SHADING DESIGN WORKFLOW FOR ARCHITECTURAL DESIGNERS

Luis E. López Ponce de León

Mentors:

Michela Turrin

Eric van den Ham

TU Delft

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SUMMARY

Content:

1. Introduction

It is common in the architectural world that not everyone involved in the business has equal opportunities in tackling all desired topics within a project, on of these topics is sustainability, which has to be handled by specialists who can not always be afforded, located or taken into consideration for some other reason in a project, regardless their positive impact in the project. Many of the buildings are being currently executed, face the lack of climate specialists but could take a step forward towards sustainability aspects, for example natural light performance and solar energy absorption.

The aim of this project is to develop a methodology to help architects who the lack of a climate specialist to become able to evaluate a static shading design, using daylight factor, useful area according to architectural program needs, G-Value reduction and sun ray tracing* as indicators and design objectives. It is important to remark that this form of performance based design is thought of for an early design stage.

In order to achieve this goal of the project, the use of parametric tools, will be used to generate the shading design and analysis and virtual reality will be use as an output in order to generate an interactive experience that will take design analysis and decision making into a higher level of understanding.

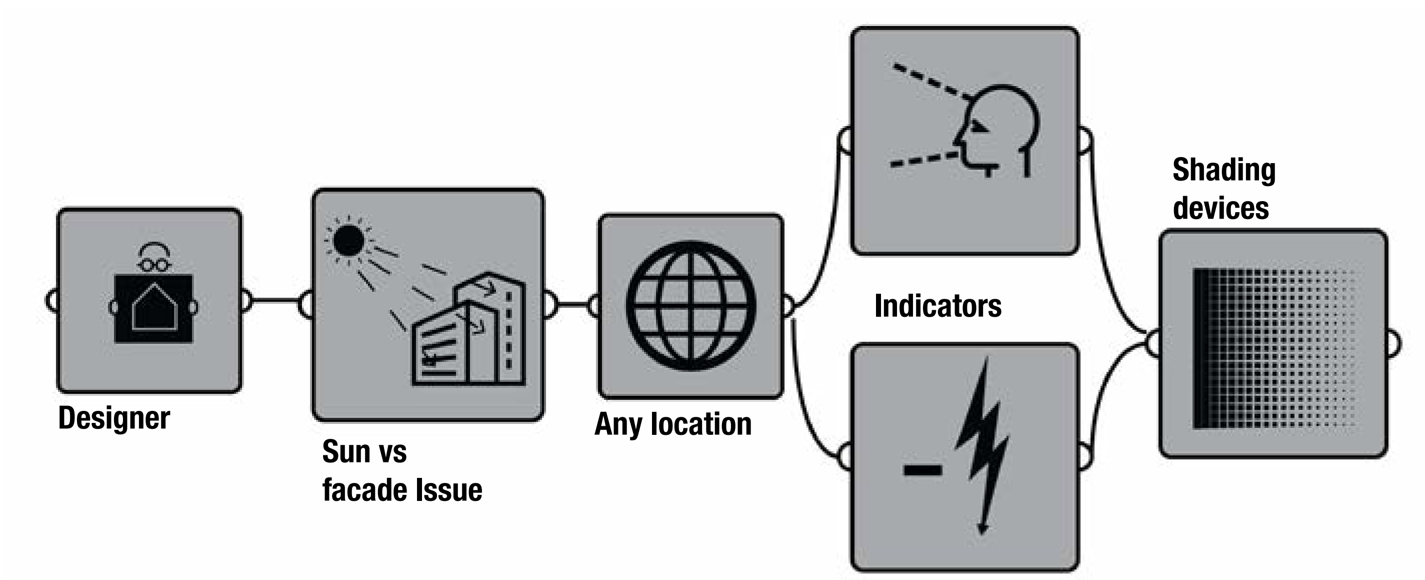


Figure 1. Early diagram for the statement of the project.

2. Research Question and subquestion(s)

General: How to design a workflow for architectural designers in order to make informed and performance driven design decisions on static shading devices in an early design stage?

Specific: Is it be possible to design a method for designing shading devices using parametric tools, optimization processes, and having a end-user friendly output?

3. Method Description

The literature review focuses on the theory on the use of shading devices taking in account, precedents on the use of shading devices, the current different postures on shading performance regarding operability. Also theory on shading device will be revised taking in account the major design parameters for shading devices such as location and typologies. Moreover the traditional design principles for calculation method will be revised in order to highlight the level of complexity and constraint of traditional methods.

The literature review also focuses on the theory and of performance indicators that are influenced by the use of shading devices, mainly focusing in daylight quality comfort specifically on daylight factor and energy performance mainly on energy reduction through g-value.

In order to support the theoretical research on the theory on sun shadings and the influential indicators a selection of case studies has been chosen to portray different sorts of approaches and goal driven design of shading devices. These examples have the intention of portraying challenging designs approaches that highlight the importance of the incorporation of technology in order to achieve specific goals regarding the needs of every building.

The opinions of experts in the fields of architecture and environmental tool development were taken into account. The selection of the interviewed architects was made upon their relevance in the architectural world of their home country (Mexico) as well as their experience on the field. Moreover, their relation with the use of passive design strategies and understanding of the benefits of being able evaluate their design decisions were taken into account.

The interviews developers and creators of Ladybug and Honeybee (environmental design tools) wer included, in order to expose their expertise on the understanding of the communication between specialists in the field of climate and sustainability and architecture, as well as their posture regarding the open source community phenomena for programming environments such as Grasshopper for Rhino.

A tool inventory revision was developed in order to determine the current state of the art of the tools within the parametric design approach. This in order to be able to understand their functionality, the expected user profile, their form of result representations, the communication towards architects and their capability of solving specific indicator that can be further optimized. Through this tool inventory research the proper platform that will help developing the required methodology will be determined, explaining its benefits amongst the others.

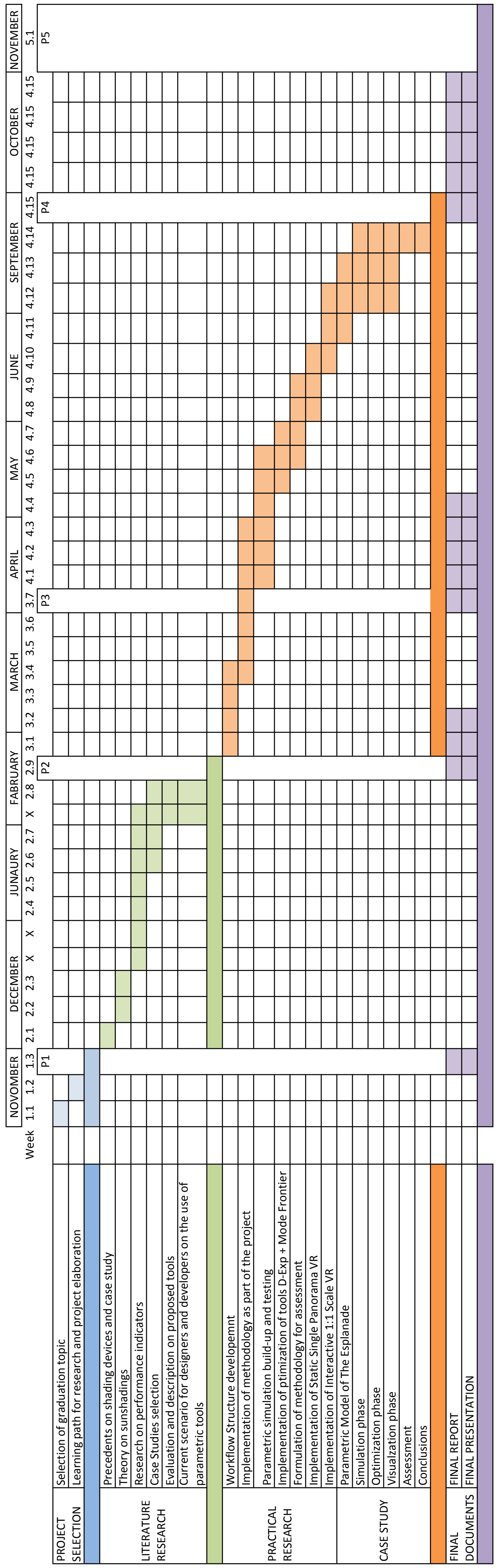
Following the theory, the generation of the workflow was achieved through the use parametric which capabilities allows end users generate a shading device, adapt it to a room in a facade in an specific location, through the use of a user-friendly front-end platform and take it over an optimization process. Finally generate 3d models that can be imported to a Virtual Reality scenario where the design and the results can be easily explored.

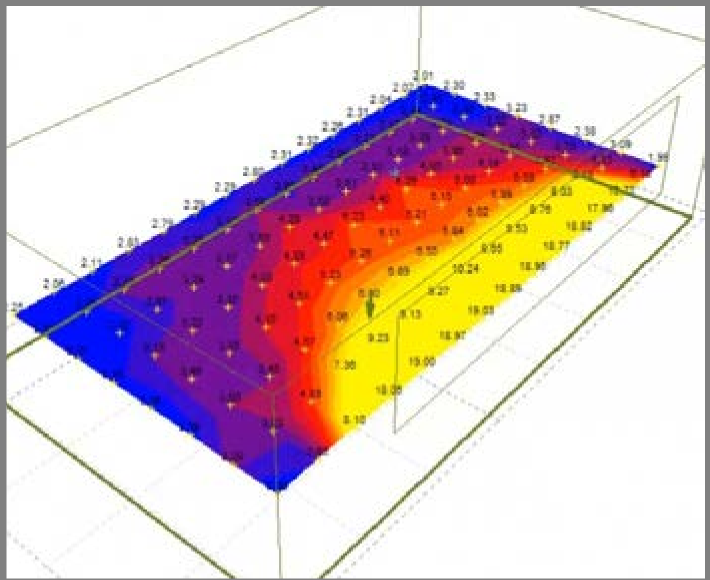
The testing of the methodology was the most relevant part of the project, Since it is crucial for the best interest of the project that the workflow is understandable and validated by the user.

The workflow takes The Esplande (Singapore Opera House) as a case study given its complex organic shape and parametric design approach. (figure 2). Additionally, during this phase, the workflow will be also tested by architecture students from the faculty of architecture of TU Delft. The final goal is to generate a process that invites architects to make informed design decisions around the design of static shading devices, using parametric tools and Virtual Reality as a form of interactive and informative output.

Figure 2. The Espalande, Singapore Opera House.

3.1 Graduation Plan





LITERATURE RESEARCH

Content:

4. PRECEDENTS

4.1 Background precedents

The concept of mechanical environmental systems emerged as a motive for exploration since the 1920´s. Later on, with the boom of energy consumption that rose during the 1960´s, it became a crucial aspect for awareness in the architectural world. Finally, it turned out to be even more concrete with notable examples thirty years later during de 1990´s with buildings by Foster (figure 3), Otto and again Rogers and Piano mentioned by Y. Masri, in 2015, mostly with the use of integrated passive systems.

Figure 3. London City Hall by Foster and Partners, an example of sustainability and passive system usage for indoor thermal comfort.

As a result of the success achieved by this prominent firms, there has been for almost 20 years now a motivation to follow this energy conscious trend in building design. Dereving from this fact, many buildings have been built merely as experiments or prototypes (D. Huesler, 2015) which, considering the costs of an investment in something as a building, might come out counterproductive in case of failure.

In attempt of creating more sustainable and adapted buildings, new design parameters like solar radiation, shading and optimum lighting were introduced as mentioned by Fuch, A. et al in 2015. Moreover, attempts to “scientize” a design problem into a very simplistic way followed in the form of design decisions (figure 4) (image from BIG) (diagram figure). Where predefined goal is disguised as a more complex informative process of the optimal form finding, where non-validated data is sustaining the design through “situational feedback.” (Y. Masri, 2015).

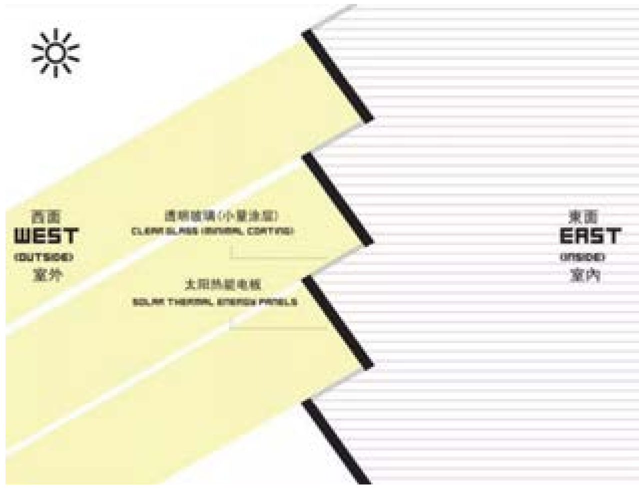


Figure 4. Sunlight diagram by BIG, an example of simplified scientized oriented goals while using solar conditions as design parameters.

Situational feedback: Making thoughts, ideas and plans explicit by writing them down or by developing an artefact, such as diagrams or other sort of tools to support an envisioned goal.

4.2 Background on the case study

Through an interview with the urban space designer ans sustainability expert in charge of the shading devices for The Esplanade, Professor Greg Keeffe, a broader perspective of how informed design choices over shading design has been evolving over the years. At that moment the design of the shading devices in 1996 it took about one year and a half, considering the total 7140 of shades in both buildings, the task was properly tackled. The main of objective for the shading design was “To generate direct protection from the solar envelope through a skin that responded to the geometry of the structure and highlighting and exponentiating its beauty”.

The focus on the design objectives resided on the following parameters:

1. Allowing the least amount of direct sunlight in the building
2. Focusing on the sunlight hours that affected the facade the largest facade area in a direct way, sunrise and sunset hours were not taken into account.
3. The curvature of the geometry was determinant in order to generate the least amount of design possibilities.

Due to the resources available, amount of computational power available at the moment and available existing software, the design strategy was limited to the use of CAD models and Radiance renderings to recreate possible scenarios of how the shading devices will have an effect on the aesthetic and natural light projection inside of the building. According to Prof. Keeffe the design of the shadings at the moment was led by a more “artistic” drive where indicators for energy or daylight performance were not directly taken into account since it was not affordable at certain moment to merge both streams of knowledge.

At the same time a major concern in the design of the shades became the decision to opt for an static shading system, this was mostly decided due to the lack of technology available to develop high-end functioning moving devices, budgetary situation and the risk of extreme humid and hot climate affecting the mechanisms recurrently.

Although the recreated shading results models turn out to be accurate, an important part of the sunlight affecting the facade at sunrise and sunset was left behind, and according to Prof. Keeffe indeed the existence of glare occurs at certain part of the day, although it did not became a design priority.

Figure 5. Shading devices from The Esplanade.

4.3 Who is Using Environtmental Design

Shady Attia et al in 2013 were able to identify the gaps in optimization Tools in order to achieve Net Zero Energy Building Design (NZEBD). Their major concern, though, is the fact that regulation has become more strict and there is no common work-flow between architects and engineers. The existing gaps according to the text vary from the lack of appropriate tools and resources to well defined problems that need to be solved. The fact that they are addressing the lack of specificity on a defined problem encourages the design of a tool that can compel with the new regulations since an early design stage, in order to prevent the production loops and backfiring projects towards the regulating authorities.

Along the paper (S. Attia et al, 2013) BPO (Building Performance Optimization) in mentioned as that the optimal solution from a set of available alternatives for the design and/or the control a problem. Dividing these criteria and combining them will result in an optimized building. It is also mentioned that visualization techniques are essential for the extraction of information. This arguments endorse the use of parametric design modelling based on as solution to develop the tool. Never the less the state in which the tool will compel with the current or any regulations is doubtful, since the goal is mainly to have a informative tool for shape generations towards shading and temperature.

Figure 6 and 7 show, according to this study, how the current situation is for NZEBD´s in regards to discipline and building typology. As it can be seen, the participation of architects is minimum in the field where theoretically are the profession that generates the challenges to be solved. The same happens for office buildings, heating and cooling strategies as well as dominant topics.

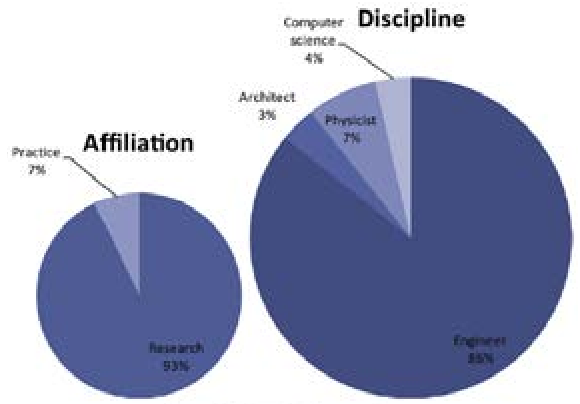


Figure 6. Disciplines that are most involved in NZEBD´s design.

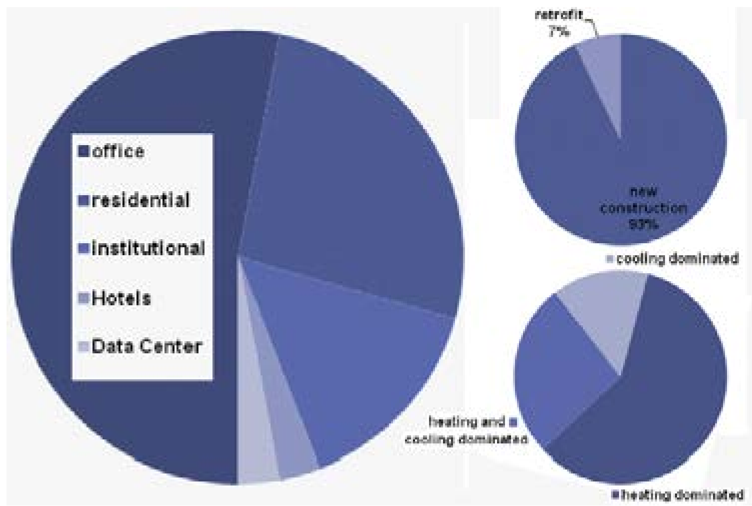


Figure 7. Most frequently takled typologies in NZEBD's design.

4.4 Postures in façades design

Façades are the architectural elements that shape and characterize the building and those that interact directly with its immediate context. Such feature plays a crucial role in terms of design, energy, comfort and temperature balance between exterior and interior (ref pending). Regarding the need for optimizing any buildings performance, two main postures dominate: static and adaptive façades. Both are considered responsive design strategies and both of them are oriented to use shading devices as mean to control glare and temperature.

4.5 Static vs Adaptive

Static strategies are the ones that use the environment, such as wind and sunlight, in order to better regulate the temperature of a building. They require low maintenance and they help to reduce the energy consumption. Moreover, they do not need any help of additional mechanical systems, resulting in a convenient economical way to achieve an energy conscious building. (figure 8)

Figure 8. Building by Woods Bagot in South Austrlia, is an example of the use of static shading devices for indoor thermal comofrt in large scale.

Opposite to static strategies, adaptive façades are the ones that incorporate mostly automatized mechanical devices capable of controlling adaptability in order to perform as climate moderators. With the help of these devices the building can adopt the ability to adapt to its environment with the aid of different sort sensors and complex robotic systems, resulting in an automatic environmental control. (W. Huesler, 2015). (figure 9)

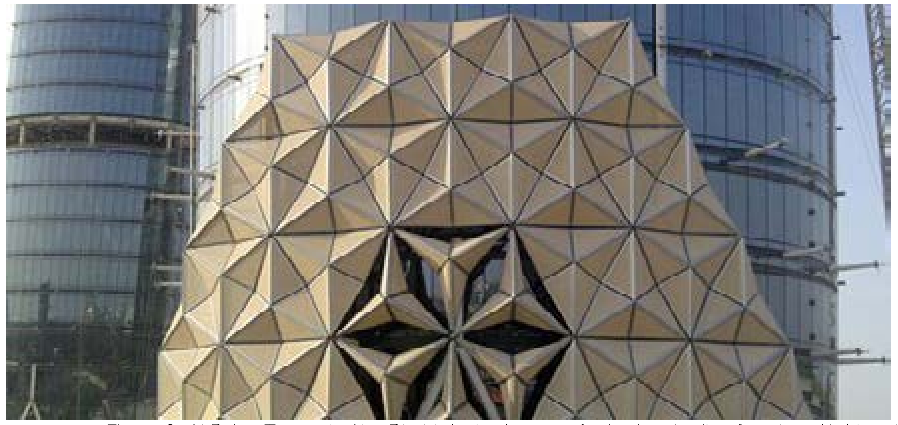


Figure 9. Al Bahar Towers in Abu Dhabi depict the use of adaptive shading façades with hi end technology, protecting a glass building in regions where high temperatures predominate.

Although adaptive façades seem to be a more integrated solution, their highly dependence on automated mechanical devices might be discouraging since many of these innovative products are not yet reliable in terms of cost, quality, installation and operation (W. Huesler, 2015). In the end, the design derives into the forcing of standardized components into a desired form, leading to a constant need of repairing and specially when using complex geometries (A.Fuch, et al 2015).

The middle ground of both of this perspectives relies within the user based operated systems in order to make the dynamic systems less complicated and reliable on the users experience. Although W. Huesler in 2015 mentioned that regularly users and control equipment do not operate regularly as it will be assumed. This constantly leads to the addition of extra mechanical systems in order to make the building operational.

The debate relies on the comparison between static and adaptive systems, where passive systems can only be chosen over when very specific concepts are taken into account such as location, height, context and use; as well as the use of solar energy and daylight and 2/3rds of a year according to W. Huesler in 2015. Opposite W. Huesler´s point of view, it was proven by S.C. Jansen et al in 2003 that with the use of blinds and high efficiency glazing the energy cost will decrease around 40% in a glazed building in the Netherlands. This case was also supported by Y. Masri in 2015.

4.6 Approach for the methodology design

Shading systems are used in order to reduce solar radiation and thermal gains, and to generate visual and indoor comfort amongst other factors. The choice between systems relies on either a non cost efficient system with lack of liability, with still a lot to be developed technologically wise but adaptive to any climate/ weather conditions, or a less tech savvy approach, with various limitations, dealing though with location, context, buildings massing and nature. It seems reasonable to incline for the most trustworthy system than an adapted, costly and prompt to failure and fixture cycles. In addition, the use of less amount of mechanical systems can also reduce the cost of a building and should be taken into account (W. Huesler, 2015).

As it also has been mentioned in 4.3 the lack of participation of designers in active sustainable design is still low in comparison to other disciplines. Therefore it becomes important to develop a workflow that can invite through the use of current design tools and new forms of exploration more architects to become acknowledged and conscious about their design choices.

It can be noticed from the information provided by Prof. Keeffe in 4.2 that the lack of use on indicators at the moment seemed a matter of miscommunication or availability in technology to generate shading designs that could meet more design parameters related to climatic indicators that allow the redesign and exploration of preliminary and extending the information beyond aesthetics where new design objectives can later be tackled .Taking this into account an approach that can take design further than aesthetics and implement a lighting and climate design indicators becomes relevant for designers to make informed design choices.

5. THEORY ON SUN-SHADING DESIGN

The proper design of sunshades will provide a balance between shading performance and heating efficiency. This will be achieved simply by decreasing direct beam penetration by projecting shadows on the window along the sunlight direction and also decreasing sky diffuse radiation.

It has been proved that the use of shading device could:

- Improve Daylight Quality Control
- Improve Indoor Thermal Comfort
- Improve a buildings general energy performance
- Generate a productive work environment

Exterior shading devices decrease direct beam penetration by projecting shadow on the window along the sunlit direction; sky diffuse radiation is also decreased because a portion of sky cannot be “seen” by the window (figure 10). Moreover sunlight is not only bloked but also diffused, softening the glare and temperature effects of direct and diffused sunlight in the working environment .(IBPSA-USA)

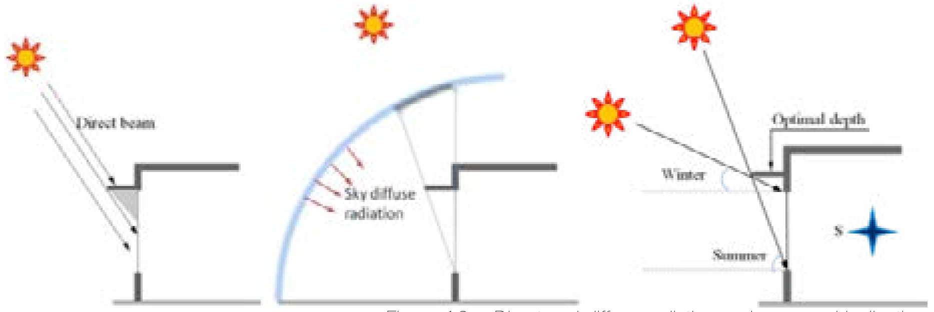


Figure 10. Direct and diffuse radiation and seasonal inclination.

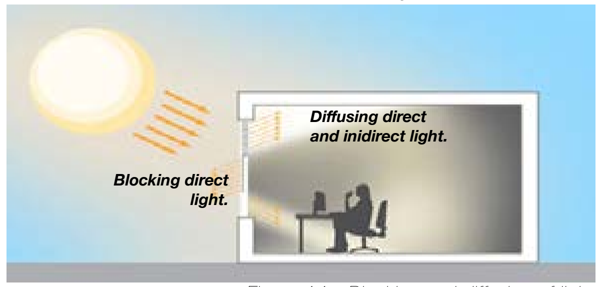


Figure 11. Blocking and diffusion of light.

In order for an architect to determine which is best option for a shading device that suits a building regarding to the main objective of this project, many considerations have to be taken into account. Such considerations embrace different sorts of parameters related to the existing general typologies of shading devices, the use of a typology according to orientation, the expected function of the building and a set of indicators that can validate the design decision.

The process begins by the selection of the proper shading device according to the orientation of the building and its interaction towards sunlight periods, this information can be retrieved from resource such as sun-path diagrams.

5.1 Influence of the location

In order to understand shading design basic concepts regarding location of an object in relation to its position on a spherical coordinate system, and the use of tools such as sun-path graph should be mentioned.

Latitude - is the angle which from 0° at the Equator to 90°, North or South towards the poles. Lines of constant latitude, or parallels, run east-west as circles parallel to the equator.

Altitude - is the angle between the object and the observer’s local horizon. For visible objects it is an angle between 0 degrees to 90 degrees.

Azimuth - is the angle formed between a reference direction (North) and a line from the observer to a point of interest, in this case the sun, projected on the same plane as the reference direction orthogonal to the zenith.

Figure 12, gives a better idea of who this lines are located in a the globe.

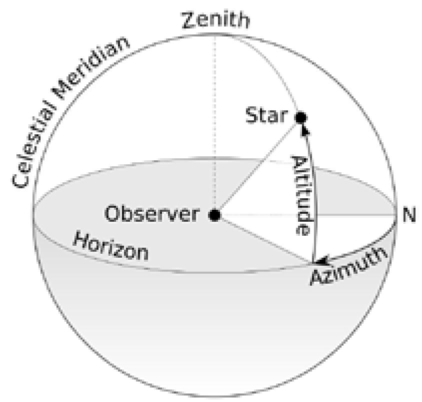


Figure 12. Imaginary lines in globe for defining sunpaths

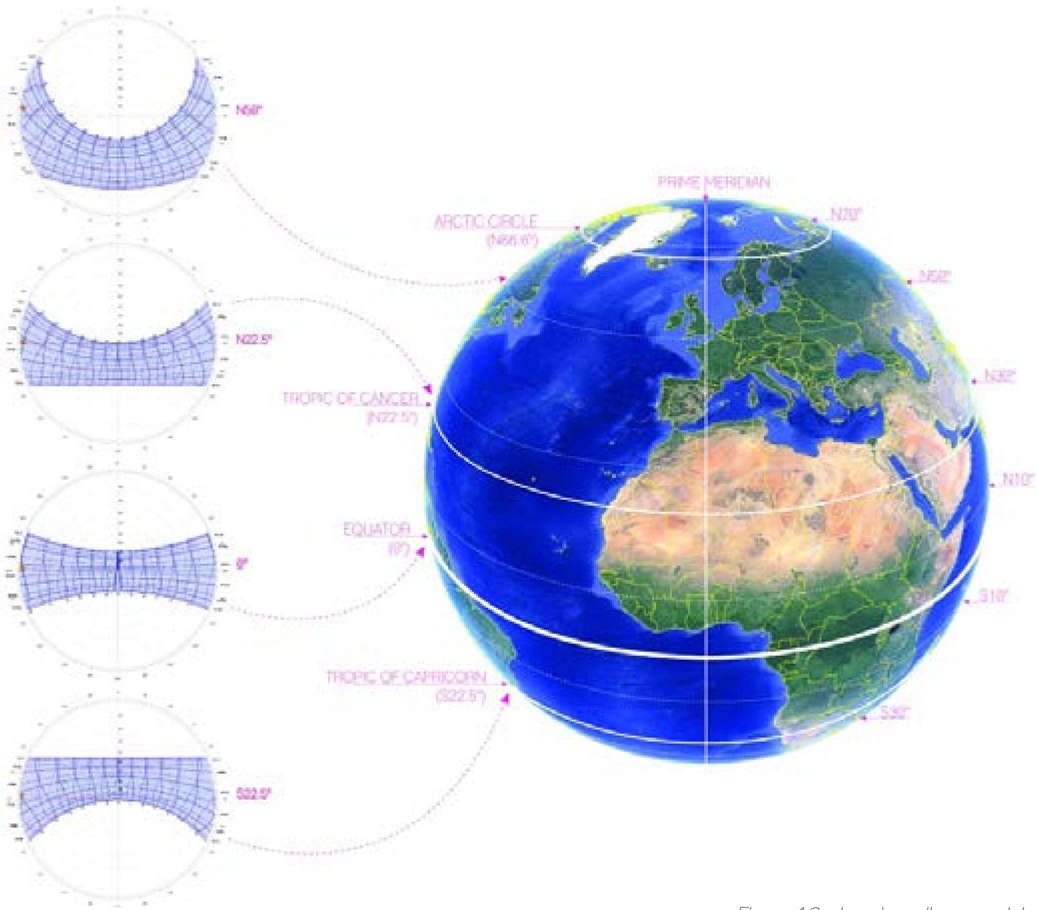


Figure 13. Imaginary lines on globe.

Sun-path diagrams are tools used to read the solar azimuth and altitude throughout the day and year for a given position on the earth. They represent spherical representation of the sky, taken looking straight up towards the zenith. The paths of the sun at different times of the year can then be projected onto this flattened hemisphere for any location on Earth (figure 13).

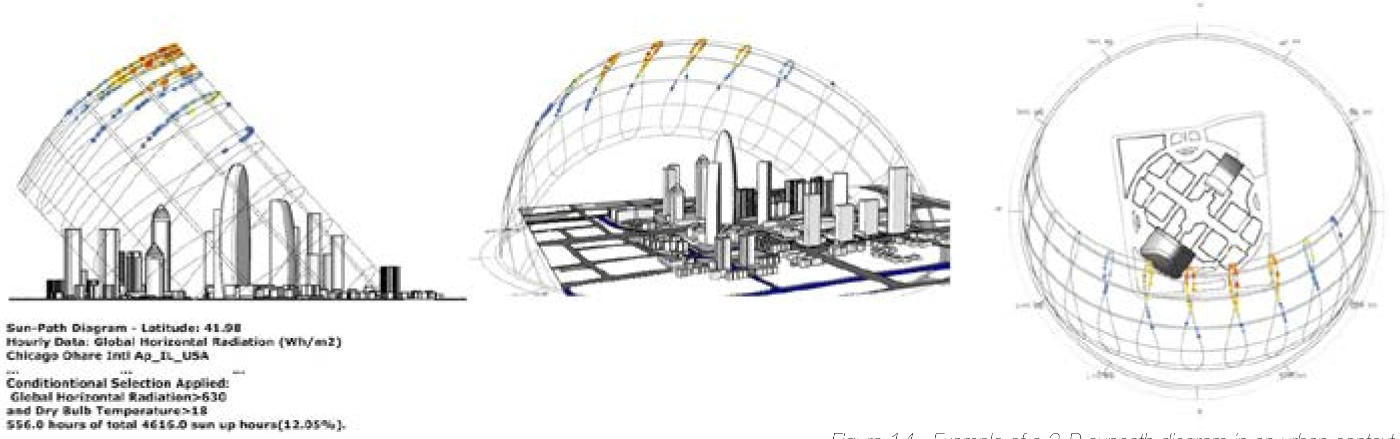


Figure 14. Example of a 3-D sunpath diagram in an urban context.

5.2 Sun-shading typologies

According to the most typical classification presented by Olgyay and Olgyay in 1957, the sun shading typologies are primarily classified as three major kinds respecting geometry: overhangs, lovers, awnings, fins and eggcrate: figures 15,16,17,18 and 20**.** A geometrically simplified classification of this basic elements and their possible combinations is presented by Lechner in 2014 figure 19, where these combinations express a more holistic starting point for a designer to generate shading devices.

Figure 15. Example for overhangs.

Figure 16. Example for louvers.

Figure 17. Example for awnings.

Figure 18. Example for fins.

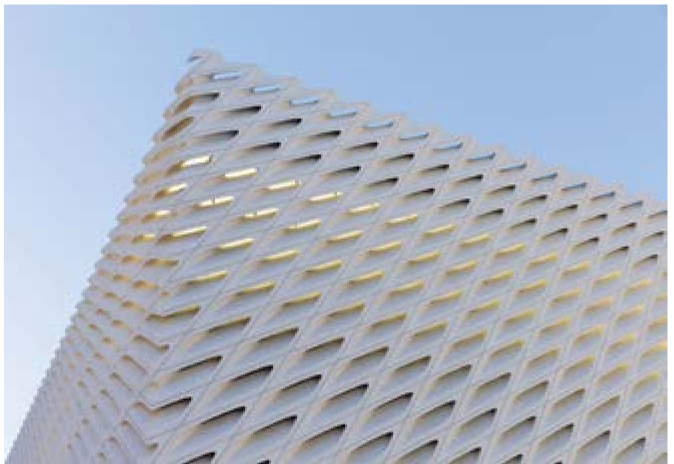


Figure 19. Example for eggcrate.

5.3 Design principles

Shading design principles have to take into account aspects related to the location and orientation of the building. These two parameters will help to determine the position, direction, size and geometry of the shading devices. Some guidelines properly explained by Olgyay and Olgyay and supported by plenty of authors and designers, have been used over the years to determine a simple approach to a first stage of shading element design. Regarding the use of these rules only the ones focusing on the relation location-orientation prevail since they are related to the physical environment. The ones related to geometry and size can also be applicable for very simple and generic situations (J. Sargent et al 2011) since the processes and tools for the size and optimized shape determination have drastically improved over the last years with the incorporation of parametric design tools to the process. Although, the so called 2D method will be also addressed later on for a general understanding of the process.

General guidelines for positioning and directing shading devices according to the location of the building have not changed, although northern and southern locations have obvious variations. The location will be determined according to the relation of the location and orientation of the building.

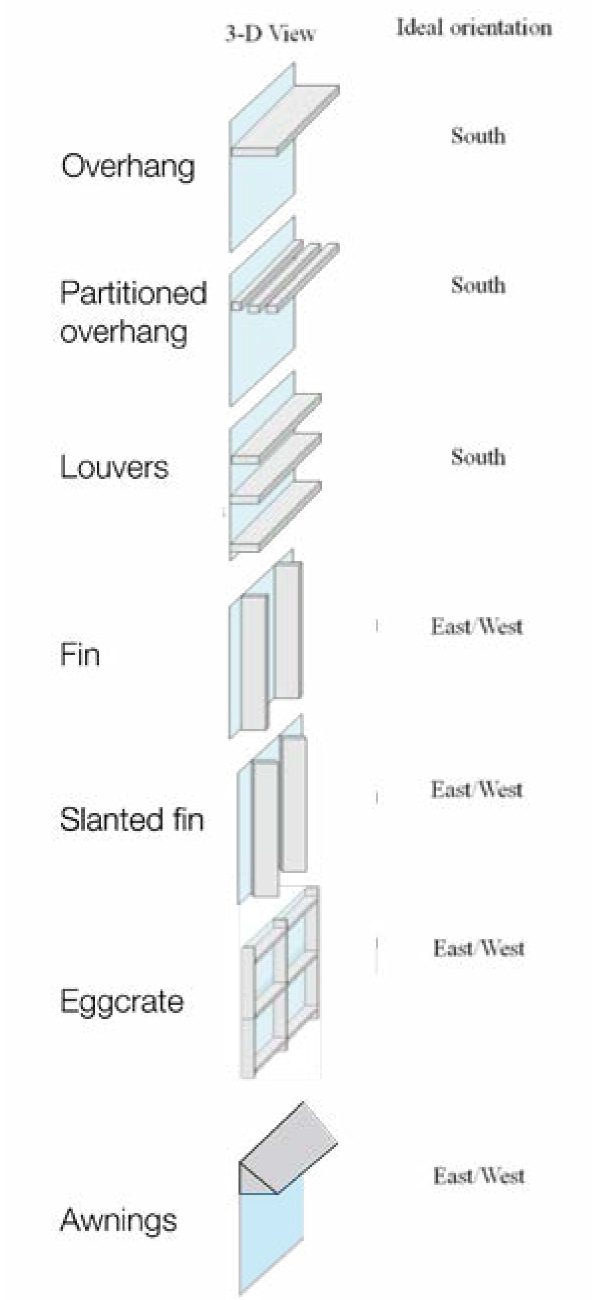


Figure 20. Lechner basic models for shadings.

