowed by daylight analysis are processed.

7. UDI calculation, each floor has testing nods and illuminance level (Lux) is calculated, with based on Barcelona.

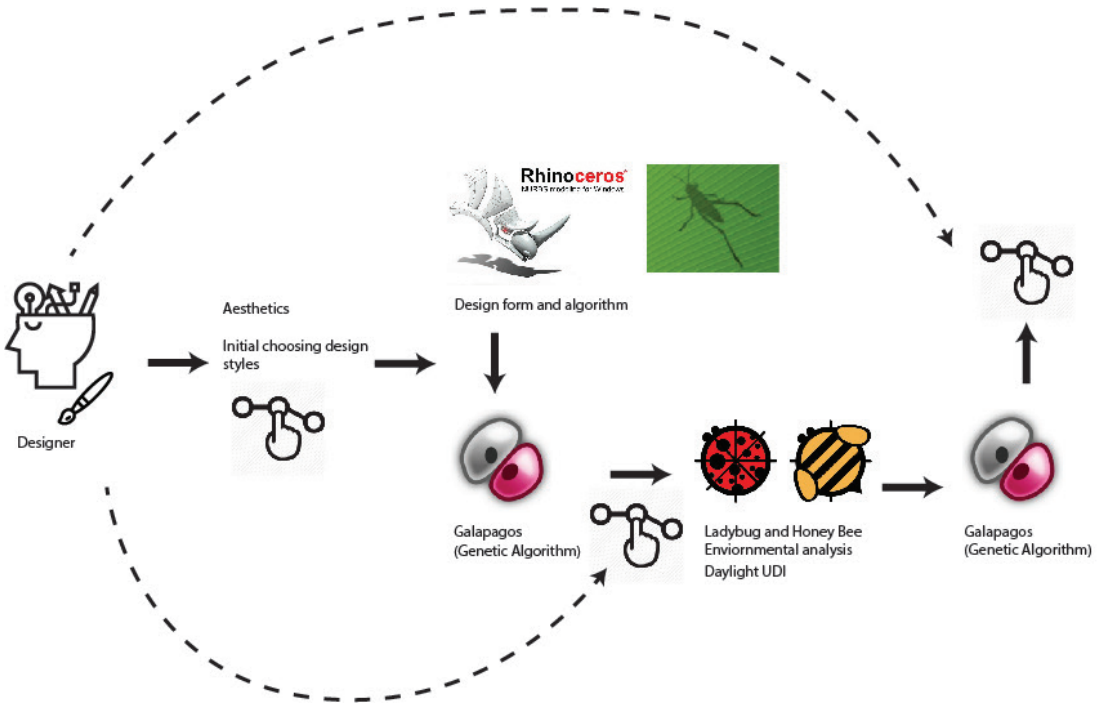
8. For the result to be satisfactory with the daylight performance, algorithm is set to find the models with its ranges being in the human comfort zone in regards to illuminance levels and sort out the ones that generate good distribution. UDI 100-2000 lux.

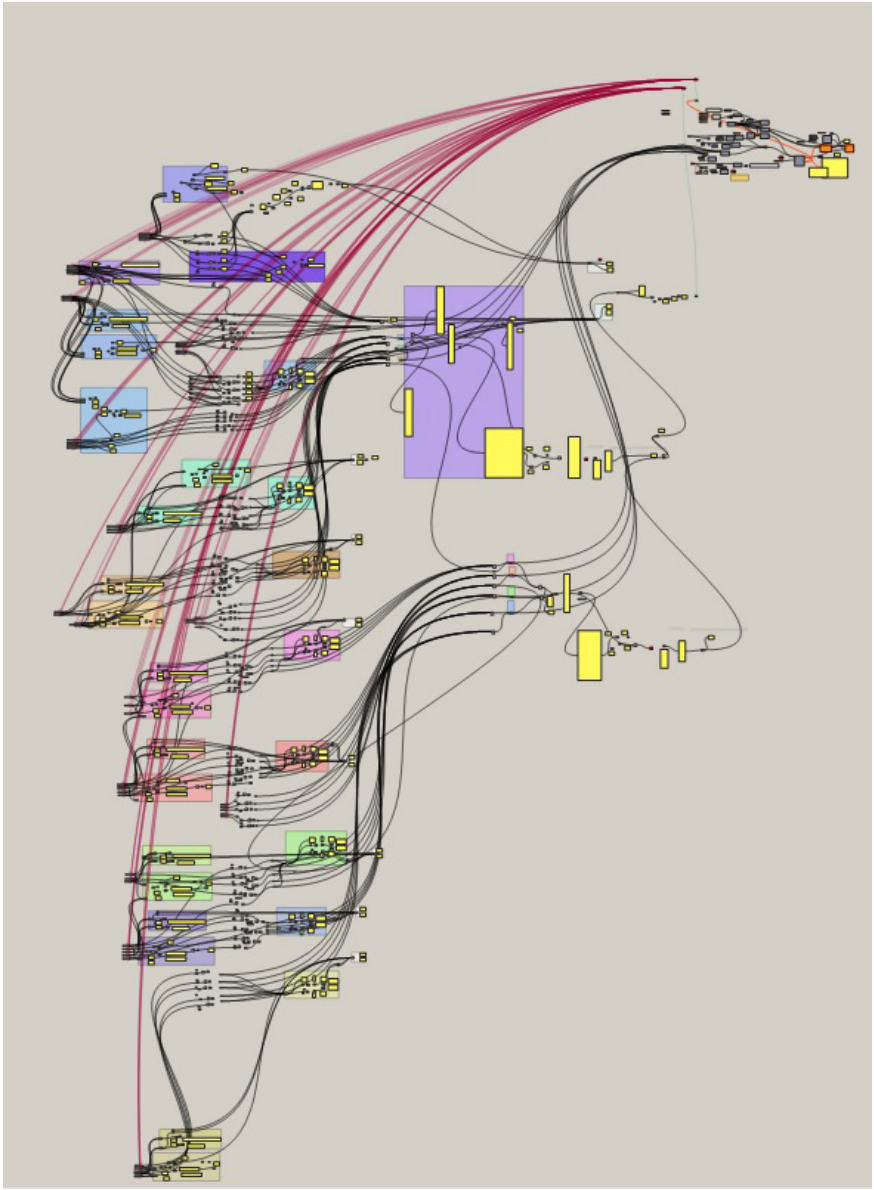
9. The numbers that came out from Multi Algorithm are assembled and quantified into one single number. This is to be applied to Evolutionary Solvers/ Genetic Algorithms (Galapagos), evolutionary principles of which is applied to problem solving.

