

# The Optimization of Static Shading Devices for Educational Building Facade in Paris

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**Abstract:** The popularity of modern architecture came to a widely use of curtain wall in all building types, whether it is “form follows function” or “function follows form”, the abuse of high window-to-wall ratio for the educational building caused various negative effects on students because of the neglect of sustainable. This research paper is a preliminary exploration for passive solar design in complex educational building. The propose is to explore the design space of good options of static shading devices for improving the performance of complex building envelope. The main approach is to combine shading device parameters with weather data and building performance metrics. This study explores the optimum shading device for the single classroom in ENPC and a complex project provided by ECHOES.PARIS in a set of scientific ways. The results show that genetic algorithm is applicable to search for the optimum shading device for small-scale architecture. For the complex building envelope, performance improvement is possible but strategies are needed to look for the better shading solution.

**Keywords:** shading device; data driven; optimization; comfort; sustainable; passive solar building design; educational building

## Introduction

Influenced by modern architecture, large window-to-wall ratio became popular in educational building. However, the negative impact caused by excessive sunlight such as visual discomfort, thermal discomfort and excessive cooling load haven't been seriously taken into consideration. According to the surveys in the Fresno district, California [\[1\]](#), classroom with pleasant view to the outside can increase students' performance. Glare from direct sun and chalkboard can cause distraction. In addition, direct sun penetration from unshaded window facing east and south is likely to cause glare issue and thermal discomfort.

There are many different ways to control the direct sun beam shining into the interior. Solar shading devices have shown the highest energy efficiency especially in warm summer climates [\[2\]](#). Alternatively, external shading device is much more effective than internal one because it blocks the solar radiation before reaching the indoor environment [\[3\]](#). Nonetheless, there are only several primitive models [\[4\]](#) [\[5\]](#) for external shading device which can only be applied to simple architectural geometry. In the context of complex architecture with huge amounts of windows and complex adjacent context, those traditional shading models will fail. Thus, data management is necessary as it can handle all the complex demands efficiently.

One of the most handy software is Rhinoceros Grasshopper<sup>1</sup>. As the analyze and optimize of sunlight need a big variety of softwares, one of the biggest advantage of

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<sup>1</sup>Grasshopper is a graphical algorithm editor that allows users to create a logic tree containing functions and parameters that generate geometry. Any changes made to the parameters affects the resulting geometry (McNeel, 2010).

grasshopper is the collaboration with other environmental softwares such as Daysim, EnergyPlus, Radiance and Openstudio.

By reason of too many variables could be involved in this research, to clarify, in order to ensure the integrity and accuracy, the weather file is Paris\_Orly\_France provided by EnergyPlus<sup>2</sup>, the classroom for the optimization is our classroom in Ecole des pont Paristech in Paris, the complex building is one of the block in Solar Generative Massing provided by Echoes.Paris, the material of the shading device is fixed. The only variables in the simulation are the parameters to control the shading geometry.

The first part of this research paper is the investigation of previous achievement about static shading device and the hypothesis of its potential. The second part is the performance optimization for the single classroom, the aim is to look for the optimum shading geometry for a certain objective room. The third part is exploring the possibility of performance optimization for the complex building envelope with shading devices.

One of the goals of this research is to provide new insight into the impact of luminance distributions by applying the optimum shading device, so as to reduce visual discomfort and thermal discomfort for the students while keep appropriate daylight for the room.

## 2 Context

### 2.1. Previous achievements

There are many school projects trying to use shading strategies such as China Academy of Art Xiangshan Central Campus (Hangzhou, 2002-2007) by Wang Shu. As shown in figure 1, the building overhanging its roof and design vertical fins on south facade [6] as shading devices. However, despite the positive efforts, daylight is only considered as some additional value for the design because of the difficulties to quantify the amount of daylight.



Figure 1: Different shading strategies  
(Photography Iwan Baan, 22/10/2007)



Figure 2: Same shading geometry in all the building  
(Cécile de Mauroy, 13/06/2017.15:34)

Another example is SOGECAMPUS (figure 2) located in Fontenay-sous-Bois, Paris. The building designed shading device for both side of the long axis facade. However, different facade won't have the same sunlight, likewise the building in the middle will have less sunlight

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<sup>2</sup> EnergyPlus is funded by the U.S. Department of Energy's (DOE) Building Technologies Office (BTO), and managed by the National Renewable Energy Laboratory (NREL). EnergyPlus is developed in collaboration with NREL, various DOE National Laboratories, academic institutions, and private firms.

because of the context. If considering the function of the shading device, they shouldn't be the same typology in different facade.

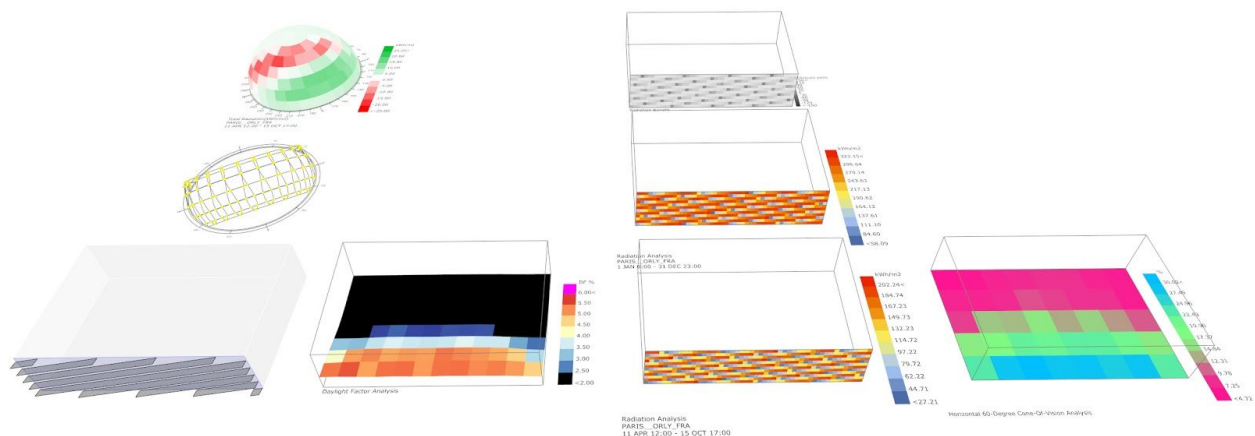
Simos Yannas is the Director of the Environment & Energy Studies Programme at the Architectural Association School of Architecture, London. He has an influential two-volume publication named *Solar Energy and Housing Design: Vol 1: Principles, Objectives Guidelines* [7], *Vol 2: Examples* [8]. It demonstrates how available sunlight can be used as part of site planning and architectural design to keep indoor temperature in comfort range and reduce energy consumption for heating. In Volume 1, he proposed designing with climate which is very different from the traditional approach to architecture design: form and function. By studying and analyzing the climate in UK, he proposed several different approaches to indoor comfort including heat loss control, passive solar heating and building forms. Despite these two books are the guidelines of housing design, the concept and the perspective of his thoughts are valuable references for environmental design.

If shading devices are well designed, the building can be much more sustainable. This is not only reflected in reduction of the energy consumption such as cooling and heating load, but also in the improvement of user experience and comfort. It is suggested that without science, architecture cannot be sustainable [9]. Science can give valuable design tools and also provide checking for use as the design develops. That is to say, for the optimization of shading device, we shouldn't rely too much on our past experience [10], a set of scientific methods is necessary.

"If I have seen further it is by standing on the shoulders of Giants."

—— Isaac Newton in 1675

This research is a further study of *SHADING MOO* research by Sebastien Perrault in *ECHOES.PARIS*. During the previous study, blades and skeleton mesh have been proposed as shading device for a shoebox, the performance of the shoebox has been analyzed with Ladybug and Honeybee plug-ins by three different analysis metrics – daylight factor, radiation benefit and view to outdoors. Figure 3 shows one derivative of blades and its analysis results. However, if the research subject is multiple classrooms with context, how to address appropriate shading device for each room become a problem. Inspired by this study, the research for optimization of shading device for the complex educational building performance was proposed.



## 2.2. The climate in Paris

Climate study is necessary [11] for the optimization because climates are specific to locations and context<sup>3</sup>. This can be reflected in the adjacent context and landscape neighboring as well as the global airflow such as mid-latitude cyclonic cells [9].