5.4 Dimensions of the shading device, 2d method (change title)

The 2-D (2 Dimensional) method for design is based on the relation of the shadow angles generated by the sun over a determined period of the year. The most common in 2-D method is the equinoctial, since it focuses on the highest and lowest inclination of the sun over the shading device. Since the sun has different inclinations over the year, the performance of the shading device can adapt according to this. The height of the window and the position suggested according to the location are also important considerations for this method. This method is merged regarding a research presented by S. Rungta and V. Singh in 2011 and by the recommendations of CLEAR (Comfortable Low Energy Architecture).

In order to design a shade for a window, the focus should be in absolute Azimuth and Altitude as the Sun is not as important as the horizontal (HSA) and vertical shadow angles (VSA).

HSA is the horizontal angle between the normal of the window and the current Sun Azimuth. The normal is the direction that the surface is facing (its orientation) when such data is known.
Therefore **HSA = Azimuth Orientation**.

VSA is the angle of a plane containing the bottom two points of the window and the centre of the Sun. That angle is made with the ground when measured to the normal of the surface.
Therefore **VSA = aTan (TanAltitude) / cos (HSA)**.

To calculate the size of an overhang the simplest method is to follow the formula:

D = H / Tan (VSA)

For total shade at target (month/hr), setting **h** to height of window from sill to top and solve for **D** (required overhang depth). For a partial shade at your target date, set **h** to an acceptable height of shadow and solve for **D**. With given overhangs, set **D** to its depth and fin **h**, the height of shadow will cast at your targeted date.

To calculate the size of a fin the simplest method is to follow the formula:

W= D · Tan (HSA)

Solving for **w**, width of shadow, or **D**, depth of fin or overhang, using the proper symbols to solve, if both solar and window azimuths are on the same south of the south vector, values must be positive. As if in their in opposite sides of south, azimuth should be set negative.

Solar Azimuth - (-Window Azimuth)= Solar Azimuth + Window Azimuth)

In order to understand the theory the following diagram depicts the relation between the components of the shading device (figure 21).

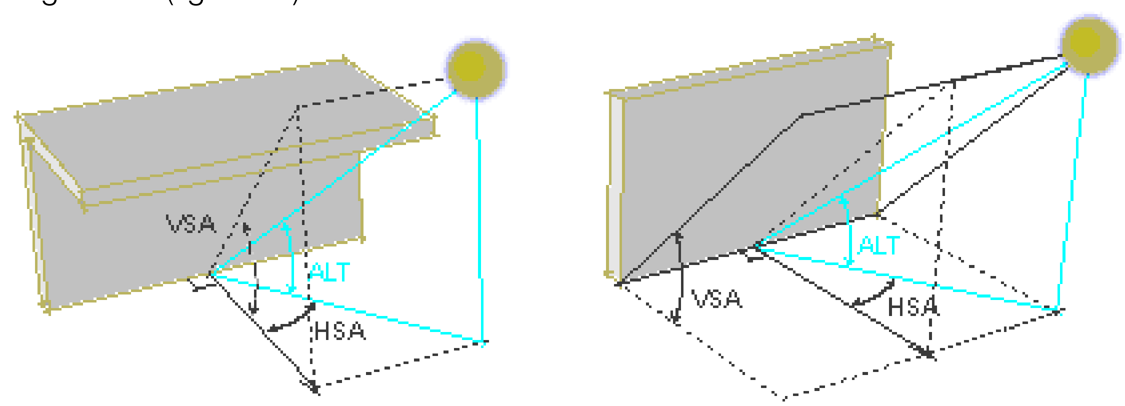


Figure 21. Horizontal Shadow Angle and Vertical Shadow Angle.

5.5 Summary of basic geometrical design

The whole process to generate a geometry suitable for a project prior to performance calculations could be defined in seven simple steps after detecting the suggested position according to orientation (S. Rungta and V. Singh, 2011) (CLEAR):

1. Find solar altitude and azimuth for target months in the sun path diagrams. Begin by tackling the facade that faces the south or north the most (depending on location)

2. Determine a geometrical typology according to every facade.

3. Select a cut-off or critical date, usually equinox dates are chose since the are the peak points of every season for temperature and references for the inclination of the sun.

4. Use the Overhang/Fin formulas, for a minimum starting point.

5. If the resulting geometry is to big, breaking it into smaller elements or dropping down a plane of the segment down to achieve an equivalent depth.

6. For east and west façades adding a vertical element like a fin might be needed, the change of adaptive strategies is taking effect.

7. Test results according relating a model to the corresponding sunpath.

8. Improve: if any of the elements results too large, make partitions using and element in the opposite direction of the one being analysed.

6. PERFORMANCE INDICATORS (change title)

As the geometric parameters for design settled for the proper design of a shading device according to the location, the next step is to improve the design according to performance parameters related to the effects of blocking or absorbing any solar loads (6.1.) on the analysed environment, such as direct, diffuse and reflected radiation. In case of this project aiming towards Daylight Quality Comfort for daylight factor, usable area and G-Vaue in order to determine a reduction of a G-Value coefficient, these parameters have a strong relation to the physical and visual comfort of a space; that when properly solved results in work effective and comfortable environment (WBDG Productive Commitee, 2015).

Given the complex and less graspable nature of this parameters the importance and relation of the indicators will be tackled and explained from a theoretical and practical point of view.

6.1 Solar Gain (edit text)

The total solar load consists of three major components (Lechner, 2014) direct radiation, diffuse sky radiation and reflected radiation (figure 22).

Direct radiation - is the solar radiation reaching the Earth's surface directly on a straight line on a clear sky.

Diffuse sky radiation - is the solar radiation reaching the Earth's surface after having been scattered from the direct solar beam by molecules or suspensoids in the atmosphere.

Reflected radiation - is sunlight that has been reflected off of non-atmospheric objects such as the ground or the build environment.

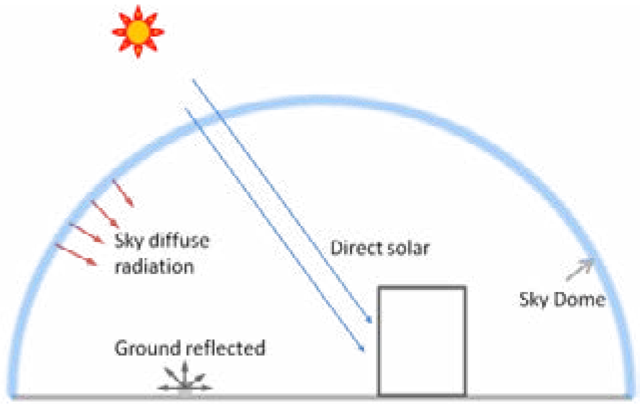


Figure 22. Forms of Solar Gain.

Radiation can be usually visualized through radiation analysis, which will help the designer can envision through a gradient the effect of the solar loads on a building (figure 23).

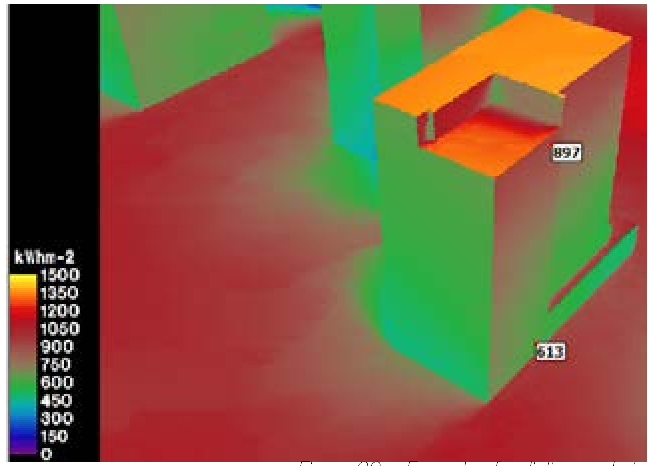


Figure 23. Example of radiation analysis.

6.2 Daylight Quality Comfort (DQC)

Shading devices can also control light by blocking direct, indirect and reflective radiations. The other most valuable characteristic could be the one of creating atmospheres that endorse the well being and the productivity of the users of the building by the proper use of daylight for determined working environments.

According to M.C. Dubois and her study in 2001 on the impact of shading devices for Daylight Quality Comfort, the most important factors corresponding to this parameter are Daylight Factor, Discomfort Galre and Visibility Glare which will be later defined. In order to comprehend in a wider way this aspects some terms such as Illuminance, Lux, Lumen, Candela and Luminance should also be described. (extracted as defined by CIE 1987,1993 and in MC. Dubois, 2001 study) (figure 23).

Illuminance

The illuminance E at a point of an area is the quotient of the luminous flux $d\phi$ received by an area element dA containing that point and the area of that element.

$$E = \frac{d\phi}{dA} \qquad (1.1)$$

The SI unit of illuminance is the lux (lx).

Lux

One lux is the illuminance produced on a surface of area one square metre by a luminous flux of one lumen (lm) uniformly distributed over that surface.

$$lx = lm \cdot m^{-2} \qquad (1.2)$$

Lumen

The lumen (lm) is the SI unit of luminous flux. One lumen is the luminous flux emitted in unit solid angle (sr) by a uniform point source having a luminous intensity of one candela.

Luminance

The luminance (in a given direction, at a given point of a real or imaginary surface) is the quantity defined by the formula:

$$L = \frac{d\phi}{dA \cdot \cos\theta \cdot d\Omega} \qquad (1.4)$$

where $d\phi$ is the luminous flux transmitted by an elementary beam passing through the given point and propagating in the solid angle $d\Omega$ containing the given direction; dA is the area of a section of that beam containing the given point; θ is the angle between the normal to that section and the direction of the beam. The SI unit of luminance is the candela per square metre ($cd \cdot m^{-2}$).

$$cd \cdot m^{-2} = lm \cdot m^{-2} \cdot sr^{-1} \qquad (1.5)$$

Figure 24. Daylight Quality Control definitions.

Daylight factor is the ratio of the illuminance at a point on a given plane due to the light received directly or indirectly from a sky of assumed or known luminance distribution, to the illuminance on a horizontal plane due to an unobstructed hemisphere of this sky. (IES, 1993, MC. Dubois, 2001)

For example if there were 20,000 lux available outdoors and 400 lux available at any given point indoors, then the DF for that point would be calculated as follows DF = 400/20,000 *100 or DF=2. Daylight factor foes from a range from 1 to 5%.
(http://patternguide.advancedbuildings.net/using-this-guide/analysis-methods/daylight-factor)

Discomfort glare is a type of glare that causes discomfort without necessarily impairing the vision of objects. Discomfort glare is a sensation of annoyance or pain caused by high or non-uniform distributions of brightness in the field of view (IES, 1993, MC. Dubois, 2001).

Disability glare is the type of glare that impairs vision or causes a direct reduction in the ability to see objects without necessarily causing discomfort. Disability glare is due to a scattering of light in the ocular media of the eye, which is not perfectly transparent. This scattered light is superimposed upon the retinal image, which reduces the contrast of the image and may thus reduce visibility and performance (IES, 1993, MC. Dubois, 2001).

In order to achieve Daylight Quality comfort (M.C. Dubois, 2001), five performance indicators should be covered to ensure that the user can be able to perform different tasks related in this case to the working environment. The parameters to be measured are: daylight factor, absolute workplane illuminance, illuminance uniformity on the work plane, absolute luminance value on the vertical plane and the luminance ratios between paper task, the walls and the video display terminal (VDT).

As it was previously mentioned in 3.4.1 Indoor Thermal Comfort (ITC) View Factor is an crucial factor in relation to comfort of the occupant, yet only the relation to the occupant position is mentioned. Another two important factors are room geometry and window geometry (C. Huizenga et al, 2006). The relation of such factors has a deep influence on the outcome of daylight interaction, regarding the user and reflecting surfaces. Both discomfort and visibility glare must be taken to a minimum and daylight factor carefully used so the effects of daylight inside a room can be favorable.

6.2.1 Indicators recommended performance value and forms of representation

For this methodology success of a proper shading device design relies on making the adequate choices in terms of performance in order to achieve certain desired values over indicators related to DQC and Solar Gain since the balance between this two topics will help to have an properly performing shaded space. For this methodology there is not a recommendation on how much energy infiltration from the Solar Gain there should be, having the minimum amount when heat gain is possible is a goal, although having an established temperature for a balance between the system and the inside is needed, a recommendation for the range of values for the temperatures is show in image 25.

Temperature / Humidity Ranges for Comfort

Conditions	Relative Humidity	Acceptable Operating Temperatures	
		°C	°F
Summer (light clothing)	If 30%, then	24.5 - 28	76 - 82
	If 60%, then	23 - 25.5	74 - 78
Winter (warm clothing)	If 30%, then	20.5 - 25.5	69 - 78
	If 60%, then	20 - 24	68 - 75

Source: Adapted from ASHRAE 55-2010.

Figure 25. ASHARAE Code recommnedations.

For DQC according to the study by M.C. Dubois in 2011 the performance indicators for the daylight factor, absolute workplane illuminance, illuminance uniformity on the work plane, absolute luminance value on the vertical plane and the luminance ratios between paper task, the walls and the video display terminal (VDT) should be as in the follwing table (figure 25). The values determined by the author are based on codes AFNOR, 1990; ISO, 2000; IES, 1993; CIE, 1986; CIBSE,1994; NUTEK, 1994. Which indicate a favorable illuminance condition over a range between 100 and 500 lx in office spaces. The ASHRAE Standard 55 - 2010, differs and gives a wider range of activities related to office work performance such as detailed drawing and prolonged and performance of prolonged and exacting visual tasks as shown in figure 26.

#	Performance indicator	Interpretation
1	DAYLIGHT FACTOR	
	< 1 %	unacceptable
	1-2 %	acceptable
	2-5 %	preferable
	> 5 %	ideal for paper work / too bright for computer work
2	WORK PLANE ILLUMINANCE	
	< 100 lx	too dark for paper and computer work
	100-300 lx	too dark for paper work / acceptable for computer work
	300-500 lx	acceptable for paper work / ideal for computer work
	> 500 lx	ideal for paper work / too bright for computer work
3	ILLUMINANCE UNIFORMITY ON THE WORK PLANE	
	$E_{min}/E_{max} > 0.5$	acceptable
	$E_{min}/E_{max} > 0.7$	ideal
	$E_{min}/E_{av} > 0.8$	ideal
4	ABSOLUTE LUMINANCE	
	> 2000 cd/m²	too bright, anywhere in the room
	> 1000 cd/m²	too bright, in the normal visual field*
	< 500 cd/m²	preferable
	< 30 cd/m²	unacceptably dark
5	LUMINANCE RATIOS	
	$0.33 < L_{paper\_task}/L_{VDT} < 3$	acceptable
	$0.33 < L_{paper\_task}/L_{adjacent\_wall} < 3$	acceptable
	$0.33 < L_{VDT}/L_{adjacent\_wall} < 3$	acceptable
	($L_{paper\_task}/L_{VDT} < 0.33$ or > 3	unacceptable)
	($L_{paper\_task}/L_{adjacent\_wall} < 0.33$ or > 3	unacceptable)
	($L_{VDT}/L_{adjacent\_wall} < 0.33$ or > 3	unacceptable)

*The normal visual field is the area that extends 90° each side horizontally, 50° upwards and 70° down from the horizon (NUTEK, 1994).

Figure 26. Daylight Quality Comfort interpretation chart.

Activity	Illumination (lux, lumen/m²)
Public areas with dark surroundings	20 - 50
Simple orientation for short visits	50 - 100
Working areas where visual tasks are only occasionally performed	100 - 150
Warehouses, Homes, Theaters, Archives	150
Easy Office Work, Classes	250
Normal Office Work, PC Work, Study Library, Groceries, Show Rooms, Laboratories	500
Supermarkets, Mechanical Workshops, Office Landscapes	750
Normal Drawing Work, Detailed Mechanical Workshops, Operation Theaters	1,000
Detailed Drawing Work, Very Detailed Mechanical Works	1500 - 2000
Performance of visual tasks of low contrast and very small size for prolonged periods of time	2000 - 5000
Performance of very prolonged and exacting visual tasks	5000 - 10000
Performance of very special visual tasks of extremely low contrast and small size	10000 - 20000

Figure 27. ASHARAE Recommended Illumination per activity.

A practical example of how can performace indicators for DQC be visualized is represented in figures 28,29 and 30.

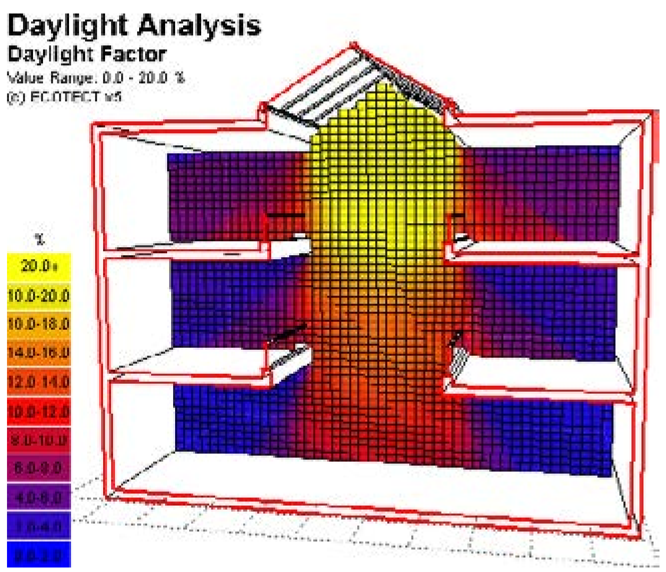


Figure 28. Daylight Factor Analysis.

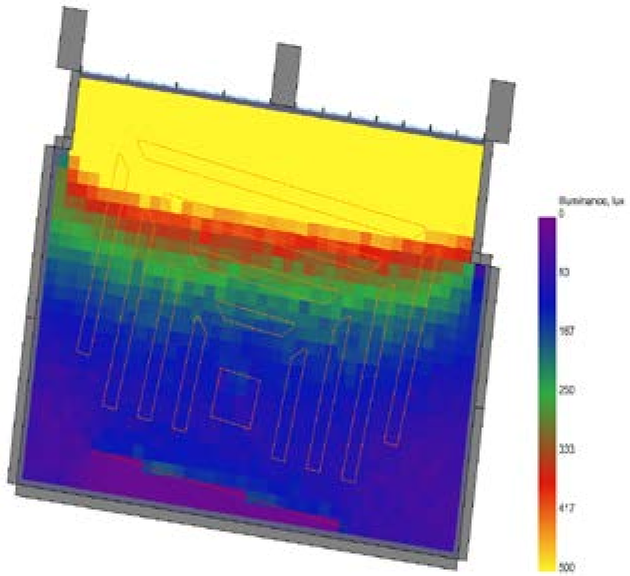


Figure 29. Illuminance Analysis.

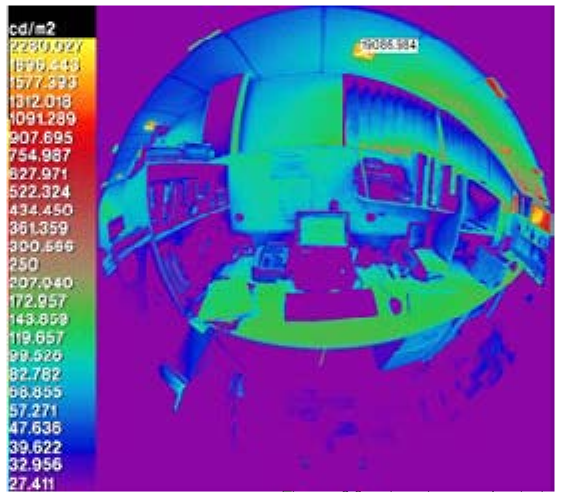


Figure 30. Luminance Analysis.

6.3 Performance indicators for the methodology

The indicators that can be retrieved out of energy and lighting simulators can be plenty, this project will be focusing specifically on Daylight Factor and G-Value of the shading+window system. The idea of choosing this indicators as objectives as a first principle is that as DF increases G-Val also increases. In order to generate optimal use of shading devices the DF must increased in order to make use of sunlight as much as possible, but the G-Val should be kept as low as possible in order to prevent unnecessary solar energy in the room.

Not only obtaining the value for the indicators is of great significance for the assessment of shading devices, but also the following steps of what can be done with such values in order take this value to a higher level of information than the suggested or admitted values according to the design objective. In the following subchapters the indicators will be explained as well as some of the possible ways in how the information can be used in order to generate a deeper level of informative design and understanding of the behaviour of the shading´s design.

6.3.1 Daylight factor

As it is mentioned in previously in chapter 6.2 Daylight factor must remain in a range 2%<5%<, where every percentage point after 5% is not affecting the indoor negatively never the less according to regulations (reference) the levels closer to 5% will always be preferred.

Daylight factor, can be categorized according to the following rates:

Under 2% – Not adequately lit – artificial lighting is required
Between 2% and 5% – Adequately lit but artificial lighting may be needed part of the time
Over 5% – Well lit – artificial lighting generally not required, except at dawn and dusk – but glare and solar gain may cause problems

Regardless the fact that the DF analysis is not directly related to an weather file, it is the orientation and sky quality configuration that in fact help the user know the percentage of light that can enter a room, as daylight is not affected by temperature but by external and internal illuminance. Daylight factor, is typically calculated by dividing the horizontal work plane illumination indoors by the horizontal illumination on the roof of the building being tested and then multiplying by 100 (http://patternguide.advancedbuildings.net/using-this-guide/analysis-methods/daylight-factor).

DF= Lux indoors / Possible lux outdoors * 100

For a DF calculations the amount of luxes taken into account are 1000 lx on a horizontal plane at any given point. The equivalent light distribution is achieved by taking into account a Tregenza dome (Tregenza, 1987), which is a 145 segment dome, from which for every segment the mentioned 1000 lx are projected (figure 30, 31 ad 32).

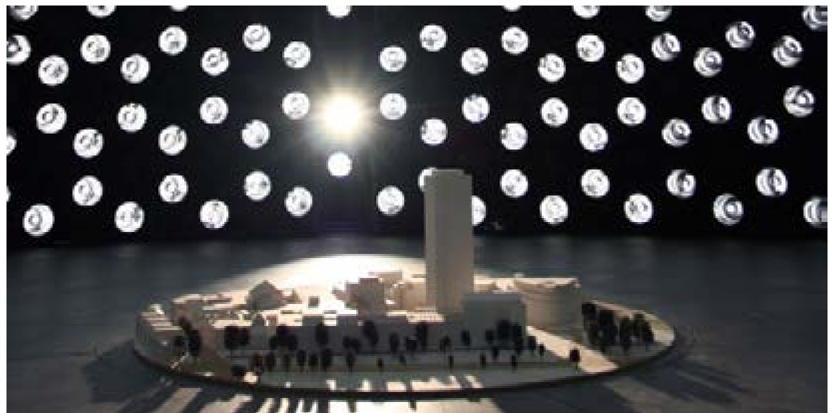


Figure 30. Physical Simulator for Daylight Factor at Cardiff University.

Figure 31. Physical Simulator for Daylight Factor at Cardiff University.

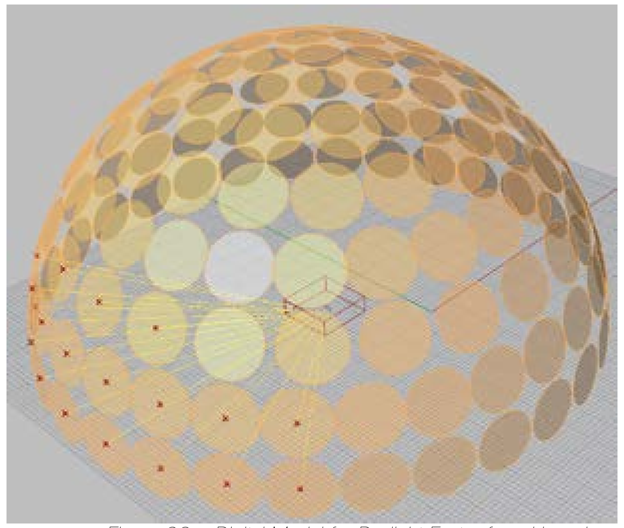


Figure 32. Digital Model for Daylight Factor from Honeybee.

The DF affects every part of the room at a different rate, for practical motives most lighting simulators focus the results mostly on how much DF affects the floor area of the model. The most logical way to present this is through the use of a grid. As shown in the diagram (do that diagram) the size of the grid and room should be proportional. A brief explanation on how to generate this grid will be further explained during the elaboration of the case study. An example of a Dayllight Factor grid is presented in image 33.

The results of the grid can help the user generate assessments towards some design decisions, since the daylight factor, the designer can use this data as a guide for generation of informed layouts regarding usable area (e.g. where to locate a desk in an office) (diagram showing that). The accuracy of the results as in simulation process depend highly in the precision of the configuration of the parameters in this case of the lighting simulation model.

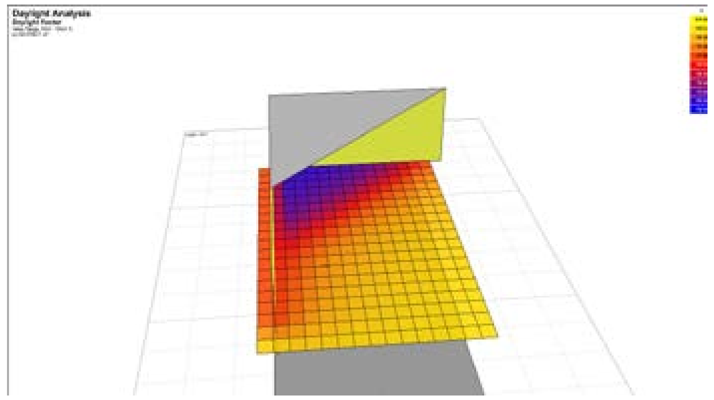


Figure 33. Daylight Factor grid analysis.

6.3.2 G-value

The G-Value accounts for the coefficient to measure the solar energy transmittance through the glass system of a room against an energy source in this case the sun. In case of this project due to the addition of a shading device to the glassed surface, the objective is to reduce solar transmittance in to the room. Given that, **0=no solar energy through system and 1=the maximum amount of light infiltrating a system**.

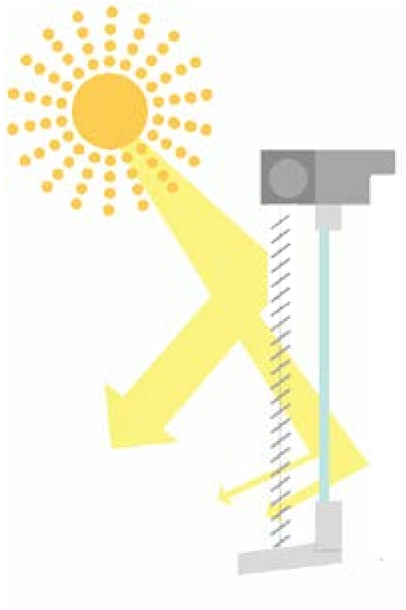


Figure 34. G-Value diagram.

In order to obtain proper results for this indicator, it is necessary to setup a model adapts to sun exposure according to the design´s needs. In order to achieve that, the construction elements which are not sun exposed should be defined as adiabatic, meaning that heat wont enter or leave the system, and will only focus the calculation on the effectiveness of the shading devices and the glassed area, with out the influence of the energy fluctuation of the rest of the room.

To obtain the G-Value, the model will be dependant on EPW files, most energy simulators will for. The retrievable information in this files is fundamental for the indicator specially the hourly radiation, which will relates the orientation and position of the analysed room. Although the simulations can be programmed for different sort of time lapses although to run the simulation in yearly is advisable.

Moreover in order to make the comparison between different shading designs, different iterations of such designs and their benefits, they will have to compared against the tested room in same conditions minus the shading devices.

It is advised to the designers keep the model as closer to a real case as possible before the assessment for results regarding the G-Value, this approach to reality will allow the simulation of more accurate results. Therefore selection for the glazing type, shading materials, and type of construction of the room (according ASHREA region classification) along with their physical properties are advised to the considered in the setup of the simulation . An feasible method to give this inputs to the simulation will be later explained through the case study.

7. CASE STUDIES

The following case studies help portray the use an interesting use shading devices as well as the application of the shading design principles. The overall intention is to provide a wider perspective on the merging of the principles of shading design and state of the art use of parametric design tools. Most of the case studies are completed projects in order to make a clearer statement of the feasibility of the use of shading devices with challenging results. The cases feature offices, schools, museums and libraries, where the use of daylight comfort becomes crucial for the correct performance of the buildings.

7.1 Over Hangs

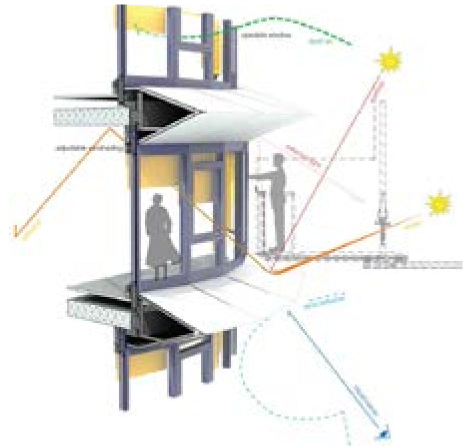


Figure 35 to 37. DUO Offices by UN Studio.

Project: DUO Offices   Architect: UN Studio   Location: Groningen, NL

This building is host to the tax offices for Netherlands, is one of Europe's most sustainable large new office buildings. The architectural response to this has been to strive for an all-round understanding of the concept of sustainability, including energy and material consumption, as well as social and environmental factors. Thus the sustainability manifests itself in reduced energy consumption.

The overhangs in the building endorse sustainability and energy reduction also they are durable and cause minimal environmental impact. The facade concept integrates shading, wind control, daylight penetration. Moreover the shading devices keep a large amount of the heat outside the building, reducing the requirement for cooling. The goals of the shading devices in this case are clear; increasing visibility for the users, reflecting our direct and diffuse light for both summer and winter, with the combination of operable windows to backup ventilation for temperature control. Modularity and simplicity play a major role in the feasibility of this project.

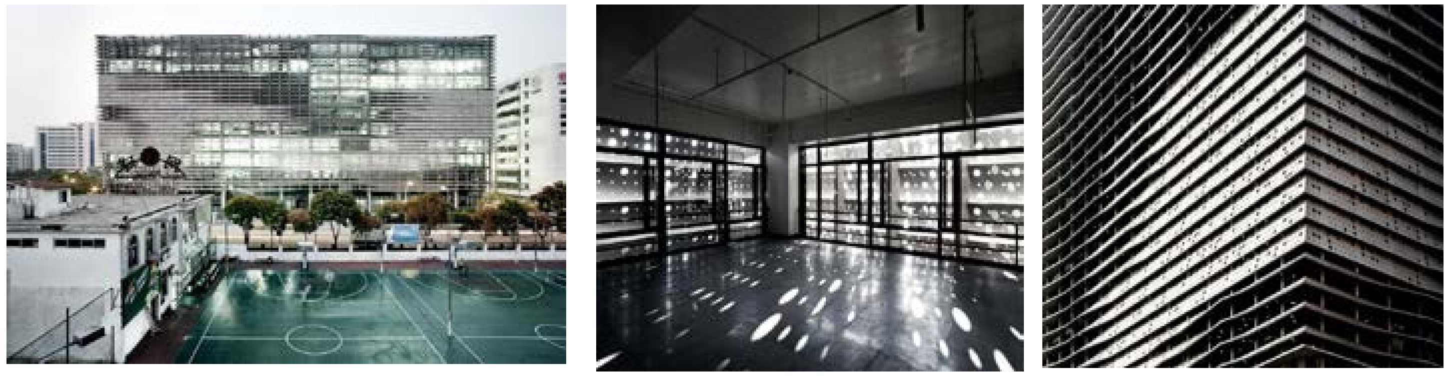


Figure 38 to 40. Lafayette 148 by Studio for Architecture.

Project: Lafayette 148 Architect: Studio for Architecture Location: Shantou, China

This building is the headquaters for Lafayette (clothing design and producer in China, the building incorporates different sorts of programs such as design studios, showroom, sample production, apartments with exercise facilities, administrative offices, and the factory. Where the effects of daylight on the interior might be needed in different ways. The material used for the overhangs was textile-like, woven concrete that is responsible for light modulation, shading and ventilation.

One the challenges was to form forty 120m(aprox)-long sun-shading overhangs, that are horizontally contiguous on the south, east and west façades of an eleven-story building. It can be appreciated that the buildings goal to host several sorts of programs in a south-east-west facade allowed the design to shift, taking shape from human labor and made it possible to host activities that require a high degree of daylight quality and thermal comfort.

7.2 Fins

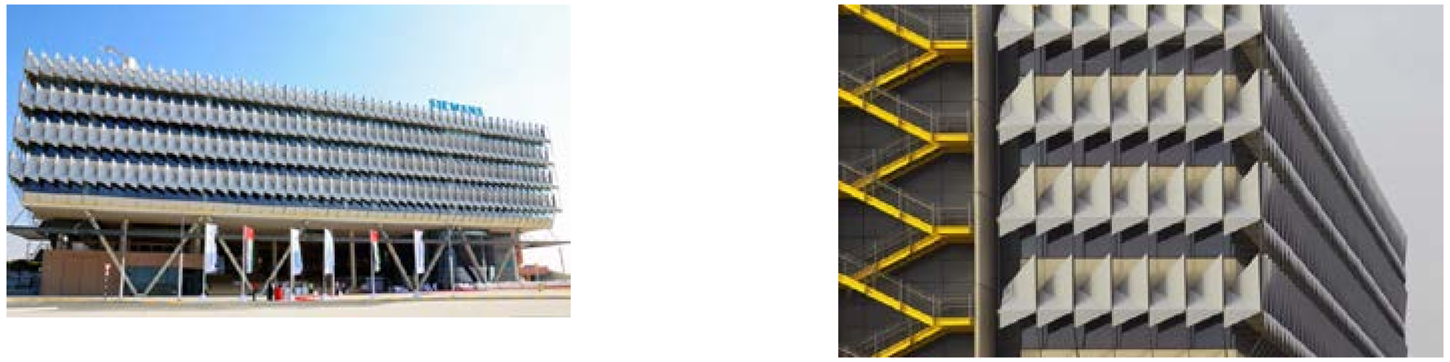


Figure 41 and 42. Siemens ME. Headquarters by Sheppard Robson.

Project: Siemens Middle East Headquarters Architect: Sheppard Robson Location: Masdar City, Abu Dhabi

The building is part of the mega project for sustainable economical hub of Masdar City in Abu Dhabi. The fin-like facade that shields the extensive glazing from solar gain, daylight and temperatures outside. The fins are made of lightweight aluminum and provided 100 per cent shading to 95 per cent of the glazed surfaces, and, along with proprietary integrated building technology designed by Siemens, contributes to energy reductions of nearly 50 percent. The geometry of each fin was parametrized in order to maximize daylight, reduce material loads, ensure the smallest percentage of solar gain, and reflects excess heat away from the glass, which is cool to the touch. According to Sheppard Robson the design was not created upon a determined aesthetic, instead it was tackled inside-out to investigate a truly sustainable solution for the building. The building went through 140 calculations to determine what materials and configurations would deliver the most efficient building.

This project portraits not only the efficiency of static shading devices but an approach where the goals are set towards sustainability in an early design stage and the building is shaped along with this objectives driven by creativity. The decrease of energy reduction is quite significant regarding they cooling energy needs that might represent a building in a the dessert, therefore is not only a case study for the use of shading devices but of great success in the fields of sustainability and energy design.

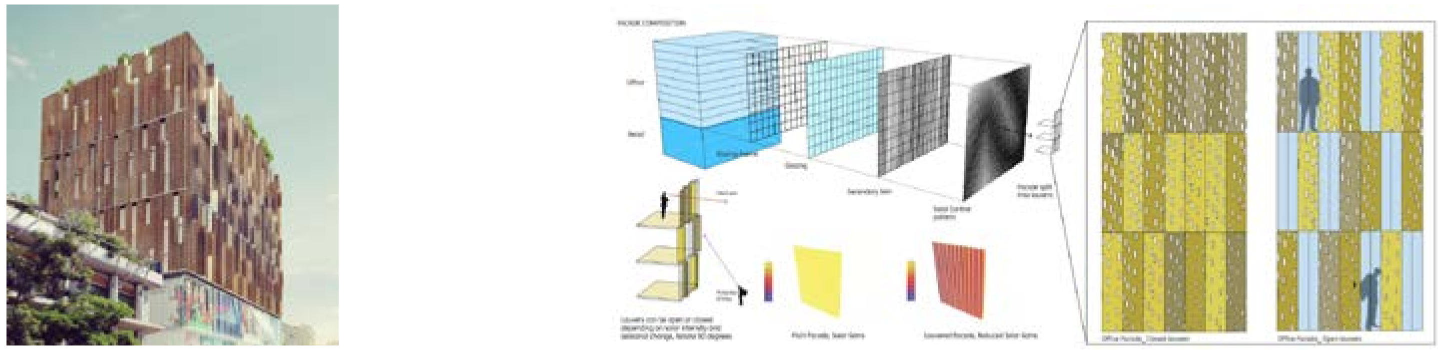


Figure 43 and 44. Mixed-Use Development by Kamvari Architects.

Project: Mixed-Use Development Architect: Kamvari Architects Location: Tehran, Iran

The building's design is based largely on local cultural contexts, like the region's reputation for r environmentalism, particularly with respect to solar energy.