10. The various numerical combinations go through this algorithm and finds several the most matching genomes.

11. Present the 9 architectural model results to the architect so that they can pick the best one that they prefer the most. This is to take away the last small unexplainable gap that architect or client might have.

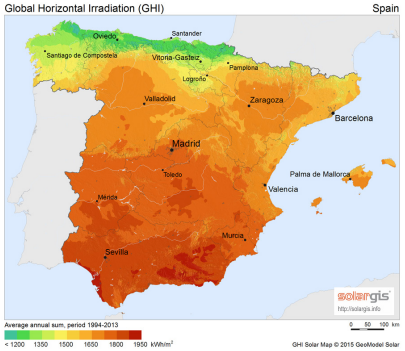
Flow chart and Simulation Algorithm

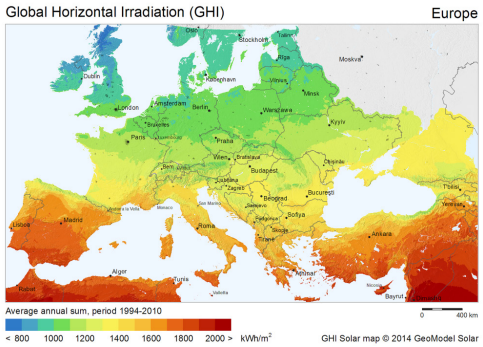




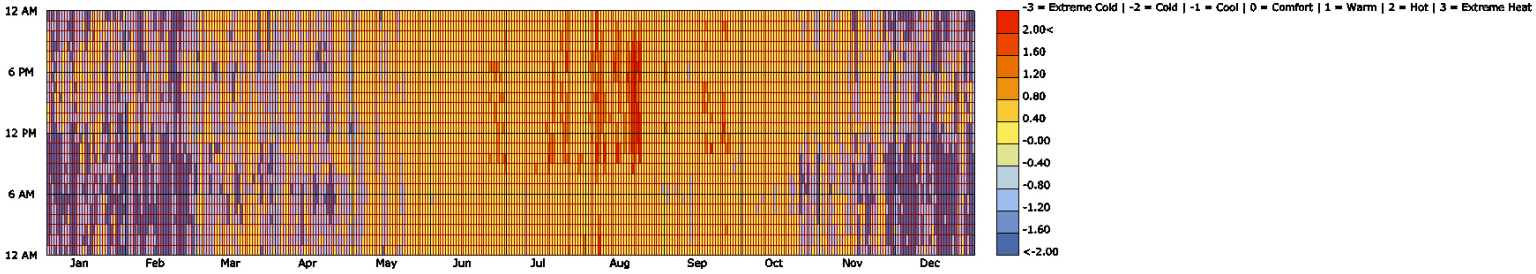
LOCATION : BACELONA
41.3851° N, 2.1734° E

Grobal Horizontal Irradiation (GHI)

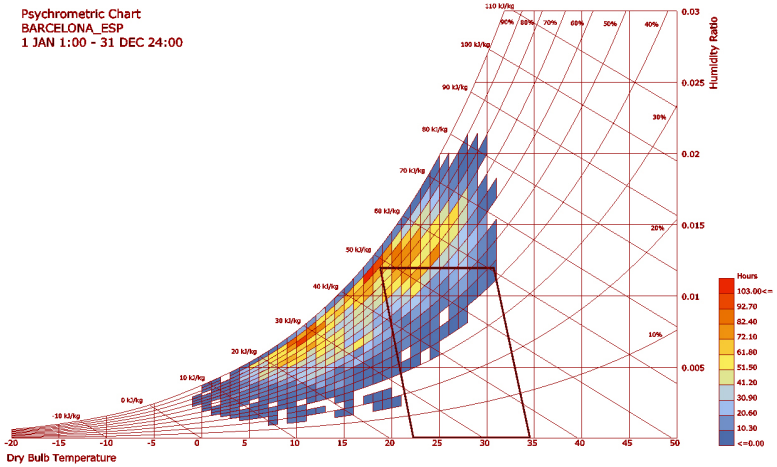




Outdoor comfort basic temperature throughout the year



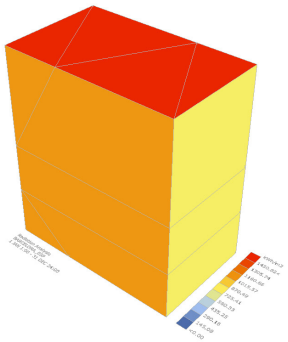
Psychrometric chart throughout the year



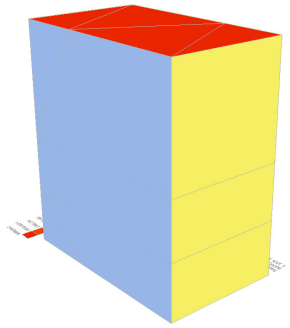
Building envelop exposal on daylight. Radiation studies by the direction and dates.

Location: Barcelona
Dimention::
Width: 11.83m / Length: 7.14m / One story Height: 3.35m / Total Builidng Height: 13.40 m /