In the meantime, correct weather data is necessary for the simulation. Weather data can be found in many websites, yet wrong data will cause inaccurate calculation. Hence, EPW file used in this research was downloaded from EnergyPlus. By the consideration of global warming which can be reflected in the increase of temperature, relative humidity, solar radiation, daylight illuminance as well as the change of wind speed and direction, to extend life cycle of static shading device, EPW file was transformed into future weather at 2050 by CCWorldWeatherGen<sup>4</sup>. With Ladybug and Honeybee, weather information can be extracted from EPW file and be visualized in Rhino. In addition, considering the optimization objective is educational building, to simplify the analysis period, occupancy period is all year between 9h to 18h.

The solar radiation admitted into the classroom may have serious impact on thermal comfort and visual comfort. In order to understand when is the harmful and helpful radiation, a diagram represents the relationship between outdoor temperature, radiation and comfort band for the average hour of each month has been generated based on Paris weather file 2050 (figure 4). As shown in the diagram, the maximum dry bulb temperature is 35.8°C in August, the minimum dry bulb temperature is -5°C in December. If considering discomfort when the average temperature is outside the comfort band, it can be concluded from figure 4 that the solar radiation is harmful in August and helpful from October to May. This can inform that shading device should minimize solar radiation in August and maximize from October to May.

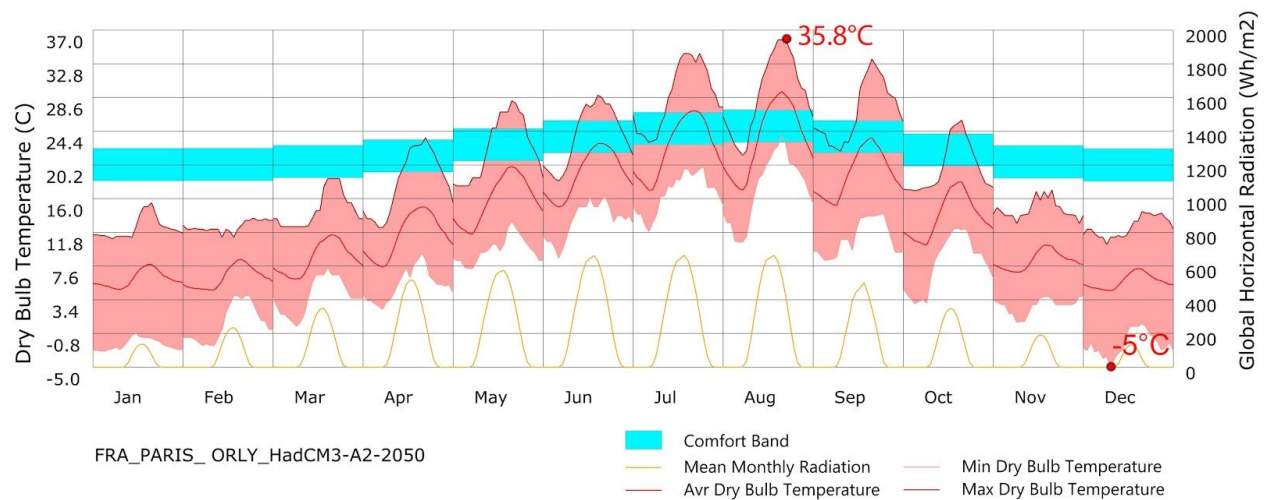


Figure 4: Outdoor temperature and radiation analysis & Adaptive comfort by ECHOES.PARIS

<sup>3</sup> The primary aim of Global Solar Atlas is to provide quick and easy access to solar resource data globally, at a click of a mouse. <https://globalsolaratlas.info/>

<sup>4</sup> The climate change world weather file generator allows you to generate climate change weather files for world-wide locations ready for use in building performance simulation programs.



### 2.3. Design requirements

Today, the lighting condition in the classroom has been improved by the popularity of curtain wall. However, without knowing the character of local climate, design large glazing blindly brings more sunlight and creates better view to outside, it also brings unwanted sunlight which causes visual discomfort and thermal discomfort.

Due to the particularity of the educational buildings, appropriate daylight in classroom and other educational spaces such as library, laboratory is vital for students. Excessive sunlight can cause thermal discomfort and glare issue, insufficient sunlight can cause students' myopia [12]. These discomfort have more effect on students as they are still growing up. They're detrimental to students' healthy and decrease productivity as well. Figure 5 shows the glare issue caused by direct sun in our classroom which also happens frequently all around the world.



Figure 5: Glare caused by direct sun

Over the years, different shading measures have been taken such as curtain, interior blinds or exterior louvers. To be noted that curtain or interior blinds are less efficient because solar radiation has already admitted into interior, it will have less contribution to lessen thermal discomfort and cooling load. Conversely, external shading devices are much more effective. As the raise of regulations and requirements for energy saving and performance, dynamic shading solution comes in which can significantly lower the energy consumption while keeps visual comfort and thermal comfort. In consideration of costs and mechanical maintain, static shading device shows its advantages and potential.

However, it's not clear for architects to evaluate what is the optimum static shading device for each window. The mainstream practice is simply design the shading device by experience, repeat and apply the same shading geometry to all the other windows. If by doing so, some spaces may still have sun exposure and some others may be even worse, cause overshadowing which could both block the sun and the views. Few architects can really design an optimum shading device which provides comprehensive comfort for indoor environment. It could be even more complicated when the context of each window are different.

Instead of boxing students in traditional classroom, the future of learning environments will be more diversified [13]. Each of the spaces will have different light or view requirements based on the content of course and teaching goal. Hence it's important to specify the shading device for each space. This can be realized by analyzing local climate and design requirements, scheme the optimization methodology, then use comparative studies and iteratives studies to look for the better solution. This methodology can be very useful for designers to take informed decisions. If shading device geometry could vary from spaces based on the corresponding

context, it can be very useful for educational facilities in providing comfortable study environment.

## 2.4. Analysis metrics

To evaluate thermal comfort and visual comfort, different analysis metrics will be studied [14] [15]. The analysis metrics are consist of two parts: First, climate-based metrics which are annual calculations and take the entire year into account, they are very heavy to compute in the simulation. Second, non-climate-based metrics for view evaluation and other metrics which doesn't need dynamic weather data. All the analysis metrics can be set up and simulate mainly by Ladybug and Honeybee<sup>5</sup>. The definitions are shown in Table 1.

Table 1: Definitions of the analysis metrics

Analysis Metrics		Definition
Non-climate based	Daylight Factor (DF)	Calculate the light condition under the worse sky scenario, this is to know if there are spaces with no adequately lit. According to BREEAM standard <sup>6</sup> , school space in Paris should have at least 60% of the occupancy space with DF > 1.8.
	Prospect Distance Evaluation (PDE)	Also called vis-a-vis. Evaluate 7 view angles range from -45° to 45°. Calculate the distance when the vectors touch other building.
	Visual Access to Landmark (VAL)	Calculate average visual access to landmark. The landmark could be green area outdoors or the recognizable monuments.
Climate based	Solar Radiation Benefit (SREb)	Represents the average subtraction of helpful and harmful radiation. The value reflects thermal discomfort and overshadowing probability.
	Mean Sun Vector in summer (MSVs)	Calculate the average mean sun vector and average sunlight hours for 6th May, 21th June and 5th August. This could be a reference for shading device parameters.
	Annual Sunlight Exposure (ASE <sub>1000,250</sub> )	Represent the area of the test point receive over 1000 lux daylight more than 250h a year. This can predict the appearance of discomfort glare in daylit spaces. According to LEED v4 <sup>7</sup> , ASE <sub>1000,250</sub> should be no more than 10%.
	Spatial Daylight Autonomy (sDA)	Describes the percentage of floor area that receives at least 300 lux for at least 50% of the active occupied hours. This metric can define whether a space has sufficient annual daylight, but it cannot identify whether the space has glare issue. According to LEED v4, sDA in school should be at least 55%.
	Useful Daylight Illuminance (UDI)	Represent for the percentage of the floor area that that meets the UDI criteria (100 to 2000 lux) for at least 50% of the active occupancy hours.

<sup>5</sup> Ladybug allows you to visualize EPW weather data, Honeybee can connects Grasshopper to other environmental softwares for building energy and daylighting simulation. These tools are able to build connection between weather data and analysis results.

<sup>6</sup> [BREEAM Hea 01 Visual comfort](#): Up to four credits - Daylighting (building type dependent).

<sup>7</sup> [LEED BD+C: Healthcare | v4 - LEED v4. Daylight](#).