The building envelope also considers environmental aspects such as solar gains as well as comfort issues such as glare. The building open on three sides has different and specific solar loads in accordance to orientation. In order to combat this issue the fin covered facade which has the ability to completely close and open is perforated using a differentiated pattern created using parametric design tools which will reduce overall heat gains on the interior of the building whilst allowing for ample daylight to penetrate the floor plates reducing the need for electromechanical features such as artificial lighting and cooling.

The relevance of this project relies on the clear intention of making use of the long known background of sustainable architecture in the middle east merging vernacular knowledge with parametric tools to achieve an outstanding result in terms of design and shading performance parameters.

7.3 Eggcrate

Project: Hanwha HQ Architect: UN Studio Location: Seoul, Korea

Figure 45 and 46. Hanwha HQ by UN Studio.

This project will be a remodel for the facade of the current Hanwha HQ. The basis for the facade expression is largely formed by the programme. By varying the placement of the facade panels a variety of programme-related openings are created. The North facade opens to enable day lighting within the building but becomes more opaque on the South façade, where the sun would otherwise have too much impact on the heat load of the building. Openings within the facade are further related to the views: opening up where views are possible but becoming more compact on the side adjacent to the nearby buildings.

Direct solar impact on the building is reduced by shading which is provided by angling the glazing away from direct sunlight, while the upper portion of the South facade is angled to receive direct sunlight. PV cells are placed on the opaque panels on the South / Southeast facade at the open zones where there is an optimal amount of direct sunlight. Furthermore, PV panels are angled in the areas of the facade where energy from the sun can best be harvested.

It is remarkable of this project how the project is designed in terms of profiting out of sunlight, by the inclusion of PV panels. It is also important to outstand the fact of using basic principles on design shading to achieve the plastics of an impressive facade with the use of standardized elements according to the program to generate a "unique" facade with only repeating them. The principles of design towards shape and orientation are covered in a safe way by the use on an eggcrate system, also in order to easily permit the blocking of direct sunlight while making energy out of the overgangs part of the shading device system.

Figure 47. The Broad by Diller Scoficio + Renfro.

Project: The Broad   Architect: Diller Scofidio + Renfro Location: Los Angeles, Unites States

This project hosts an art gallery in the city of Los Angeles where temperatures are usually high. Besides climate, blocking direct daylight becomes a crucial part of the functionalities, since sunlight must gently penetrate the interior without over-exposing the artwork, generating a diffuse daylight environment that allows the user to explore the museum is one of the searched goals.

Also the openings are oriented in such a way that overheating is prevented. In the case of this building the egg-crate not is not only facade responsive but also works as a full envelope that cover al facade plus the roof referred to as "the veil". All four façades are perforated in order to their corresponding orientation in order to have the same daylight environment in the building. Although the north facade is also fully covered perhaps to prevail the integrity of the aesthetics of the building, since covering a north facade is not really needed by shading design principles. Regarding temperature control it is safe to say that since the program demands it the backup of mechanical systems might be used in order to protect the integrity of the exposed artwork.

Figure 48 to 50. Tokyo National Art Gallery by Kisho Korkawa.

7.4 Louvers

Project: Tokyo National Art Gallery   Architect: Kisho Kurokawa
Location: Tokyo, Japan

The project for biggest art gallery in Japan consists of very large atrium facing south, with very large courtain wall with an undulated shape, the strategy to tackle from the shading point of view was to block direct light and generate an affect of diffuse light on the inside to create a lightened but comfortable atmosphere. Given the orientation the louvers must be horizontal and long enough to protect the atrium for direct sunight and direct radiation.

On the aesthetics of the building the matching of glass atrium and glass louvers shows an interest of keeping the integrity of the building and a sense of lightweigtness and transparency. To decrease the reflection of of light and create discomfort glare, the louvers are most likely of sadnblasted to prevent decrease the potential reflectivity properties of glass.

http://www.arcspace.com/features/kisho-kurokawa/the-national-art-center/

7.5 Awnings

Figure 51 to 53. King Fahad National Library by Gerber Architekten.

Project: King Fahad National Library   Architect: Gerber Architekten Location: Riyadh, Saudi Arabia

The project is a renovation for the former 1980´s library building, the library is also part of the plan of the Saudi Arabian Kingdom for investing in efficient energy use, therefore the conservation of the building and the use of sustainable strategies for passive cooling and natural lighting were appropriate.

The use of comprised teflon-coated fiberglass membrane cloth that forms the awnings attaches to a grid of pre-stressed stainless steel cables arranged in a recognizable Arabic pattern, the facade shades the building from the harsh sun but allowing daylight quality comfort for the users. Given the strong temperatures and intense sunlight of the location, the building is covered with the same sort of dense pattern around the whole building making a reference to vernacular architecture and protecting the building from all sorts of solar loads using just a single modular strategy.

This project is referenced in the field of shading devices also to projects such as Al Bahar (mechanical adaptive facade) tower in Abu Dhabi, with the great difference that the efficient use of a passive strategy mostly using cables and teflon membrane makes a more sustainable bulding in terms of energy use, and also allowing a dynamic geometric facade. Endorsing the idea of the use of static shading combined with aesthetics, over more complex shading systems.

Figure 54 to 56. SAHRI by Woods Bagot.

Project: SAHRI   Architect: Woods Bagot Location: Adelaide, Australia

The creative force behind the SAHMRI building, it represents an intersection between art, science and innovation. The exterior of the structure is made of 15,000 steel-framed triangles that form a diagrid and was designed to maximise natural daylight while minimising sun glare and energy use. The proper assessment of daylight quality is of major importance since the building hosts a medical research center.

Each triangle panel has a moulded metal point integrated into the piece that varies in width and angling depending on sun exposure. Therefore sunshades extend out or draw back into the building as you move around the construction. They are designed to deal with the environment in order to give view and natural light to the researchers in the building.

The desire of designing a organic shaped building lead the designers to hold on RHINO and Grasshopper for parametric design tools for both geometry and energy design to find a key balance between form and function. Sunshade device forms were reduced from 300 variations to just 20 across all 15,000 panels – fewer styles allow for necessary diversity to accommodate shape and orientation of the building and facilitating their production.

8. EVALUATION AND DESCRIPTION OF PROPOSED TOOLS

8.1 Relevance of working in an integrated design platform

The current situation in information exchange between engineers and architects; is one where the engineers usually hand-in technical results presented as reports and spreadsheets; instead of stepping into the integration of design, where energy and components for building the indicators playing major roles (M. Sadeghipour et al, 2013). In order to achieve the concept of Building Excellence Approach there is a pursue towards the design of more cognitive buildings that suit climate, program and control strategies (W. Huesler, 2015); the line between the architectural creative mindset and the more technical one of engineers has to be controlled in a way where both parties can communicate and understand each others intentions to tackle concepts such as the shading and natural lighting of buildings, this communication process has been developed over the past years with the continuous use of virtual and visual mock-ups that allow to explore more integrated solutions, predicting in a better way the future behaviour of the building. This sort of tools have been integrated as a part of the Building Excellence Approach, which is not limited to architects and engineers but also contractors, suppliers and maintenance, all as part of this new continuous workflow.

As part of this evolution of the workflows some tools have been created for such means, as described by Mostahpa Sadeghipour creator of Ladybug *"the simulation data from non integrated software can not be used to generate the next iterations of design"* (M. Sadeghipour et al, 2013), to support this statement Ladybug has been designed to work in the operational platform of Rhino Modelling + Grasshoper, which is mainly used for design purposes.

Also experts on facade production products Federico Momesso and Massimiliano Fanzaga from Permasteelisa group recognize the new complexity levels in the building industry and compare it with the automotive industry where early-stage design plays a major role in the collaboration between parties, even collaborating with the owner in order to achieve the best technical and budget oriented solutions. Part of Parmasteelisa´s success is their focus on trying to share a common language in their workflow with their peers regarding the location, making use of an standardized IT environment where anyone can work with the projects at the same time, perhaps a new level of collaboration process in the integrated design flows.(http://compassmag.3ds.com/#/Industry/CUSTOMIZED-EFFICIENCY)

8.2 Overview on the methodology over a integrated design platform

The complexity of building design has evolved thanks to the continuous exploration and experimentation from the architectural world to achieve the ultimate design and performance on their buildings in terms of geometry, program, scale, technology and sustainability. Given the new development of tools for integrated design workflows that are allowed within parametric design platforms such as Grasshopper for Rhino, aspects regarding topics such indoor comfort of buildings should be left behind or given full responsibility to the specialists. Architects now have the opportunity to approach their designs in a more holistic way and offered the opportunity that allows them to have better control of their decisions since an early design stage. Therefore making a deeper development involving new levels of abstraction in tools involving indoor thermal comfort through a methodology integrating architects seems plausible.

8.3 Evaluation of parametric energy design plug-ins based on grasshopper for Rhino: Diva and Ladybug + Honeybee

Diva along with Ladybug and Honeybee (LB+HB), were deeply analysed as possible options for the methodology development. The tools were chosen given that they are integrated to and open source platform for development and most likely will continue to improve, also the can be become easily a part of a integrated workflow in contrast with proprietary tools that demand a constant change of languages to perform tasks. As the tools were compared it was notices that LB+HB in comparison to DIVA have a set of tools for weather visualization and analysis. Aside from the visualization of solar feaure LB+HB can also help visualize wind and amongst many other features radiance. In terms of of energy analysis most tools are very complete given that they are both programmed based on on Open Studio which helps to incorporate analysis and libraries from Energy Plus and Radiance.

A major differentiator between both tools in the field of energy design is that HB+LB have created tools to simulate passive and mechanical strategies for energy optimization. More over the amount of specialized tools within LB+HB makes the tool more flexible and gives the designer more exploration freedom. It has to be noticed that HB+LB work in progression, once the options of visualizing data are exhaust in Ladybug the next step is to run simulations in Honeybee in order to retrieve numerical data that will help the designer know a building in terms of energy and will be able to make decisions.

(More information of the evaluation can be viewed in the image Appendix Tool Analysis)

	DIVA Single energy zone calculator	***LADYBUG + HONEYBEE*** Multiple energy zone calculator
Analyse weather data		✓
Visualize weather data	✓ Only sun envelope, position and fan.	✓
Environmental Analysis		✓
Representation customization and unit conversion		✓
Access to Radiance Material Libraries	✓	✓
Radiance analysis	✓	✓
Daylight Simulator	✓	✓
Energy Plus Material Access	✓	✓
Energy Plus Zone Simulator	✓	✓
Enery Plus Energy Simulator	✓	✓
Open Studio mechanical and passive heating/cooling appliance library		✓

Figure 57. Tool comparison table DIVA vs Ladybug + Honeybee

8.4 The need for optimization

As it can be understood there are a several amount of parameters that have to be considered the design of a shading device and indicators that can be looked at in order to assess the most adequate shading design. Parametric design tools can easily help change variables and allow the user to visualize variations of the design almost in real time, record, compare them and simulate digital environments for energy and lighting analysis through plug-ins as the ones presented in 7.3. Regardless the benefits of parametric design searching for the most adequate design through a varied range of possible solutions, can be a time consuming task.

Due to the time implications of revising all the variations of the model, optimization becomes a feasible option in order to generate all the iterative simulations in one single and more accurate process. The amount of results will grow exponentially as the parameters in the design do, due to the multiplication of possible variations of the model. Optimization can also be time consuming but that will variate significantly according the designers computational resources. The goal of optimization is to obtain the most of the indicators according to their nature, with the least amount of values on the design parameters.

Most tools dedicated to this sort of computational operations can usually inform the user about the contribution of every design parameter towards the objectives, though the use of several types of graphs the help the user understand the logic behind every design, a detailed insight over optimization on the workflow, will be presented further on in chapter 13. This becomes very significant in the design process and the assessment for a design that is able works optimally towards the design objectives, due to that fact that the user will be acknowledged about which design variables are actually causing contributing to the desired goals and which become less significant. For this project the chosen tool was modeFRONTIER, the reason for this is the recent development of a bridge between Grasshopper and this software, linking multiobjective optimization with parametric design through the use of a test component developed by Esteco (creators of ModeFRONTIER). The use of the component is possible due to its connection to a recently developed plug-in named D-exp, which allows the Grasshopper simulations to run in modeFRONTIER and later to be explore optimized results in Grasshopper, a more descriptive explanation can be found in 7.6.

8.5 Optimization tools, modeFRONTIER

The fact of having several indicators to tackle with different design parameters, calls for the need of the implementation of a multiobjective optimization process. In case of this project G-Value and Daylight factor will be taken as the two main objectives to tackle. The design parameters will change according to the Sunshading design theory presented in 5. As it is recalled location will call for a preferential design and the dimensions of the shading devices will vary according to the Azimuth Orientation.

The implementation of the of modeFRONTIER will be used as a precise method to have access to optimized solutions, “Assessing the response of a complex structure often requires a large number of simulations which can be computationally expensive. The Response Surface Methods in modeFRONTIER generate reliable meta-models able to approximate the multivariate input/output behaviour of such multifaceted systems, improving the quality of the design knowledge and accelerating the optimization step based on real physics models.” The developer for modeFRONTIER is ESTECO, a proprietary software developer, since the objective of this methodology is to include a precise optimization process to the workflow a bridge between parametric design tools will be needed.

It must be mentioned that the complexity of both, the geometric output and the simulations of involved in the parametric model, will determine final the computational expense of the optimization process. As modeFRONTIER´s workflow is considered to be fast running in its search and optimizations algorithms.

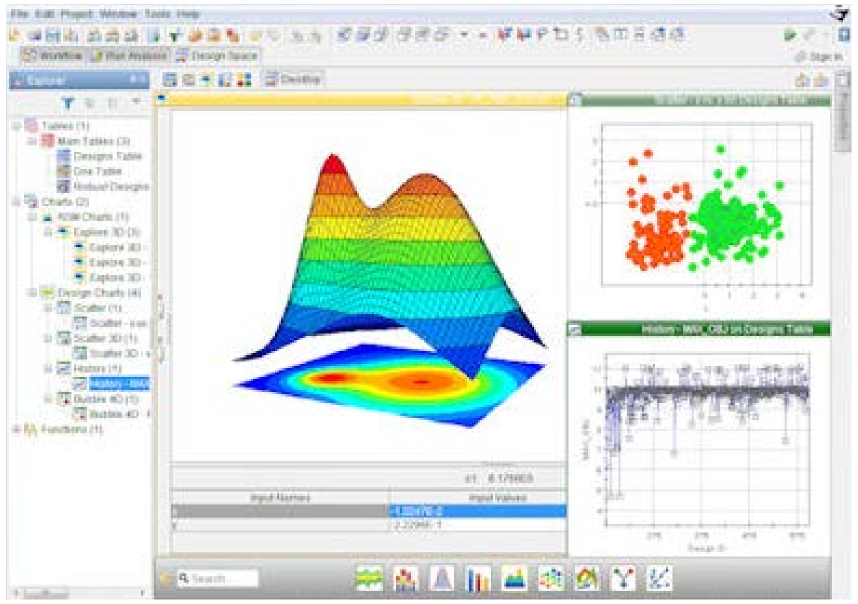


Figure 58. Mode Froniter work interface example.

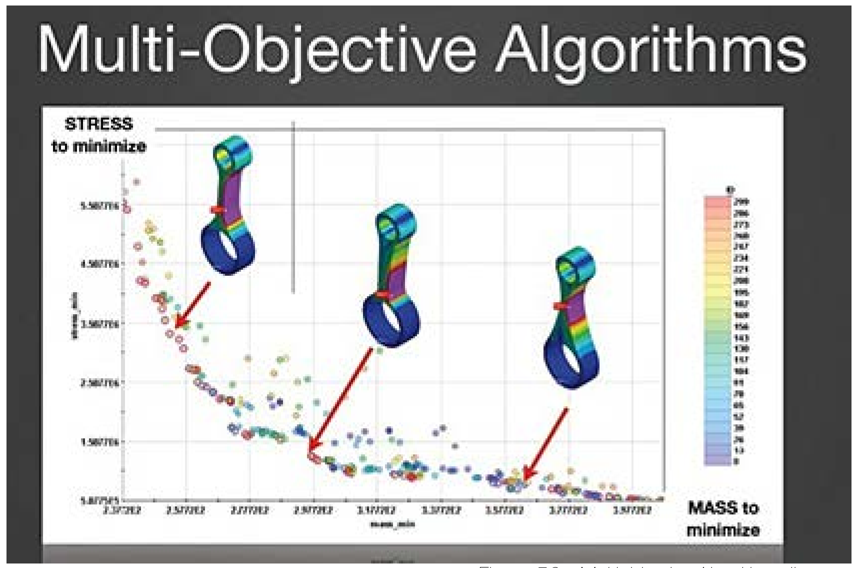


Figure 59. Multiobjective Algorithm diagram.

8.6 The use of D-Exp

Through the current workflow, it can be concluded that regardless the possibility of being able to achieve and informed design decision with valid supporting information, the process is still truncated by the lack of communication between the visual design environment offered by parametric design tools and the objective focus of the optimization tools. The uncertainty of which is the best design possible prevails, aside from the fact that optimization software such as modeFRONTIER is highly precise and informative but still not linked to the parametric design process in terms of possible real time solutions offered and visual capabilities.

Therefore the implementation of a tool that can help generate a bridge between this communication gap is needed. Partially the innovation part of this project will be driven by the use of a tool capable of running parametric environmental processes through an optimization tool, that then can also use the data generated by modeFrontier in order to generate graphical informative results as same as 3D models of the feasible results in order to proceed in a more fluent path in the informative design process.

The answer to this need was found in a recently developed tool named D-Exp, which was created in TU Delft by Rusne Sileryte, Ding Yang and Michela Turrin. This software interacts as a communicating path between GH and modeFRONTIER , wih the possibility to run GH simulations into an externam optimization software, with the possbilit to access to statistical data, and model information in the parametric design tools. The communincation is possible due to a GH component developed by ESTECO specially for the communication with MF.

This plugin is divided into two main parts, Optmization and Exploration. Optmization works as the link between GH and modeFRONTIER, while expoloration links back modeFRONTIER to GH as a visual aid and data filtering tool (figure 59).

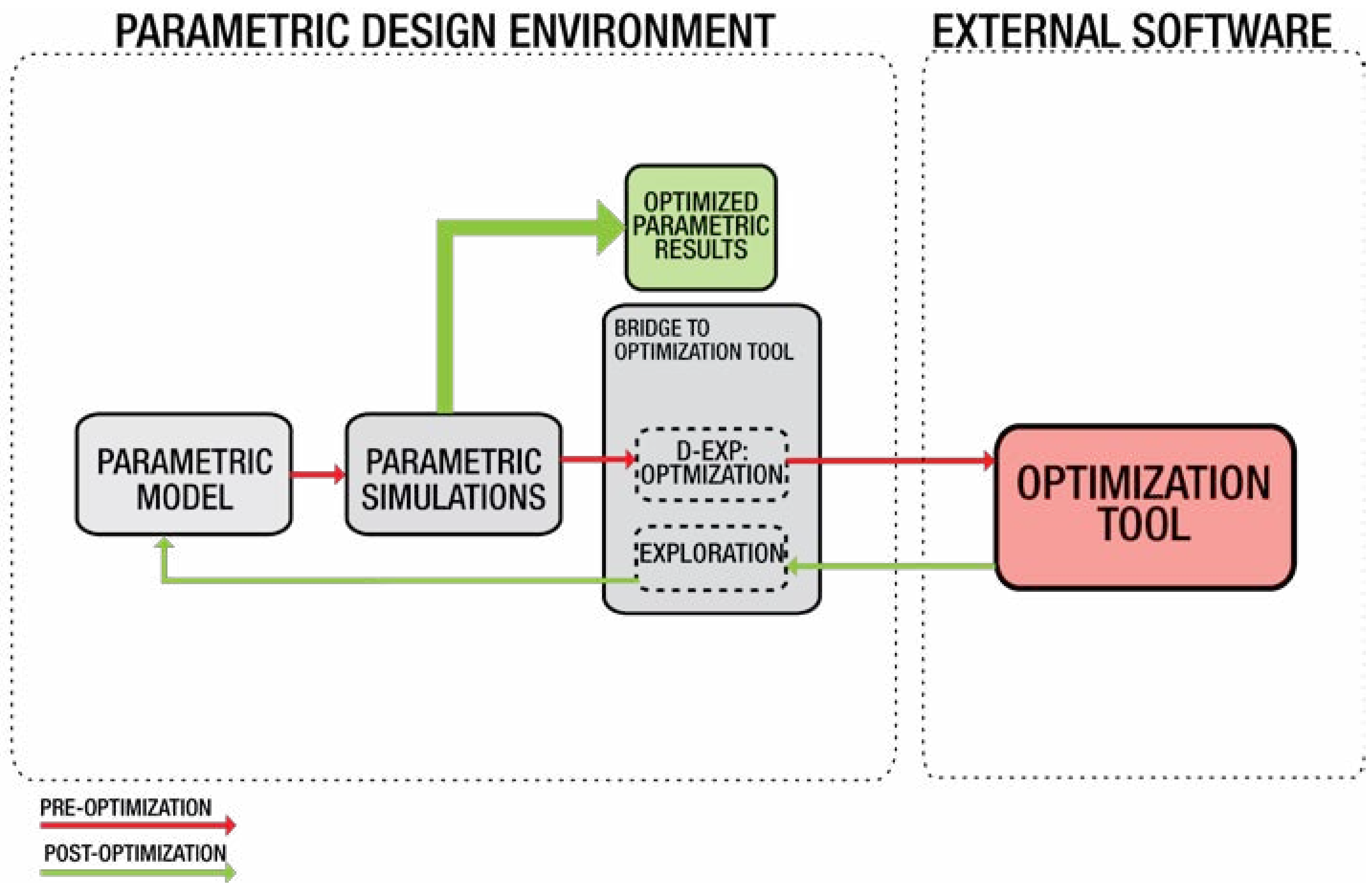


Figure 60. Pre-optimization and post-optimization diagram.

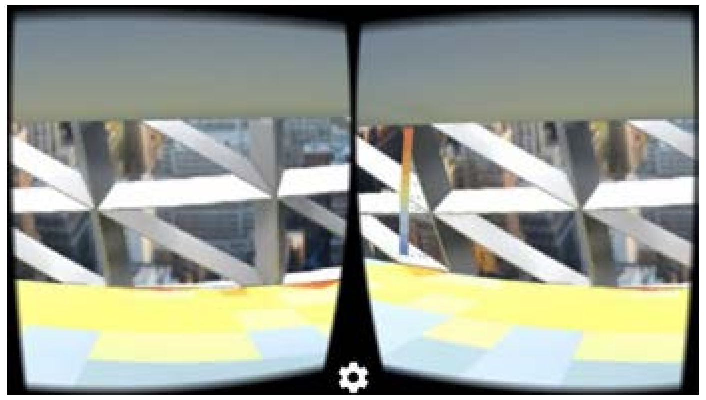
8.7 Virtual Reality as form of communication

The benefits found in the use of Virtual Reality are the ones of creating an immersive, informative and even amusing form of experience. Through the research on this topic, different ways of representing Virtual Reality were consulted, which resulted in "Interactive live scale simulation" and "Single node panoramic view".

Single node panoramic view is a more simple form of VR representation, the access to this form technology needs a less demanding infrastructure which is any mobile device with a gyroscope (smart phone, tablet), a simple Virtual Reality display device such as Google cardboard(R) and access to an open source application or platform to display the models.

The application used for this project is TheConstruct which is an open source Virtual Reality simulator in experimental phase developed by Piort Juchnowicz and Kristaps Karniitis, which is still developing. The advantage of this form of representation is portability, although it lacks of the level of interaction offered by the Interactive live scale simulation.

Regardless the limited level of interaction is offered through this application, it is possible to generate walk-throughs, which allow a certain degree of the exploration. The user will not be able to freely move around the space or modify the position of objects in the model, but will have access to 360º degree spherical panoramas from a single point of view.



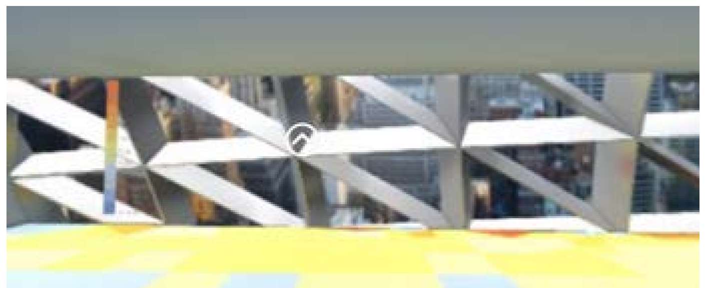


Figure 61 to 63. TheViewer and TheConstruct static panorama VR interface.

As a form of taking the interaction between the user and information to a higher level, the implementation of Virtual Reality is used in the work-flow as a form of output and feedback source. As shown by T. Majumdaret al (2006), the use of Virtual Reality played a key-role in the design experiment using VMM (Virtual Reality Mock-up Model) to generate design reviews for the design of court a court room, assisted by people from the court and related agencies. During this design review the use of virtual models made a successful difference from "on screen" representation in before the generation of ply-wood 1:1 scale model rooms, direct feedback of preliminary design. Although the technology implemented by T. Majumdar et al is now outdated, it shows a clear structure to set bases for further development in the use of VR as a form of assessment and direct feedback on a design (figure 64 and 65).

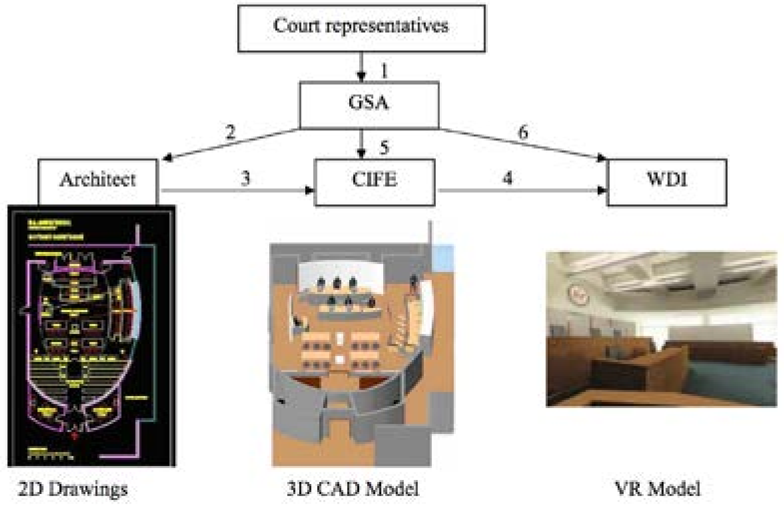


Figure 64. VMM Workflow.

Figure 65. VMM Users experimenting a form of VR in order to provide feedback.

A more sophisticated level of exploration is showcased in an early application of VR by P. Dunston at al (2006) where the use immersive virtual mock-ups was used in order to determine the proper layouts and functionality of highly demanding functional spaces such as hospital rooms (figure 66 and 67). In this paricular case the immersive expericed is focused on detailed movements of medical equipment and furniture on a concealed space and how will hospitals emplyees would be able to manipulate such equipment freely. A relevant feature of this example is the user of the space providing inputs for an assessment in order to generate conclusions over how the space is being in used and how to improve. The use of VR becomes fundamental to oversee future problems in the current design avoiding polite guesses or adaptation of the space or the users beforehand.

Figure 66. User testing a medical facility indoor space.

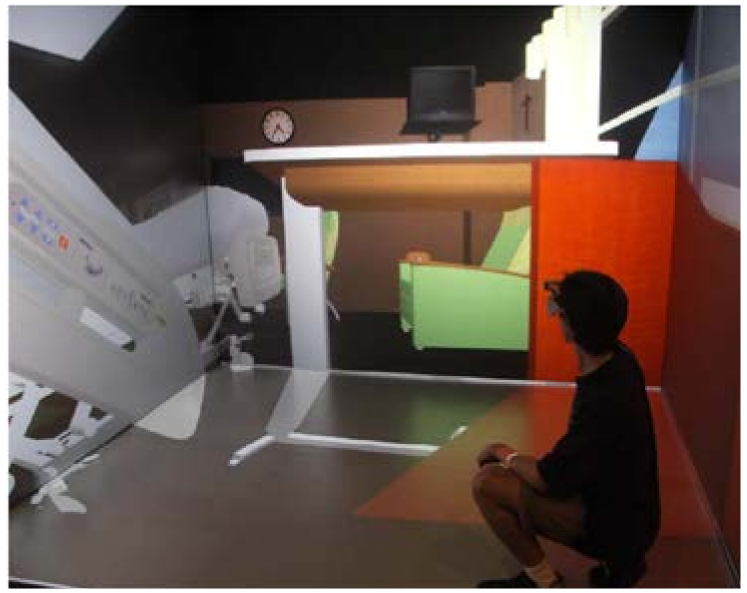


Figure 67. User testing a medical facility indoor space.

Related to visual confort an experiment done by A. Heydarian et al (2015), implements the use of IVE´s (Immersive Virtual environments), in order to generate the mock-up of the virtual office in order to determine the use and control of natural and artificial light. The immersive experience of this project allowed the users to manually experiment with different sorts of lighting and shadings until they found the environment sufficiently comfortable.

Conclusively it was found that "human performance, perception and behaviour in an immersive virtual environment to not be significantly different than that in an actual physical environment" (figure 68), endorsing the fact of the use experience of the users working in parallel to accurate Virtual Reality 3-D models for design goals which are not graspable as daylight quality can be, can be taken down to a point where its assessment possible.

Fig. 1. Physical office (left) vs. virtual office (right).

	Group 1	Group 2	Group 3	Group 4
Artificial Lighting System	Manually turning the lights on/off	Manually turning the lights on/off	Manually or semi-automatically turning the lights on/off	Manually or semi-automatically turning the lights on/off
Shades for Natural Light	Manually operating the shades	Manually or semi-automatically operating the shades	Manually operating the shades	Manually or semi-automatically operating the shades

Figure 68. Comparison of artificial lighting vs Shade for Natural Light

The technology used in this experiment relies taken BIM (Building Information Modelling) models through rendering process and finally to a Virtual Reality environment generator. Posteriorly this model will be transferred to first person VR devices such as headset, displacement sensors and motion trackers. In contrast to the courtroom and medical facility previously mentioned examples (figure 69), this experiment is generated without the use of external projectors and focuses on the experimentation of immersive and interactive environments.

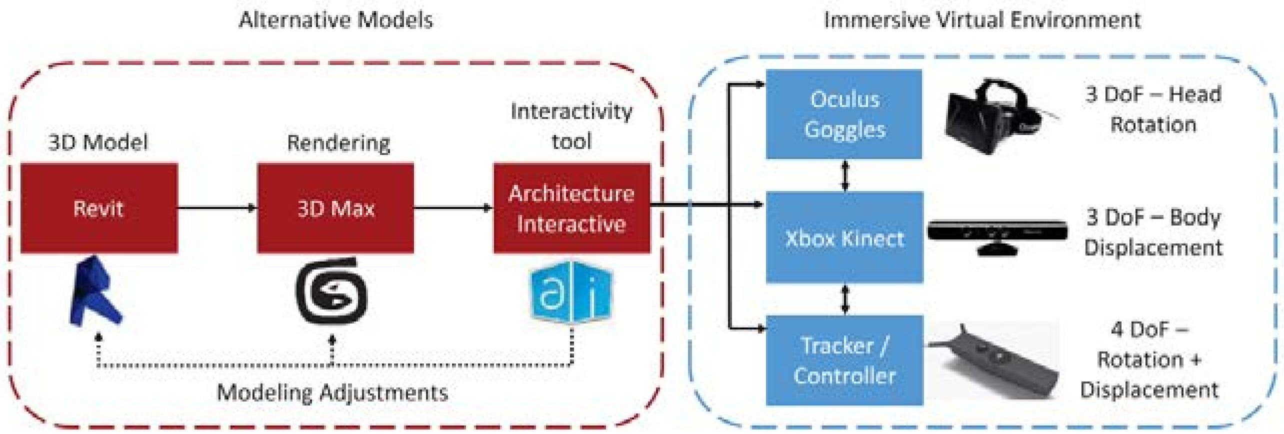


Figure 69. Comparison of artificial lighting vs Shade for Natural Light

The previously presented examples show different levels of immerisiveness in the Virtual Reality experience, aiming towards differnt goals and using different stages of technology development. Although they all feature the use Virtual Reality is a higher degree of representation for assessment and informed decision making. The evaluation of a design with the use of VR as previously mentioned can prevent regretable design choices for a space or at least rise awareness of the design choices. It is also important to mention the involvement of the different stake-holders in the design process in order to make the design choices with a higher level of understanding and participation.

From the presented forms of interactive virtual environments, live scale, interactive and fully immerisve simulation is the most sophisticated of all since it allows a deeper level of experience for the user. The access and knowledge of the manipulation of this technology for this project is granted to the VR-Research group of TU-Delft.

The platform used to access this form of Virtual reality for this project consists of a infrastructure of VR-googles, spatial sensors, navigation controllers and high performance computational graphics.

The Virtual Reality lenses are the main access to virtual reality since through them, the user will be submitted to virtual space that will allow the visual exploration of the space, design options and detailed models. The space modelled for iterative walk-through feature is possible due to the use sensors that limit a physical space for the user to move around "inside the model", through the use of the virtual space is as big as the user needs.

Figure 70 and 11. HTC Vive Virtual Reality Gear.

8.8 Integration of a Front End in the parametric environment

Due to the fact that possibly not users are savvy on the topic of parametric design platforms the use of of user friendly access the work-flow is needed. This was possible due to the use of Humaun Ui, a paramtric plug-in that allows the user to take parametric features into a simplified form of control more related to regular computational environments. In this project not all the parametric features of the model will be included due to their complexity and computational expense. The use of the how this user friendly is applied n the project will be better showcased in chapter 13.

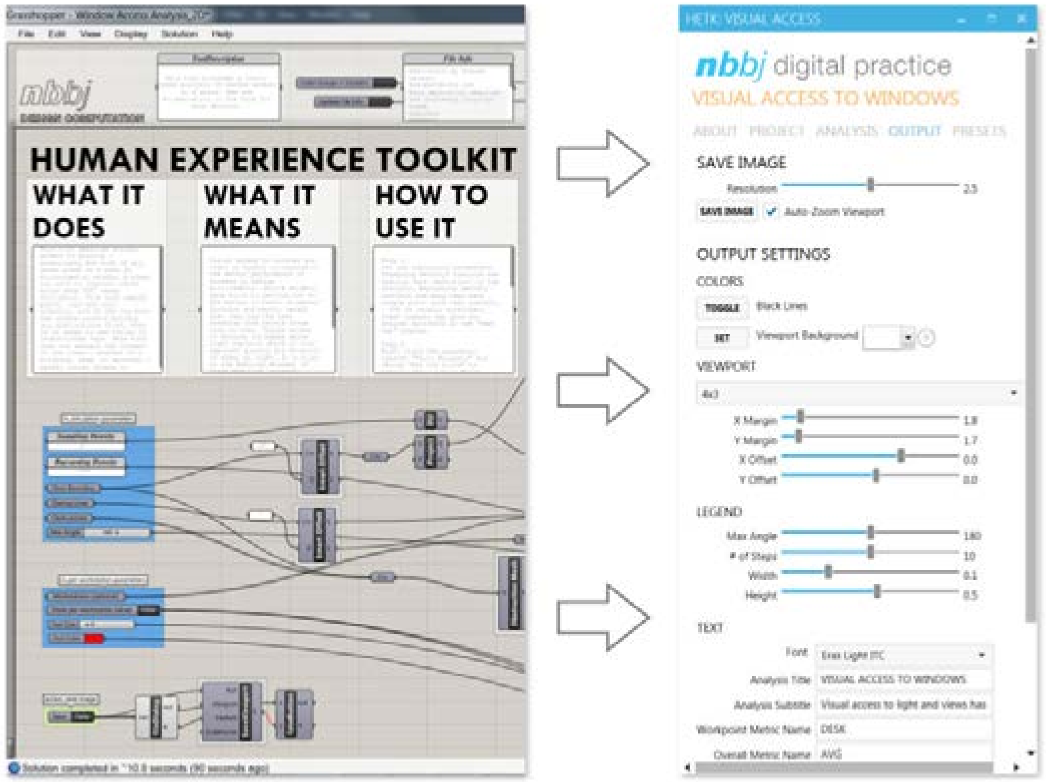


Figure 72. Human UI interface example interface.

9. CURRENT SCENARIO FOR DESIGNERS AND DEVELOPERS ON THE USE OF PARAMETRIC TOOLS FOR ENVIRONMENTAL DESIGN

9.1 Designers current point of view

Interview 1- Rodrigo Pantoja Calderón

Subject: Incorporation of sustainability and energy tools into the design process and interpretation of current flow presentation of data.

About the interviewee: Rodrigo Pantoja is young emergent architect in Mexico, with most of the work outside of the capital of the country. His firm Evo_Lab is committed to work with sustainability, the scope as in many other architecture firms stands in the "situational feedback" side of design.

The reasons for the interview are below listed:

A. The firm usually aims for low-tech solutions to theirs projects, given this passive systems must be use to achieve certain sustainable goals.

B. Their project NAMA a Designers manual to good practices in Social Housing in Heat-Dry and Heat-Humid zones, is a proof of the intention of using energy related tool, how far did the went from the simplistic representation is an important way of measuring the use of energy performance tools in emergent economies.