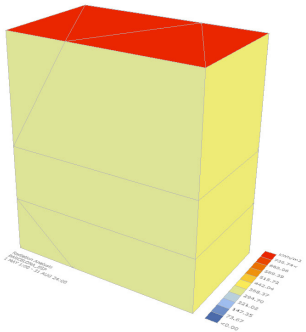
Radiation whole year



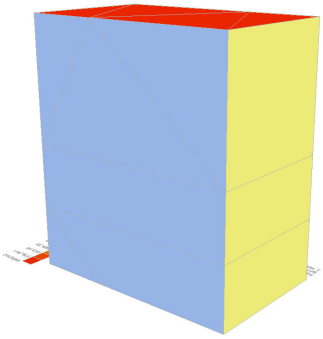
Radiation whole year, north view



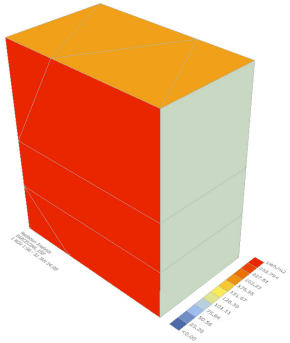
Summer radiation
May 1st - Aug 31



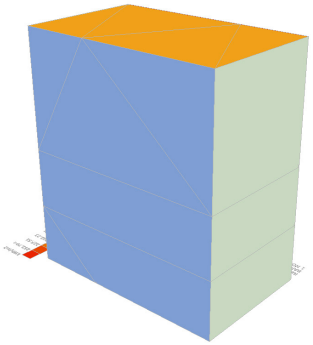
Summer radiation, north view
May 1st - Aug 31



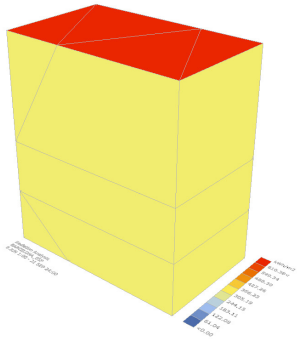
Winter radiation
Nov 1st - Jan 31



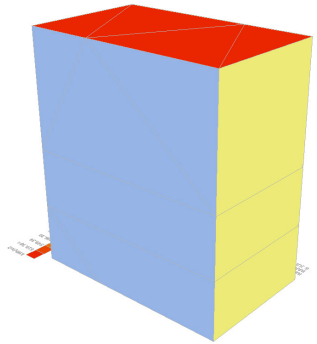
Winter radiation, north view
Nov 1st - Jan 31



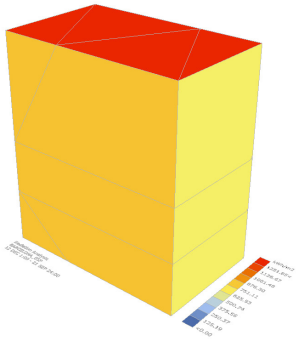
Summer solatice radiation



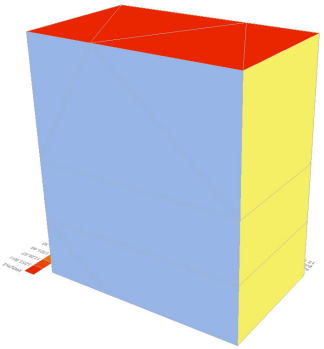
Summer solatice radiation, north view



Winter solatice radiation



Winter solatice radiation, north view



Design Data : Building Geometry

METHODOLOGY

The research utilizes basic forms came from the modern architect Toyo Ito's facade renovation of "Suites Avenue Aparthotel" in Barcelona. However, the form and its design usage would be different from Toyo Ito's façade. We will use gap between sea wave shapes serve as windows for daylight while amount of light and glare can be adjusted by their dimensions and locations. The tilting angle of the design serve the function of eaves and control the angle and amount of light.

DESIGN

Building's Surface Area where the sea wave façade is mounted. (Figure 1) We will designate its width and height as W and h. The research is designed such that it can be adopted in various sizes and shapes of the building.

DESIGN OPTIONS INTO EQUATIONS

Methodology

Design

Building's Surface Area where the sea wave façade is mounted. (Figure 1) We will designate its width and height as W and h. The research is designed such that it can be adopted in various sizes and shapes of the building.

Design Options into Equations

Design by how many waves there are in first row horizontally. Different number of imaginary Rods will be placed and marked as nR.
For example, (Figure 2) is 3R and (Figure 3) is 5R
In (Figure 2), the distance between two rods is w/(R+1) (1)

Design by the variations of depth, in other words, amplitude difference of each wave. (Figure 4)
For example, d, d/2, d/4 (Figure 5)

Design by different number of horizontal wave lines. Since the surface is divided by m, number of divided surface is m+1
For example, (Figure 6) is when m=2
In (Figure 6),
the distance between two lines is h/(m+1)
And m + 1 < h (2)

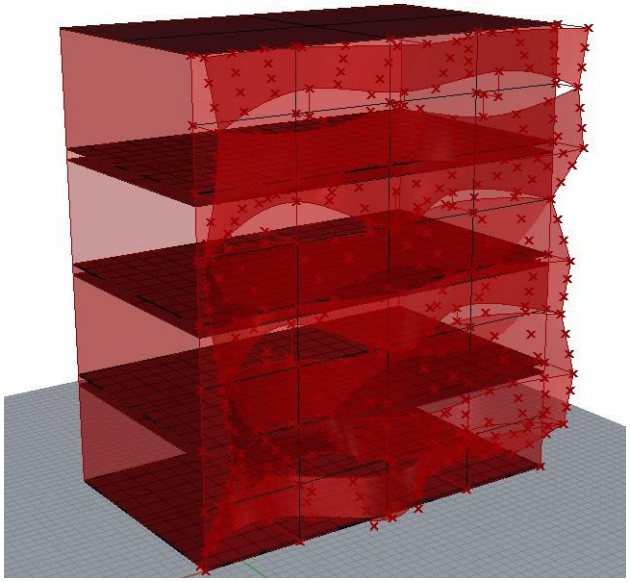
Design by whether the d is negative or positive. See (Figure 7). Or by connecting the center point of each rod, estimate d. When this connected line is to be 0, d is either – or +.
Here, for example, let's say R=4, which means there are 4 Rods. (Figure 7) The equation of the graph can be + - + -. ¬¬
There are numerous possibilities, such as + - + +, + + - +, + - - +, - - + +… (Figure 8).
To avoid the mere parabola shape and maintain the base line of "sea wave shape", there should be at least one negative and one positive d. (Figure 9)

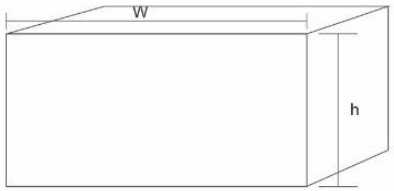
Resulting Equations

See (Figure 10) and (Figure 11). Let's say, left top hand comer point is P_1,1(X, Y, d_1) . X=w/(R+1) , Y=h/(m+1)
Therefore,
the point P_1,1 is (w/(R+1), h/(m+1),d_1). (3)
In addition, Z= (d_1+d_2) × w/(R+1)×1/2 (4)

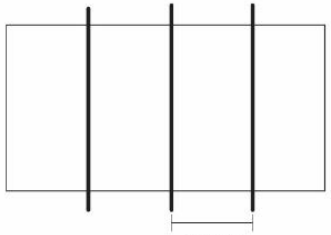
In conclusion,
P_(i,j)= (i × w/(R+1) , j × h/(m+1) , d_(i,j)) (5)

With this equation, we now know all the x, y, z value of every point, regardless of any shape that was formed by the sea wave façade.
In NURBS Geometry tool, Grasshopper (Gh), use command 4 points to form surface. For example, in (Figure 12).
This command makes a surface with P_1,1, P_2,1,P_1,2 , P_2,2, which are four end points of the surface.