## 2.5. Customized interface

Despite the convenience of grasshopper, another complexity is looking for the right button in grasshopper canvas. However, Human UI plugin offers a solution. By considering of the complexity of the code developed in Grasshopper, a customized interface (figure 6) has specifically been designed to simplify the workflow. All the analysis metrics simulations presented in sections 3.1 and 3.2 have been conducted by this tool.

## 2.6. Outline of genetic algorithm

Genetic algorithm can be quite useful for the shading device optimization as it links shading device parameters with analysis metrics results. Finding the right balance can provide appropriate sunlight and good thermal comfort while maintaining a good view to outside at the same time. In grasshopper, there are three famous genetic algorithms—Goat, Octopus, Galapagos. Each of them are excelled at different design criteria. The choice of the algorithms should be argued with reference to the nature (and number) of objective functions and of the variables. Table 2 shows the characteristic of each genetic algorithm.

Table 2: The characteristic of the genetic algorithm (by Cyril Douthe)

Plug-in	Algorithm	Type	Objective	Method
Goat	COBYLA	local	Single objective	Pseudo Gradient (linear approx.)
	BoBYQA	local	Single objective	Pseudo Gradient (quadratic approx.)
	Subplex	local	Single objective	Simplex like (or Nelder Mead)
	Direct	global	Single objective	Subspace exploration
	CR2	Global	Single objective	Evolutionary algorithm
Galapagos	Simulated annealing	Local	Single objective	
	Evolutionary	Global	Single objective	Simulated annealing
Octopus	Genetic algo	Global	Multi-objective	Evolutionary algorithm

According to the characteristics of these three genetic algorithms given in the table 2, when looking for multiple solution at the same time in each iteration during the optimization process, if using Goat or Galapagos, a new objective function which contains values of analysis

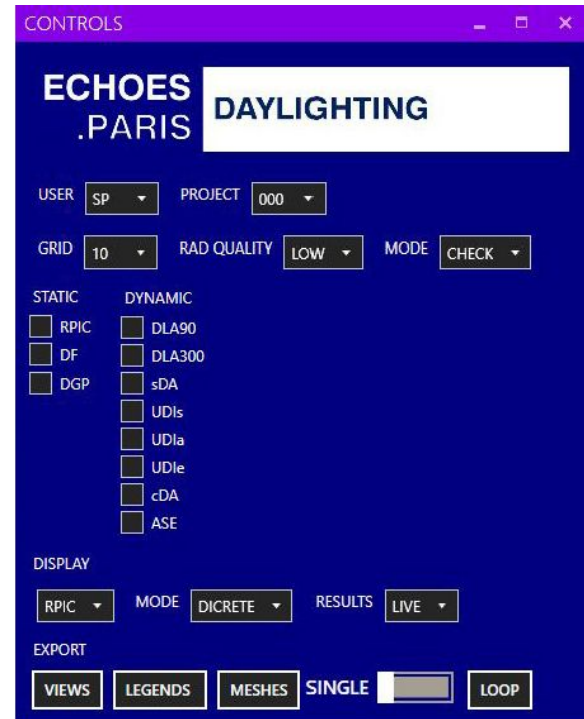


Figure 6: Customized Interface by ECHOES.PARIS

metrics need to be set up. Alternatively, weight can be assigned to the objective in order to add priority to a metric. If using Octopus, it is possible to run multi-objective at the same time and also export pareto front<sup>8</sup> in the end which can be used for visualization and results comparison.

Given the above, Octopus is more useful to search multiple results in the early stage, Goat and Galapagos are more potent to search for final results.

## **2.7. Hypothesis Investigation**

The climate of Paris is oceanic type, hot time is not long but daytime last long in the mid-term of the year. Thus, the priority for a school in terms of comfort is visual comfort instead of thermal comfort. By reason of different daylight and view requirements in different teaching spaces, is it possible to implement shading device that can reduce glare issue while keep good view and adequately lit for each space? In consideration of different context and requirements, how to choose and optimize a sun shading system? What are the best shading option that can be implemented for each space? How to design static shading device for the whole building that can improve visual comfort without cause overshadowing?

Through optimization process, genetic algorithm can search for multiple derivatives in parallel, each of the result will has its own advantages in different performance aspect. If develop an objective function that consider the weight of each metrics for respective space, it is possible to find the optimum shading strategy for the complex building.

## **3 Methodology**

### **3.1. Performance optimization for single classroom**

This process will study three commonly used and promising shading devices – blades [16], double-layer blades and perforated panel [17]. By optimizing the performance of our classroom in ENPC with different shading typologies, the relation between shading geometry and the performance of single room can be quantified, results can be the reference for the performance optimization for the complex educational building which may have multiple function in the next process.

Figure 7 shows the workflow of optimization process for our classroom. It contains three parts: inputs, analyze & optimize model and outputs. Inputs contain EPW weather file and analysis shoebox which are fixed parameters, parameters that control shading device geometry are the variable in the simulation. To evaluate the performance of the single classroom, six analysis metrics was chosen from table 1 for “Analysis Metrics” procedure, all of these metrics will be evaluated before implement shading devices, this is to examine the current conditions of the classroom and address the discomfort aspect for optimization. Metrics from 3 to 6 were chosen for the optimization process as they represents thermal comfort and visual comfort. Outputs have three parts, the first part is the optimization results exported from Octopus. The second part is the analysis results of all the six metrics which will only be analyzed before and after applied optimum shading device. The third part is result analysis in order to understand which metric has been improved and give guidelines for the optimization of complex building.

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<sup>8</sup> For a given system, the Pareto front is the set of parameterizations (allocations) that are all Pareto efficient.



For the optimization process, Octopus will use shading device parameters as genomes and analysis metrics result as objectives. By changing inputs parameters, analysis model will run the simulation and pass results data to Octopus. After that, Octopus will compare the results with previous then change input parameters and search for better solution.

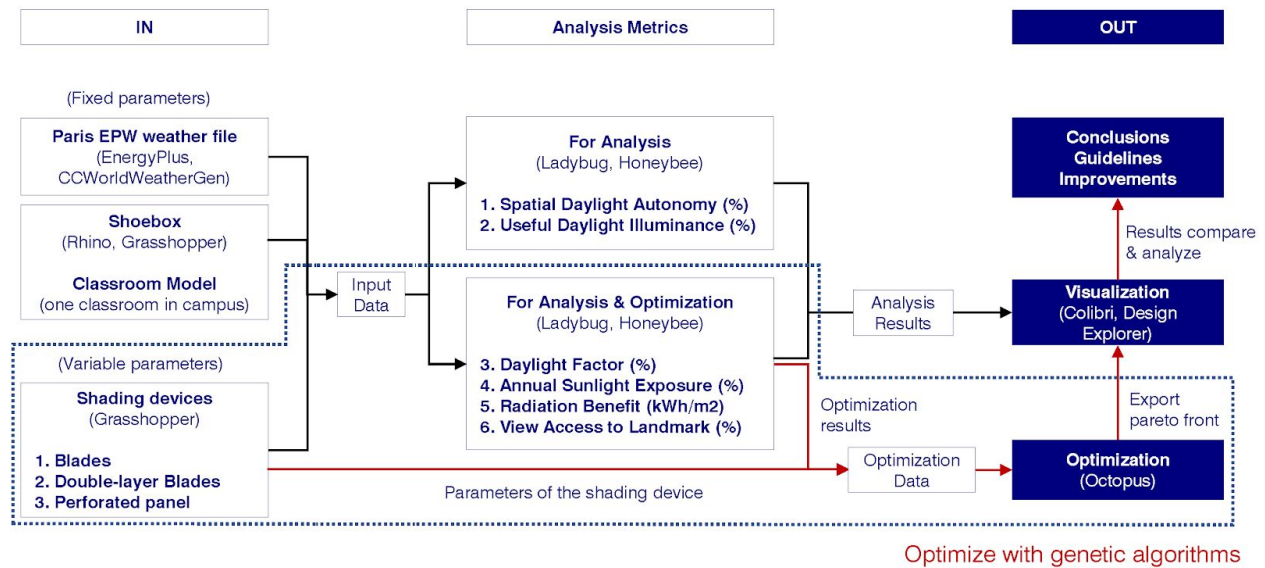


Figure 7: Workflow for single classroom optimization

### 3.1.1. Modeling the classroom and campus building

The main building of Ecole des ponts Paristech is on the east part of the Carnot building (figure 8) headquartered in Marne-la-Vallee (suburb of Paris), France. Connected by a big intersecting atrium, the building has three long, low glass building running parallel to the west-east axis. Each building has four floors with 133 meters long and 18 meters high.