Questions:

1. How important is sustainability in your practice? Indeed it has become more important over time, although regarding our context the use of low-tech strategies is more common, although I think we should know more about the science of within our buildings. We find it fascinating that in such a big country homes are built in the same way in the north or the south.

2. Through NAMA, the use of some energy saving related tools is well noticed, what is the information you extracted from these models? We were working with a certified consultant from the SISEVIVE project which is an initiative of the Mexican social housing government entity with the Deutsche Gesselschaft making a program for sustainability improvement, but its is not open source and they are just around 20 certifiers in the country.

3. Did you consult any climate or energy specialists after taking your energy related design decisions? Not usually but in case for the NAMA we used the SISEVIVE certificated expert.

* If so how was the approach, and what did you expected from the specialist? If any previous experiences with specialists, have you had any sort of communication barriers?

4. Do you use energy design or climate data representation tools? What are the tools/process you usually use for energy design? (if the answer is YES, go to question 9, if the answer is NO, go to question 5 to 8) We started using some visual representations of sunpaths and shadow dropping from Ecotect but not further than that.

5. Can you tell if this new data presentation is clear enough to understand and incorporate to the design process or it still to technical? (show images or energy analysis based on plug in inventory) I were not very much related to the images further than the sun path, everything was not really clear.

6. Are you familiar with integrated design with the aid of parametric design tools such as GH with all its plug-ins? No, but we would really like to make it a part of our design process, same as making physical models also energy modelling should be included.

7. How would you incorporate these tools in your practice? As I told you it would be nice to have it as a part of our design process, it is clearer for the architects it would be great, since small firms have to solve everything and it will be great if we could use the tools in an easier way.

8. What would stop you from using them? N/A

9. What are the highest technical challenges found in the process of energy design from the architectural point of view? One of the energy design experts from SISEVIVE helped us with the NAMA project; the data is really hard mostly based in numbers but this is as graphical as it gets (figure 10, sisevive).

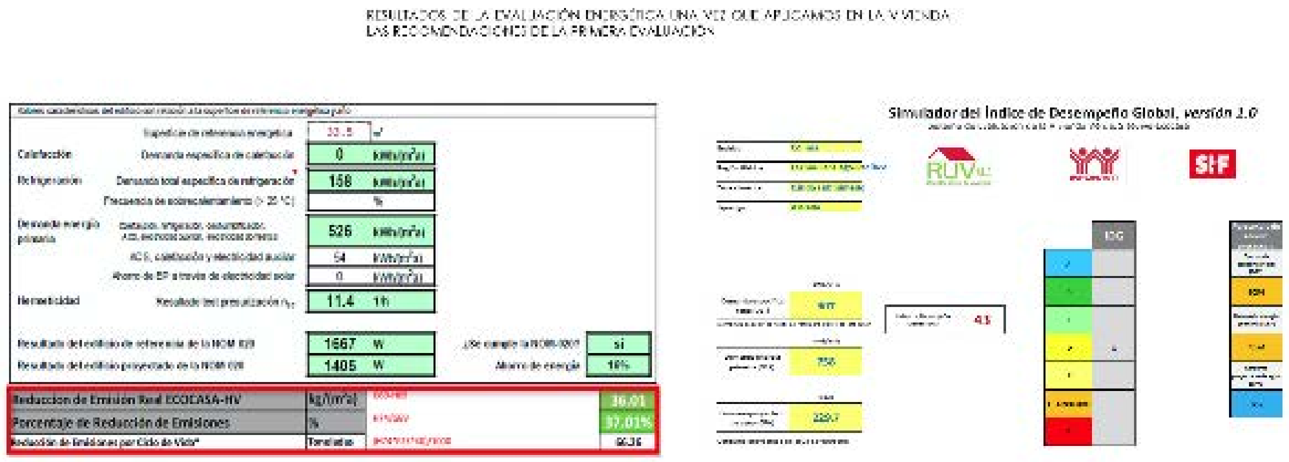


Figure 73. Example of a Sisevive result sheet present to the consulter.

Interview 2- Miguel Angel Lira Filloy

Subject: Incorporation of sustainability and energy tools into the design process and interpretation of current flow presentation of data.

About the interviewee: Miguel Angel Lira is one of Mexico´s most outstanding architects with a practice running for over 20 years specializing in M, and L scale corporate buildings. He has experienced and seen the shifts in the applied technology in Mexico.

The reasons for the interview are below listed:

A. How is his practice has been adapting to new technology in design tool related.

B. From his experienced point of view how important are for his firm the sustainable practices energy related.

C. As the information is now a day presented from tools such as ladybug, how easy for him is to understand/relate to this information.

Questions:

1. For how long have you been practicing architecture? And what is the scale and scope of your projects and clients? For more than 20 years and the scales my firm manages are from residential villas to master plans.

2. Do you use sustainable practices in the design process in your firm? How do you incorporate it? (Resource saving /energy generation / energy saving) I do not particularly use these tools in my practice but I have taken a diplomat on the subject of "Sustainable cities and communities", where basic concepts where addressed such as orientations, heat gain and loss, but not in a technical way I just know the benefits of certain practices but not qualitatively.

3. Through which means do you apply these features? (Analog /digital) Our approach is more from the traditional architects side, we analyse our projects from a vernacular point of view, but we don't deal with hard data, it is more about concepts, in block layouts.

4. How far do you go in the design process regarding sustainability before handing in data to and specialist? The specialists get involved since the beginning of the project just after the architectural project is ready in a pre-phase, then we get advice from the specialist regularly in terms of the effects of sunlight and wind, then if something has to be changed in order to achieve certain aspects we do those changes.

5. Whilst having experiences exchanging information with specialists, what have been the main barriers in communication? Fortunately the process has always been really fluent, never the less sometimes we get severe positive feedback when out design decisions will compromise the building´s positive behavior, The we take a step back and take the advice and fix it, is the argument is strong enough. We have always tried to convince our energy specialists to generate information that is easy to understand and synthesize for us "what are you telling me with all this information?"

6. Do you use energy design or climate data representation tools? What are the tools/process you usually use for energy design? (if the answer is YES, go to question 11, if the answer is NO, go to question 7 to 10) No, we work in a very architectural traditional way.

7. Can you tell if this new data presentation is clear enough to understand and incorporate to the design process or it still to technical? (show images or energy analysis based on plug in inventory) I am familiarized a with the images related where architectural space is shown and those I can understand easily because of the diplomat I took, but not the other technical graphs I would like to have more simplified answers just in case I need it.

8. Are you familiar with integrated design with the aid of parametric design tools such as GH with all its plug-ins? The younger people in the office know all this new things I am not aware in particular, but if those skills and tools will help us solve in a determined moment a certain project we are not closed to use them.

9. How would you incorporate these tools in your practice? Yes, if it improves our design quality anything is welcome. We are incorporating BIM software such as Revit in our production technique process.

10. What would stop you from using them? Nothing we are open to learn, architects need to know a bit of everything. But I would also like to better let the specialist do their work I trust and its not entirely determinant to me.

Overview from interviews to Architects M. Lira Filloy and R. Pantoja

According to Ms. Arch Miguel Angel Lira (M. Lira Filloy, 2015) senior architect at Springall & Lira, the current scenario in his practice of 30 years designing for architectural projects for middle scale to master plans mostly in Mexico; the scenario is one where the by his age al cultural background *the use of tools such as AutoCad was the limit of technology use in the design process*. When the project demands it he trusts a group of specialists from structural to energy and environment, form which he expects synthesised answers and *if arguments are important enough redesign is considered* . In the recent years of his practice he has been more acknowledged to sustainability since he took a diplomat on *"Sustainable Cities and Communities"* where the benefits of sustainable practices were *not tackled from a qualitative point of view*. As an architectural office they are *open to learn about and use new technology* and its use as long as it benefits the projects, and *now they have implemented the use of BIM* in their design process.

In contrast, the smaller firm EvoLab lead by Ms. Arch Rodrigo Pantoja (R. Pantoja, 2015) is which younger practice stands to a scenario more representative of the smaller scale architecture firms in Mexico. This represents a context with an scope of clients more onto the *low-tech side and traditional architecture* and less resources to pay for specialists. Although with the NAMA project he had the opportunity to work with specialists to solve energy design and water use problems for social housing across Mexico, ***"We find it fascinating that in such a big country homes are built in the same way in the north or the south" (citation).*** Through the NAMA project, they learned about the *SISEVIVE* (reference) which is *only used by certified experts*, with report based results; making this a very narrow picture for the designers interested in the incorporation of energy design. Regarding an approach to energy design in the office, things *do not go further than drawing sunpaths or shadow dropping in Ecotect*. The relation to for him to the images produced by the energy design tools were not totally clear, he did not relate with any more than he uses at his office, therefore on his behalf there is a recognition of using energy design tools as part of the workflow ***"As I told you it would be nice to have it as a part of our design process, it is clearer for the architects it would be great, since small firms have to solve everything and it will be great if we could use the tools in an easier way."*** (R. Pantoja, 2015)

The coincidences between this two professionals are that they are not using design tools in their architectural practice. Even though one Miguel A. Lira´s firm has more experience dealing with specialists they are willing to incorporate energy design practice as part of the workflow in order to take better design decisions, supporting this ideas EvoLab´s posture is the one of incorporating and thinks the span of user of energy design tools should be broader and more open to the architectural audience. When some relevant images related to the energy design, they partially understand the image or had no idea how to relate those results to a design process. They knew all the data was useful, but would trouble turning the results into a creativity trigger but recognize their informative potential.

9.2 Developers point of view

Interview 3- Chris Mackey

Subject: Incorporation of sustainability and energy tools into the design process and interpretation of current flow.

The reason for the interview are below listed:

A. Christopher Mackey along with Mostapha Roudsari have created Ladybug and Honeybee an avant-garde Rhino+GH based plug-in for visualizing weather files and making energy simulations respectively.

B. Their plug-in is one of the most users friendly and less technical within the possibilities of interaction with the creative mind-set of designers.

C. The level of abstraction of the software it quite well described but still a bit unclear to the architect creative mindset.

This interview has conducted more as a chat, where the interviewee Chris Mackey expressed his opinions, points of view and relevance of the tools he has developed with his partner Mostapha Roudsari which will be also interviewed, this chat took over several subjects, which will be addressed within this overview:

MINDSET ON DESIGNING LADYBUG (LB) AND HONEYBEE (HB):

In the past we noticed the existence of many tools, that were incredibly limited trying to deliver so many answers in real time that in the end they became extremely limited, making many assumptions for the designers leading to inaccurate answers, for example Sefaira. This mentality of wanting fast answers to complex problems is really a major discourage for us tool developers. It takes a level of expertise to get to understand certain amount of information. There are a lot of skills the user should know and teach himself, that it why while designing for LB and HB it is preferred that the process is understood component by component.

MOTIVATION TO DESIGN THIS TOOLS:

Mostapha LB before the partnership, never the less both of us had started trying to design with passive principles, proposing design out of the box, while using out basic thermodynamic principles but we had no idea whether they will work or not.

Mostapha war particularly interested in passive systems because of his background which is Iranian. We had the a motivation to apply ideas regarding energy use that could work on our early designs, as every other students, we got asked “How you know this works?”. There was not simple set of tools to proof us right and then we realized none of those out of the box ideas will stand unless their validation could be proved.

When we started working with some tools we found such as Design Builder and Diva, they worked like hammers, a tool designed to do something very well. Tools that the as soon that the user tries something atypical or outside of the norm, then the tool must be “forced” into solving such problem but in a sort of improvised way. Regarding that we realized we did not need a new tool but a tool-kit. Even tools in Grasshopper like the extension for diva results very inflexible. Then the philosophy turned into that one that instead of having just one component that solves everything, there are a huge amount of components to customize the workflow, making them adaptable to any projects.

ENERGY DESIGN AND ARCHITECTURAL EDUCATION

Something should be learned and some things should not, everyone will not be motivated to achieve a deeper knowledge in the energy subject. Certain aspects like the position of the sun, making a sunpath and how to use it just the basic. Not every architect should run energy models, it its a big investment to understand everything behind, making conclusions that are incorrect or do not even produce results but help to argue the design is energy conscious is really dangerous. In that aspect many energy modelling tools might end up misleading rather than helping achieving proper results.

Instead there should be dialogue with the different sort of architects, there are the architects who actually know a lot about energy modelling, they will help their peers with less knowledge to use determined "tool" to solve any problem that could come along. Not everyone should have expertise on everything. On the other hand it its better to have peers who do something really well instead that many things not well. This spectrum helps the specialization of your workteam, as they complexity of energy design demands, it would be better to have someone who really knows for example thermal or daylight very well.

COMMUNICATION GAPS

Prior to energy design modelling was integrated into a platform such as Grasshopper, the existent tools over simplified models into boxes. Now a days Grasshopper has helped eliminating those gaps allowing more complex geometries be a part of energy modelling.

By know there are tasks I can do very quickly myself after I got to master the tools we develop. Although at certain point it is very important to pass a simplified version to someone else, otherwise it is easy to get overwhelmed with the capabilities existing in LB and HB. For example, know a days I am working on an energy model that deals with radiation vs the size of the HVAC system being designed. I can not give this script to someone and expect them to know how it works, but a simplified version related to the shading device they are designing for the facade. From that point I know they have enough knowledge to run that model for all their shade cases. Simpler versions are important to hand in to someone else.

Although the biggest gaps are not computational, they are social; like passing on information and accepting different levels of expertise in different kind of problems. The biggest gap in practice yet is still between architects and engineers. Engineers have harder time to evolve, they feel more comfortable relying on tools ans tasks they have been doing since they are reliable and good at them, but not really interested on their capacity of doing new things. The cultural gap is also huge barrier to overcome rather that a particular software or technological barrier. Proprietary software issues are also a gap to overcome with engineers since they keep the model to themselves. But now a days the peer pressure of the community of developers now a days in common platform like Grasshopper has helped engineers to move to open source tools.

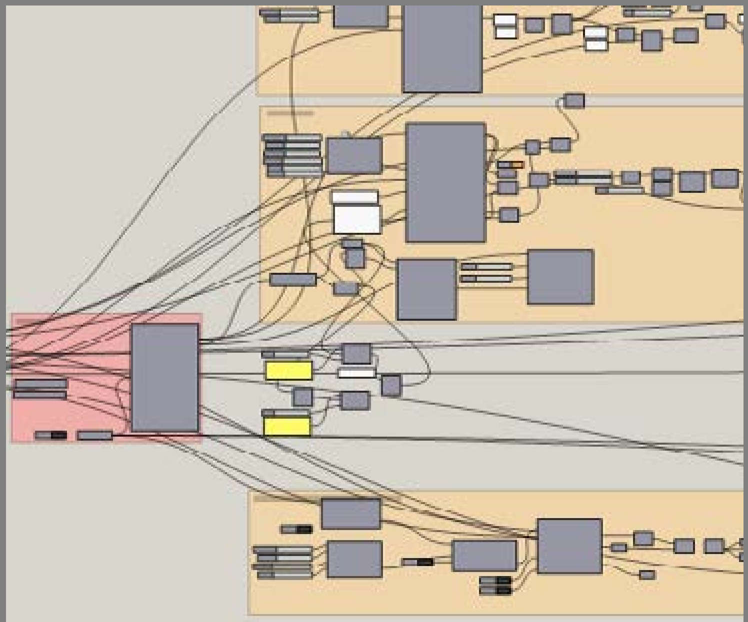
Another one of the breaches comes while learning, most common questions in the forums come from designers trying to jump steps, instead of trying to understand for example the energy model from a box the begin from the most complex model the could. Not really taking time to understand they need to learn this step by step instead of just jumping into energy modelling. Even while teaching I think that sometimes I have jumped to many steps and explained things that students were not ready to understand. There are fundamentals that have to be learned before stepping into the tools, it is important for the users to understand the metrics and the issues involved, for example why you can use radiation for a series of things. Also understanding what you are trying to achieve before you test and simulate with energy. Going to HB is just the step after LB is exhausted.

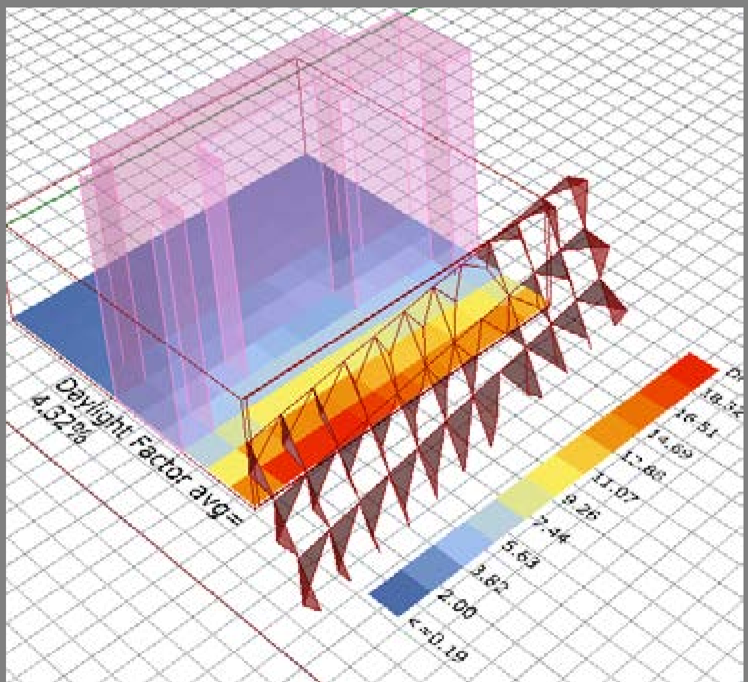
Something should be learned and some things should not, everyone will not be motivated to achieve a deeper knowledge in the energy subject. Certain aspects like the position of the sun, making a sunpath and how to use it just the basic. Not every architect should run energy models, it its a big investment to understand everything behind, making conclusions that are incorrect or do not even produce results but help to argue the design is energy conscious is really dangerous. In that aspect many energy modelling tools might end up misleading rather than helping achieving proper results.

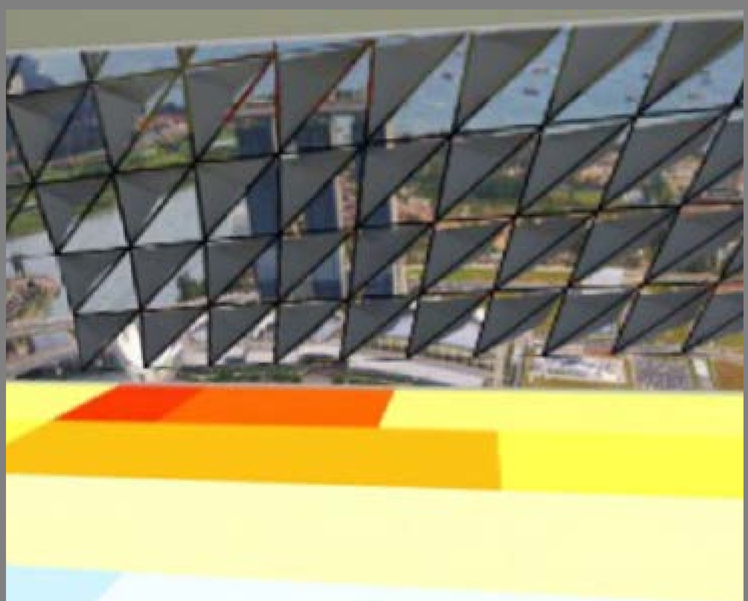
Overview from interviews to Chris Mackey:

The idea of Ladybug and Honeybee is act as a toolkit for the visualization of wather data and the performance of energy design tasks. According to Chris Mackey co-creator of the plug-ins their idea was to create a collection of tools in form of paramteric components with an specific function, avoiding the need to force the tool towards a result most likely full of assumptions. He compares the plug-ins he has developed with a tool box and the other plug-ins as hammers, "As long as all your problems look like nails a hammer will be perfect, but when you problem does not look like a nail anymore you have to use a hammer as something else."

According to what Chris Mackey expressed on this interview, the major concerns now a days are on the technological gaps or the integrated design workflows but in the communication between parties from architects and engineers collaborating in the design process to internal communication between peers in a office. His opinions about his interaction in the professional world on daily basis reveal a deeper interest in delivering simple tools and procedures that solve specific energy design problem to his peers, that handing in the whole analysis procedure he has gone through as an expert so other participants in the projects can interact with simple version of such tool and can take decisions.







PRACTICAL RESEARCH

Content:

10. WORKFLOW STRUCTURE

The workflow has been divided into 5 phases: Design, Simulation, Optimization, Visualization and Assessment.

1. Design - At this phase a parametric model of the building in question is elaborated . The involvement at certain extend of environmental tools begin since the location of the building has to be defined as well as the building´s massing and program. Knowing the context and the program of the building becomes important for the proceeding step which is the conceptual design of the shading devices. As a result of the merging of a building design, architectural program, location and a concept for the shading, an adapted parametrized shading design is the result.

2. Simulation - This phase is where the simulations for daylight and energy will take place. A parametric model for both indicators is elaborated, this models are based on a realistic representation of the building since physical and optical properties of materials are taken into account. The results of this simulations are the input for the design goals of the optimization process.

3. Optimization - The optimization phase takes into account the resulting parametrized shading design and the daylight and energy parametric models to generate a optimized results that match the design objectives of the project, which will vary according to the needs of each project. During this process highly valuable sets of statistical information (most of them charts and graphs) for comparative and conclusive purposes are created. Those results will be later used to support the assessment of the design.

4. Visualization - As a form of post optimization process a selection of the results generated over the previous step will be taken into Virtual Reality for exploration. The design features elaborated during the previous phases, which characteristics can be showcased in a form of 3-D model will be part an interactive and immersive environment that will lead endorse the assessment of a design.

5. Assessment - During this phase; based the post optimization results of both on how the statistical information and the visual outputs cope with the fitness functions and expected behaviour of the design, making a choice or a re-evaluation of the design is expected through this phase.

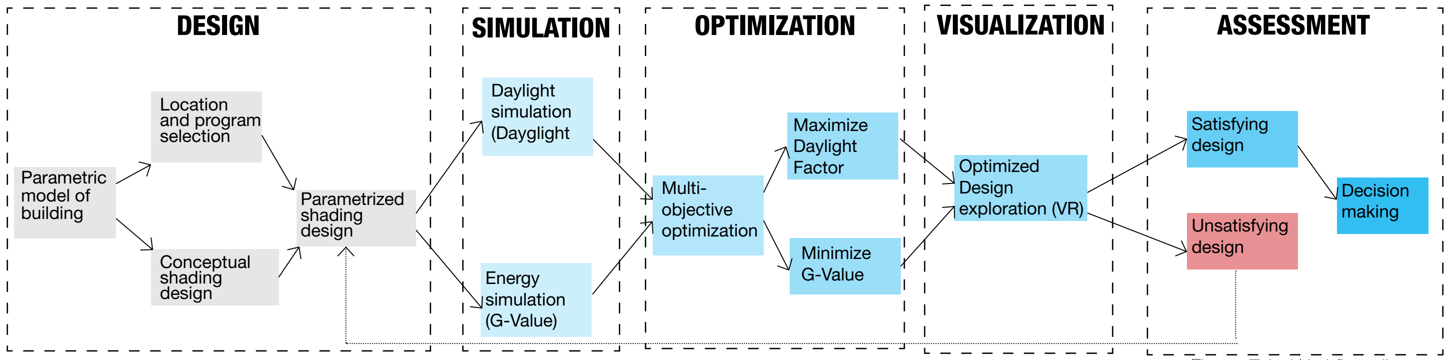


Figure 74. Workflow diagram.

10.1 DESIGN

10.1.1 PARAMETRIC MODEL OF BUILDING

In order to generate the parametric model of the building, the massing and the program have to be defines to a certain extent, this is becomes relevant since the characteristics of the building will determine the geometrical behaviour of the massing, most likely establishing a specific set parametric rules for the design which may influence the concept of the shading design.

The parametric model of the building will allow to be able to develop shading devices according the conceptual needs of the project; such as the level of responsiveness according to the general concept of the building and the desired level of customization.

The parametric model can be decomposed into basic building components of a building such as facade, windows, slabs, walls and roofs. This components can be later used by a designer as a starting point of reference to generate an adapted shading device concept.

10.1.2 LOCATION AND PROGRAM SELECTION

At this step, the selection of the corresponding EPW (Enegy Plus Weather) file for the project´s location will be made, the data retrieved from this file will allow the environmental visualization such as the sunpath, mean radiant temperature graph, Tergenza Daylight factor dome and ray-tracing. Such information is useful in order for the user to have a broader perspective of how the building in question relates to its specific environmental conditions, for example: the peak dates for solar altitude and the relation between the building´s façades and how and when they are affected by solar irradiation according to orientation.

The program selection is important due to that fact that at this point it is easier to determine for which rooms and/or programs the shading devices will be designed for and their orientation in the building. The fact that the chosen programs could also have a different typology, and every program could have different needs for daylight distribution or solar gain, can be an starting point for determination of design parameters, which will take as a point of departure the theory on shading devices, mentioned in chapter 5.

10.1.3 CONCEPTUAL SHADING DESIGN

At this point creativity becomes the limit for the designer, the only constraints possible are determined by the theory on shading devices. A brief example of what can be achieved for challenging designs are portrayed through case studies pointing, out different sorts of shading typologies in chapter 7.

It is of sum importance to have a fluent design process that during creativity stage to takes into consideration some aspects to make the design phase clearer and fluent. Try to keep elements modular, think a step forward on fabrication and production technique and try not to overcomplicate de design. Impressive design and visual effects on buildings can be achieved with simple and well thought design elements.

10.1.4 PARAMETRIZED SHADING DESIGN

At this step the use of the information retrieved from the location and program selection, in combination with the shading concept will give the designer guidelines to generate a parametric model of shading that adapts to different sorts of conditions. At this stage the desired design functionalities such as scaling, rotation, aperture, deployment should be implemented into a the parametric model according to a logical connection between the environmental information and the shading´s behaviour. Since, the resulting parameters will later be used as the design inputs for the optimization process; it is important to mention that the components that generate the permutations of the shading devices remain as few as possible, therefore a model with an integrated parametric behaviour is recommended. This, in order to reduce the computational expense time during the simulations.

10.2 SIMULATION

10.2.1 DAYLIGHT SIMULATION

The daylight simulation; which in this project mainly is focused on daylight factor, will be based on the composition of the optical properties of materials. Material properties for finishings for walls, floors, roofs, windows and shadings that can be used in the analysed space are basics for the setup of the simulation model in order to create results as real possible, this optical properties can be accessed through different validates sources that will be later explained. The outcome as it has been mentioned in 6.3.1 will be a representation of the yearly average for even natural light distribution through a gradient that indicates communicates the values through color and an indicative percentage.

10.2.2 ENERGY SIMULATION

The energy simulation will be also based in the material composition construction elements, although in this case the focus it will be on the physical properties, which are provided through libraries based ASHRAE codes, which validate of the inputs used in the simulations. Through this simulation it is possible to know the influx of energy in a room or any construction element. Although for the sake of the project it will be based on the infiltrating energy through the glassed surface and how much of this energy can be absorbed by the use of shading devices having a result and index for the reduction of G-Value and also the amount of energy (Kw/m2 hr) is prevented from infiltrating throughout a year.

10.3 0PTIMIZATION

10.3.1 MAXIMIZE DAYLIGHT FACTOR

The maximization of daylight factor through optimization has the objective of achieve the possible higher average results for this indicator for a yearly calculation. Through the use of shading devices, the daylight factor is aimed to be decreased and or controlled in order to generate an even distribution of daylight in a room.

As the indicator is determined to be maximized through the optimization process out of the optimization process a big sample of possible results will be generated, although only some of them will be useful. The results that fit the daylight factor results established by the designer according to the project will be the ones to be selected for the next phase of the workflow.

10.3.2 MINIMIZE G-VALUE

Minimizing the G-Value with the use of shading devices is almost certain, due to the fact that their effect by default is blocking the energy coming through the glass in the room. Through the optimization process, it is possible to determine the highest degree of minimization of the value while at the same time allowing the Daylight factor to have a positive influence on the design. At at certain extend the indicator can result as a consequence of the level of effectiveness of the design and how it copes with the Daylight factor. Therefore the results taken in account for G-Value for the following phase wlill highly depend on their performance on daylight distribution.

10.4 VISUALIZATION

10.4.1 OPTIMIZED DESIGN EXPLORATION (VR)

At this stage it is possible to explore the optimized results, not only in for daylight factor and g-value reduction; the visualization of the results in a VR are a very valuable and immersive form of representation to extend the possibilities of making an assessment due tot the fact that the spatial exploration is taking the designer a step further to understand the benefits of the optimized results. Although the graphs and charts the show the correlation, Pareto front and relative strength of design parameters are still the thread from where the modification, selection and value of a design will be based from.

Since the workflow is based on parametric design tools the visualization of results con be broaden to the showcasing of other aspects related to the parametric model such as: amount of material used for the shading devices in a determined area, weight of the shading devices, energy savings, etc., the amount of information that can be extracted out of the model for the benefit of the designer is limited only by what is needed to be explored from every project.

For this project the exploration will be based on the following design objectives:

1. Daylight factor maximization, through the Daylight Factor grid.
2. Useful area regarding the targeted Daylight factor value.
3. G-Value reduction.
4. Ray-tracing (demonstrative indicator directly retrieved from the visual environmental tool).

The VR environment offers the possibility to study the design of the shading devices into detail and explore them in a 1:1 scale, change from one from one of chosen design to another in real time, make a walkthrough analysed space and be able to visualize other aspects of the design that relate to aesthetics and view.

For this project the VR exploration will be made through two different degrees of VR exploration:
1. Interactive live scale simulation.
2. Single node panoramic views.

10.5 ASSESSMENT

10.5.1 SATISFYING DESIGN

A satisfying is the one the best copes with the expected behaviour of the shading devices according to the design objectives. In order to call a design satisfying according to this workflow it should compile with the following characteristics:

1. Daylight factor coping with the desired natural light distribution objective, while aiming for the maximum levels of natural light.
2. The maximum floor area that fits between the DF design objectives.
3. The design that contributes the most with the reduction of the G-Vale of the glazed area.
4. A design the blocks most of the sun rays hitting the window of the room in question.

It is recommended to explore the results from the Pareto front, since according to the optimization this will be the designs that best cope with the fitness functions and objectives.

10.5.2 UNSATISFYING DESIGN

An unsatisfying design leads the designer to make a revision on the parametric model along with the optimization statistical data, with the goal of finding through model and data analysis the causes of the unsatisfactory results. A practical way to find a correlation can be easily spotted from the relative strength resutls of the design parameters and objectives, along with the parametrical behaviour of the shading model and the permutation possibilities and how and if the parametric design model is properly related to the environmental tools inputs.

10.5.3 DECISION MAKING

Once that through a thoroughly analysis of the data provided by optimization process and by immersive exploration techniques is done, the assessment for the best results is now possible. Depending on the design stage and specific factors around each project, the decision factor might shift. Nevertheless the design objectives suggested in this project can be used as a valid guideline in order to make an informed design decision.

11. METHODOLOGY IMPLEMENTED ON THIS PROJECT

Through this chapter an a detailed step by step explanation process on how the workflow is applied will be made. An overview of the implications as well as how the project was approached using the knowledged acquired through the literature research and the use and application of the tools involved in order to make this workflow possible will be showcased. This chapter will follow the same order from the workflow structure from chapter 10, with deeper insights on every phase and step, with technical a approach and a perspective from a designer while implementing the workflow. Posteriorly a case study example will be showcased in order to understand how the workflow was applied to the tackled case study project based on the envelope, and parametric principles of The Esplande (Singapore Opera House).

11.1 Design - Parametric Model of the Building

The parametrization of the model of the building implies the decomposition of the model into parametric construction elements that a designer can use as starting points or guidelines for the shading devices. The most relevant features to use the parametric model with can be the following:

1 - Model of envelope.
2 - Slab subdivisions generated in the envelope.
3 - Subdividing the slabs into a module(s) to fit the glass is part from the architectural program in the facade.
4 - Location of the architectural program in the envelope.
5 - Locate architectural program behind the window subdivision of the envelope.

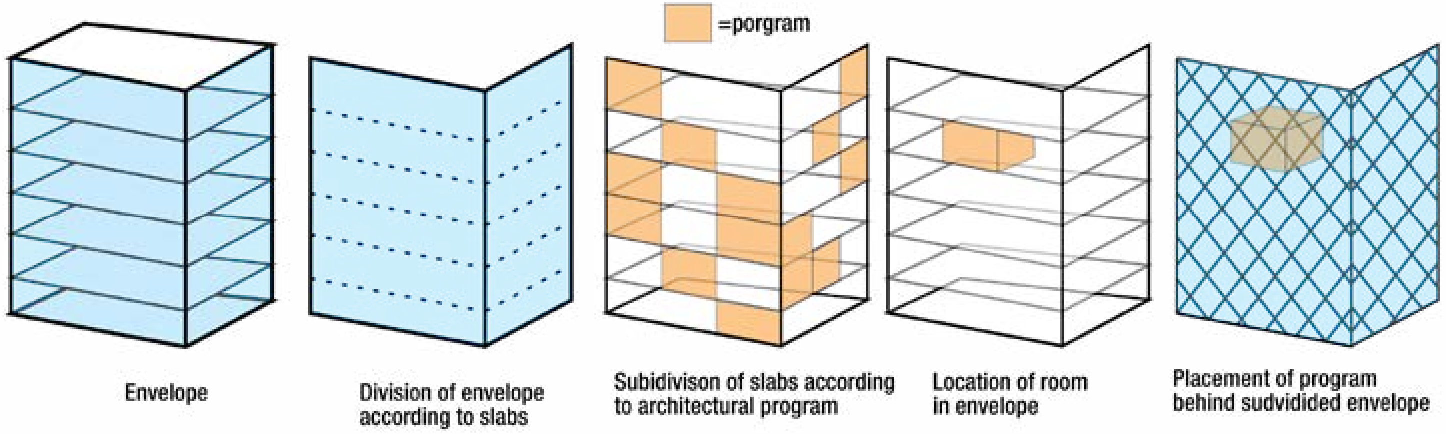


Figure 75. Parametric Model step 1 to 5.

The information generated from the parametrized massing of the building, will allow the model to be flexible enough to have a broad expand of possibilities over the following steps, since through the parametric model of the building, for the user to visualize all the possibilities existing for the internal location of the each architectural program.

11.2 Design - Location and program selection

As it has been mentioned in 10.1.2, at this step the first approaches of the building massing with the EWP files will occur. The selection of the EPW files can be made either through the online Energy Plus library or the local files on the users system, it is recommended to use the local files. Testing in several locations gives a broader sense of the implications of designing in different latitudes, it is expected for a designer to have a defined site before designing but it recommended to test is different locations for experimentation purposes when a user is new to the process.

For this step the visualized interaction of the building will be features in the workflow are a sunpath, a yearly drybulb temperature graph, the Tergenza dome, and the ray tracing simulation for the sunlight over the day with the highest temperatures over the year. At this step is it recommended to focus the attention of this features not only in the building as a whole but into specific programs that want to be tackled, since through this workflow customization of shading devices according to program and their location in the facade is possible.
From the EPW files it is possible to retrieve visualization resources and environmental data that will later relate to the environmental model, such resources are:
1- The Tergenza dome > Daylight factor
2 - Energy flow and window total energy > G-Value
3 - Sunpath and drybulb temperature graph > Ray-tracing

At this step is it recommended to focus the attention of this features not only in the building as a whole but into specific programs that want to be tackled, since through this workflow customization of shading devices according to program and their location in the facade is possible.

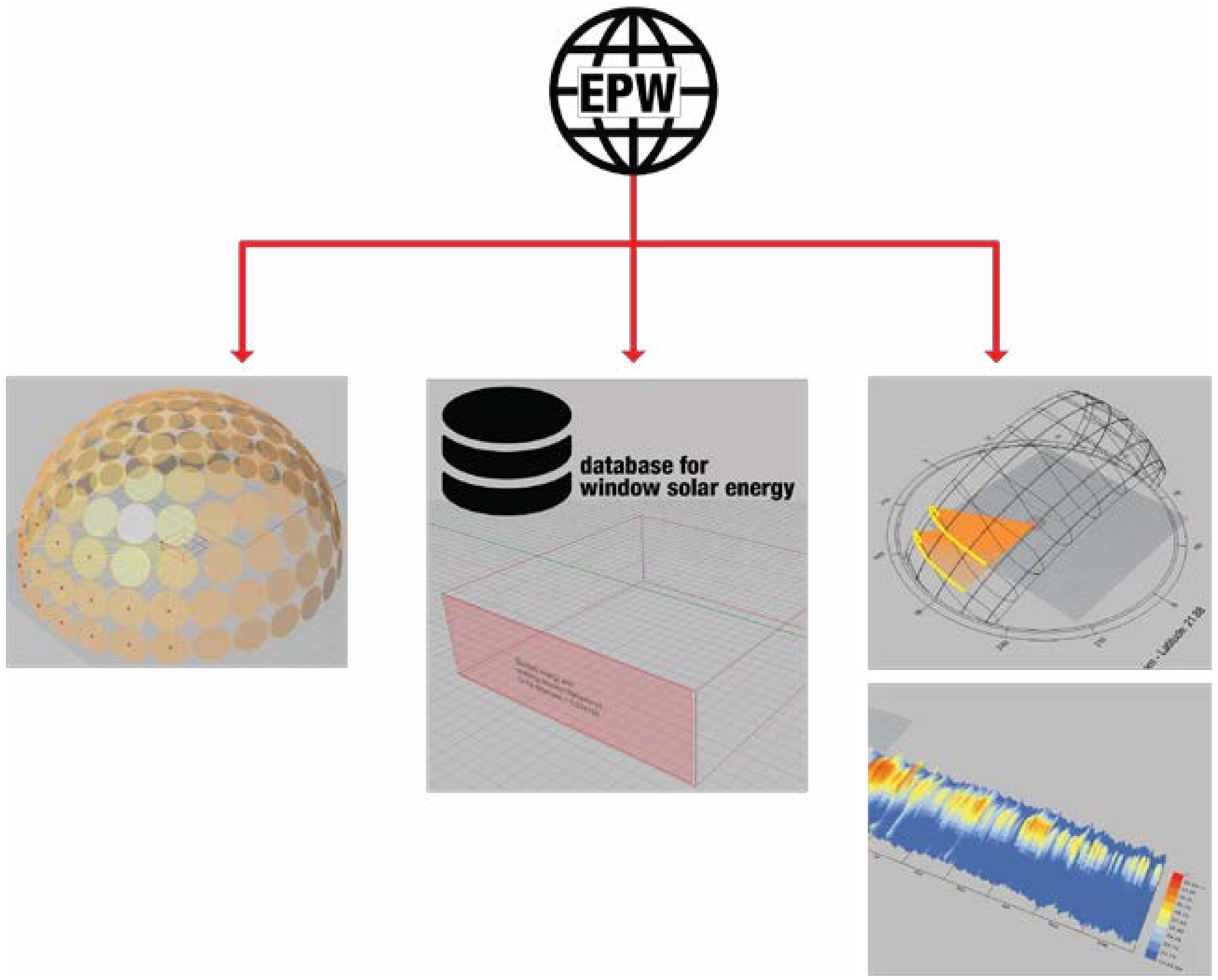


Figure 76. Information retrieved from EPW files.