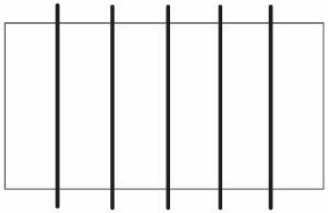


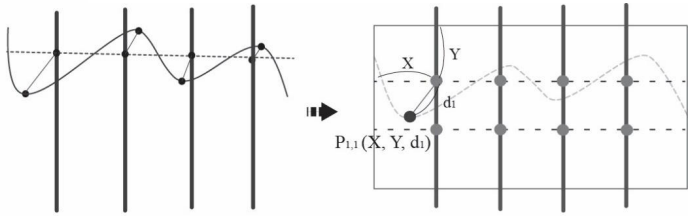


(Figure 1)

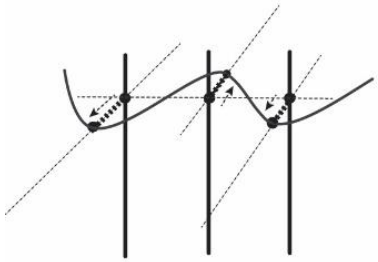


(Figure 2)

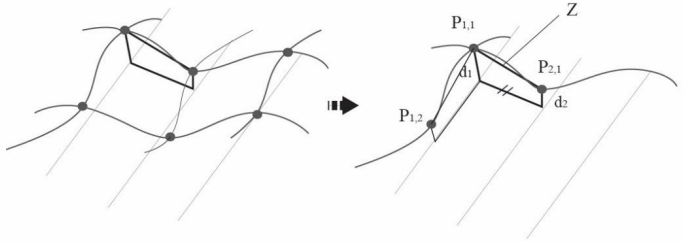

(Figure 3)



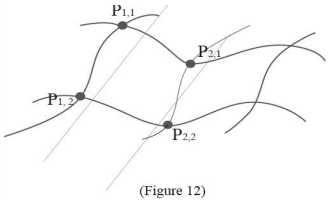
(Figure 10)


(Figure 4)

(Figure 5)



(Figure 11)



(Figure 12)

DESIGN OPTIONS AND QUANTIFYING AESTHETIC VALUE

Categorizing possible design forms of the facade to match individual's aesthetic sensibility. First, quantify the design and allow the architect or the client to choose design options by stating their desired form. Then, for the design styles that are close to the desired forms, add environmental factors. Categorize the resulting forms into 9 different options and allow the architect or the client to choose amongst these options again for the final form.

To explain the shape clearly. List the characteristics of the façade style by cutting the panel into sections and recognizing their shapes from the top view. As an option, the overall façade shape can be formed like (Figure13), by multiple selection of each design style A-1, A-2, B-1, B-2, C-1, C-2, D-1, D-2. Here, A-1 and A-2 is opposite value options, number 1 or 2 have to be chosen in A. Therefore, example, one
can choose A-1, B-2, C-1, D-2.
A-1. Winding, High frequency wave shape and Short period
A-2. Smooth, Low frequency wave and Long period
B-1. High pitch, Protrude and High wave
B-2. Low pitch, Even, Low wave and Preference for straightness
C-1. Preference for concavity, Many numbers of concaves
C-2. Preference for convexity, Many numbers of convexes
These depends greatly on surroundings of the building,
on site limitation, on the size of room's limitation and
how far the light should reach, and on comfort level of
heat temperature, light and glare.
As a whole façade,
D-1. Preference for consistency and uniformity, Simple D-2. Preference for inconstancy and irregularity, Complex NURBS Geometry tool, Grasshop per (Gh), is used.
Each floor has 2 façade panels as in the upper panel and lower panel, like (Figure 13). They would function as overhang and constrain window exposure. The Daylight would be controlled by the façade's angle, shape and the gross area.
The sample building is 4 floors high. Here, each point has 3 dimensional locations, X- axis, Y-axis and Z-axis (x , y_xz, z). Value of y varies from y_1 (xz) to y_2 (xz). The point travels straight, along the Y-axis. Its value is defined by given values of the x and z.

First point at the top and on the most left hand side is point (0, y_00, 0). In addition, the point at the bottom on the most right hand side ends with point (5, y_58, 8).
There are total of 5 points in X –axis along the building's width. Since it is 4 floors high, there are 8 points in Z-axis. In equal distances apart, there are total of 5 points located along the straight line of X-axis on the building's edge. These points project in and out perpendicularly to the/ straight line of X-axis on the building edge. Each point's y values are connected in Number Slides through NURBS Geometry tool, Grasshopper (Gh). Accordingly, these are moving points' y values within certain given ranges. Likewise, in façade, one story has at least the total of 15 controlled points.
Using NURBS Geometry tool, create interpolated curves through a set of these points. Construct a parametric curve that passes through a set of points. (Figure 14)
In addition, using Lagrange interpolate, the curve is,