In order to ensure the authenticity and accuracy, our classroom in ENPC was chosen as the optimization object. The classroom is on the third floor of the middle building (P321 bis). The distance from the previous building is 16.4 m, the height of the previous building is 18 m. The classroom is a rectangular space with 15 m long, 4.6 m wide and 2.75 m floor to ceiling height. The only window is fully glazed facing south. For the lack of information, visible transmittance for window was set to 0.8, the material used for floor, ceiling and walls were default materials from Radiance library. They are all fixed parameters. The model is shown in figure 9.

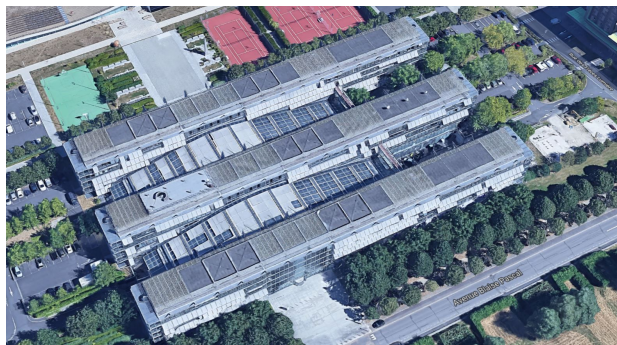


Figure 8: Carnot building. Google map 2018



Figure 9: Modeling the classroom

### 3.1.2. Current situation of the classroom

Before dive into optimization process, the current performance of the classroom without shading device should be examined. (figure 10). The aim is to address when shading device is needed and which discomfort aspect need to be reduced.

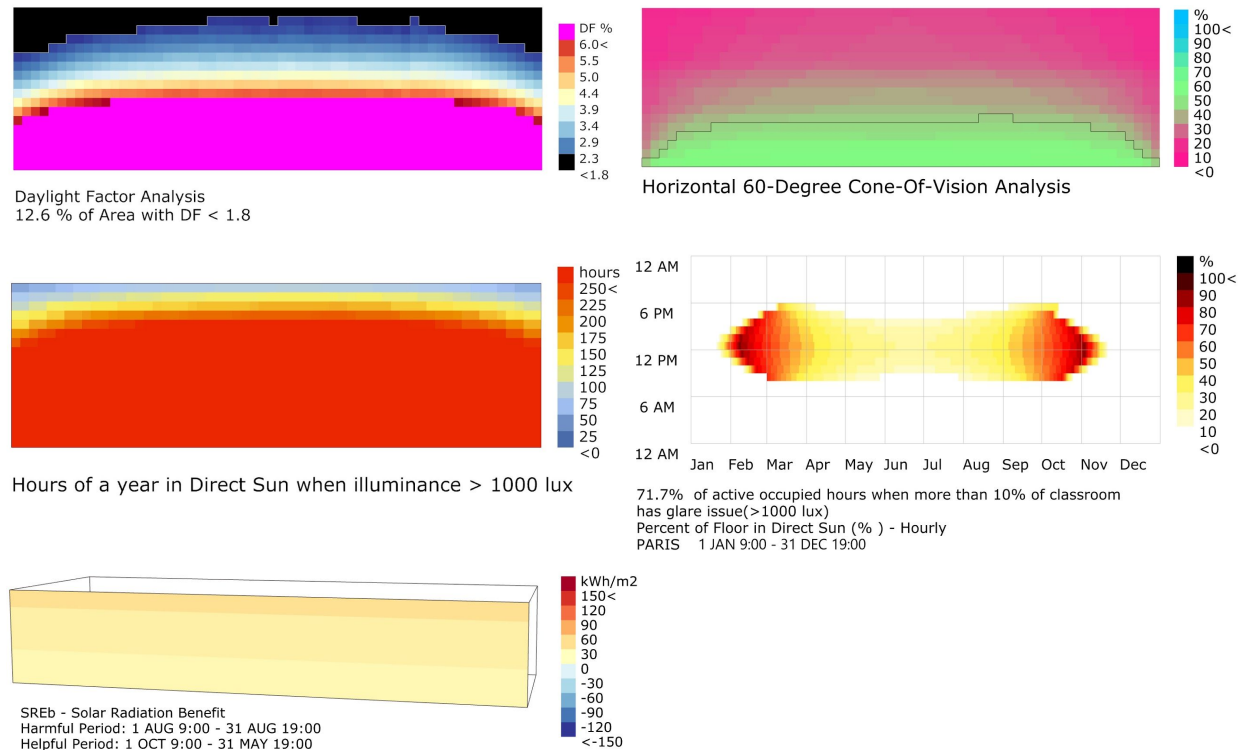


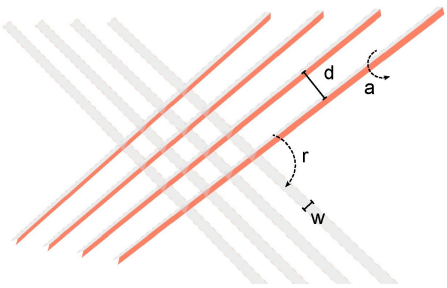
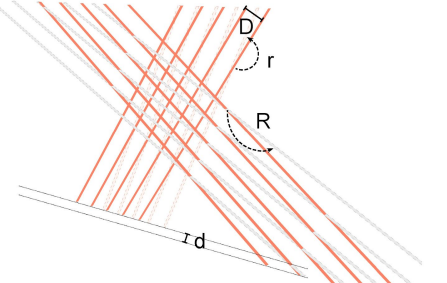
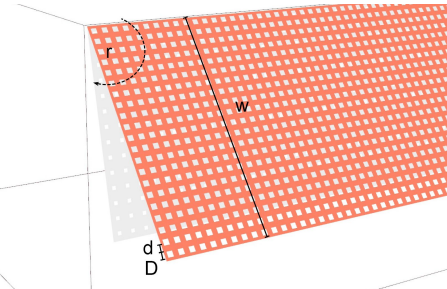
Figure 10: Analysis results for the current classroom

According to the analysis results, 87.4% of the space has DF more than 1.8, this means the classroom has adequately lit throughout the year as 80% is BREEAM requirement for educational building. Due to fully glazed facade on exterior wall, the current view represents for the maximum view value for this classroom. For glare issue, high “hours in direct sun” value for the majority test points means that the classroom has high potential suffer from glare discomfort. This is also reflected on annual graph which shows 71.7% of occupancy hours in a year that the classroom has more than 10% of space has glare issue. The diagram also shows that glare happens during February and November. To evaluate thermal comfort and overshadowing probability, solar radiation benefit (SREb) was developed. It calculates the average subtraction of helpful and harmful radiation. The higher value represents better thermal comfort and less overshadowing. The analysis period was defined by figure 4.

### 3.1.3. The parameters of the shading devices

Due to the variety of styles of shading typologies, in order to simplify the design space, four parameters (table 3) have been defined for each of three selected shading typologies [16][17] as representative studies, all of their material were the same customized aluminum.

Table 3: Input parameters of the shading devices

Input	Parameters	Images
Blades	<ul style="list-style-type: none"> <li>d: Blades distance (0.1 ~ 0.3 m)</li> <li>w: Blades width (0.1 ~ 1 m)</li> <li>a: Blades inclination (<math>-45^{\circ} \sim 45^{\circ}</math>)</li> <li>r: Blades rotation (<math>-90^{\circ} \sim 90^{\circ}</math>)</li> </ul>	
Double-layer blades	<ul style="list-style-type: none"> <li>D: Blades distance (0.1 ~ 0.5 m)</li> <li>d: Distance of two layers (0.1 ~ 0.3 m)</li> <li>R: Front layer rotation (<math>-90^{\circ} \sim 90^{\circ}</math>)</li> <li>r: Back layer rotation (<math>-90^{\circ} \sim 90^{\circ}</math>)</li> </ul>	
Perforated panel	<ul style="list-style-type: none"> <li>w: Width of panel (0.5 ~ 2 m)</li> <li>d: Distance of holes (0.005 ~ 0.1 m)</li> <li>D: length of side (0.01 ~ 0.1 m)</li> <li>r: Incline of the panel (<math>0^{\circ} \sim 90^{\circ}</math>)</li> </ul>	

Moreover, to avoid light penetrating through the corner, shading geometries have been extended (figure 11).