Since it is possible to have different sorts of rooms in the buildings and they may all differ in: dimensions, needs for daylight distribution and solar gain according to program and typology, it becomes important to have the possibility to select and locate every sort of program that needs to be analysed in order to test it in various locations in the envelope to determine the position where the design objectives can have a better performance.

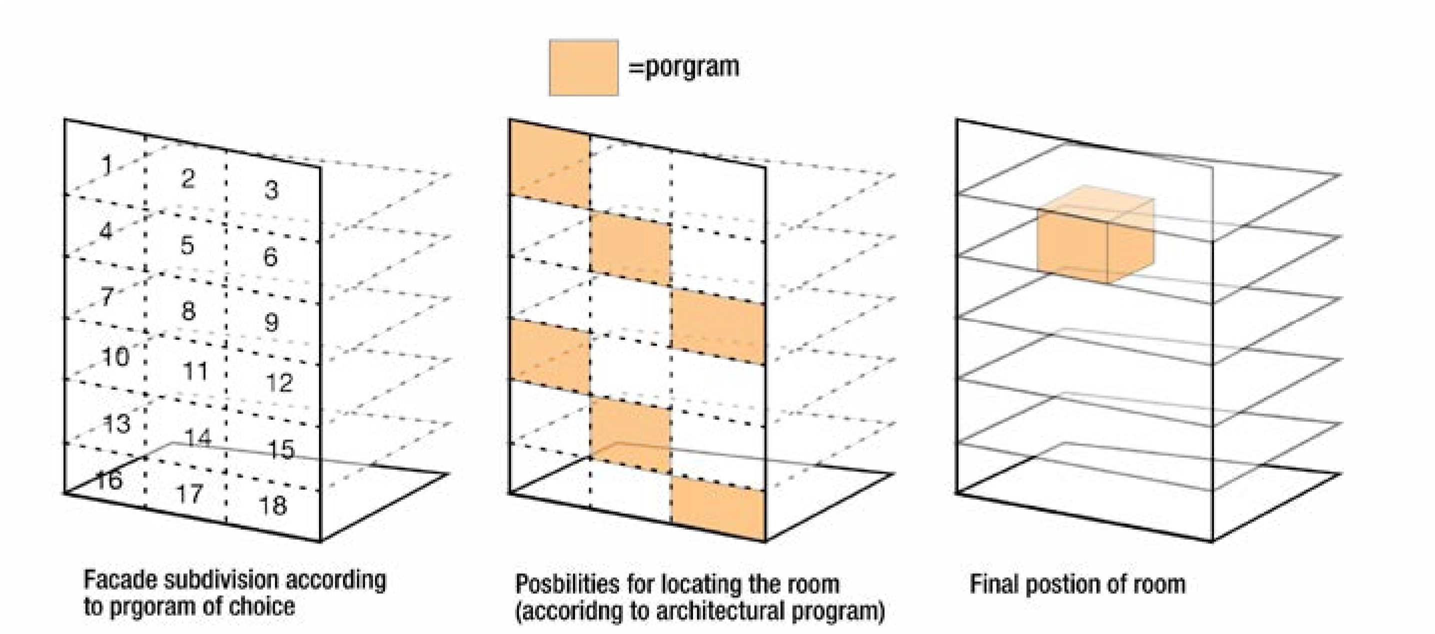


Figure 77. Position in facade selection diagram.

11.3 Design - Parametrized shading design

As it has been stated during the previous chapters, the main goal of the workflow is to use this resource for endorsing creativity hand by hand with results that validates shading design through, feasibility and functionality and goal oriented design, using parametric design tools.

Therefore in order to generate and adequate shading device for any design the following levels of design before having making assessment based on Design Variables.

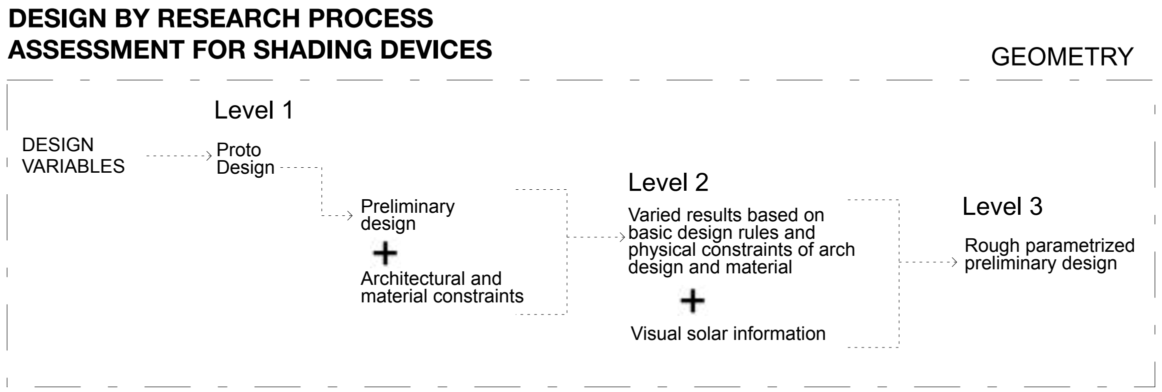


Figure 78. Assessment for shading devices diagram.

Design Variables are the design parameters bounded by objective design decisions that can help foresee the desired result and work through it. The Design Variable depend of two separate categories of parameters, Constrained Parameters and Unconstrained Parameters. Constrained Parameters are established once the design initial design concept for the shading is ready, and they are bounded by the sets of parametric rules based on the orientation of the shading design (as explained in chapter 5) and by dimensions which are related in this case to lessen the drawbacks of the design in terms of accessibility, regulations and maintenance.

In contrast the Unconstrained Parameters are related to other aspects that will help fulfil the designers desires such as the design´s appearance such color and material and will affect the designs performance in further steps of the methodology and the relation to the context, which is defined the location of the building in relation to the globe. Other responsive design features like biomimicry could be part of this sort of parameters but the subject is not part of this research.

Level 1: Generation of a parametrized Proto Design:

The proto-design will be the outcome of the combination of the designers vision of the shading devices as a final product and the adaptation of such design into the orientation rules for shading devices from (# number of chapter). Therefore from this step some parametric aspects of the model could be taken in account such as variant dimensions like depth, height and rotation for example.

In this level of the design it is important to be acknowledged of the constraints that will make the design to begin feasible, functions such as accessibility for repairs and installation of the devices, dimensions that allow an easy maintenance on regular basis, and constraints according to the knowledge of local regulations (e.g. overhangs may not exceed certain size due to the urban code) are handy to be known and taken in account during this phase. This set of parameters will keep control of the range of the modularity and size variation that the design should be constrained to.

If by this point of the early design stage there is a clear idea on the desired material, and production technique that is wanted or has to be applied in order to make the design realistic becomes useful. In the case of the material since it will help with further steps for the energy and radiance simulations which need some information of the physical properties to make a more accurate design as well as its presentation and maximum existent dimensions.

And as for production technique, it will help the user also to know constraints dependent on availability in the market for the production of the design as well as the industrial limitations in terms of fabrication. An example for a common production technique could be the maximum thickness of a sheet that can be put through bending in a press, or the maximum bending that can be achieved with the selected material. An example of a more sophisticated form of production technique could be related to the maximum size of modules possible to be 3-D printed in certain kind of machine with an specific material thread.

Figure 79. Bent and modulated metallic louvers

Figure 80. 3-D printed facade

Level 2: Proto Design towards performance:

The design performance is related to the adaptation of the building towards its context. The data provided by EPW (Energy Plus Weather) files, plenty of useful information can be retrieved such as, Tergenza dome models, solar vectorial information, energy flowing through window elements, that will help the designer feed the project with information that will support their assessment. On this level the designer is able to have a sense of how the design of the model is interacting with its context. This is just a informative contextual phase, more precise data will be sustained with the help of energy models, which will be defined in the following design levels.

Level 3: Geometric Modeling and Energy Modeling

During this level, the designer will have to test the design in the context and the environmental conditions of the site. The results depend highly on the configuration not only on the parametric geometry model but also on the energy and radiance model in order to have the most accurate simulations. Both energy and parametric model configuration and strategic components will be further explained.

Due to the multiple design results that can derive from a parametric model, it is necessary in this scenario to consider the use of optimization in order to test all the possible results through the simulations. The evaluation of multiple objective and multiple design parameters from a comparative point of view is regularly a tedious and hard to keep track of.

11.4 Design - strategic approach

The configuration of the model will be dependant on massing of the building and the goal is to generate a model that can help the design to achieve the users determined Design Variables. Second Skin and Additive façade are two of the main approaches towards shading design, the differences between this approaches is the direct relation of the shadings towards the glazed area of the building (add example buildings that theatre with spikes and Emerson college).

As it can be seen from figures# (buildings) the approach highly depends on the design intentions. The main difference is the direct relation of the shading elements on the design of the shades over the fenestration in case of additive design, in the case of the second skin method is the fact that the shading device design is not dependent on the module of the windows since it will be generated from a responsive but not fully dependant surface that may allow higher design freedom in terms of modulation and patterns just to name a few design parameters.

Since the Additive approach is dependent on the fenestration design, usually a geometrical decomposition of the windows will drive the design of the shading devices, therefore the geometrical components in this case the perimeter of what represents in the model the glazed area.

Figure 81 Additive facade approach.

In case of the Second Skin approach, the independence of the surface could allow a different configuration of the shading elements, the generation of a pattern derived from this surfaces can allow several sorts of subdivision elements and tessellation patterns.

Figure 82. Second skin approach.

Regardless the designers choice, any of this approaches will allow the user to define the initial stage for the Design Variable to be taking into account in order to follow to the Proto-Design that will lead to Levels 1 to 3 of shading device design.

It must be stated that this is just a generic workflow for configuration a proto-design of shading devices and the complexity and possible future constraints of the process highly depend on the platform the user is basing on to generate the geometry and the design concept.

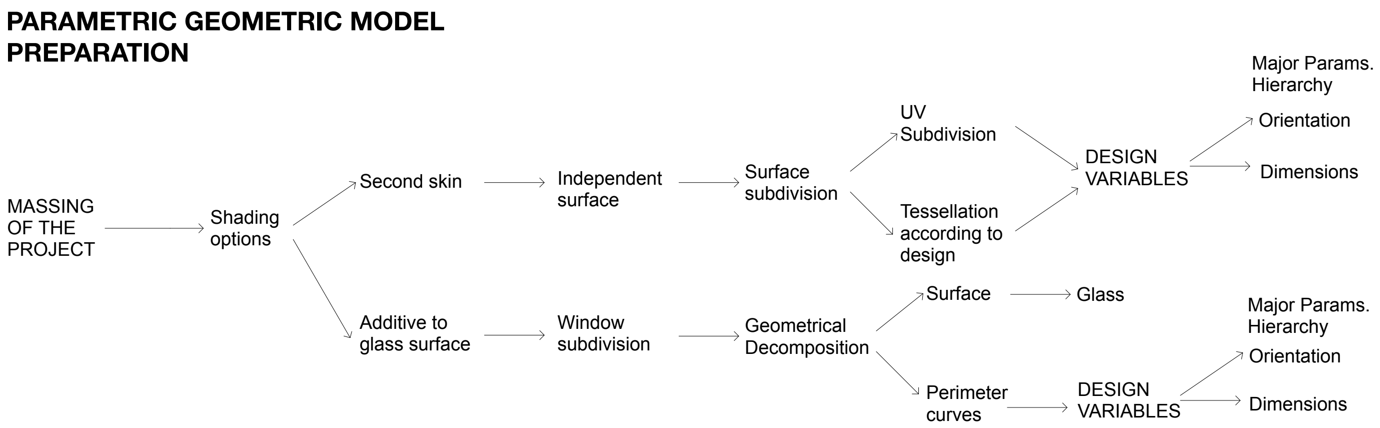


Figure 83. Parametric geometric model preparation diagram.

11.5 Design - Parametric geometry modelling

Once the geometric approach is defined, the Design Variable can now take part of the process. Meaning that the user will have total control of the of the shaping of the design of the shading devices. The capability of the shading devices to perform parametric features such rotation, inclination and scaling towards a direction and testing all variations can help the user understand the implications and feasibility of the geometry of the shadings in terms of design and even fabrication (e.g. if the rotation angle <X° surfaces overlap), as well as improving the functionality and capability of adaptation of the design to a determined environment which will be essential in the following steps of the methodology, as mentioned in 11.3 on Constrained parameters.

Even though Unconstrained parameters do not affect the geometry of the design, in fact they will have and will have a influence on the results of the light and energy simulations (e.g. the effect due to temperature increment reflection cause by color), the relevance of physical characteristics and how they relate to the indicators will be further explained.

If the designer has already a possible preference on using certain material, production technique for the elaboration of the shading devices as final product, it becomes useful during early design stage since it will help consider further steps towards innovation, fabrication and feasibility of the production in relation to their particular characteristics.

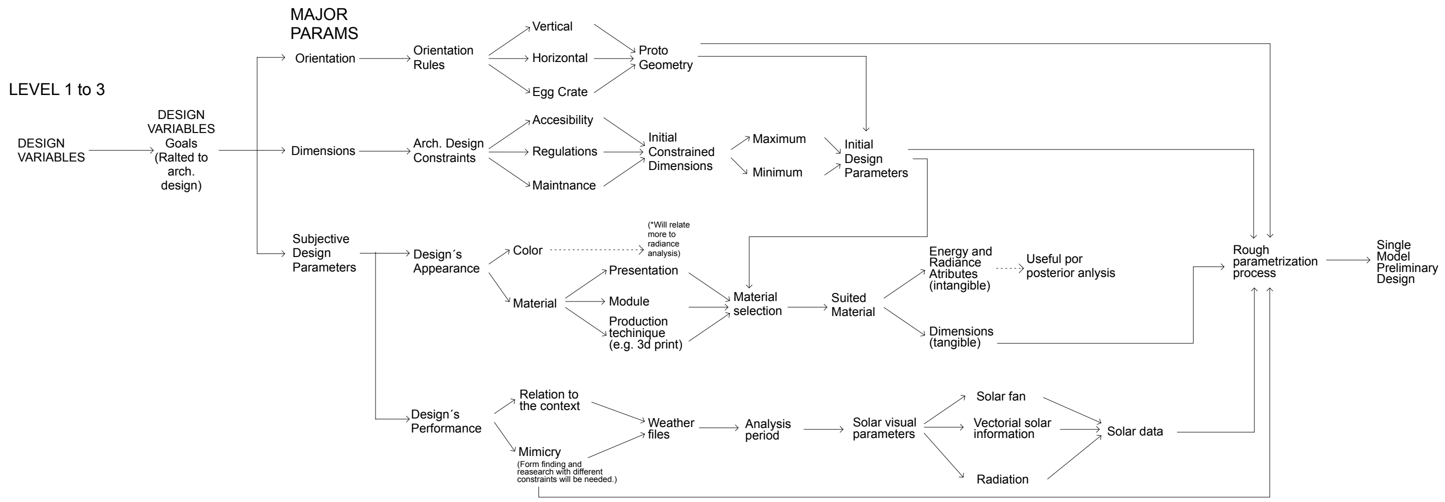


Figure 84. Parametric geometric model diagram.

11.6 Design - approach towards a successful shading design

Regarding the design of shading devices, the parametric of behaviour of the geometries should be understood, usual desirable performances on the design all according to the orientation rules previously explained on 5.3.

In order to create a shading device system it could be advised that, while parametrizing the design to avoid using absolute "0" as a starting point dimension for variables such as scaling since it will just consume computing time in the simulation as it will be producing useless shading devices which length is null. A good starting point as previously explained in 11.3 is to take in account the minimal sample that can be manufactured in the desired material as well as the maximum, taking in account other aspects related to dimensions that will allow the feasibility of the design, such as maintenance, accessibility.

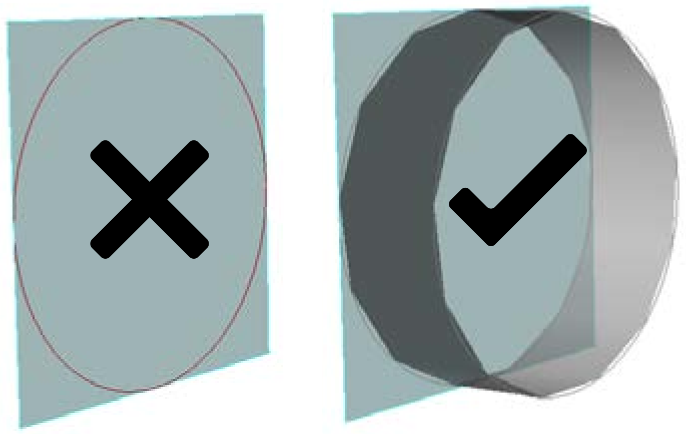


Figure 85 - Avoid having 0 as an extrusion value.

Regarding parametrization variables such as rotation, it is advisable that the rotation angles can correspond to iterations that avoid the collision of the surfaces, which will result in the impossibility of fabrication. This issue can be spotted by simple observation or by a parametric definition, observation is the technique used in this project.

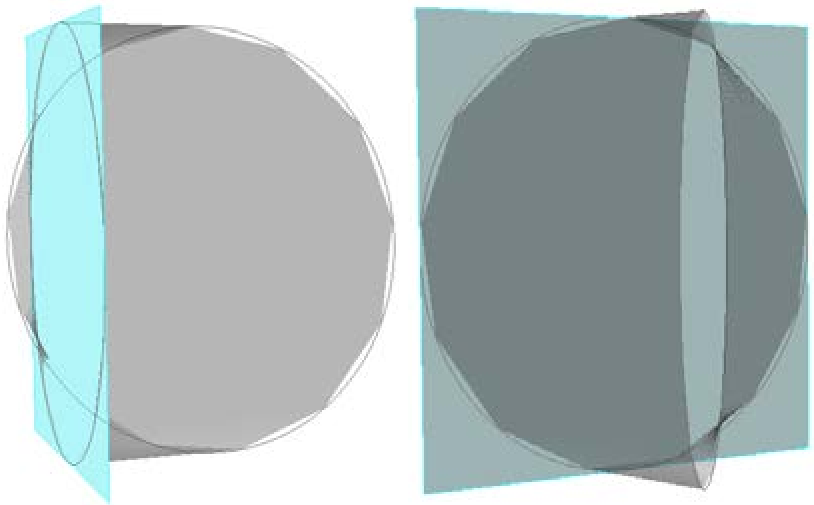


Figure 86 - Collided/overlapped surfaces that must be avoided.

The design as an additional element to a glazing façades whether through additive facade or second skin technique, it should always provide a minimum amount of light. Therefore avoiding design with iterations that can cause complete blind spots in a facade becomes a wanted feature, this means that the user should parametrize the model in a way that the maximum step of which ever parameter determines the opening should be never be larger or equal than the window size.

12. SIMULATION

12.1 Simulation - Lighting simulation model

A lighting model showcases the relation between the inside faces of the surfaces of a model room, reacting to the sunlight allowed into the interior, and for the means of this project the effect of the shading devices as regulator for lighting performance. Light reflectivity, glare and energy absorbed, through the generation of metrics that can help the user perform a series of analysis for indicators look at in this workflow.

In case of the lighting and energy simulation models in order to achieve accurate results the model has to be parametrized into three different aspects: zones, decomposition of surfaces into construction elements and material assignation. The decomposition of the model room can be referred as the dissection into its basic elements: roofs, walls, ceilings, roofs, windows. In most cases shading devices are taken as context element or addition since they are not usually part of the basic construction elements.

In order to generate realistic results out of the simulation, physical characteristics should be embedded into every construction element, by this point it will is useful for the designer to have an idea of what would be the materials, and colors that will be used for the interior of the model room. As every particular element will have an effect and contribution on the results of the simulations. Every construction element should have a designated materials. Physical characteristics such as color and roughness (texture) will be useful for solid elements, in the case of windows, glassing characteristics as color, Tvis, and RGB transmittance, or refractive index are useful inputs. The materials and physical characteristics for every element can should be able to retrieved from any of the native radiance libraries which are most likely sure to be part of any software related to lighting simulation. A suggested method on how to choose the proper parameters for "solid" materials and glass will be further explained.

The accuracy of the simulation in most cases will be dependent on the refinement assigned by the user, since for means of representation lighting simulators often represent data through meshes and false color images.

As the materials that define can vary depending on the design goals and function of the room, and will affect the value on the indicator, every material that can have a variation will be taken in account as a parameter. The precision of the daylight simulation, will rely on the amount of iterations that are generated. This has to be taken in account regarding the computational cost of every iteration on the simulation process.

A common workflow for the setup for a parametric energy simulation can be followed through the following diagram (figure 87).

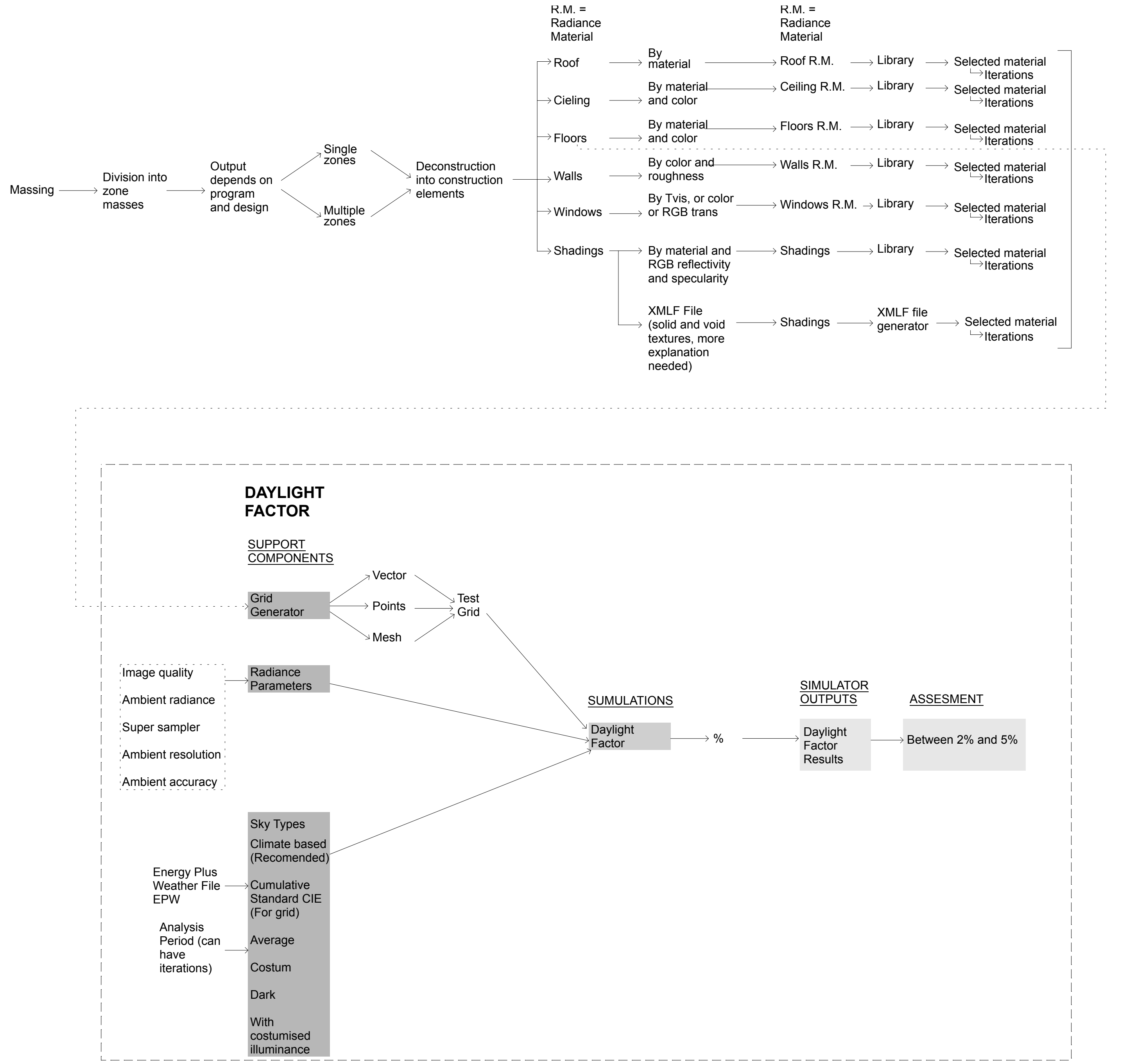


Figure 87 - Lighting simulation model digram.

12.2 Simulation - Energy simulation model

The energy simulation showcases the relation between the energy absorbed by the surfaces that allow the infiltration of solar irradiation through a window, as well as how much of this energy can be blocked by the use of shading devices, towards a goal of effectiveness that will be measured in this case by the G-Value.

The outputs from the simulation (building, shading devices and context) and the EPW file (location), will provide information that allows assessment. For the methodology the constraints of the model will be set in order to generate an environment where there is not influence from any external factors preventing energy to fluctuate in the model room and altering the results of the g-value as mentioned 6.3.2. Therefore the indoor and outdoor temperature should be set to the same, preferentially the one suggested by ASHRAE-2008 which will be 24ºC, this in order to focus only on energy exchange.

In order to obtain a valid result for a G-Value it is important to assess for a comparative point where the analysed glazing system does not include the shading devices, this will provide the designer with a frame of comparison where the indicator will be assessed based on the fact the G-Value is equal to:

Total Incoming Energy/Total Incident Energy

A common workflow for the setup for a parametric energy simulation can be followed through the following diagram (figure 88).

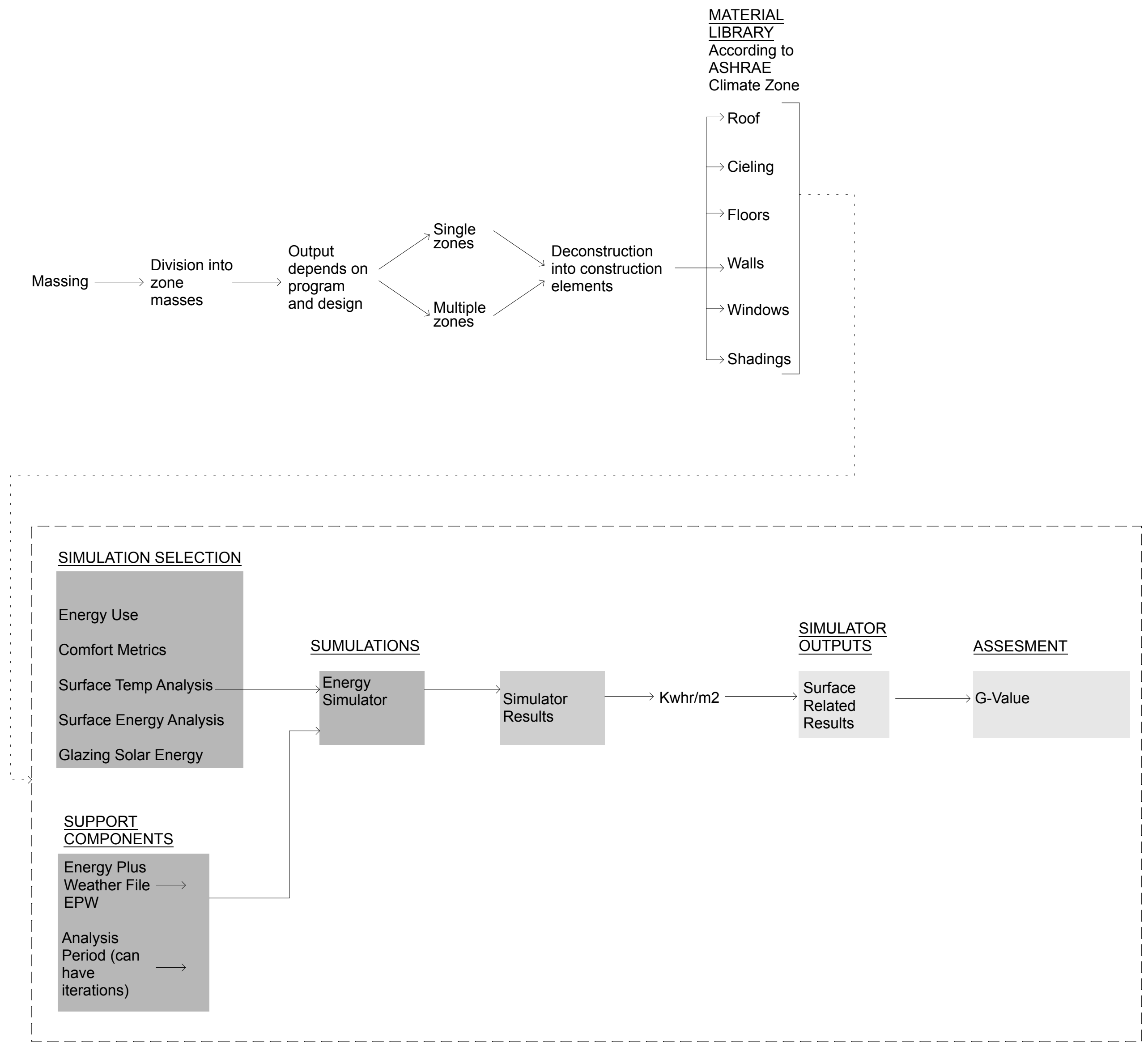


Figure 88 - Energy simulation model digram.

12.3 Simulation - Material selection

The material selection process for daylight simulations is based on color and material selection as mentioned in 12.1, simulation software usually will contain a library based on color selection and materials, these sorts of libraries are usually expandable or can rely on validated sources such as the Radiance Color Picker, which will be explained in 12.3.1. The information that will make the simulation possible is the Red, Green and Blue color properties, as well as the roughness, specularity of the material and texture. For daylight simulation purposes every solid material is taken in account as “plastic”.

For energy simulations, the ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) codes become an essential part of the energy modelling since the will work as a parameter to determine a set of variables that will correlate to every building element of the model. Depending on the designated climate zone most simulators will only show options for the indicated set of constructions according to the climate related to the ASHRAE codes in order to make a fast selection. Although most simulators will also allow the possibility of the user to create its own materials and constructions (show image of this climate zone and “wall”). It most be pointed out that material libraries from energy simulators often provide information about the physical properties of the materials, information that could be used for corroboration with other sources such material provider catalogues. The data usually given from the material libraries will be regarding relevant outputs such as dimensions of a construction system (thickness), building sequence, U-value, R-value, G-value and in case of windows optical and thermal properties.

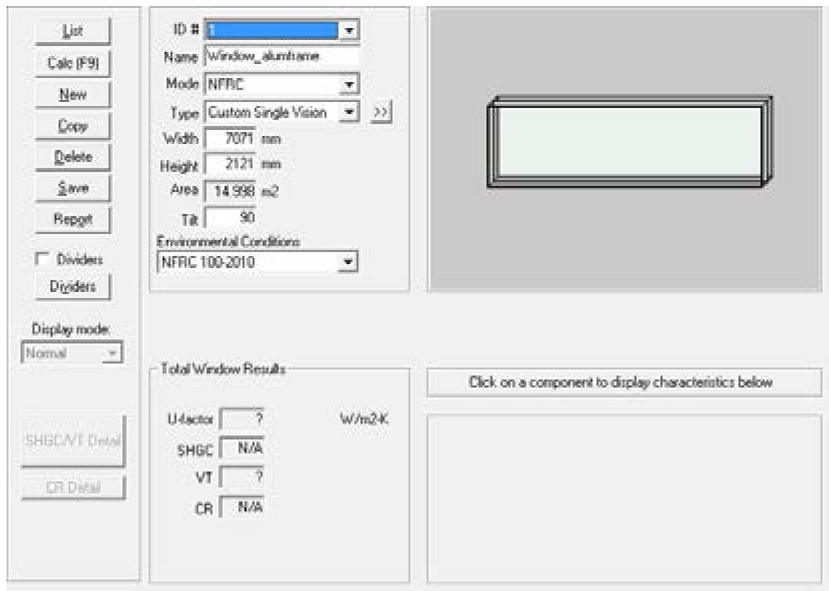
12.3.1 Simulation - Generating a glazing material from a validated source (for window properties, for energy and daylight simulation)

In order to generate a glazing material for the window system that will be used as part of the model, a very reliable source can be the Berkley Lab Window Software, a software that contains a wide variety of glass systems that currently exist in the market and have been broken down into the physical and optical characteristics such as U-Value, transmittance visibility (T-Vis), solar heat gain coefficient, visible absorption, front an back emissivity of the glass, as well as physical characteristics for the air gaps if existent in the system for example air or argon.

This tool allows the user to generate customised glazing systems, since window frames can also be simulated, although with far less precession that the glass since the materials available are presented in a more generic way and the options are limited to aluminium, wood and plastic.

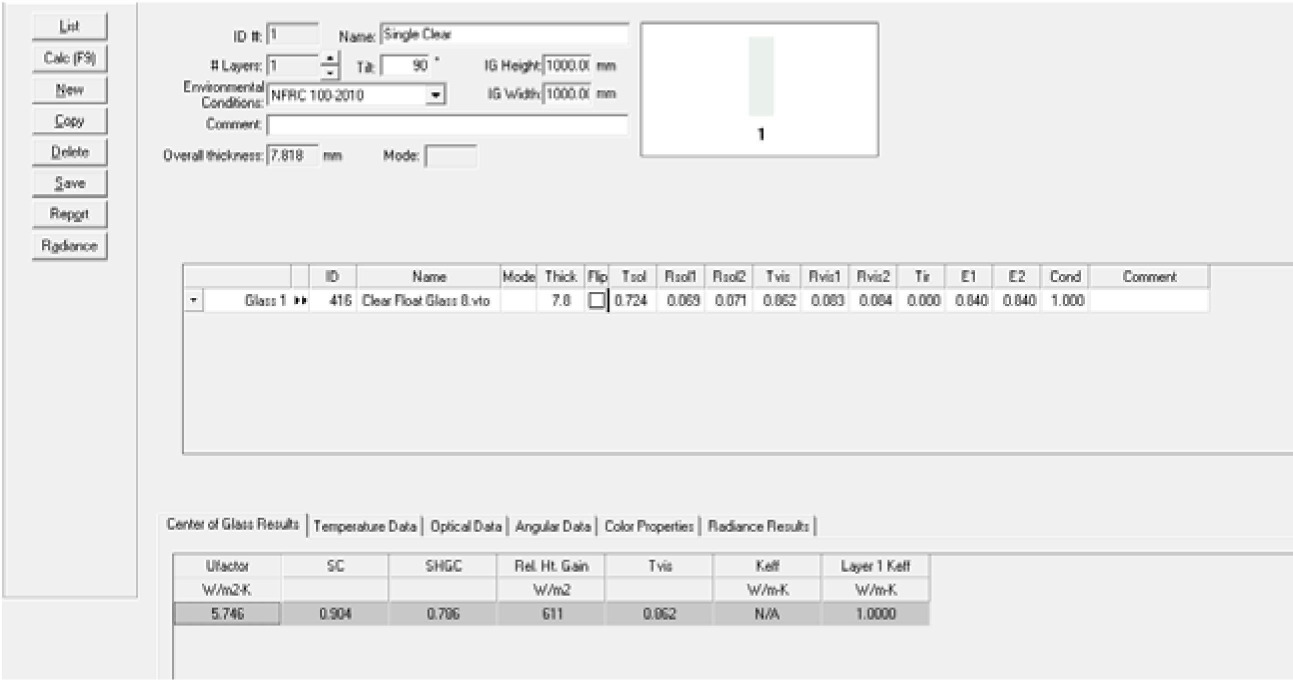
For a more meaningful utilization of the tool it could be advised to the designer to have an idea of what kind of glass will be used in the building in order to make a more meaningful selection.