$$\sum_{i \in points} p_i \emptyset_i{}^{(l)}(t) \qquad (6)$$

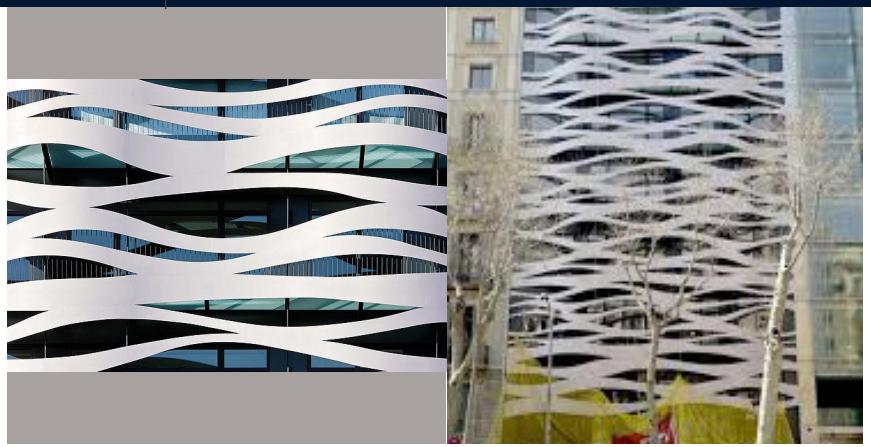
It uses Lagrange polynomials, 1 at the relevant point and 0 at all others to construct the curve. If an interpolation is drawn by a polynomial of degree of 4, graph is gradual and rounded (Figure 15). If an interpolation is drawn by a polynomial of degree of 14, it is steep and pointy (Figure 16). Here, we gave a polynomial of degree of 3(Figure 17).

A-1 and A-2 have the same design language category but, aesthetically, they possess opposite characteristic. A-1 is Winding, High frequency wave shape and Short period while A-2 is Smooth, Low frequency wave and Long period.

Current Toyo Ito's facade with single story building

DAYLIGHT PERFORMANCE ANALYSIS WITH 5 STAGE OF THE BUILDING OPTIONS IN BARCELONA:

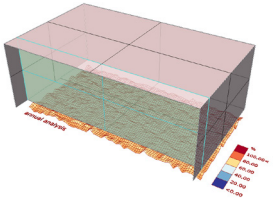
TOYO ITO 'S SUITES



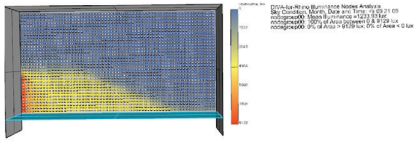
It is flat shading withought degree of tilting, no overhang. In other words, no depth on the exhisting shading.

Dimention::
Width: 11.83m / Length: 7.14m / One story Height: 3.35m
Materials
Wall : Interior and exterior: White patinted wall: R reflectance 0.8316 / G reflectance 0.8116 / B reflectance 0.72266
Window: Glass : R Transmittance 0.08 / G Transmittance 0.08 / B Transmittance 0.08
(Material Ref: Berkeley Lab Window 7.4 software)
(Material Ref: Singapore university of technology and design with MIT_ Design for climate and comfort lab:: http://lighting-materials.com/)

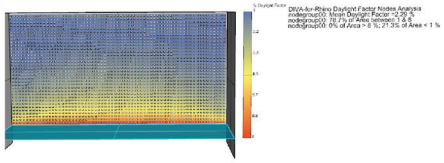
Before Renovation - Without Seawave Facade



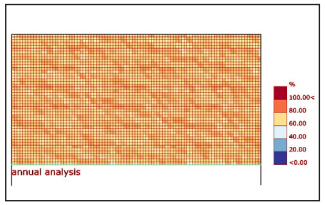
Mean Illuminance 1233.93 lux
SEP 21



Mean Daylight Factor 2.29%
SEP 21

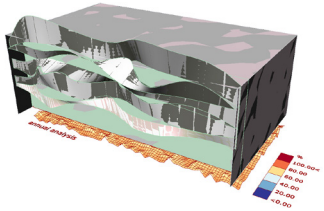


UDI

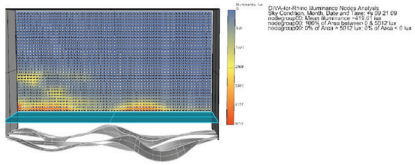


DATE: ANNUAL ANALYSIS
UDI RANGE: 100~2000 LUX

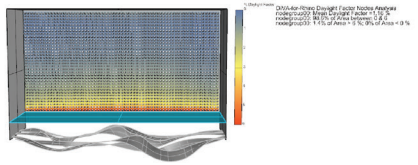
After Renovation - With Seawave Facade



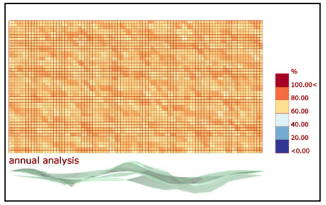
Mean Illuminance 419.61 lux
SEP 21



Mean Daylight Factor 1.16 %
SEP 21



UDI



Single story building with no sea wave facade

USEFUL DAYLIGHT ILLUMINANCE (UDI) PERFORMANCE ANALYSIS WITH 5 STAGE OF THE BUILDING OPTIONS IN BARCELONA:

Date: Annual Analysis
Location: Barcelona
Wether data: (https://energyplus.net/weather-download/europe_wmo_region_6/ESP//ESP_Barcelona.081810_IWEC/all)

UDI range: 100~2000 lux

Dimention::
Width: 11.83m / Length: 7.14m / One story Height: 3.35m

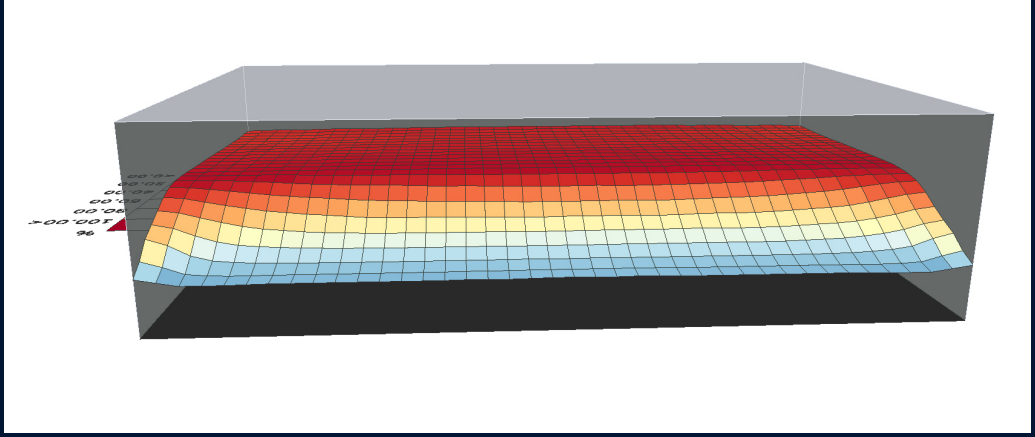
Materials
Wall : Interior and exterior: White patinted wall: R reflectance 0.8316 / G reflectance 0.8116 / B reflectance 0.72266
Window: Glass : R Transmittance 0.08 / G Transmittance 0.08 / B Transmittance 0.08