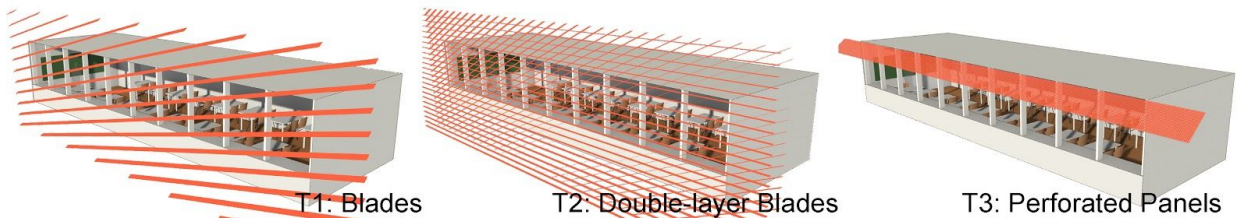


Figure 11: Extended shading geometries

### 3.1.4. Performance optimization for the classroom

The optimization process was conducted by Octopus in order to optimize multiple metrics. To ensure the efficiency of the optimization process, DF, ASE<sub>1000,250</sub>, SREb and VAL have been examined. To set up Octopus, genomes are shading device parameters, objectives are four analysis metrics results. Population size was set to 50, max generations was set to 5.

The running time of each shading typologies were 2h, 4h and 15h, this is because of the algorithms for each shading typologies are different, lead to the time difference for analyze.

After running the simulation for three shading device individually, pareto front can be exported from Octopus. For result visualization and comparison between different derivatives, Colibri plug-in and Design Explorer interface were used. By comparing and analyzing the result of derivatives, shading device parameters can be narrowed down. The new design space can be fed to Octopus genomes and run optimization for the second time, repeat this step.

As shown in figure 10, glare issue is the main problem of the classroom. To ensure view to outdoors, VAL is considered as second importance. By adjusting the selection range, derivatives with values outside of the range will be hidden. For example, if select small “ASE” values, derivatives with small “DF<1.8” values and “view obstructed” values will be hidden. By using several selection bars, derivative 565 for blades shading typology has been selected as one of the optimum pareto front among the other derivatives (figure 12). Analysis metrics and corresponding parameters are shown at the bottom left.

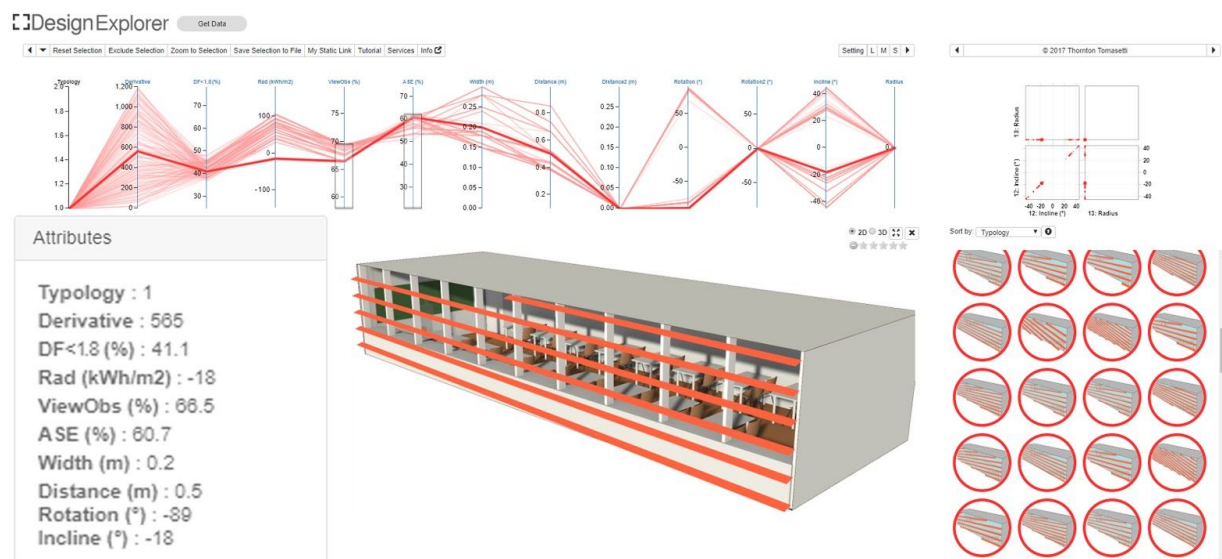


Figure 12: Pareto front in Design Explorer

To evaluate if blades shading derivative 565 can improve the general performance, the classroom has been analyzed by all the six analysis metrics along with this shading geometry. Table 4 shows the analysis results with and without the shading device.

Table 4: optimization results

	Non-climate based		Climate-based			
	DF>1.8 (%)	VAL (%)	SREb (kWh/m <sup>2</sup> )	ASE (%)	sDA (%)	UDI (%)
No Shading	87.6	43.1	-14.6	73.1	99	58
With Shading	69.7	33.4	-18	58.5	85.6	91
Improvement	-17.9	-9.7	-3.4	+14.6	-13.4	+33

notes: 1. In improvement row, “+” means good result, “-” means shading device made it worse.

2. Solar radiation benefit (SREb) value “-14.6 kWh/m<sup>2</sup>” means the average helpful radiation in cold hours is smaller than harmful radiation in hot hours.



### 3.1.5. Summary and conclusions

Even though blades shading derivative 565 causes little reduction in DF, VAL, SREb and sDA, but the reduced sDA is still higher than 55% which is the minimum requirement for schools described in LEED v4 – Daylighting. Alternatively, it's obvious that this shading geometry can improve UDI up to 91% and reduce ASE to 58.5%, these significant improvements are prior than maintain VAL and increase SREb.

The metrics used for the classroom can reflect the comfort level in visual comfort and thermal comfort. According to derivative results of pareto front from three shading typologies, despite some derivatives have significant improvement in SREb, but it causes overshadowing which has high negative effect on daylighting metrics. This suggests that blades has better advantages for improving the overall comfort than the other two shading typologies. If reduce the design space for blades parameters, it is possible to find better derivatives.

## 3.2. Performance optimization for complex educational building

### 3.2.1. Introduction of Solar Generative Massing project

Solar Generative Massing project studies the impact of sunlight and gravity on form, generates building scenario based on direct sunlight access parameters. The final geometry is based on “two hours morphology” instead of human experiences. That is to say, the orientation of the rooms and its context have more possibility than any real project. It can be a very good reference for optimizing the building performance with shading device.

The building has 12 floors in total. To simplify the model, each floor is 3 meters high. Facade is fully glazed, the size of each unit is 1.2 x 2.8 m with Visible Transmittance 0.8. The material of floors, walls, ceilings are the default radiance materials, the material for mullions and context buildings are “Context” material in radiance material.

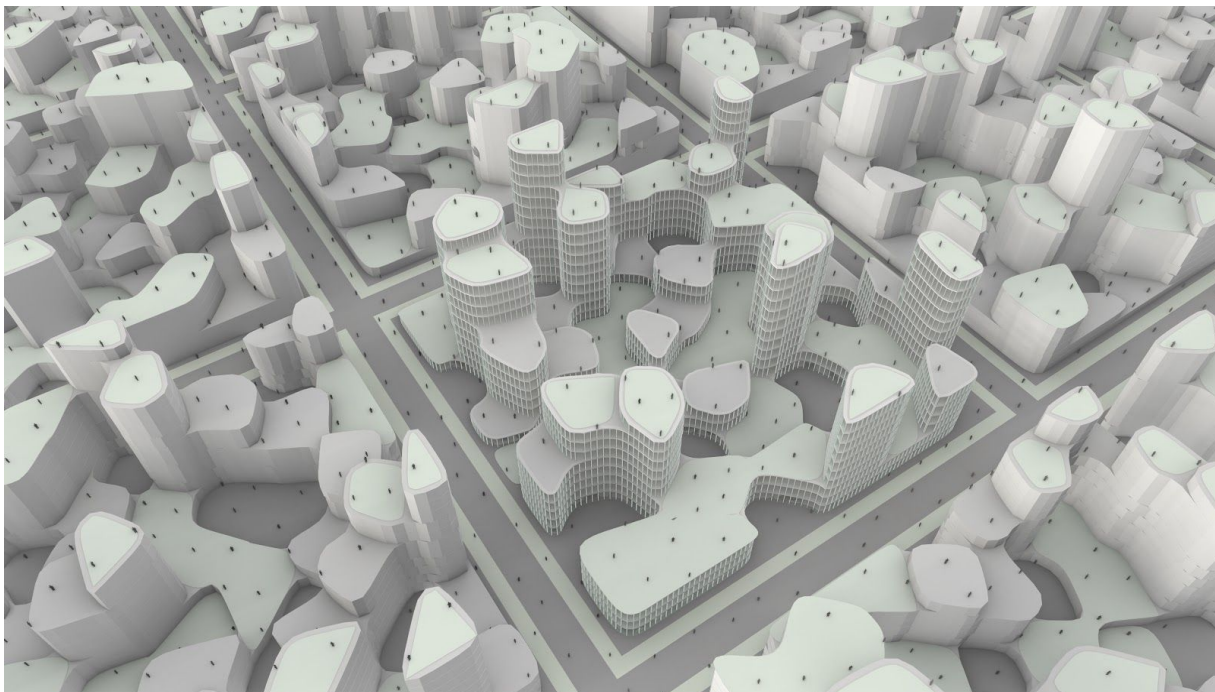


Figure 13: Solar Generative Massing project (CC BY-NC-ND 4.0 - 2018 - ECHOES.PARIS)



### 3.2.2. Current situation of the building

Apart from the metrics used in the single classroom, for the big scale architecture, other analysis metrics for evaluating the performance of the whole building need to be considered.