In the end the results for the chosen glass will be written in a report based on Energy Plus calculations, which are supported by Honeybee. A synthesized version of the process of the glass selection can be followed in the next images. (Figure 89 to 92)



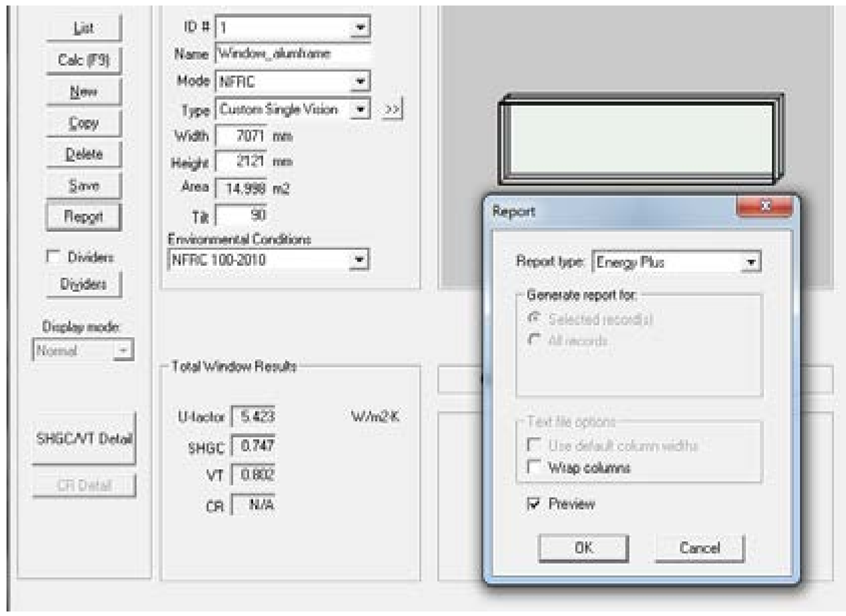
Step 1. Setup the dimensioning of the window.

Figure 89.



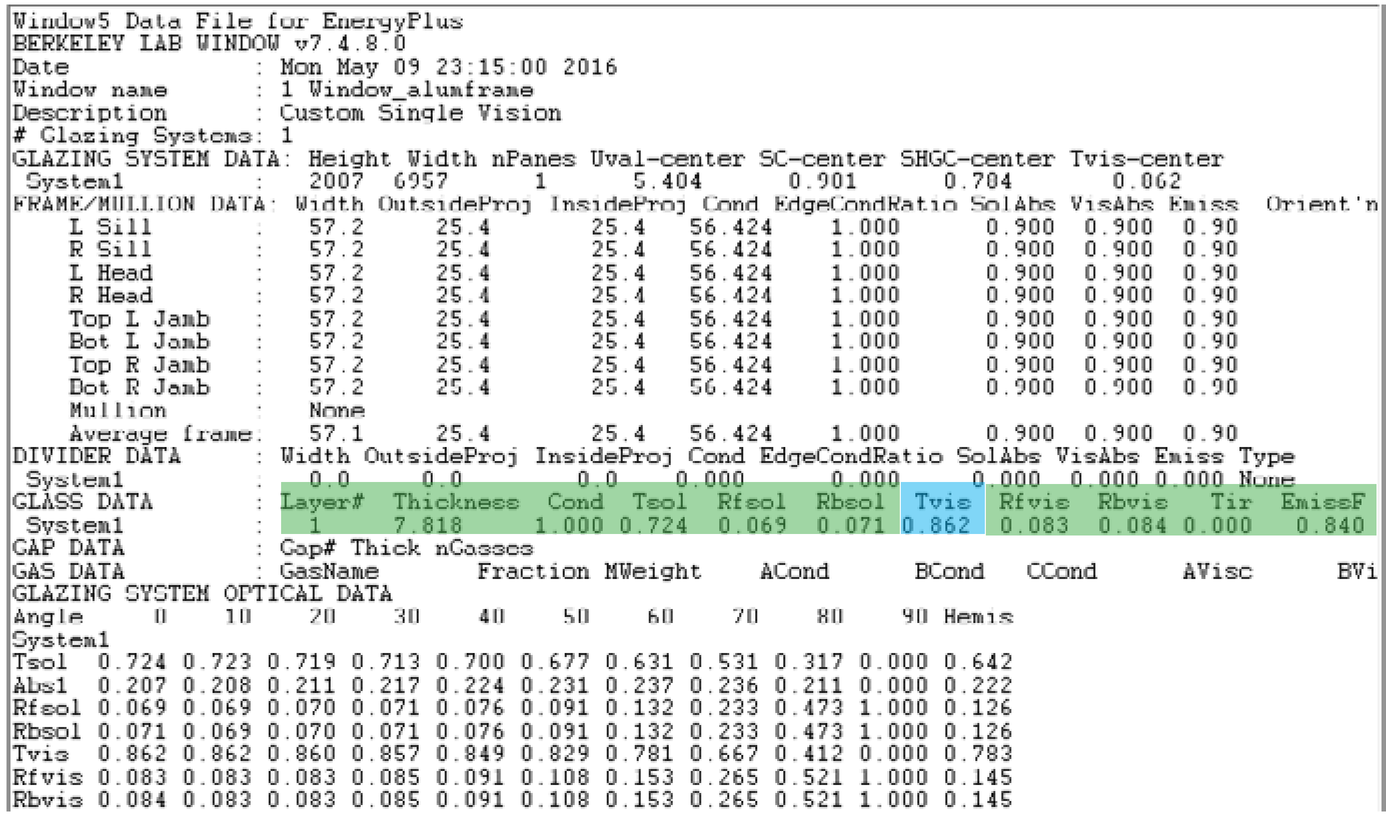
Step 2. Create a window according to the needs of the project, from embedded library of glass.

Figure 90.



Step 3. Calculate for the physical characteristics of the chosen design and create a Energy Plus report type.

Figure 91.



```
Window5 Data File for EnergyPlus
BERKELEY LAB WINDOW v7.4.8.0
Date                  : Mon May 09 23:15:00 2016
Window name           : 1 Window_alumframe
Description           : Custom Single Vision
# Glazing Systems: 1
GLAZING SYSTEM DATA: Height Width nPanes Uval-center SC-center SHGC-center Tvis-center
 System1            :   2007  6957     1      5.404       0.901       0.704       0.062
FRAME/MULLION DATA: Width OutsideProj InsideProj Cond EdgeCondRatio SolAbs VisAbs Emiss  Orient'n
    L Sill          :   57.2     25.4        25.4   56.424    1.000      0.900  0.900  0.90
    R Sill          :   57.2     25.4        25.4   56.424    1.000      0.900  0.900  0.90
    L Head          :   57.2     25.4        25.4   56.424    1.000      0.900  0.900  0.90
    R Head          :   57.2     25.4        25.4   56.424    1.000      0.900  0.900  0.90
    Top L Jamb      :   57.2     25.4        25.4   56.424    1.000      0.900  0.900  0.90
    Bot L Jamb      :   57.2     25.4        25.4   56.424    1.000      0.900  0.900  0.90
    Top R Jamb      :   57.2     25.4        25.4   56.424    1.000      0.900  0.900  0.90
    Bot R Jamb      :   57.2     25.4        25.4   56.424    1.000      0.900  0.900  0.90
    Mullion         :   None
    Average frame:      57.1     25.4        25.4   56.424    1.000      0.900  0.900  0.90
DIVIDER DATA        : Width OutsideProj InsideProj Cond EdgeCondRatio SolAbs VisAbs Emiss Type
 System1            :   0.0      0.0        0.0     0.000      0.000     0.000  0.000 0.000 None
GLASS DATA          : Layer#   Thickness   Cond  Tsol  Rfsol  Rbsol  Tvis  Rfvis  Rbvis  Tir  EmissF
 System1            :   1      7.818      1.000 0.724  0.069  0.071 0.862  0.083  0.084 0.000  0.840
GAP DATA            : Gap# Thick nGasses
GAS DATA            : GasName       Fraction MWeight    ACond      BCond    CCond      AVisc      BVi
GLAZING SYSTEM OPTICAL DATA
Angle     0    10    20    30    40    50    60    70    80    90 Hemis
System1
Tsol  0.724 0.723 0.719 0.713 0.700 0.677 0.631 0.531 0.317 0.000 0.642
Abs1  0.207 0.208 0.211 0.217 0.224 0.231 0.237 0.236 0.211 0.000 0.222
Rfsol 0.069 0.069 0.070 0.071 0.076 0.091 0.132 0.233 0.473 1.000 0.126
Rbsol 0.071 0.069 0.070 0.071 0.076 0.091 0.132 0.233 0.473 1.000 0.126
Tvis  0.862 0.862 0.860 0.857 0.849 0.829 0.781 0.667 0.412 0.000 0.783
Rfvis 0.083 0.083 0.083 0.085 0.091 0.108 0.153 0.265 0.521 1.000 0.145
Rbvis 0.084 0.083 0.083 0.085 0.091 0.108 0.153 0.265 0.521 1.000 0.145
```

Step 4. Use the values (highlighted) as inputs for the energy simulation process.

Figure 92.

Figure 89 to 92 - Steps for window selection in Berkley Lab Window Software.

The necessary information in order to generate a window system that both works for Daylight Factor and Energy simulations can be taken out from the report generated from Window 7.4, the results marked in green will work as inputs for the energy simulation and the value for Tvis in blue, will be the input for the R, G, B transmittances values as Honeybee can evaluate and understand this values and convert them into the proper value for every color transmittance according the Tvis. Tvis (Visible transmittance) is the amount of light in the visible portion of the spectrum that passes through a glazing material (reference), as shown in (figure 93) Tvis is also known as VT.

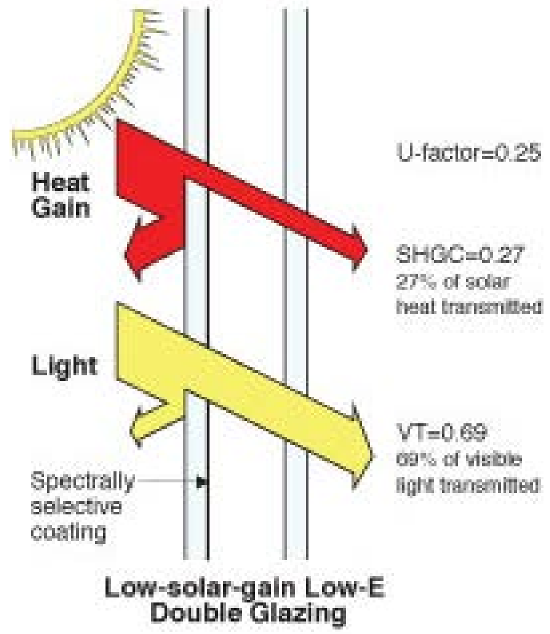


Figure 93. TVis diagram.

12.3.2 Simulation - Generating solid materials from a validated source

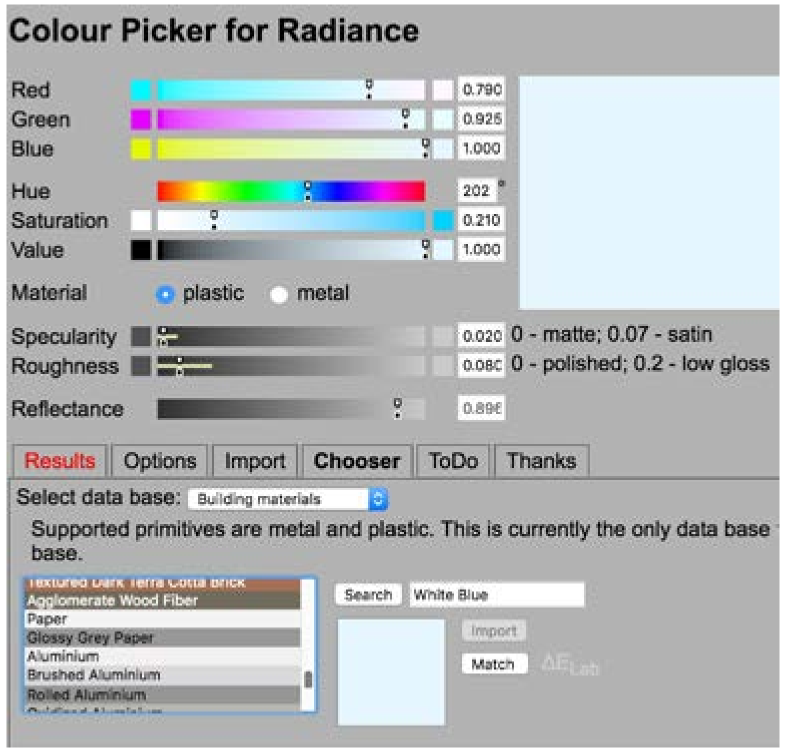
In contrast to the procedure to generate a window system for the model, in case for the solid materials the way to obtain the properties for lighting and energy simulations will be retrieved from different sources. The materials for lighting simulation are based on optical and color proprties of the materials and the materials used for energy simulations are based on physical and thermal properties which will taken out from the libraries provided by the ASHARAE codes.

Lighting simulation materials:

As opposite to the glazing, colors and other “solid” materials such as wood, concrete or metals, usually from a product manual do not have technical guide that may help the designer to make a technical set-up for a simulation as glassing will do with optical properties. Therefore it is advised to use http://www.jaloxa.eu/resources/radiance/colour_picker/index.shtml from where materials can be picked based on their Red,Green,Blue, specularity and roughness (Christoph F. Reinhart , 2010) which is a very intuitive tool in order to retrieve from the necessary information, as shown in the following images (Figure 94 to 96).

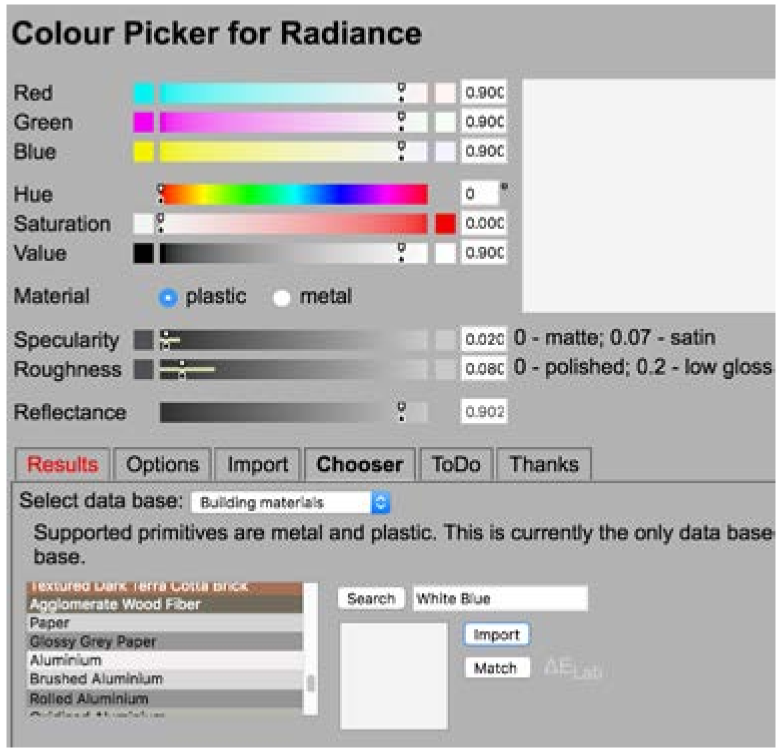
All the data generated from this source will be used as a direct input for daylight simulations, this is becuase the format output, can be easily exported to an daylight simulator since the output is based on the Radiance database and format which is the source of material information for most tools as it was presented over the literature review.

Same as in the selection for glazing materials, it is advised by the designer to have a general idea of how the design look like in terms of interior materials and colors since this will help the workflow to be more fluent and precise.



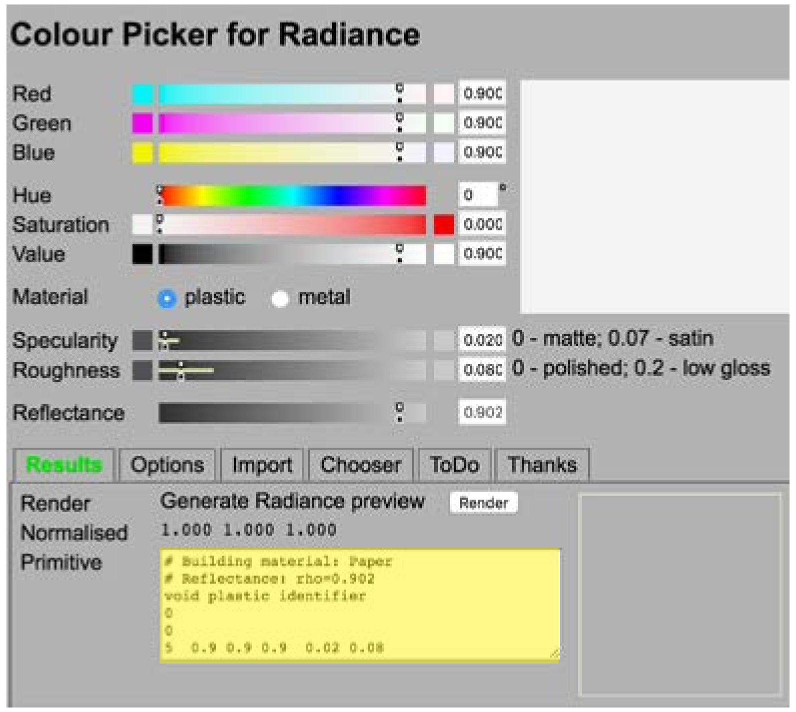
Step 1. Select material to generate radiance code, from Chooser.

Figure 94.



Step 2. Match the material in order to obtain all the data from the color and physical characteristics sliders.

Figure 95.



Step 3. Generate results and import them to the Radiance simulator material library.

Figure 96.

Figure 94 to 96 - Steps for Radiance color picker tool.

Energy simulations materials:

In order to generate the materials of the model for the energy simulations, the material can be accessed through a embedded libraries on the simulation software that will be limited to the ASHRAE material library according to a climate zone. The simulation software will proportion the user with physical properties, and the list of materials that compose every part of the construction element, as it is shown in the following images (figure 97 and 98).

Specifically the materials that will be used for the shading devices may be used for the energy simulations, since the existent databases for energy simulations are based on ASHRAE codes and materials for shadings are not included. The Honeybee component that accounts for shading was created to convert the Radiance material properties generated in the color picker into a form of information that Energy Plus can interpret.

The tables below show the climate zone number for a wide variety of International locations. Additional information on international climatic zones can be found in ANSI/ASHRAE/IESNA Standard 90.1-2007 *Normative Appendix B – Building Envelope Climate Criteria*. The information below is from Tables B-2, B-3, and B-4 in that appendix.

International Climate Zone Definitions

Zone Number	Zone Name	Thermal Criteria (I-P Units)	Thermal Criteria (SI Units)
1A and 1B	Very Hot –Humid (1A) Dry (1B)	9000 < CDD50°F	5000 < CDD10°C
2A and 2B	Hot-Humid (2A) Dry (2B)	6300 < CDD50°F ≤ 9000	3500 < CDD10°C ≤ 5000
3A and 3B	Warm – Humid (3A) Dry (3B)	4500 < CDD50°F ≤ 6300	2500 < CDD10°C < 3500
3C	Warm – Marine (3C)	CDD50°F ≤ 4500 AND HDD65°F ≤ 3600	CDD10°C ≤ 2500 AND HDD18°C ≤ 2000
4A and 4B	Mixed-Humid (4A) Dry (4B)	CDD50°F ≤ 4500 AND 3600 < HDD65°F ≤ 5400	CDD10°C ≤ 2500 AND HDD18°C ≤ 3000
4C	Mixed – Marine (4C)	3600 < HDD65°F ≤ 5400	2000 < HDD18°C ≤ 3000
5A, 5B, and 5C	Cool-Humid (5A) Dry (5B) Marine (5C)	5400 < HDD65°F ≤ 7200	3000 < HDD18°C ≤ 4000
6A and 6B	Cold – Humid (6A) Dry (6B)	7200 < HDD65°F ≤ 9000	4000 < HDD18°C ≤ 5000
7	Very Cold	9000 < HDD65°F ≤ 12600	5000 < HDD18°C ≤ 7000
8	Subarctic	12600 < HDD65°F	7000 < HDD18°C

Depending on the Energy plus ASHRAE zone there is an specific set of material recommended to use for energy simulation purposes.

Figure 97. ASHRAE Zone classification.

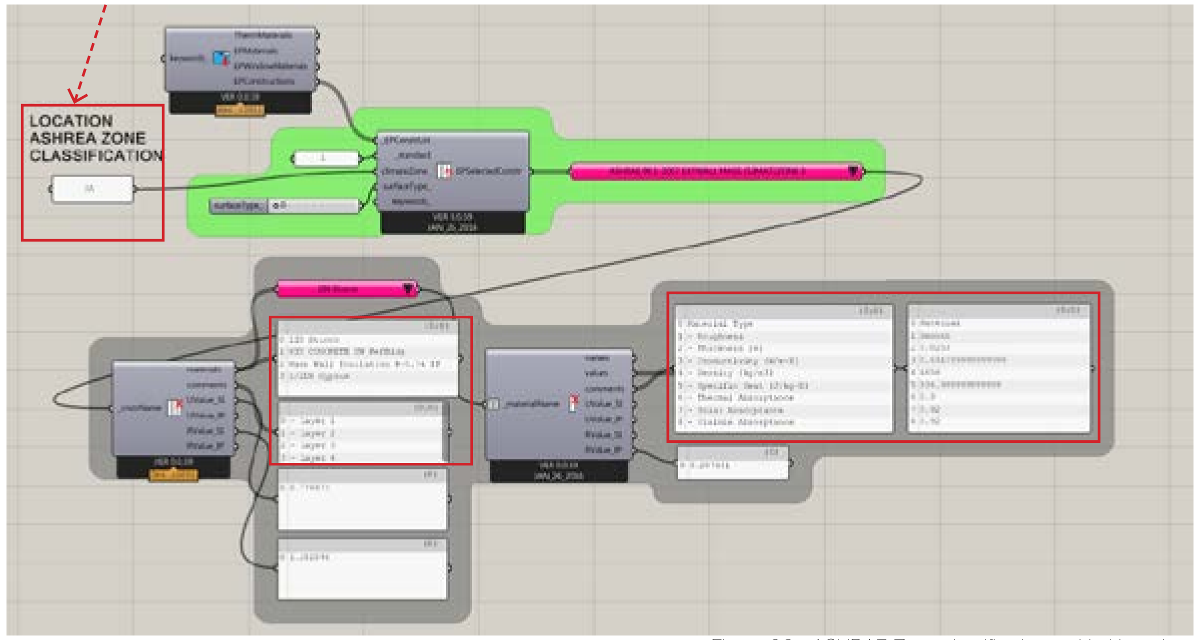


Figure 98. ASHRAE Zone classification tool in Honeybee.

13. OPTIMIZATION

13.1 Optimization - The parametric model and the optimization process

In following paragraphs an explanation on how to setup a model for optimization will be addressed step by step from the design of the shadings, the construction of the models for the simulations and preparing a model for a multi objective optimization process.

The optimization process is the product of the relation between design parameters and design objectives. In this project, since the project takes into account two design objectives which are Daylight Factor and G-Value, the process will be multi-objective. Since the goals of this two indicators work in opposite directions, the Daylight Factor has the intention to be maximized, while the G-Value will be minimized, this makes the optimization process work in a more fluent way since the objectives will not get conflicted.

The design parameters such as rotation, scaling dimensions, population (amount of devices) that will define level of complexity of the shading device, is entirely a designers choice, it must be highlighted that the complexity is proportionally direct to the computational expense. It is advised to keep the parameters as simple and practical as possible. The parameters will be taken in form of a numerical value and will be taken from the parametric components that allow the permutation capabilities of the design in the parametric model.

In this project the optimization tool will be bridged from Grasshopper to modeFRONTIER (optimization software of choice), through D-Exp a plug-in which has a connection capability between both tools. Design parameters and objectives will both be retrieved from Grasshopper and captured in modeFRONTIER through D-Exp, which well help modeFRONTIER to run the light and energy simulation in Grasshopper. The reason to use modeFRONTIER is the level of sophistication of the post optimization process, from where a wide range of charts and graphs are available to use as a back-up resource for the design choices as well as the capability to understand the correlation and level of influence between design parameters and objectives.

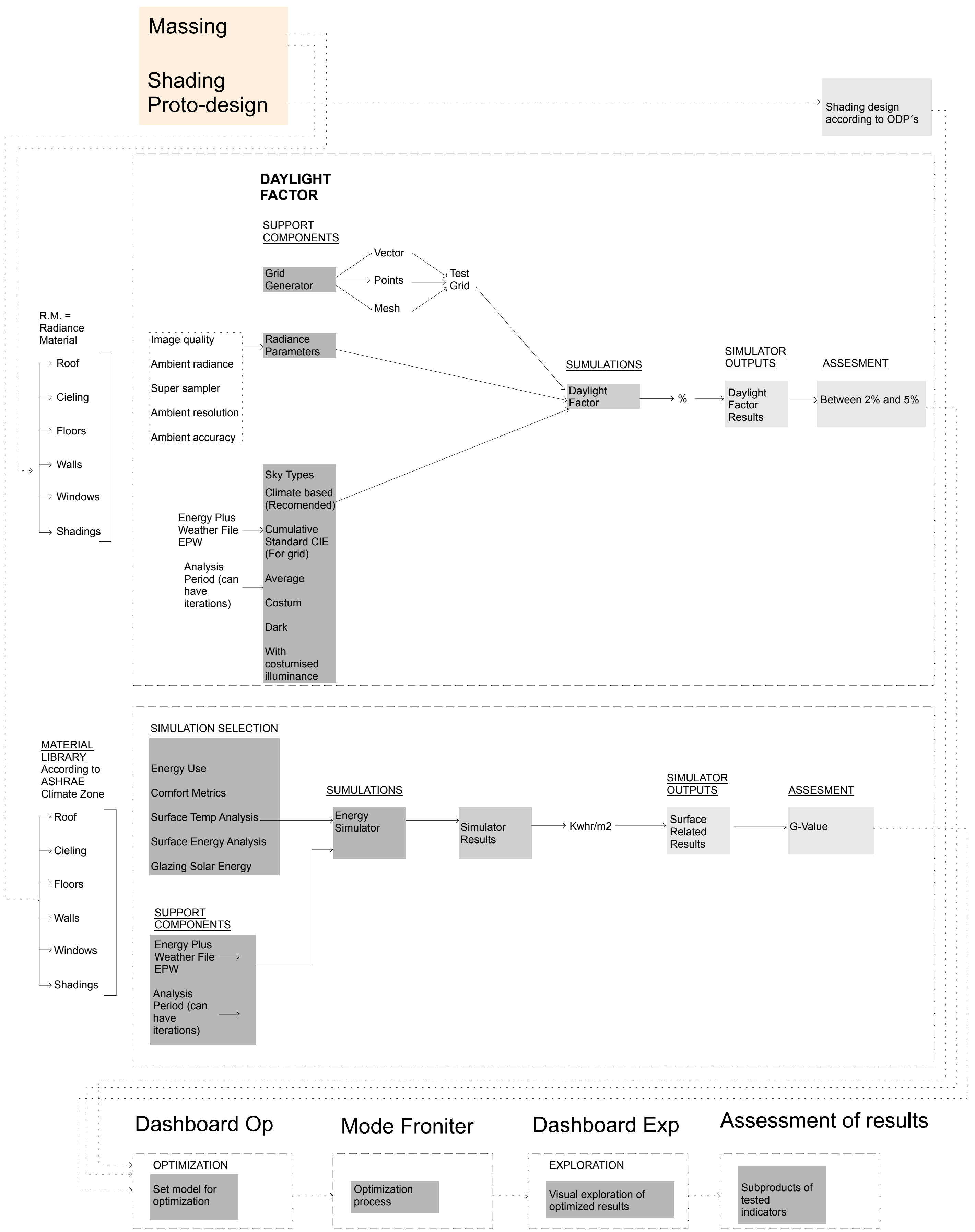
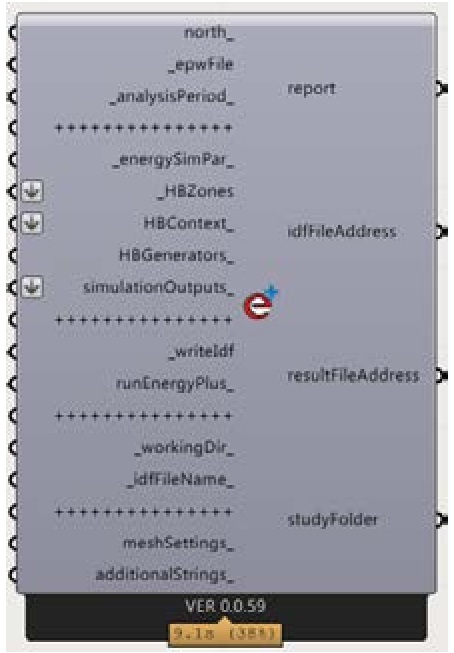


Figure 99. Parametric model for optimization diagram.

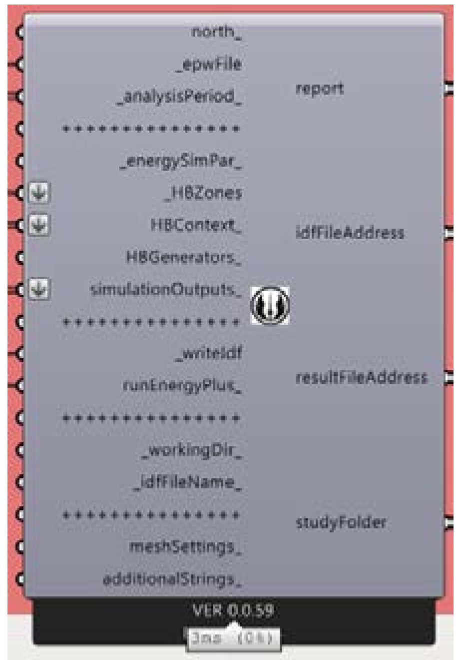
13.1.1 Opmitimization - Limitations and customisation of Energy Plus Honeybee

Specifically in the chosen software used for energy simulation, a communication issue was found in order to run the optimization. This issue involved the editing of the energy plus simulation component, since the simulation needs to set the shading devices as a mandatory input for the optimization process, and the native input of the component does not have that feature. A line in the Honeybee EP simulator scripts had to be edited in order to take the shading devices (HBContext) as compulsory input. This situation shows the capability of interaction between the user and the software to the point that tools are editable and adaptable to specific functions.




```
if _writeIdf == True and _epwFile and _HBZones and _HBZones[0]!=None:
```

Figure 100. Energy Plus native component for Honeybee, code line indicates that HBContext (shadings) is not a mandatory input.




```
if _writeIdf == True and _epwFile and HBContext_[0] and _HBZones and _HBZones[0] !=None:
```

Figure 101. Energy Plus modified component for Honeybee, modification indicates that HBContext (shadings) is a mandatory input.

13.2 Optimization - Setting up an optimization model in D-Exp for modeFRONTIER

This phase consists creating the setting of the design parameters of the model room, the shading device and selecting and adjusting the views that will be generated for the exploration phase. During this phase the database that includes files to inform about the input, output results as well as a collection of images for exploration will be created. From the input files contain the numerical information that will make the creation of an optimized result in the form of a 3-D model possible.

A summarized series of steps for optimization in modeFRONTIER are the following:
1. Create an optimization map (figure 95).
2. Settle the boundaries for the inputs, same values as the ones used in the design parameters (figure 96 and 98).
3. Define the direction of the design objectives (outputs) for maximizing or minimizing.
4. Define the amount of solutions that optimization can be bounded to (figure 97).
5. Run the optimization from modeFrontier in parallel to the one from D-Exp (figure 99).
6. Visualization and analysis of the graphs for the results of the optimization.
7. Export results for exploration in modeFRONTIER.

In order to setup the optimization process, the names and numerical value range (maximum-minimum) inputs and names of the outputs on both the D-Exp definition and modeFRONTIER should match, in order to generate the information for the database.

The range that cover the span numerical values, becomes important since the optimization software will have to replicate every possible iteration of the parametric model (figure#). The optimization round implicates a considerable amount of computational resources which will vastly depend on the kind of simulations, as well as the available computational power. More information can be found in the image Appendix for parametric models.

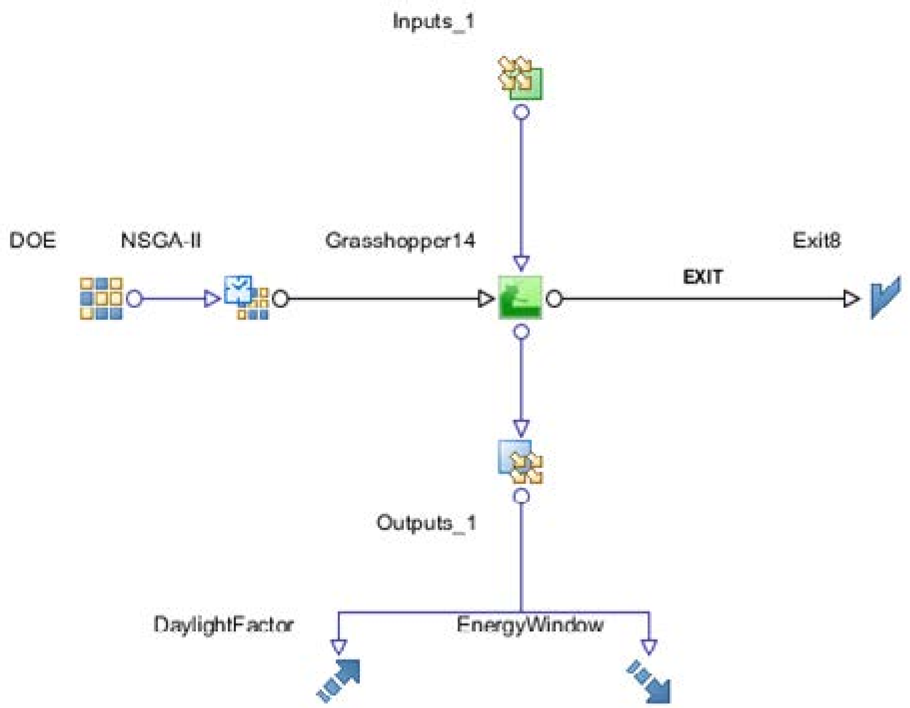


Figure 102. Optimization map.

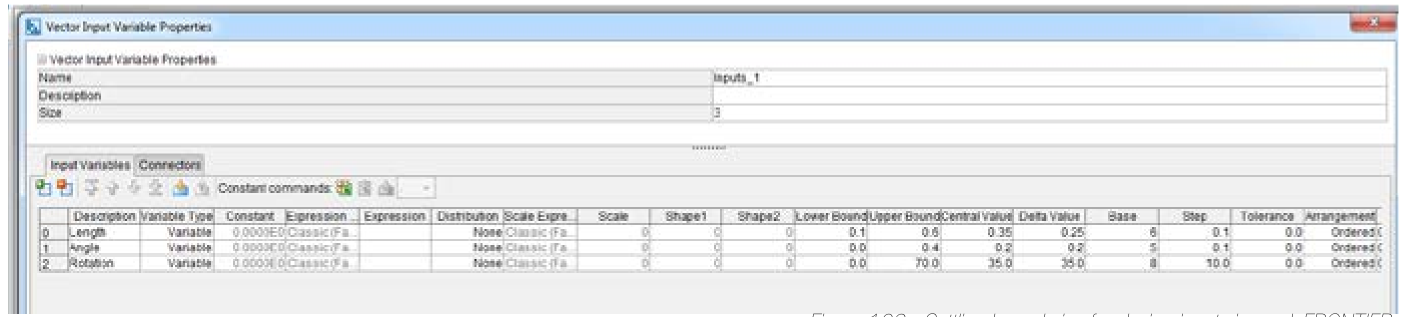


Figure 103. Settling boundaries for design inputs in modeFRONTIER.

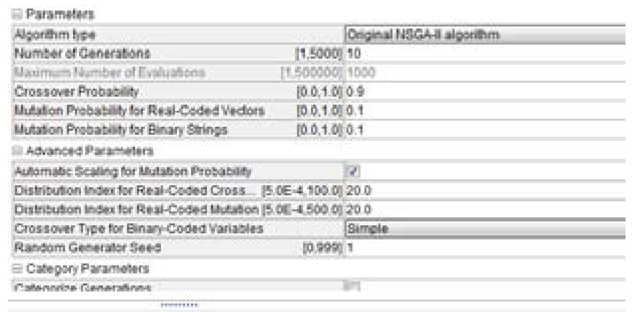


Figure 104. Solution bonding in modeFRONTIER.