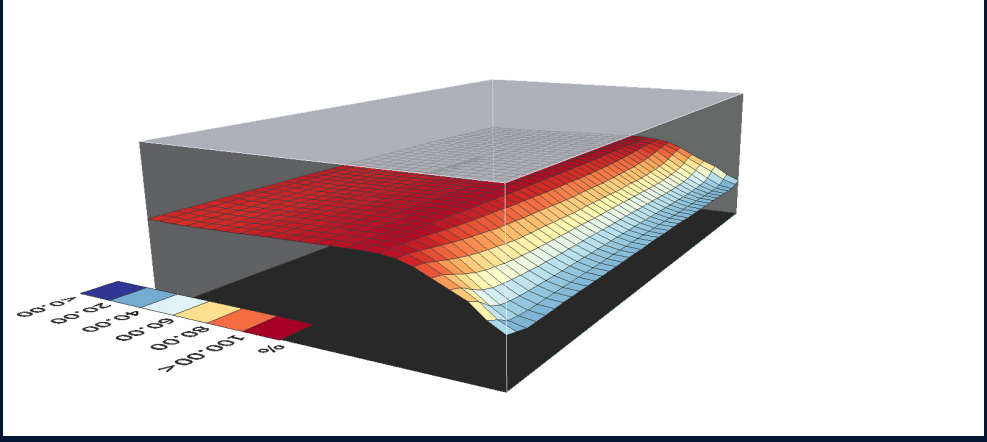
(Material Ref: Berkeley Lab Window 7.4 software)
(Material Ref: Singapore university of technology and design with MIT_ Design for climate and comfort lab:: http://lighting-materials.com/)

The image showing the UDI in the range of 100 ~2000. It is annual analysis, analysed through out the year.

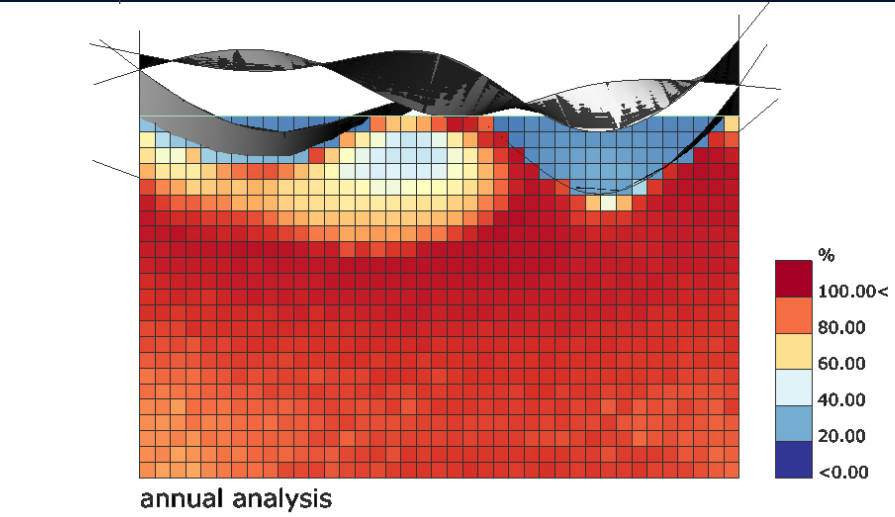
This metric bins hourly time values based upon three illumination ranges, 0-100 lux, 100-2000 lux, and over 2000 lux. It provides full credit only to values between 100 lux and 2,000 lux suggesting that horizontal illumination values outside of this range are not useful. (Ref: http://patternguide.advancedbuildings.net/using-this-guide/analysis-methods/useful-daylight-illuminance)

The images showing the graphical percentage values. Colors are showing percentage of UDI that is in the range of 100-2000 lux.

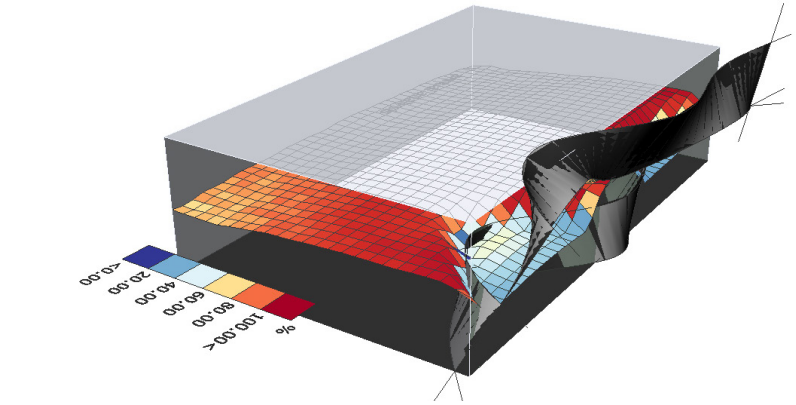


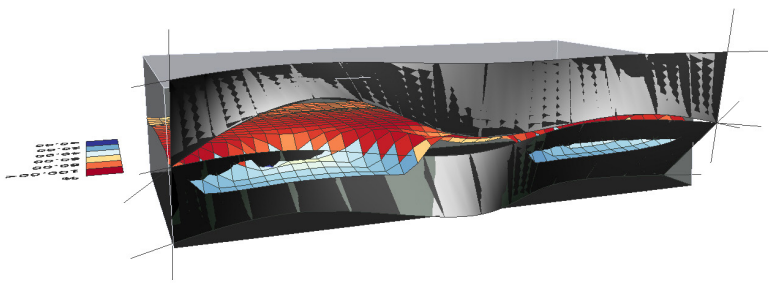


It is showing a one story of the building in Barcelona with the size and portion of the original builing.