Prospect distance evaluation (PDE, also called vis-a-vis) can be a good metric for the complex building envelope because it evaluates the building performance in a more macro perspective. PDE can also be used with VAL, The landmark used in this project is outdoor green area in each atrium and on each roof, spaces closer to them will have better performance than the other. It is worth mentioning that when in an actual project, landmark could be the recognizable monument, this may have a big affect on shading device design. Mean Sun Vector in summer (MSVs) is another metric that can give a direct idea about the sun position and sunlight hour intensity in hot season.

Figure 14 to 16 show the analysis results of SREb, MSVs, PDE, VAL, ASE<sub>1000,250</sub> and sDA for building facade and each floors. As shown in SREb image, facade facing south at higher floor have higher value than other places, this is mainly because of the influence by the adjacent building. In MSVs image, each line represents average mean sun vector and sun exposure hours for the corresponding unit. This can indicate which sun position has the most impact on respective facade unit. In PDE image, the prospect distance for each facade can indicate whether a space is in the corner, this can give guidance about whether a glazed unit should be closed by opaque wall due to the limited outdoor view. VAL image indicated which facade unit have better view to green area.

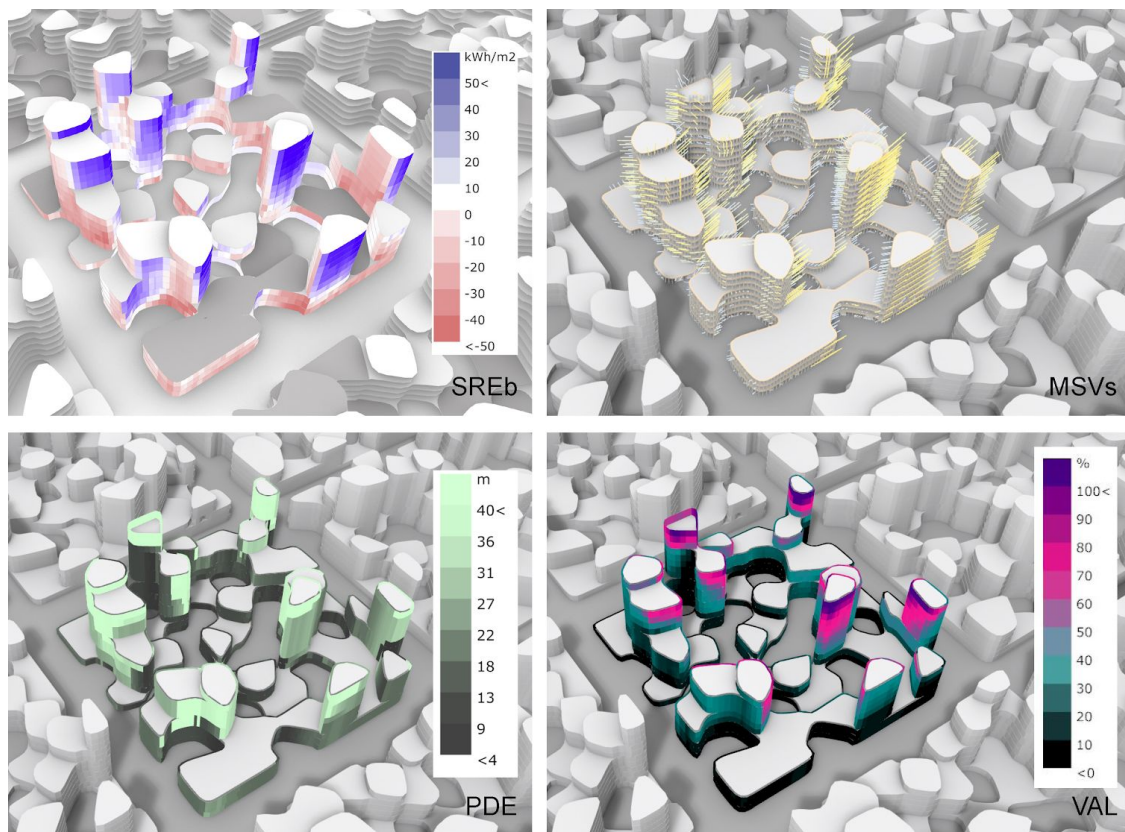


Figure 14: Analysis Results for Building Facade by ECHOES.PARIS

Figure 15 shows ASE results has been calculate for each floor. It shows that all the facade unit facing east, south and west have high potential suffer from glare discomfort. Figure 16 shows sDA results for each floor. It indicates that almost all the space has enough daylight.