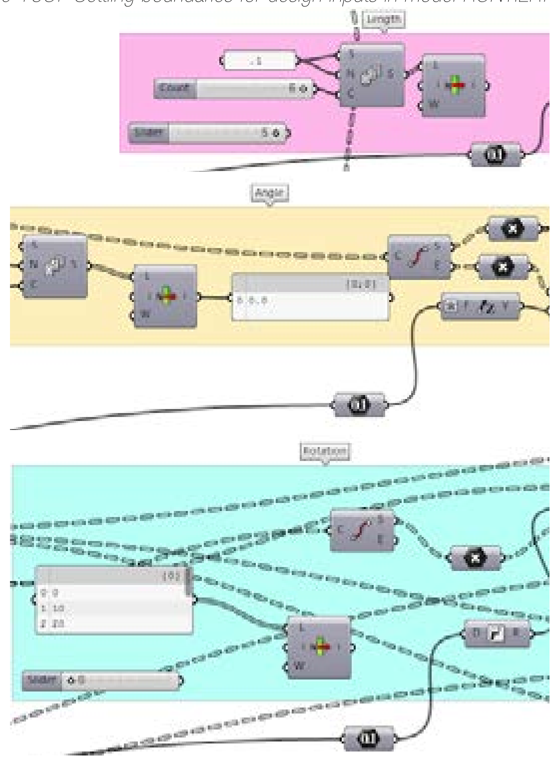


Figure 105. Settling boundaries for design inputs in GH.

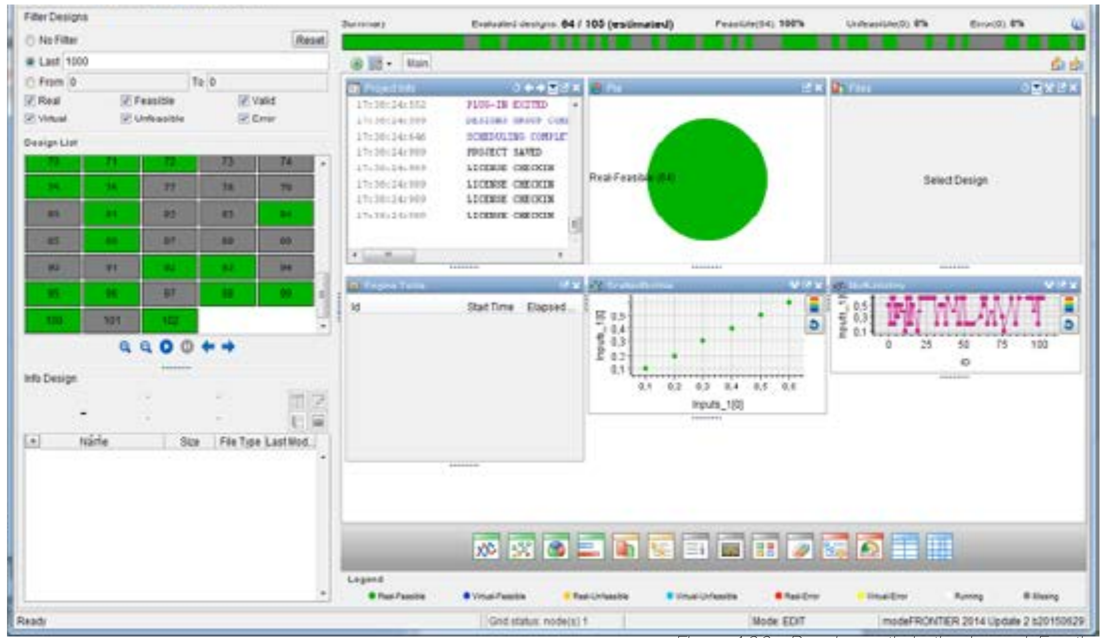


Figure 106. Running optimization in modeFrontier.

Optimization round

The analytic process of modeFRONTIER as it has been mentioned will run as much as defined by the user, and will change according to the needs of the project. The green results represent a feasible answer, red in which this case is not present represent infeasible and gray represents a communication error between the interfaces (software).

13.3 Visualization - Postoptimization in modeFRONTIER

As a product of optimization, the results are given through several sorts of graphs offered by optimization tools. This tools are very useful and will be the thread to follow in order to retrieve the results that will be selected for visual exploration in further steps. Through all the available graphical support representation methods offered by the optimization tool of choice, three of them have been selected in order to be used as guidelines in the workflow and are the following:

1. Scatter chart (Pareto front)
2. Scatter matrix
3. Relative strength

1. Scatter chart (Pareto front)

A Pareto Front, is a 2D graph that shows the feasible and real results from a optimization analysis figure 100. Depending on optimization goals that are taken in account and how they are supposed to respond towards the design parameters, the design objectives are usually maximized or minimized, regarding the priority given to every objective. For a project with two variables such as this one, which design objectives aim in opposite directions, the relation of the parameters will be linear and exponential as show in figure 101.

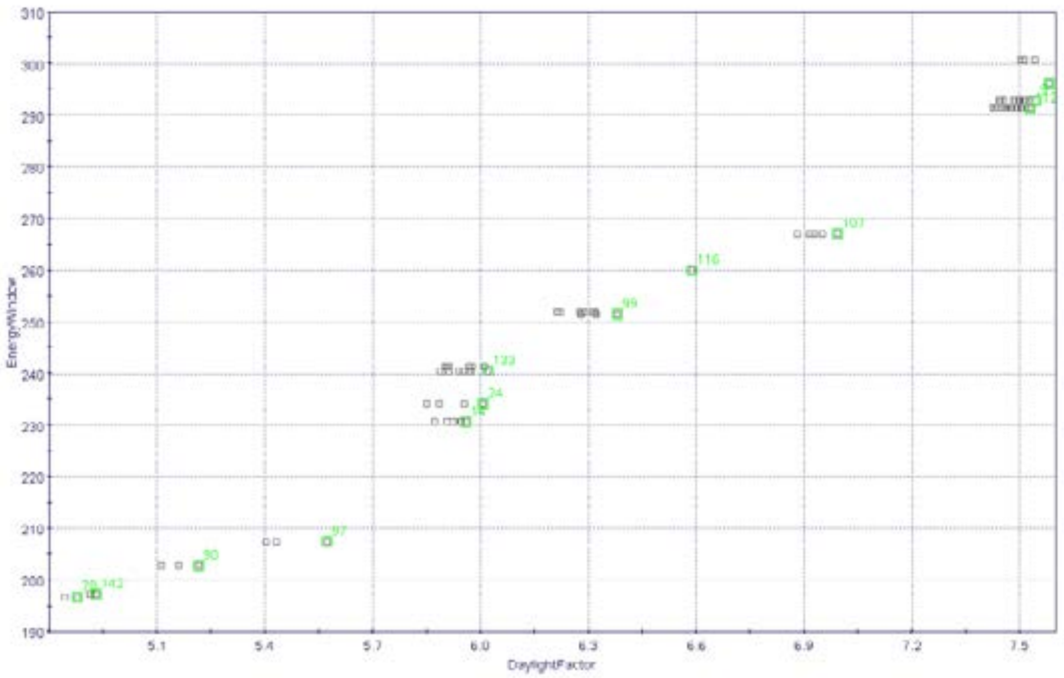


Figure 107. Pareto front example..

2. Scatter matrix

Other supporting graphs such as Scatter matrix are able to inform the user about the behaviour of the system. For example figure 101, showcases the relation and the influence of the design objectives towards the results. Where depending on the level of correlation the cloud point (green points) will be arranged in such a way that the most feasible answers are the less scattered, and also where the two design variables were are looking for meet in an X,Y axis, the pink rectangle from figure # represents a quadrant of the graph meets is where the design objectives will meet correlate according to the work-flow, this quadrant of the graph is also where the Pareto results exist. The other graphs represent as well the correlation between design variables, and variables towards objectives.

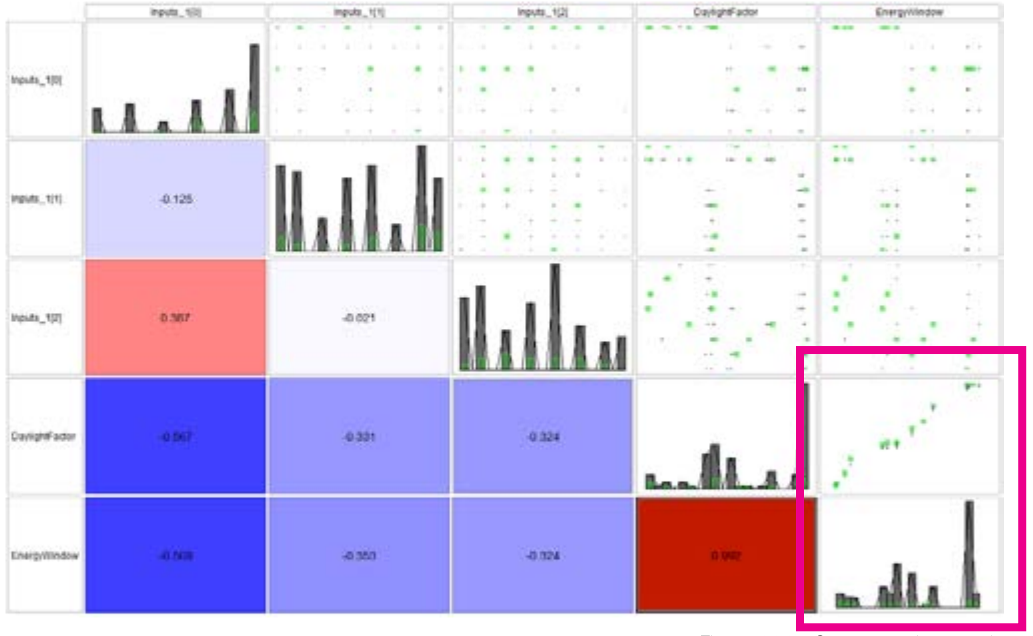


Figure 108. Scatter matrix example.

3. Relative strength

It is also possible to know the degree of influence of every design parameter towards an specific design objective, this sort of information is useful to a designer due to the fact that it is starting point to inform about what design parameters influence the most, and can be used as a guideline to know if the parametric model should be modified in order to improve the performance.

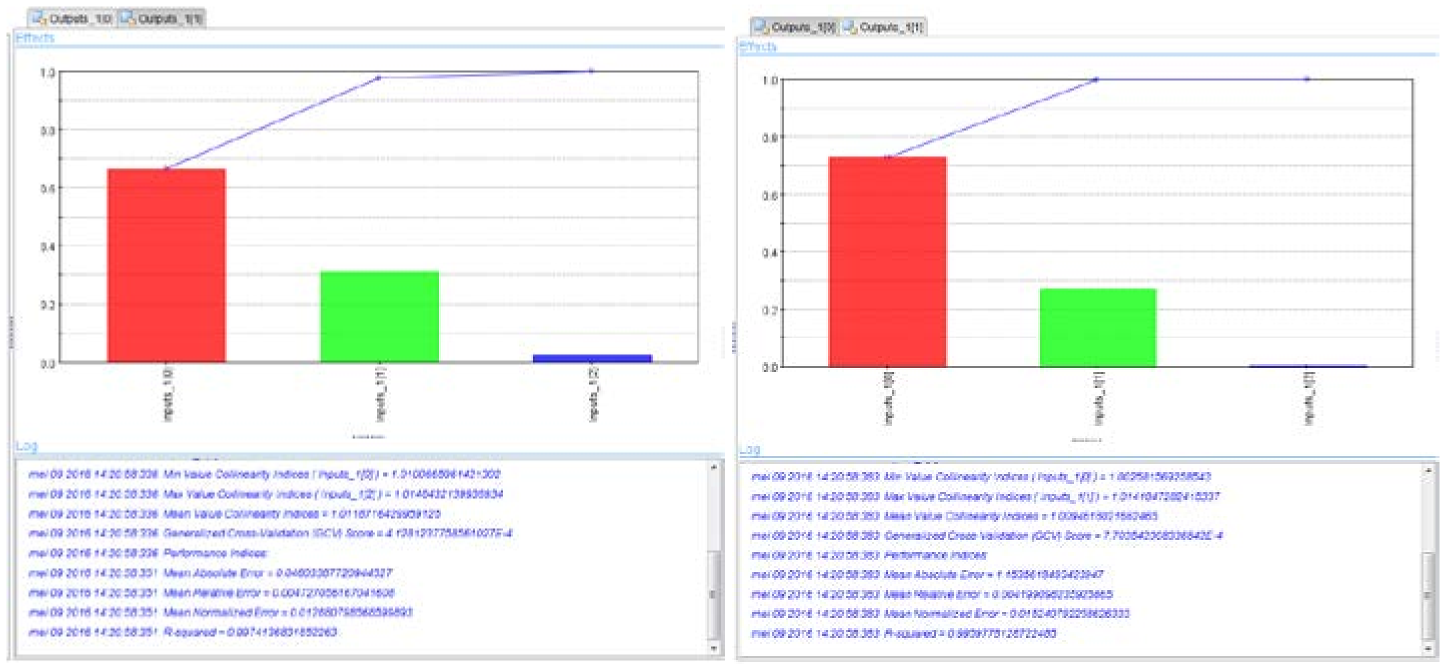


Figure 109. Relative strength graph example.

In order be able to continue towards the exploration phase of the optimization using Dashboard, the use of database management software will be needed in order to classify the results into feasible, real or Pareto. The recording of the database of results will be logged in .csv (comma separated values) files or excel files, which contain all the data generated for every possible result. Pareto and feasible real results will be the ones taken into account for the workflow.

Id	M	Category	angle	id	length	rotation	daylightfac	energyinwi	MaxDaylig	MinEnergyinwindow
0	FALSE		0.2	28	0.4	0	4.90686	146.0566	4.90686	146.0566
1	FALSE		0	30	0.5	0	5.767791	169.3224	5.767791	169.3224
2	TRUE		0.4	84	0.1	50	5.110349	122.7392	5.110349	122.7392
3	FALSE		0.2	31	0.2	10	6.659419	194.8277	6.659419	194.8277
4	FALSE		0	34	0.4	0	6.88593	201.4992	6.88593	201.4992
5	FALSE		0.2	0	0.5	10	3.816628	130.7952	3.816628	130.7952
6	TRUE		0.4	1	0.2	0	4.526395	114.2254	4.526395	114.2254
7	TRUE		0.2	35	0.2	20	6.428721	190.7028	6.428721	190.7028
8	FALSE		0.4	2	0.6	70	2.120814	85.8313	2.120814	85.8313
9	FALSE		0.2	3	0.6	20	3.100349	111.3684	3.100349	111.3684
10	TRUE		0.1	88	0.1	50	9.621977	277.3187	9.621977	277.3187
11	TRUE		0.2	4	0.2	0	6.891163	193.6241	6.891163	193.6241
12	FALSE		0.4	36	0.3	10	3.662209	101.5614	3.662209	101.5614
13	FALSE		0.3	5	0.5	10	3.16907	104.6675	3.16907	104.6675
14	FALSE		0.1	6	0.3	50	6.354302	205.6359	6.354302	205.6359
15	FALSE		0	7	0.5	40	5.191512	171.1113	5.191512	171.1113
16	TRUE		0.4	37	0.5	0	2.710698	84.5863	2.710698	84.5863

Figure 110. Pareto front real and feasible result table.

This data input to the database reader in this project is managed through PGAdmin-III (SQRL Database reader). Image 103 shows a set of results where the ones which are TRUE belong to the Pareto front.

13.4 Visualization - Exploration of results in Dexp

One of the most interesting featurs of D-Exp is the possibility to explore the relevant to the project through an image which shows how the model looks in the Rhino modelling space. Also though its filtering capabilities, it is possible to showcase results according to certain conditions that result meaningful according to the nature of the project; for example a condition could be “All feasible results for G-Value in a descending order”. Another important characteristic is that the images showcases the result, include the values for the design parameters the generate the solution, number of solution (result) and result for design objectives.

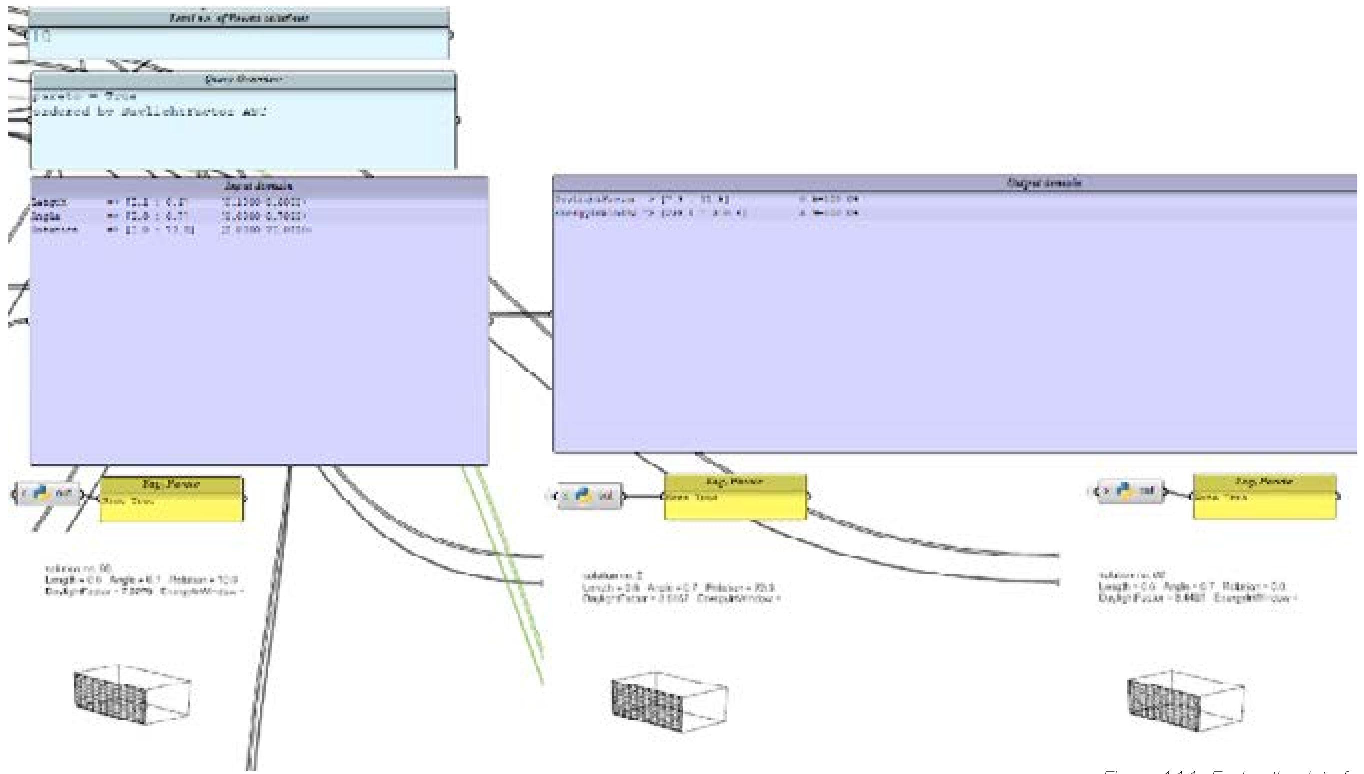


Figure 111. Exploration interface D-Exp..

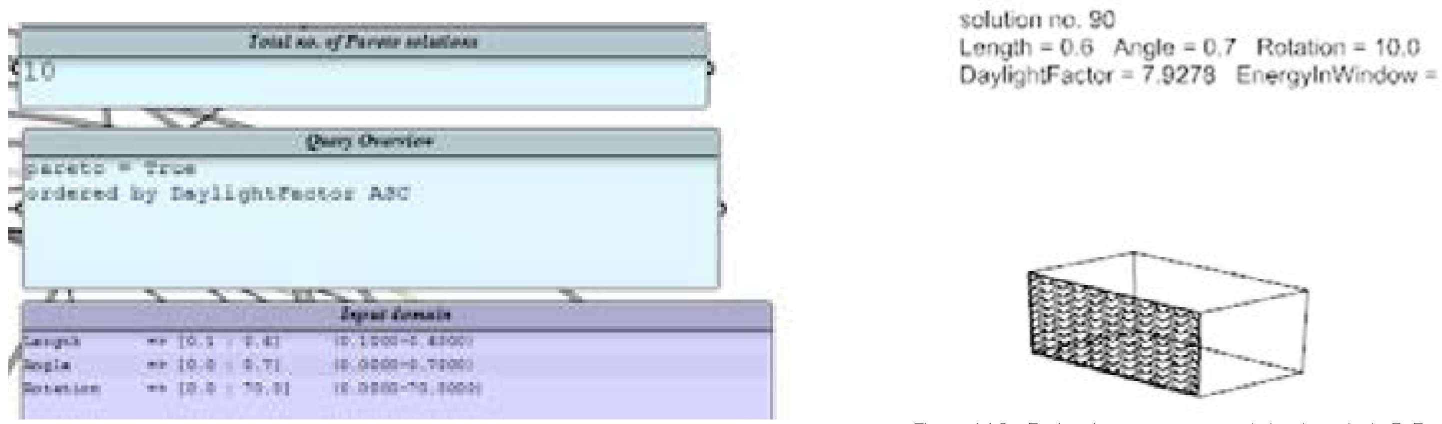


Figure 112. Exploration parameters and visual results in D-Exp.

It is also possible to access the database directly to generate the models that are needed a long as a database for the results is created in D-Exp, this facilitates the exploration of the results if the amount is considerably small and can limit the process to the exploration directly into the parametric environment for the results that have been spotted as Pareto front, real and feasible.

13.5 Visualization - 3D Model generation and translation into VR

At this point of the methodology the designer is aware of the capabilities of the management and showcasing of the results from of a parametric design, to a optimization software and back again to an exploration of the optimized designs. Yet the values generated for the indicators will still go through an post optimization process, where the technical knowledge and creativity of the designer to make use data interpretation will be determinant to demonstrate the helpfulness of a shading device through the use of the visual representation of parametric design. The post optimization process for this methodology in the forms in the following subchapters. For Daylight Factor the subproducts of Daylight factor will be: Total Daylight Factor, Useful area with DF values test against layout, and for G-Value: Reduction of the energy in glazing system through the shading devices.

DAYLIGHT FACTOR

The total DF of the room, will be portrayed through a color mesh which is part of the parametric daylight model. This is a way to visualize the values according to a color code and deduct which areas in the analysed room are actually coping within the desired DF ranges and will depict, the natural light distribution.

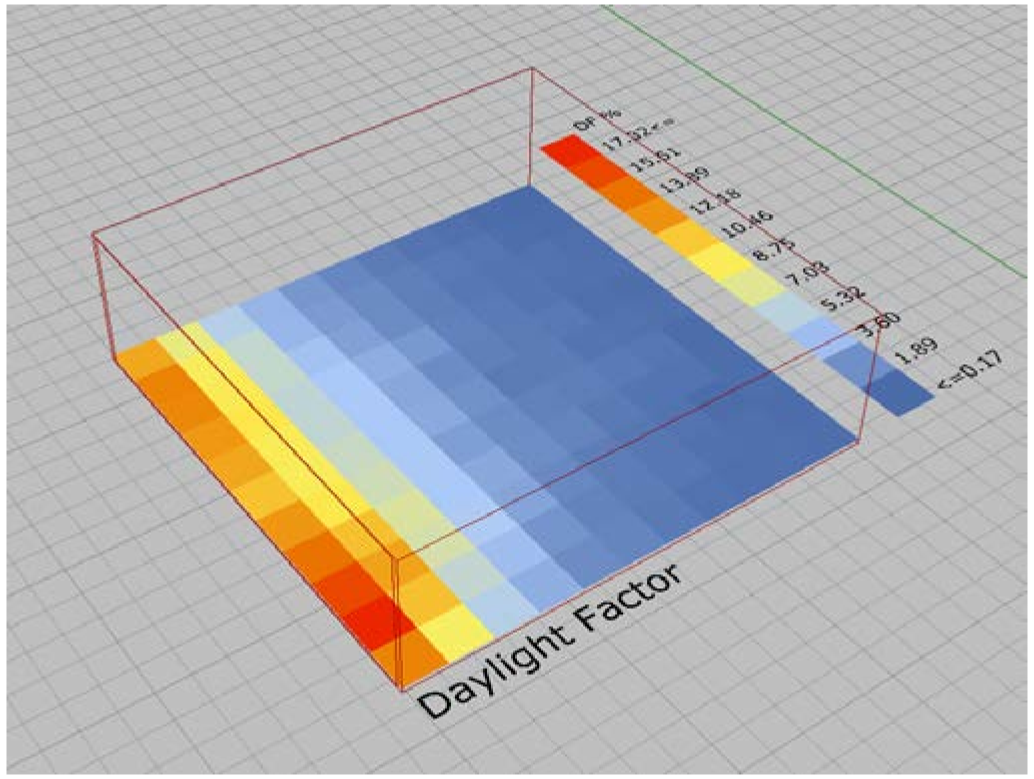


Figure 113. Daylight Factor color mesh model.

USEFUL AREA WITHIN DF VALUES

Through the use of the parametric modelling it is possible visualize the data that fits in the desired range of daylight factor. This will be helpful to visualize how the shading design is actually contributing to room, and assist in the determination of the performance of an architectural feature such as layout of an interior. The area will be determined out of selection the values that fit the design objective´s goal, and can be highlighted through any sort of 3-D representation, in this workflow an extrusion of the area was the choice.

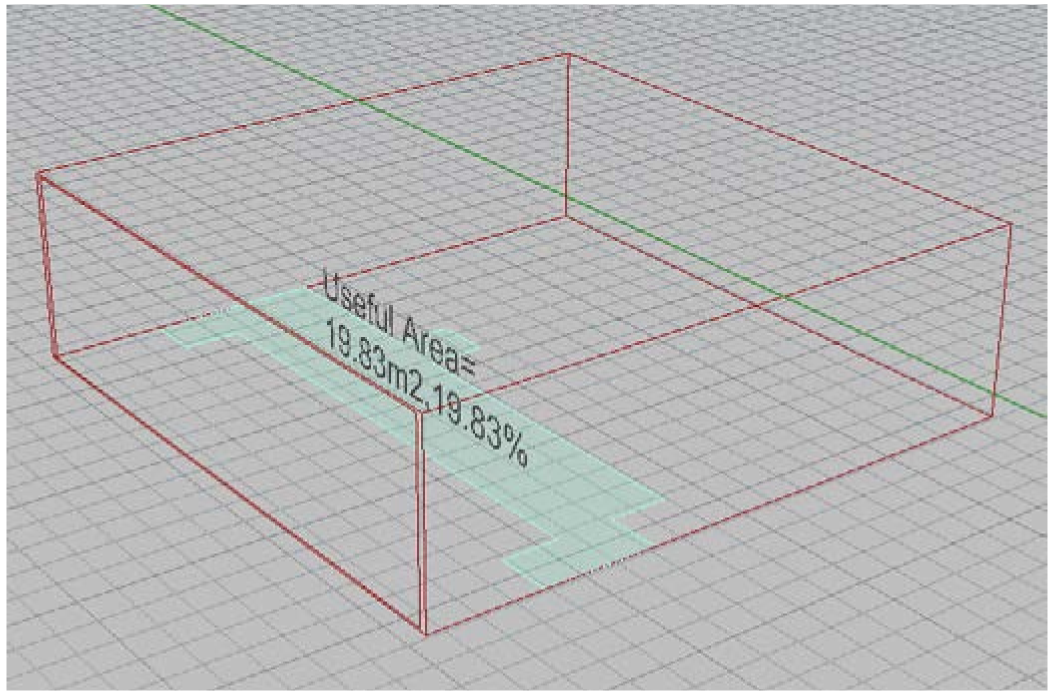


Figure 114. Useful Area within Daylight Factor values model.

G-VALUE REDUCTION

Through this indicator as it mas been mentioned, it is possible know for the amount of energy being prevented to entering the room and how the G-Value as been reduced. For visualization purposes in this case, there is not a clear from of presentation although through the use of text the values are displayed and will inform about the energy being absorbed by the shadings and the G-Value reduction.

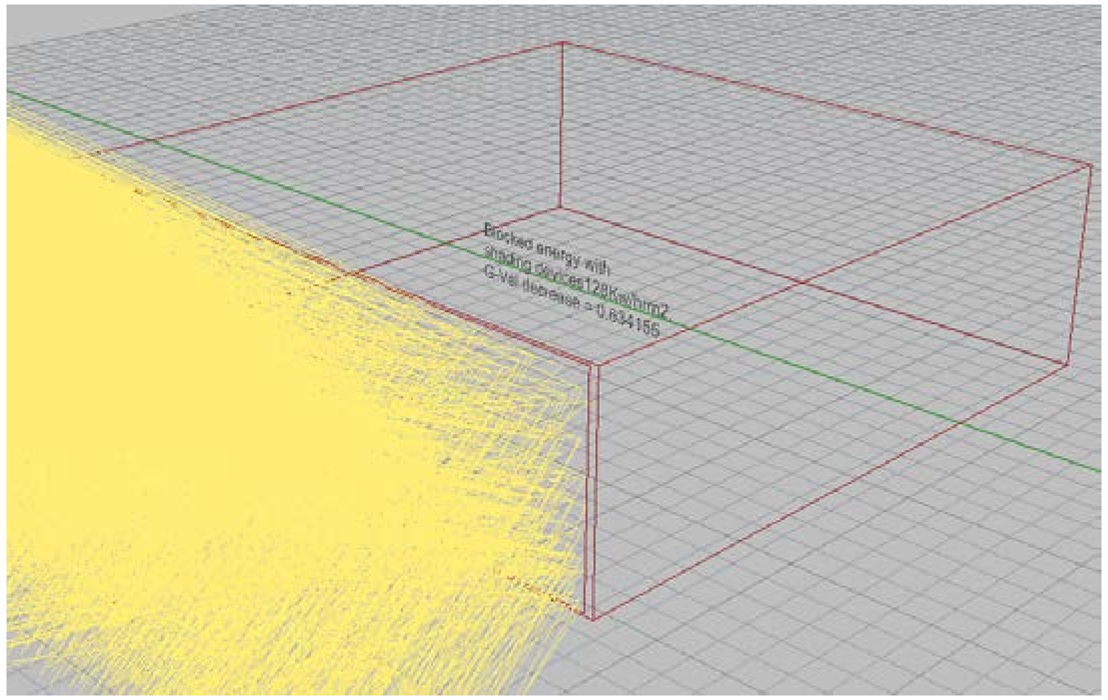


Figure 115. G-Value reduction model.

13.5 Visualization - 3D Model generation and translation into VR

Once the results have been selected can go through post a optimization process which as mentioned in 10.4.1 two different sorts of approaches will be used in the workflow: Interactive live scale simulation and Single node panoramic views. Every approach follows are different steps and offers a different level of complexity in the output.

Interactive live scale simulation:
Is generated through a VR engine and must be explore through the use of speceliazed gear which includes the use of controls and sensors for the exploration and manipulation of the model. The technology in this sort of simulation allows the possibility visualize the model into a 1:1 scale and make a walk-through that in case of the shading devices will make the affordable to visualize a real approach of how the shading will affect the visibility and aesthetics of the facade, also the shifting from one result to another becomes possible.

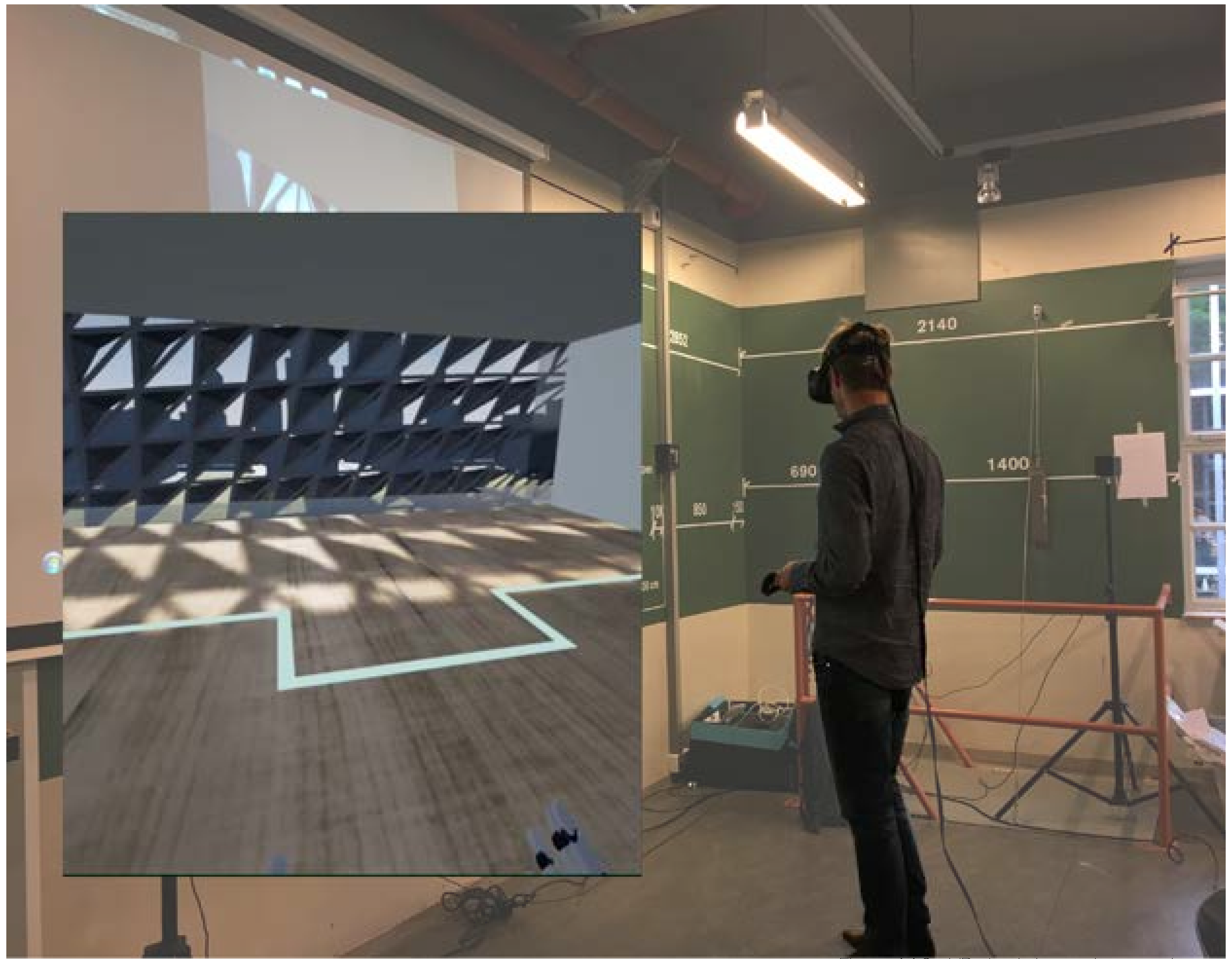


Figure 116. VR simulation environment in use..

The steps that have to be followed in order to generate a Interactive live scale simulation, are the following:
1. Generate the 3d results from the parametric model with the use of the simulation model.
2. Import parametric optimized model into a Virtual Reality simulated environment tool.
3. Program setting for controlling navigation.
4. Freely explore the model.

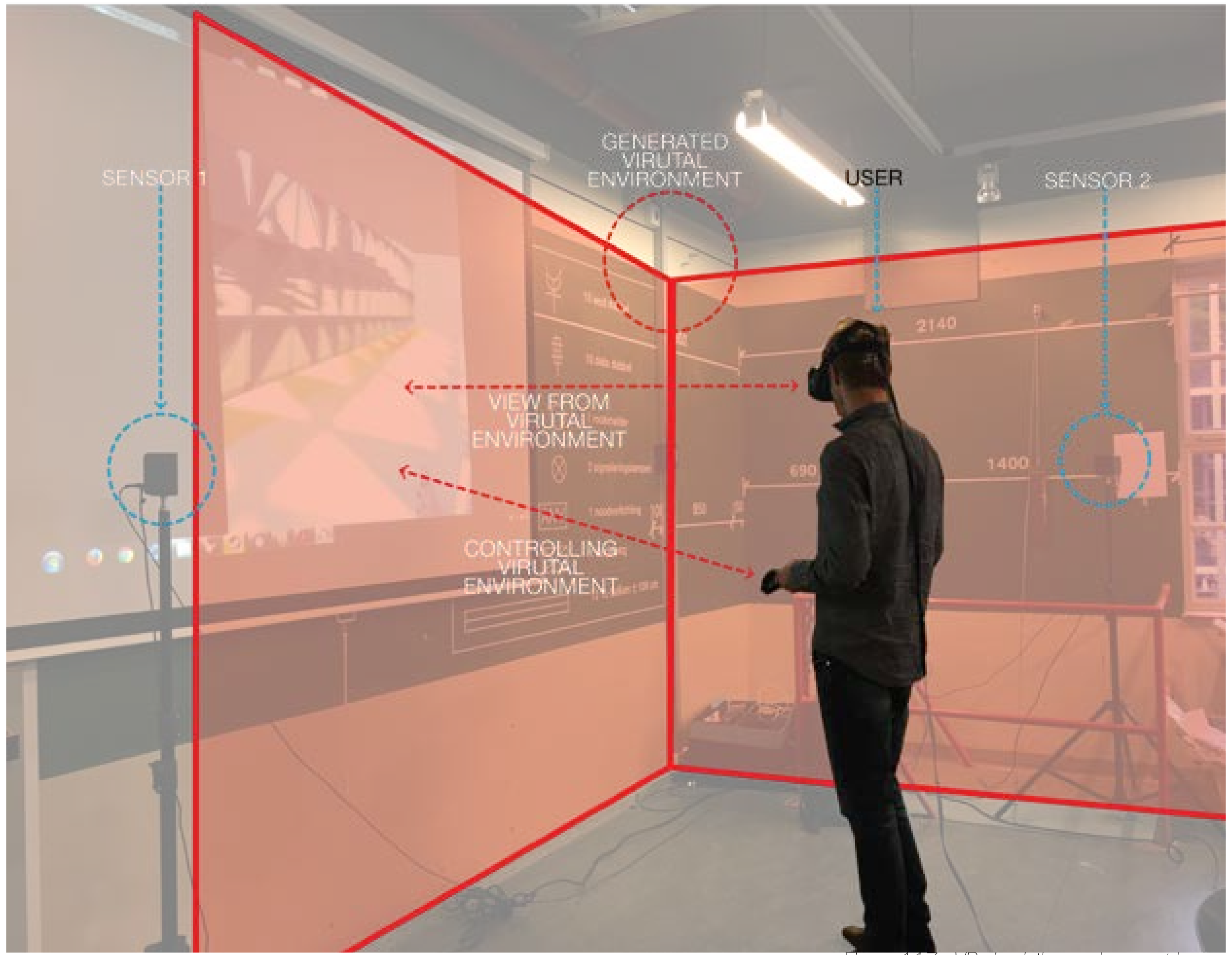


Figure 117. VR simulation environment in use.