annual analysis



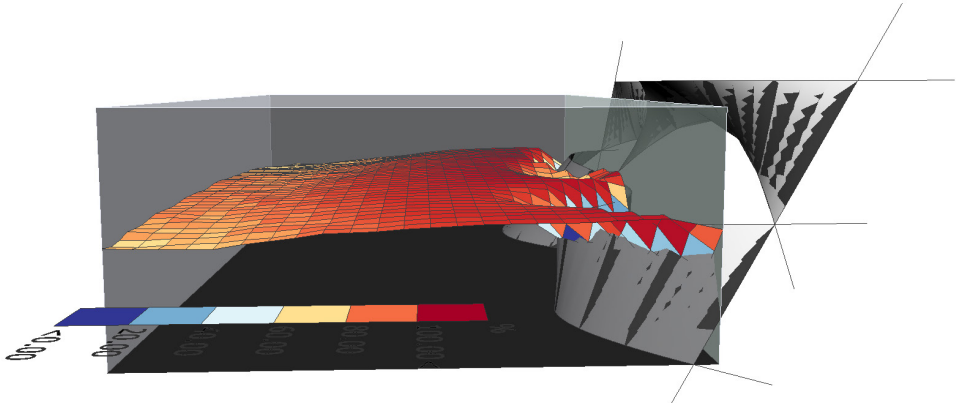


Single story building with Genetic Algorithm (GA) produced facade

USEFUL DAYLIGHT ILLUMINANCE (UDI) PERFORMANCE ANALYSIS WITH 5 STAGES OF THE BUILDING OPTIONS IN BARCELONA:

It is tested with one story building with GA produced facade. Annual UDI that is in between 100 lux to 2000 lux, is showing in the range from 20% to 100%. It is in comfort range.

Date: Annual Analysis
Location: Barcelona /Wether data: (https://energyplus.net/weather-download/europe_wmo_region_6/ESP//ESP_Barcelona.081810_IWEC/all)
UDI range: 100~2000 lux
Materials
Wall : Interior and exterior: White patinted wall: R reflectance 0.8316 / G reflectance 0.8116 / B reflectance 0.72266
Window: Glass : R Transmittance 0.08 / G Transmittance 0.08 / B Transmittance 0.08
Seawave Facade: Polished Aluminum and Polished steel : R reflectance 0.65 / G reflectance 0.65 / B reflectance 0.65
(Material Ref: Berkeley Lab Window 7.4 software)
(Material Ref: Singapore university of technology and design with MIT_ Design for climate and comfort lab:: http://lighting-materials.com/)



Full story building with Genetic Algorithm (GA) produced facade

USEFUL DAYLIGHT ILLUMINANCE (UDI) PERFORMANCE ANALYSIS WITH 5 STAGES OF THE BUILDING OPTIONS IN BARCELONA:

It is tested with full story building with GA produced facade. The images on the left is indicating annual UDI, that is in between 100 lux to 2000 lux, is showing in the range from 20% to 100%. 70% of the floor area is in the over 60% of the UDI. It is in comfort range.

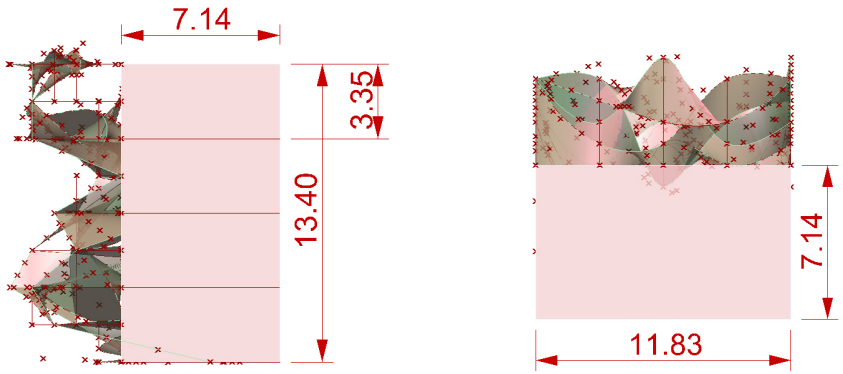
Date: Annual Analysis
Location: Barcelona
Wether data: (https://energyplus.net/weather-download/europe_wmo_region_6/ESP//ESP_Barcelona.081810_IWEC/all)

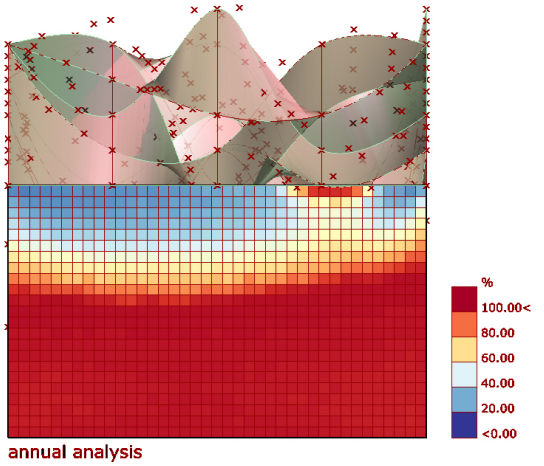
UDI range: 100~2000 lux

Dimention::
Width: 11.83m / Length: 7.14m / One story Height: 3.35m / Total Builidng Height: 13.40 m /

Materials
Wall : Interior and exterior: White patinted wall: R reflectance 0.8316 / G reflectance 0.8116 / B reflectance 0.72266
Window: Glass : R Transmittance 0.08 / G Transmittance 0.08 / B Transmittance 0.08
Seawave Facade: Polished Aluminum and Polished steel : R reflectance 0.65 / G reflectance 0.65 / B reflectance 0.65

4 stories building dimensions in meters





Full story building with optimized facade that integrating individual's aesthetic sensibility and environment based daylighting performance : 1st test

USEFUL DAYLIGHT ILLUMINANCE (UDI) PERFORMANCE ANALYSIS WITH 5 STAGES OF THE BUILDING OPTIONS IN BARCELONA:

1 ST TEST WITH ALL 8 DESIGN OPTIONS SET TO AVERAGE (MIDDLE) GENETIC ALGORITHM WITH GALAPAGOS

Date: Annual Analysis
Location: Barcelona
Wether data: (https://energyplus.net/weather-download/europe_wmo_region_6/ESP//ESP_Barcelona.081810_IWEC/all)

UDI range: 100~2000 lux

Dimention::
Width: 11.83m / Length: 7.14m / One story Height: 3.35m / Total Builidng Height: 13.40 m /

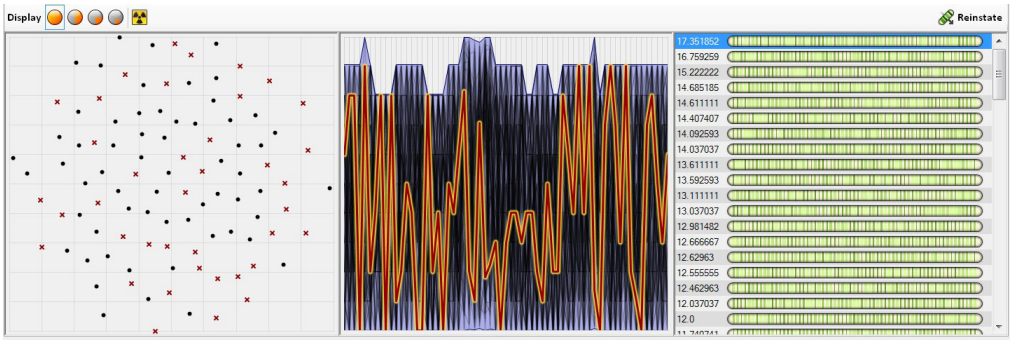
Materials
Wall : Interior and exterior: White patinted wall: R reflectance 0.8316 / G reflectance 0.8116 / B reflectance 0.72266
Window: Glass : R Transmittance 0.08 / G Transmittance 0.08 / B Transmittance 0.08
Seawave Facade: Polished Aluminum and Polished steel : R reflectance 0.65 / G reflectance 0.65 / B reflectance 0.65

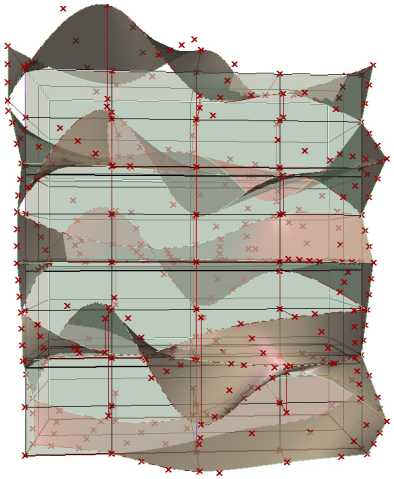
(Material Ref: Berkeley Lab Window 7.4 software)
(Material Ref: Singapore university of technology and design with MIT_ Design for climate and comfort lab:: http://lighting-materials.com/)

Generation and chrome

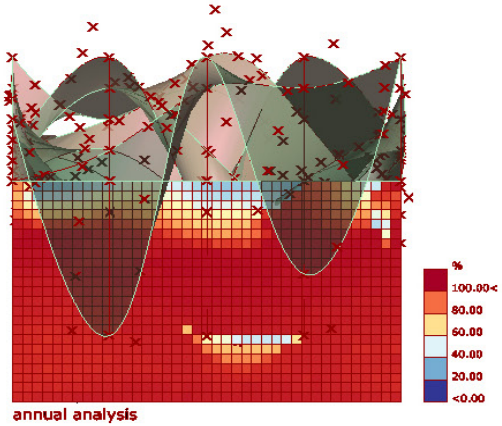
GENETIC ALGORITHM (GA) PROCESS
AESTHETICS + ENVIRONMENTAL

The Genetic algorithm goal is set to 8 design options to be average (middle)
Design result with Genetic Algoritm that is closest to goal condition was value of 17.351852.
Used Galapagos to find the genoms that matches the most.
The algorithm finds out the forms that matches the asthetics value and the best performance, both together.

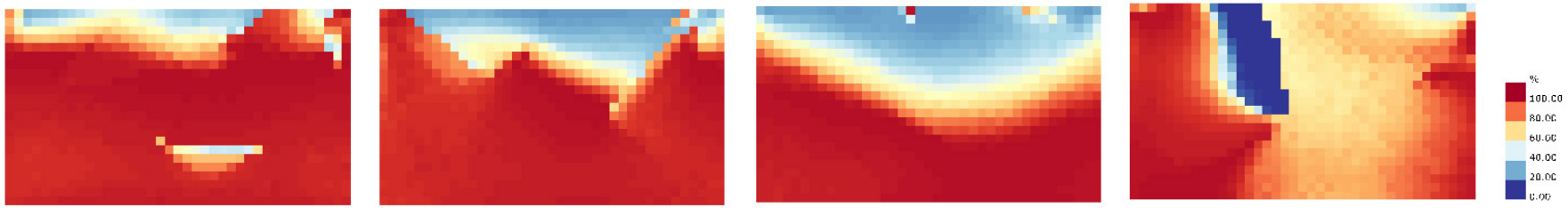




The image on the left is showing the facade form that satisfyig the 8 design options to be average (middle), which is the Genetic Algoritm (Galapagos) value of 17.351852.
As one can see from the material list, the facade is made out of high reflect material , which is Polished Aluminum and Polished steel, that each RGB reflectance of 0.65.
The seawave facade that is located more of west is tilted toward south west and more opend up. Also it is fliped to reflect the more daylight into the bulding in the late afternoon to before the sun set.
On the other hands, that is located directly to the south, large portion of the facade is covered by the seawave facade.
The facade that is located more of east is tilted toward south east and it is adequatly opened up to inlet the morning sun and light up the room with the proper amount of sun light.



The image on the left is showing the top view of the building. In addition, below is showing UDI of a whole year for each floor.
It is showing UDI value of from 100lux to 2000lux. Therefore, 1st floor UDI is stil in acceptable rate. However, the time for finding proper genome can be extended in Galapagos algorithm and there might be more chance to findd the better seawave facade form that would be more higher performance.



annual analysis 4th floor 3rd floor 2nd floor 1st floor