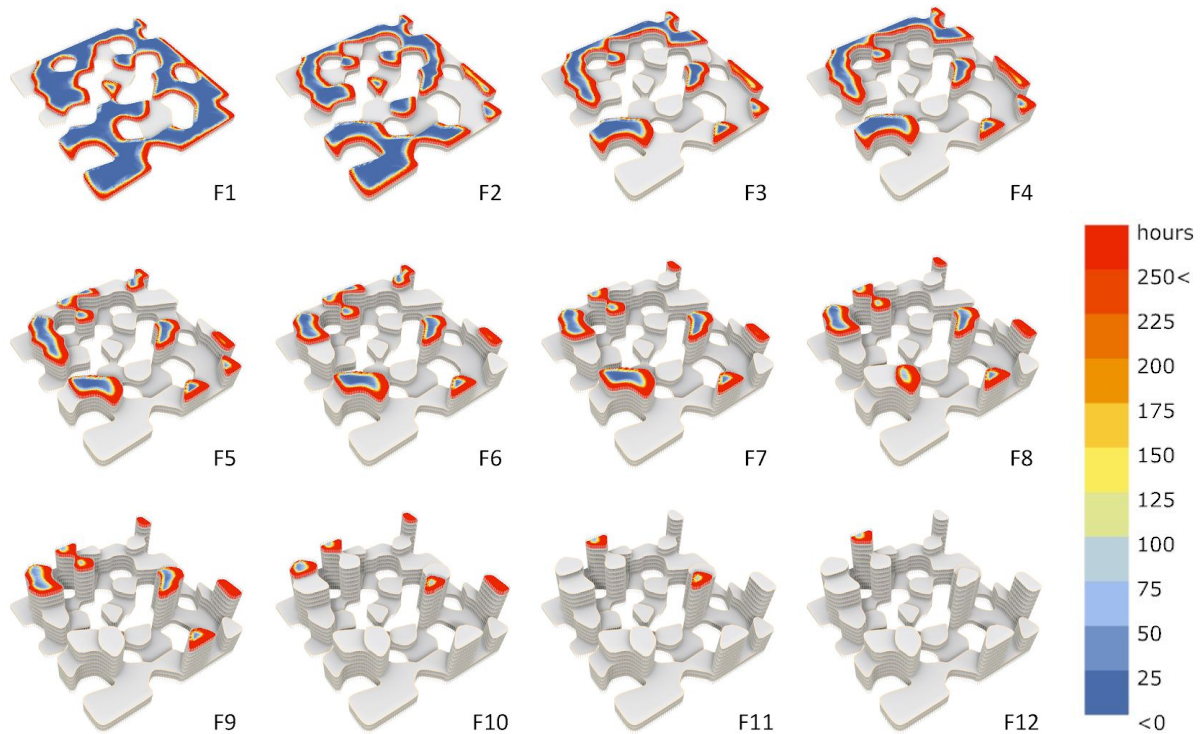


Figure 15: Annual Sunlight Exposure results for each floor

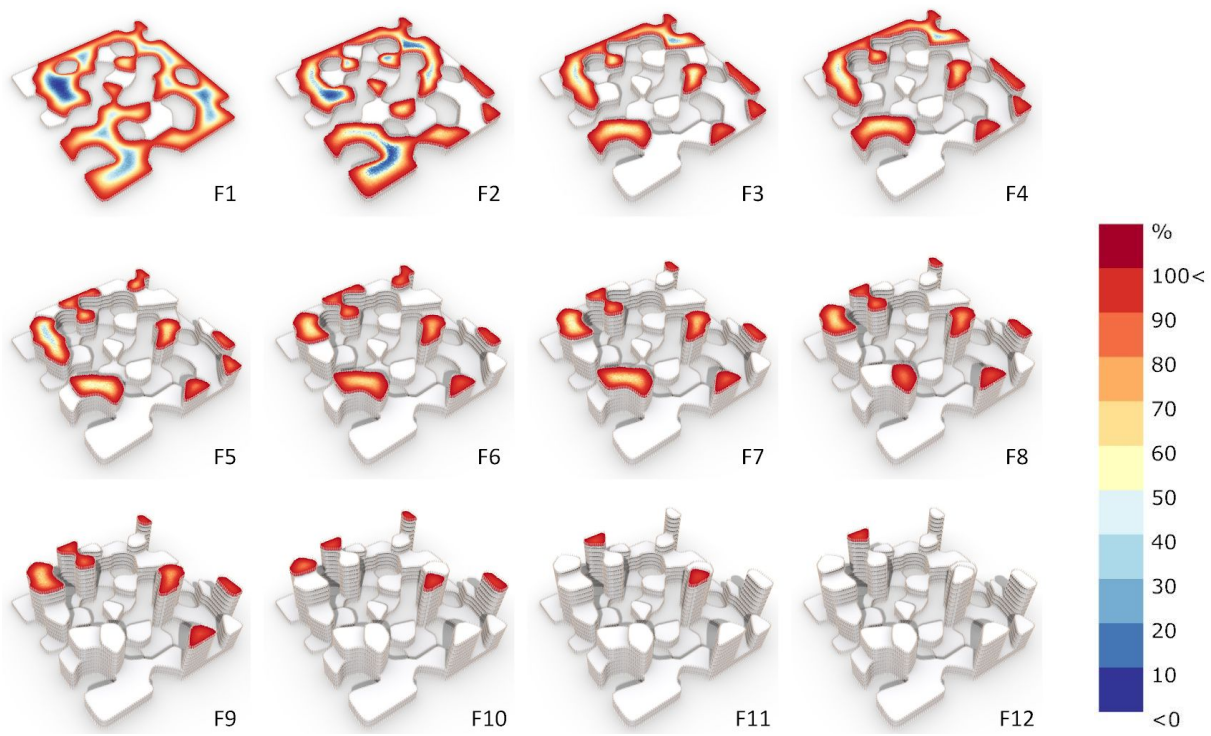


Figure 16: sDA results for each floor



### 3.2.3. Performance optimization for complex educational building

In this process, the optimization surfaces are the whole building facade with 5404 glazed units and all the floors with more than 120 000 test points, the context is the building itself and another 8 adjacent buildings. These data are way too heavy for genetic algorithms to run the optimization. Even though there is only one parameter for shading geometry and one objective function, data load is still very heavy for Galapagos or Goat. Instead, the optimization methodology should be explored based on the analysis results showing above.

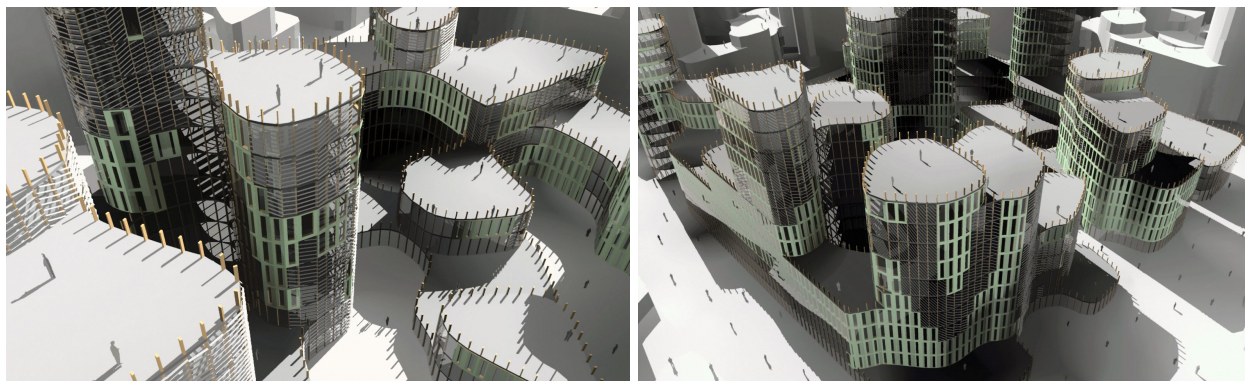
First, all the facade units were divided into four sections by analysis metrics results because each space has different context and requirements. To evaluate the daylight quality for each space, a group of test points 2 meters away from each window center were chosen along with the corresponding ASE<sub>1000,250</sub> value. After that, a strategy with four steps is designed to separate the facade units into four sections.

1. When PDE is smaller than 8 meters, set to opaque wall. This is to consider when other part of the building or the adjacent building is too close to the facade units.
2. When ASE > 250h and MSVs > 6h, set to shading device. This is to find facade units which has too much sunlight hours and high glare probability.
3. When VAL > 10% and SREb > 0, set to fully glazed. The idea is to keep high VAL for the units and maximize solar radiation in cold days.
4. The rest of window units are partial opaque walls. The window-to-wall ratio is linked with ASE value in order to reduce glare issue and ensure adequately lit at the same time.

Second, customize shading geometry for each selected facade units. It consist of three steps. The principle is based on analysis metrics results computed in 3.2.2.

1. Since daytime is longer in mid-term year, to reduce potential glare issue, blades should be perpendicular to the mean sun vector as it can block sunlight more efficiently.
2. The width of blades can link with ASE<sub>1000,250</sub> value, the higher the wider. The width is set to a range from 0.05 to 0.5 m.
3. The distance of each blade can link with the MSVs value – sunlight hours. The longer the sunlight hours, the further the distance of the blades. The distance of the blades are set to a range from 0.1 to 0.4 m.

At this point, shading device parameters are all determined. Figure 17 shows the final shading device design for the whole building in several different views. These radiance images were computed by Ladybug and Honeybee, the time is set to 9am on 21th June.



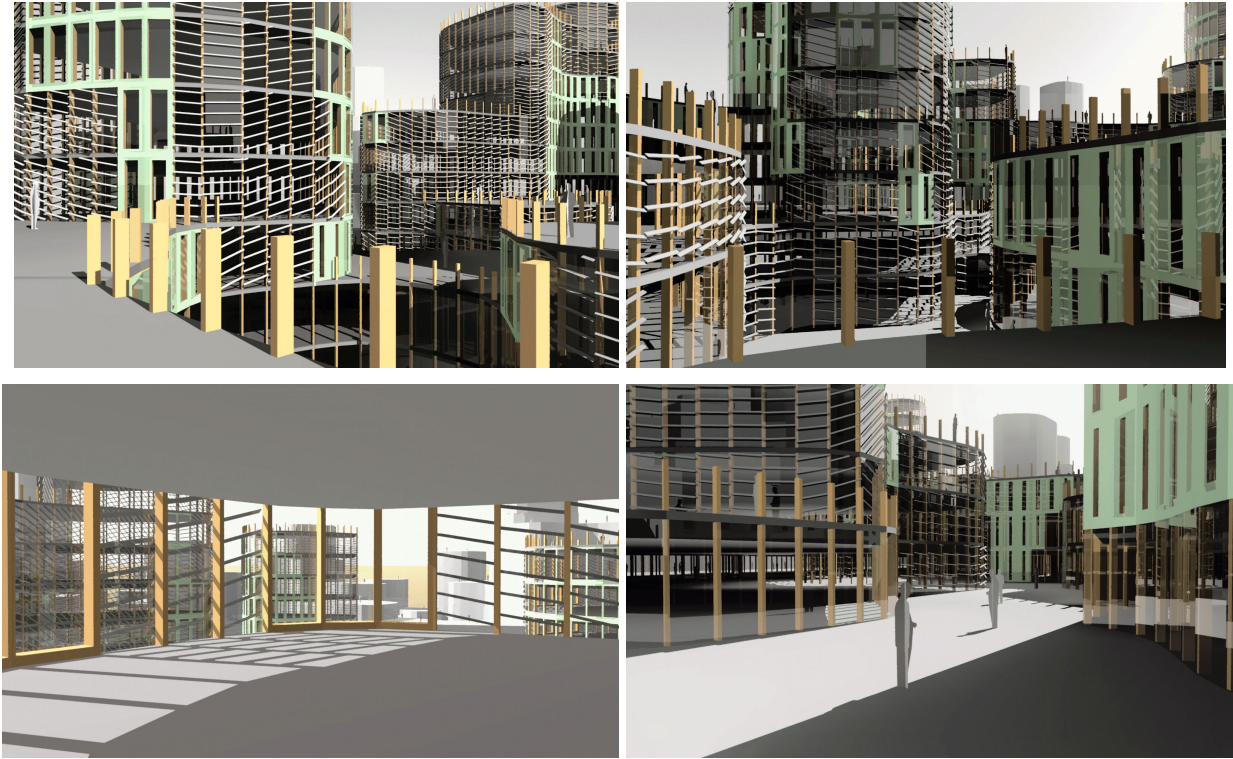


Figure 17: shading device scenario

In order to verify the feasibility of the methodology elaborated above, the analyze for the building performance with shading device has been conducted. Table 6 shows the daylighting performance of the building with and without shading device.

Table 6: Performance of the building for each floor (from F1 to F12) with and without shading device

	ASE <sub>1000,250</sub> (%)	sDA (%)	UDI (%)
No Shading	37.8, 48.7, 67.3, 76.3, 79.2, 92.6, 93.3, 94.9, 98.1, 99.2, 100, 100, 100	75.3, 85.2, 94.9, 96.3, 95.5, 99.4, 99.3, 99.4, 100, 99.4, 99.4, 99.3	60.4, 59.9, 51.4, 48.8, 42.5, 33.4, 35.5, 26.4, 25, 8.2, 4.4, 0.7
With Shading	30.3, 40.2, 48.9, 50.7, 58.4, 63.5, 67.2, 74.4, 76.5, 85.3, 89.6, 89.3	62.6, 74.3, 84.3, 88.1, 95.4, 98.3, 98.6, 98.8, 99, 98.9, 99.2, 98.9	76.6, 77.4, 74.4, 70.1, 62.9, 55.8, 47.2, 36, 29.9, 9.5, 0.5, 1.1
Improvement	+7.5, +8.5, +18.4, +25.6, +29.1, +26.1, +20.5, +21.6, +13.9, +10.4, +10.7, +10.7	-12.7, -10.9, -10.6, -8.2, -0.1, -1.1, -0.5, -0.4, -1.1, -0.2, -0.5, -0.4	+16.2, +17.5, +23, +21.3, +20.4, +22.4, +11.7, +9.6, +4.9, +1.3, -3.9, +0.4

note: In improvement row, “+” means good result, “-” means shading device made it worse.

### 3.2.4. Summary and conclusions

With the shading strategy defined above, the indoor comfort for each floor of the building have been successfully improved to a certain extent, this can be reflected in the reduction of ASE<sub>1000,250</sub> and the improvement of UDI. Despite sDA is slightly reduced, the majority of sDA value are still higher than 55% which is the minimum requirement in LEED v4 for universities, colleges and higher education building to comply.

The original intention of choosing this project is because of its complexity. However, it turned out to be difficult for genetic algorithm to deal with such amount of data. That is why strategies were developed for the optimization of shading geometry instead of just running genetic algorithm. Nonetheless, if recomputing the analysis metrics with higher setting to increase the accuracy of the analysis results data, it is possible to address better shading device on the basis of the previous derivative presented above. If the function of each space are declared, the shading geometry is able to be designed based on corresponding requirements. Alternatively, other analysis metrics and shading strategies can also be developed.

#### **4 Lesson learned and conclusions**

Through this research, data management plays the key role in the optimization process whether it is a single classroom or a complex building, all the inputs data can be linked with performance outputs data. Likewise, common sense and previous design experience are more of a hindrance than a help.

It is possible to search for the optimum shading device for small-scale architecture. For the big-scale architecture, especially the complex building envelope, strategies are needed to look for the better shading solution. There is no perfect shading device, but it is worth to explore a better shading solution. I hope this research paper could be a guideline and give some inspiration for architects, engineers and other students who are interested in optimizing the performance of architecture facade with shading device.

#### **5 Steps forwards**

The parameters of the shading devices can be more flexible and the language of the geometry can be more diversified, three shading typologies and their parameters in this research are some examples to introduce the way to explore the optimum shading devices. In future, material, aesthetics and morphology can also be involved into the shading design.

Apart from visual and thermal comfort, energy saving is also a vital factor for architecture design. It is worth mentioning shading device can also create energy if integrate photovoltaic panel. It is also notable that the optimization of the static shading device can give benefit to energy conservation in one season but detrimentally in another if not properly sized or located. Thus design a proper shading device is a far-reaching task.

In addition, static shading device has its own limitation. There can be many changes in the real world especially in urban context. The succession of new projects will affect the solar radiation a building receives. Moreover, due to global warming, it will alter the amount of heating and cooling degree hours, These changes may decrease the performance original design. Due to the excellent performance of kinetic shading device [\[18\]](#), it can be another path to explore.

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## References

1. Group, H.M. [\*Windows and Classrooms: A Study of Student Performance and the Indoor Environment\*](#). Calif. Energy Commision 2003, 37, 414–435.
2. Laura Bellia, Francesco De Falco, Francesco Minichiello. *Effects of solar shading devices on energy requirements of standalone office buildings for Italian climates*. Applied Thermal Engineering, Volume 60, Issues 1–2, 2 October 2013, Pages 397.
3. Jeong Tai Kim, Gon Kim. *Advanced External Shading Device to Maximize Visual and View Performance*. DOI: 10.1177/1420326X09358001
4. Mohammad Arif Kamal. *An Overview of Passive Cooling Techniques in Buildings: Design Concepts and Architectural Interventions*. 2012
5. WN Hien, AD Istiadji. *Effects of extrenal shading devices on daylighting and natural ventilation*. 2003.
6. Francesco De Luca, Hendrik Voll and Martin Thalfeldt. *Horizontal or vertical? Windows'layout selection for shading devices optimization*. Tallinn University of Technology, Tallinn, Estonia. 2015
7. Simos Yannas. *Solar Energy and Housing Design: Volume 1: Principles, Objectives, Guidelines*. 176 pages. AA Bookshop. 1994. 978-1-870890-45-8.
8. Simos Yannas. *Solar Energy and Housing Design: Volume 2: Examples*. AA Bookshop. 1994. 978-1-870890-37-3.
9. Steven V Szokolay. *Introduction to Architectural Science: The Basis of Sustainable Design*. Publisher: Architectural Press (1637). ASIN: B01JXMZXI4.
10. Kyung Sun Lee, Ki Jun Han and Jae Wook Lee. *Feasibility Study on Parametric Optimization of Daylighting in Building Shading Design*. 20.16.
11. Nathaniel Johnson, Adrian Turcato, Erik Olsen. *Potential for Improved Outdoor Comfort by Design in U.S. Climates*. 2017
12. Richard Hobday. *Myopia and daylight in schools: a neglected aspect of public health?* SAGE journals. 2015. DOI: [10.1177/1757913915576679](https://doi.org/10.1177/1757913915576679)
13. Koroma, Eeva, Olsson, Lena. [\*A Future Learning Space: The Classroom?\*](#) 2008. DiVA.
14. Vincenzo Costanzo, Gianpiero Evola and Luigi Marletta. *A Review of Daylighting Strategies in Schools: State of the Art and Expected Future Trends*. Creative Commons Attribution
15. Daylighting Pattern Guide.  
<https://patternguide.advancedbuildings.net/using-this-guide/analysis-methods>
16. Intercepting sunlight: horizontal overhangs or louvers for solar orientations.  
<http://www.2030palette.org/shading-devices/>
17. Y.-S. Kima et al. *Luminous characteristics of shading materials for office buildings: Perforated panels vs. Fabric blinds*. July 2010 LEUKOS The Journal of the Illuminating Engineering Society of North America 7(1):227-240
18. Fahad Alotaibi. *The Role of Kinetic Envelopes to Improve Energy Performance in Buildings*. J Archit Eng Tech 4:149. doi:10.4172/2168- 9717.1000149