Single node panoramic view:
This form of VR output is the less sophisticated of both, but it has the advantage of portability, since it does not need specialized VR gear to be explored only the use everyday technologies such as a portable device with a gyroscope (smartphone, tablet) and a simple VR visualization gear such as cardboard googles. The single node panoramic view allow a the visualization of a 360º view of room from a single point of view, meaning that the exploration of the results its bounded to an image and not an interactive model, although valuable from perspective of sharing information and having a quick access to the images.

The steps that have to be followed in order to generate a Single node panoramic view, are the following:
1. Generate the 3d results from the parametric model with the use of the simulation model.
2. Render the model into a spheric cube or 360º panorama in the rendering engine of preference.
3. Import the rendered images into a 360º panorama visualization app or platform
4. Generate a walkthrough of the results.

Figure 118. VR simulation environment in use.

14. ASSESSMENT

In order to be able to make an assessment for a shading design, regarding the possibilities that the building parametric model offers, it becomes useful to test a room under different conditions for location in a facade if its possible, as it happens in this project. This will give a broader perspective on how the shading design performs, given that the design parameters might create substantial differences depending on their position, of course depending on the level of complexity of the model and scale of the building.

As more than one analysis for the same room will be made, it is possible to determine which position of the room in the facade can suit better according to the expected from the indicators.

In order to generate an assessment given the different degrees on the complexity of communication between statistical information, 3-D environmental visualizations and Virtual Reality, the design selection would have to work should follow the next levels:

1. Level 1: Analysis and selection of post optimization results, directly from the statistical data presented in the optimization tool, select the results which have a higher percentage for average daylight factor and maximum usable area possible. The focus of the selection of the sample can be made through a comparative process looking at “Pareto and real results” and will depend on the amount of pareto results and how the similarity amongst them.

2. Level 2: The selected sample of results, are submitted to the daylight and energy simulation software in order to retrieve the 3-D models so the first visualizations of the optimized results in the optimization software. Based on the expected from the design objectives, which will be showcased in the parametric model such as size of the useful area and its location in the room as well as the distribution of daylight factor and even aesthetics, it becomes possible to discard from the optimized results which can be taken to next level of representation. At this point also ray-tracing will be involved in the process, only the results that will taken into account, the reason for this is the computational expense involved to produce the sun-rays.

3. Level 3: At this level the assessment the results can be analysed in deep detail through post optimization features through Virtual Reality, exploration of the design objectives in the model rooms, detailed visualization of the shading device, a 1:1 scale in order to enthuse the effect of the shading device in a room from an architectural point of view, interactive simulation for model for reconfiguration of layouts in real time and exploration of detailed models of the shading devices.

14.1 SATISFYING DESIGN

A way to make a assessment on how satisfactory a shading design is could be to determined by:

1. Daylight factor coping with the desired natural light distribution objective, while aiming for the maximum levels of natural light.
2. The maximum floor area that fits between the DF design objectives.
3. The design that contributes the most with the reduction of the G-Vale of the glazed area.
4. A design the blocks most of the sun rays hitting the window of the room in question.

This parameters for assessment highly depend on additional knowledge about the context and the implications of the use determined characteristics in the building, for example the drawback effects of using large glassed façades in tropical climates or the lack of natural light sources in buildings in Northern latitudes.

An example on how to determine if a shading design is satisfactory could be:
1. Daylight factor between 2% and above aiming for the least use of artificial light.
2. Maximum area larger that 30% of the floor space within the admitted DF values.
3. G-Value decrease at least from above the average, solar gain in the glass reduced at least by a 50% (.5 index).
4. Ray tracing achieves the blocking of more of 90% of the critical light beams.

As it was mentioned previously only the results that comply with the necessary characteristics to go through all the assessment levels can be considered as possible satisfactory design. The exponential level of detail of every assessment level will give the designer different sorts of feedback on the benefits of every design.

14.2 UNSATISFYING DESIGN

In order to determine the lack of success of shading design, it would be recommended to take such sample of design to level 2 of assessment, since the optimization is based on statistical data that gives and referential input, and so do the parametric and environmental platforms tools for visualization, but still the knowledge and the user´s input on the project design influence in order to draw conclusions. Nevertheless if the design exploration in level 2 of assessment is still not satisfying or adaptable to the needs of the design objectives, a revision on the parametric shading model might be needed.

Through the statistical information from the optimization process it can easily be detected which design objective is the less influences or which design parameter has the least level of correlations towards the objectives. Based on that a decision on where in the parametric model a modification is needed can be easily addressed. It is The knowledge on how the parametric shading design operated is highly important.

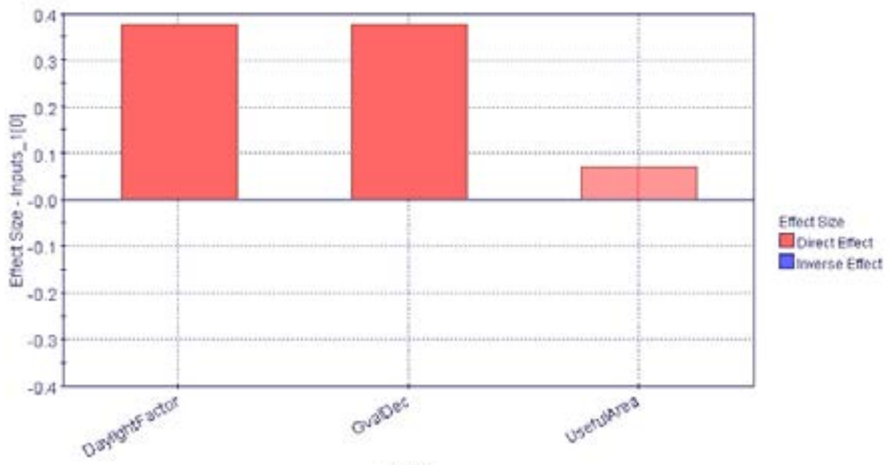


Figure 119. Relative strength graph.

14.3 DECISION MAKING

The focus of this worfklow is a point of departure as in a early design stage is a method to help designers to begin the process of searching for design that can perform better through a set of informational outputs in order to endorse informed design decisions.

Therefore, once a result sample has been taken through the three levels of assessment, it is possible to make a decision on the most convenient shading devices, since by now the design expectations must be fulfilled to a reasonable extend.

As the degree of detail grows through each assessment level, it becomes easier for a designer to make a decision since the information becomes more graspable. Different aspects of the designers mind set like the value of aesthetics or adaptability of a design might emerge in order to improve an already satisfactory design.

15. TECHNICAL IMPLEMENTATIONS AND INNOVATIVE VALUE OF THE WORKLOW

An important step forward on innovation from this workflow is to demonstrate the current possibilities for designers and engineers to merge knowledge inputs from different perspectives for the sake better understanding on how a design can prove to be functional, in case of this project for the use of daylight.

The technical implementations regarding the innovation of this workflow rely on the combination of two streams, which can be classified in technical and visual.

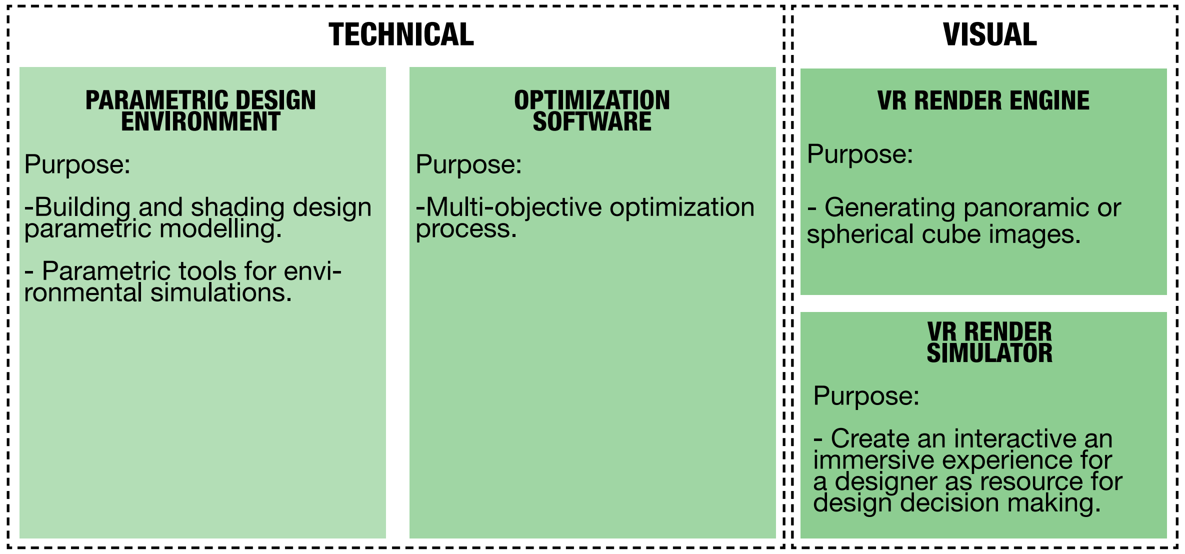


Figure 120. Workflow components.

1. Technical :Powerful and vast tools for PARAMETRIC ENVIRONMENTAL DESIGN, with the combination of sophisticated OPTIMIZATION TOOLS tha endorse and facilitate, decision making.
2. VISUAL: Innovative forms of immersive visual representation, real-time interaction between the model and the user and in some possibility for portability.

The most relevant technical implementations is the possibility of communication between optimization and parametric tools, since it is the drive and what makes the workflow possible. As it has been mentioned form this sources for all the information and offer the possibility for constant access for real time modification of the parametric design and feedback, before the translation into 3-D parametric model.

The innovative value relies on the possibility of transformation of the information levels from highly technical, to visual and interactive with out losing focus on the indicative information for the design objectives, is one of the implementations that become highlights of this project. Also the possibility to have to levels of sophistication in the VR representation becomes relevant due to that fact that Virtual Reality operated from high-end gear is still an emerging topic, while the use of cardboard googles and panoramic views are becoming more usual rapidly, this allows that process of visualizing the results of the product on a quite easy way. Nevertheless interactive VR endorses the assessment of the project in question, through the possible level of sophistication which broadens the possibility for inputs in the process of decision making.

USER FRIENDLY INTERFACE

This method offers the possibility to operate some features in the parametric model through a user friendly front-end. As it has been mentioned in previously in chapter 7, the user friendly interface becomes a bridge in the communication between the users programming the parametric model and other users which input resides in other fields such as climate or facade in case of this project.

The parametric features embedded in the user friendly interface can function the following levels:

1. Pre optimization phase:
- Selection of EPW file for site
- Selection of facade
- Program selection
- Location in facade
- Activation of the environmental simulations

2. Post optimization phase
- Selection of EPW file for site
- Selection of facade
- Program selection
- Location in facade
- Optimized result selection
- Activation of the environmental simulations

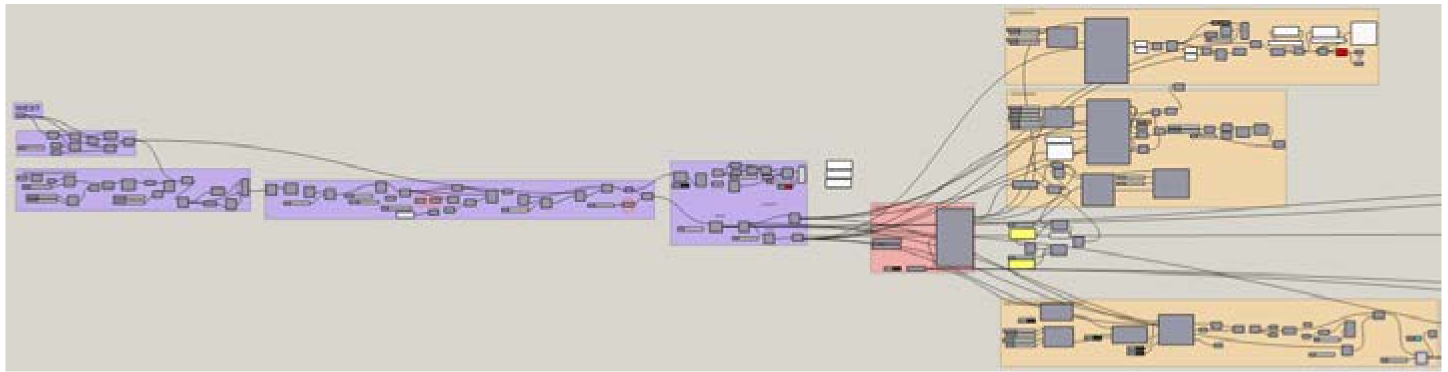


Figure 121. Complex Grahopper Environment.

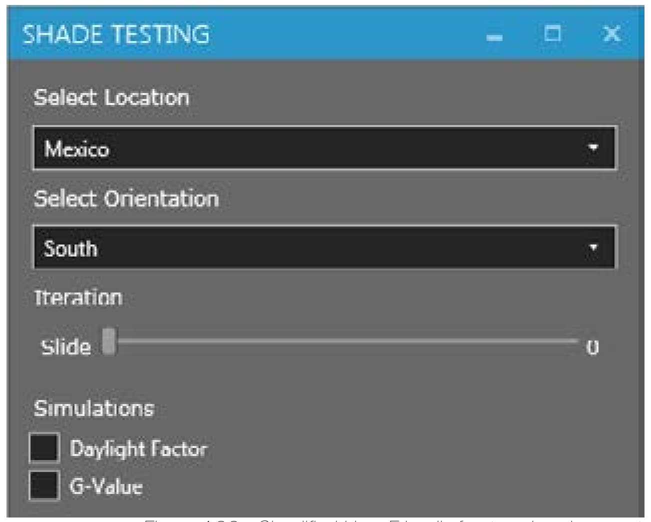


Figure 122. Simplified User Friendly front-end environment.

16. Conclusions

The research of this graduation project was focused on defining a work-flow that can help architectural designers make informed design choices for static shading devices. The goal of this project was to design a workflow that facilitates the process of decision making through the use of valid indicators focusing on daylight quality and energy. The development of this workflow required learning of parametric environmental software, experimentation of recently developed plug-ins and a currently growing knowledge parametric design tools in general.

In order to have a better perspective on the current use environmental software applied on architectural design, interviews to experts on the field were an important point of departure that made evident the need of integrated workflows that can solve specific problems, that reduces uncertainty in the desgin choices for environmental design and support the decisions when specialists are not available.

Also the developers of one of the analysed tools for environmental design were interviewed, their input resulted useful due to that fact that from their own perspective they can only focus on putting together knowledge and solutions to the environmental design challenge in the form of tools but it is up to the designers to know how to link architectural design with their offered environmental design platform. Having the perspective on both sides was conclusive to determine that useful of this project if oriented for designers.

The research was divided into two parts, theoretical and practical. Through the literature research I was able to learn on the basic principles of shading design such as understand the traditional ways of design adequate shading devices, the use of the different shading typologies according to orientations as well of the benefits of an properly used shading design. Also through the research different postures on the posture of how to tackle the topic of shading design were taken into account, the choice for static shading devices came from the fact that they are more commonly used and affordable in the world and require less additional inputs in order to fabricate them. Through the literature research the two main indicators for this project were defined. Daylight Factor and G-Value decrease were selected due to the fact that they era easy to understand and both are assessed two very graspable indicators.

The practical research began with the tool analysis for the current state of the art of the available tools was needed in order to determine which parametric tools for environment was the best choice in terms of simplicity to use, outputs that covered the indicators that wanted to be tackled and the best forms of presentation. The final choice for the parametric environmental tool came down to Ladybug and Honeybee.

In order to take the design to another level of sophistication and accuracy optimization was added to the workflow. The input involved the use of recently developed tools such as D-Exp which is linked to modeFRONTIER the optimization tool of choice. Regardless of how interesting the use of this tool is, the experimental phase that its currently going through gave the project a level of uncertainty, but not enough not make it possible. In the end it was possible to achieve accurate an real results from the parametric design software, the use of parametric environmental tools and the optimization process. Making the worklflow at this point useful but yet not appealing on its output or user friendly.

As it was mentioned having the optimized results solved for the indicators was not enough, through the revisions of the workflow it two aspects were found:
1. The complexity of the GH interface made it difficult to explain the workflow to second or third parties.
2. The output could take a step forwards in terms of interaction and exploration from the user.

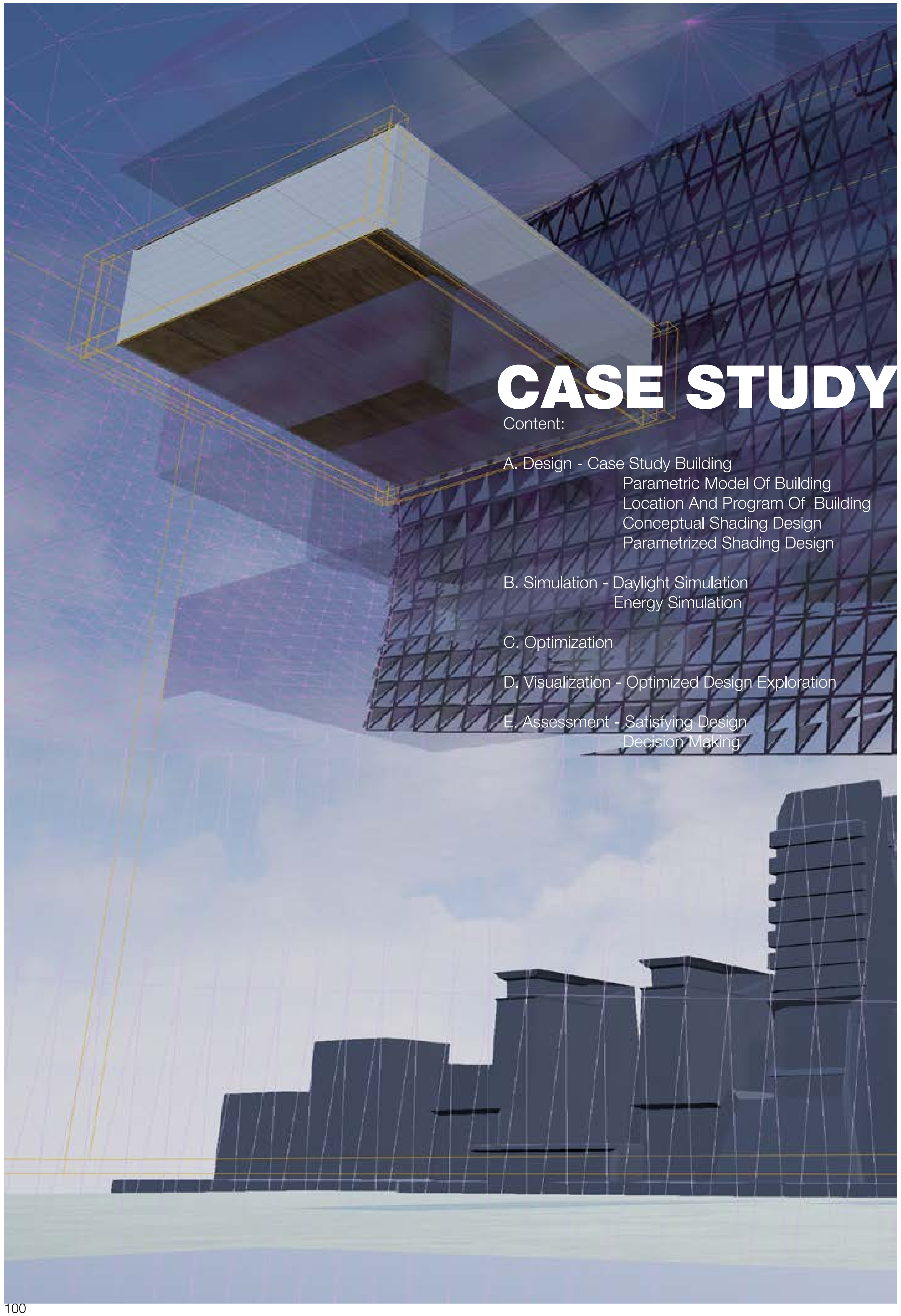
The solution to the first issue was the development of a front end, in order for the user to be able to use de workflow through a more generic interface such as a window. The solution to make the output more interactive was solver through the use of Virtual Reality in two forms, which were static (portable), interactive (more sophisticated but not portable).

With the use of the envelope of The Esplande as a case study to implement the worfklow, it has been proven that the methodology functions and can be adapted implemented in different sorts of programs, with different needs and into complex geometry envelopes and with responsive shading devices. Moreoeover it has been proven that shading devices can be submitted to a workflow with interesting forms of exploration in different levels, from the parametric design, to optimization and to VR exploration, these levels of insights are needed in order for architects to take steps further into making informed decisions, based on facts and perhaps they might become more common in the near future.

16.1 Recommendations and further development

One of recommendations of this projects focused to future researchers and students into considering the use of experimental tools with the expectation of constant and consistent results. Although it is highly valuable for this developers that their tools, workflows and methods are used into new projects of different topics with the goal of improving and knowing the limits of their work.

In terms of the exploration of the use of shading devices many indicators were left behind due to the time structure of this projects, topics such as indoor thermal comfort, visibility and luminance were left behind but the still could become part of this workflow at a certain point.



CASE STUDY

Content:

A. DESIGN - CASE STUDY BUILDING

The case study for this project is will take into account the location, geometry and parametric principles of the shading design for the envelope of the Singapore Opera House “The Splande”, specifically the Concert hall building. The ASHRAE climate zone that belongs Singapore is 1A and B for tropical and subtropical climate.

The reason to choose this building is the geometrical complexity of the envelope, the parametric principles of the shading design, and the iconic value of the building. An important fact about this building is that the geometrical solution for tessellation of the envelope and the shading design was gone without the use of parametric design tools. Considering its complexity it is important to demonstrate how the evolution of design tools for geometry, environment along with optimization have made analysis and design decision process more feasible designers.

Figure 123. View of the Esplanade complex.

Figure 124. Esplanade facade used for case study.

The tables below show the climate zone number for a wide variety of International locations. Additional information on international climatic zones can be found in ANSI/ASHRAE/IESNA Standard 90.1-2007 *Normative Appendix B – Building Envelope Climate Criteria*. The information below is from Tables B-2, B-3, and B-4 in that appendix.

International Climate Zone Definitions

Zone Number	Zone Name	Thermal Criteria (I-P Units)	Thermal Criteria (SI Units)
1A and 1B	Very Hot –Humid (1A) Dry (1B)	9000 < CDD50°F	5000 < CDD10°C
2A and 2B	Hot-Humid (2A) Dry (2B)	6300 < CDD50°F ≤ 9000	3500 < CDD10°C ≤ 5000
3A and 3B	Warm – Humid (3A) Dry (3B)	4500 < CDD50°F ≤ 6300	2500 < CDD10°C < 3500
3C	Warm – Marine (3C)	CDD50°F ≤ 4500 AND HDD65°F ≤ 3600	CDD10°C ≤ 2500 AND HDD18°C ≤ 2000
4A and 4B	Mixed-Humid (4A) Dry (4B)	CDD50°F ≤ 4500 AND 3600 < HDD65°F ≤ 5400	CDD10°C ≤ 2500 AND HDD18°C ≤ 3000
4C	Mixed – Marine (4C)	3600 < HDD65°F ≤ 5400	2000 < HDD18°C ≤ 3000
5A, 5B, and 5C	Cool-Humid (5A) Dry (5B) Marine (5C)	5400 < HDD65°F ≤ 7200	3000 < HDD18°C ≤ 4000
6A and 6B	Cold – Humid (6A) Dry (6B)	7200 < HDD65°F ≤ 9000	4000 < HDD18°C ≤ 5000
7	Very Cold	9000 < HDD65°F ≤ 12600	5000 < HDD18°C ≤ 7000
8	Subarctic	12600 < HDD65°F	7000 < HDD18°C

Figure 125. ASHRAE Climate zone chart.

A. DESIGN - PARAMETRIC MODEL OF BUILDING

In order to generate the shading devices testing, it was necessary to develop the parametric model the building, the base model of the building was a model of the envelope (fig 126) of the Concert Hall, in order to be able to locate the testing rooms in the facade that functions according to the building geometry, the envelope was decomposed into the following (example is showcased into a simple facade, figures 127,128, 129, and 13.):

1. Division of the facade into stories with the use of representation of slabs according to the expected height of the program, in this case 3m. (fig 128)
2. Subdivision of the facade with the use of the projected slabs in order to determine possible points of departure for generating the glass faces of the program rooms, 5mts distance. (fig 129)
3. Generation of the possible locations of the program rooms if the facade, 54 rooms are possible. (fig 130)

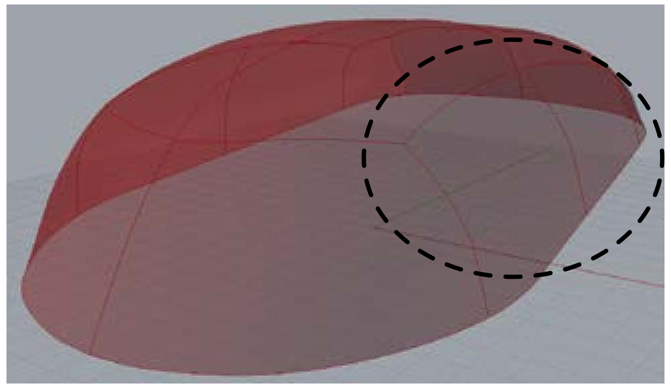


Figure 126.

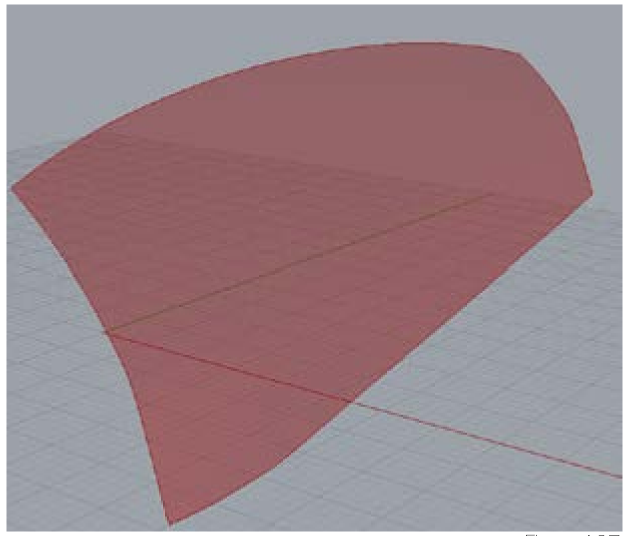


Figure 127.

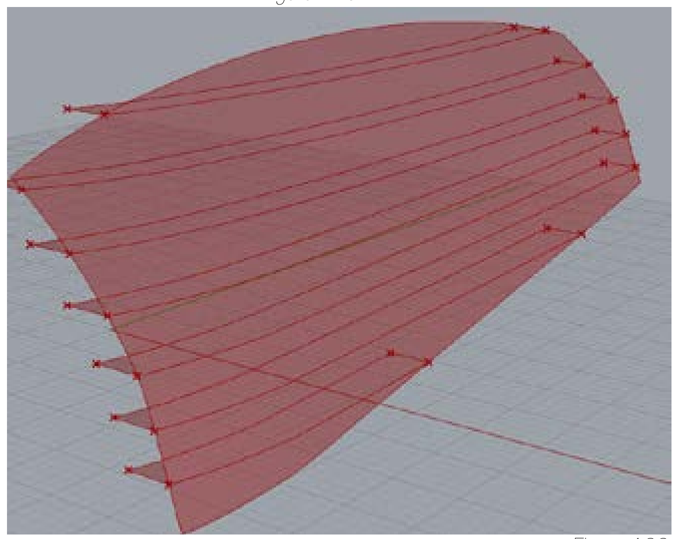


Figure 128.

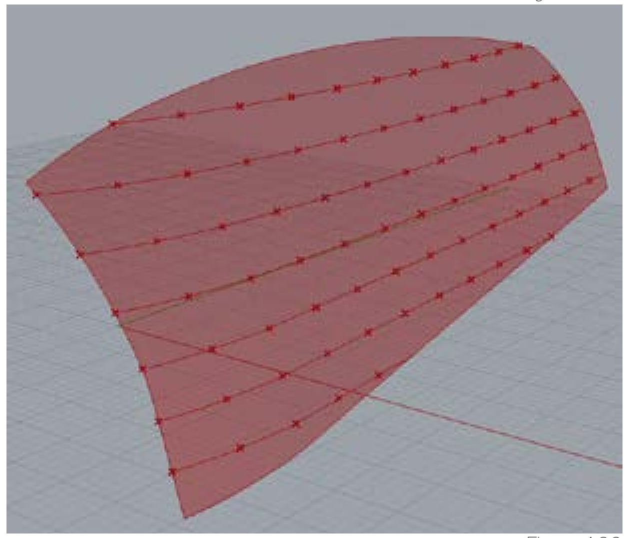


Figure 129.

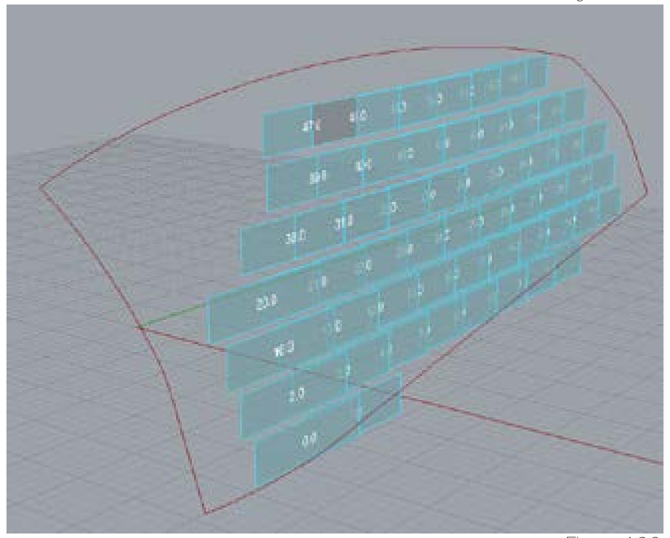


Figure 130.

Figure 126 to 130. Parametric model of building.

A. DESIGN - LOCATION AND PROGRAM OF BUILDING

The program decided to be tested is a sample office of 10x10m floor area. Which will be tested in different positions in the facade in order to determine which location would be the best based on the results generated through the optimization process for daylight factor, g-value decrease and usable area according to natural light distribution.

The chosen parameters where the following:
Location: Singapore
Facade Orientation: East
Porgram : Office 100m2
Positions to test at: 2, 24 and 46

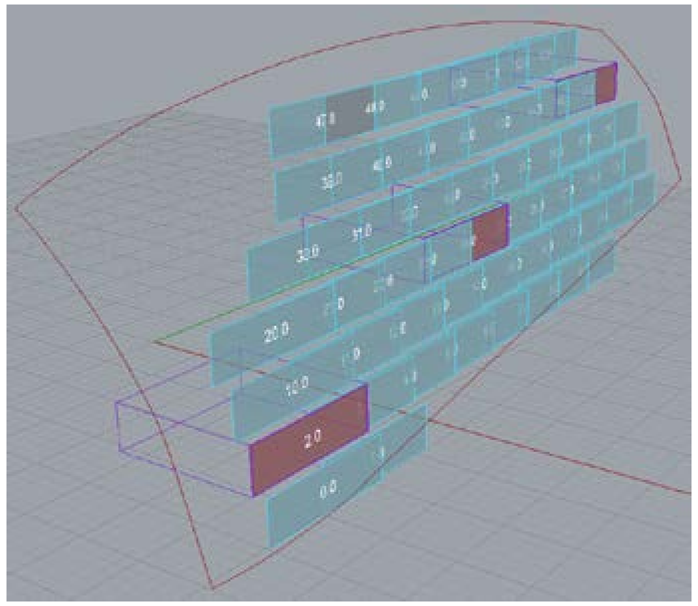


Figure 131. Selected rooms.

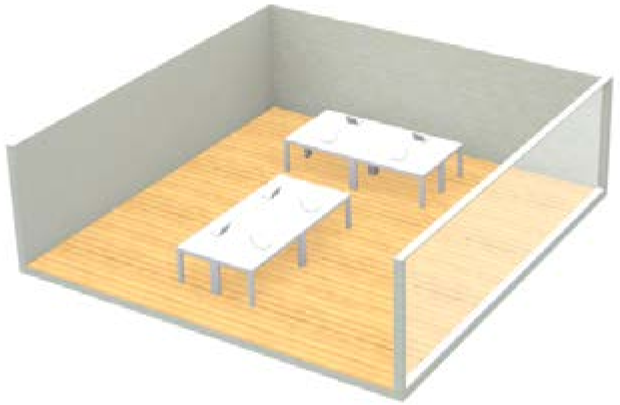


Figure 132. Model room with materials.

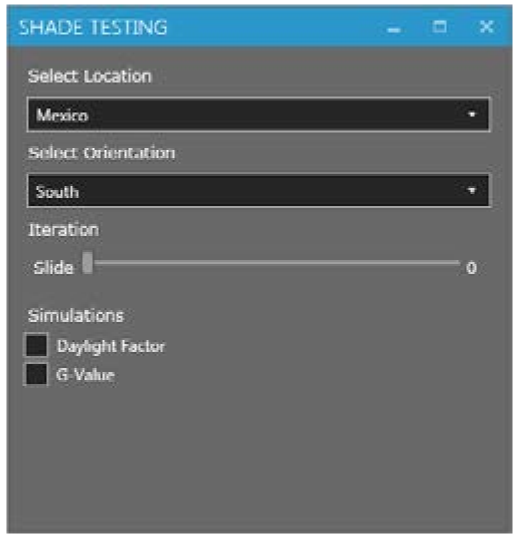


Figure 133. Simplified User Friendly front-end environment.

A. DESIGN - CONCEPTUAL SHADING DESIGN

The conceptual design taken into account was the slanted awning used through the whole envelope of The Splande. Although through the conceptual and parametric design phase, it is intended that the shadings have a controlled number of variations that focus on aspects such as visibility range and scale which according to the workflow will be part of the objective design parameters. As it showcased in the following diagrams fig.136 and fig. 137 represent that basic windows according to the envelope tessellation and a basic shading device.

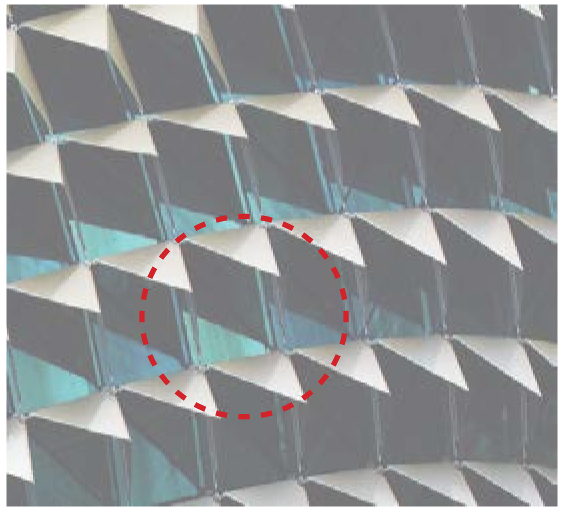


Figure 134. Facade sample awning.

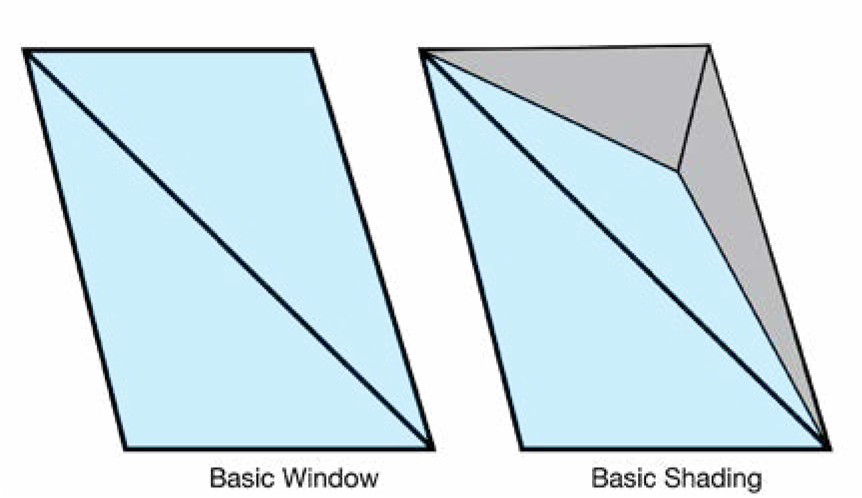


Figure 135. Basic window sample.

In order to never loose visibility through the shading devices, the design aims to have a range of visibility in from 30% to 75%.

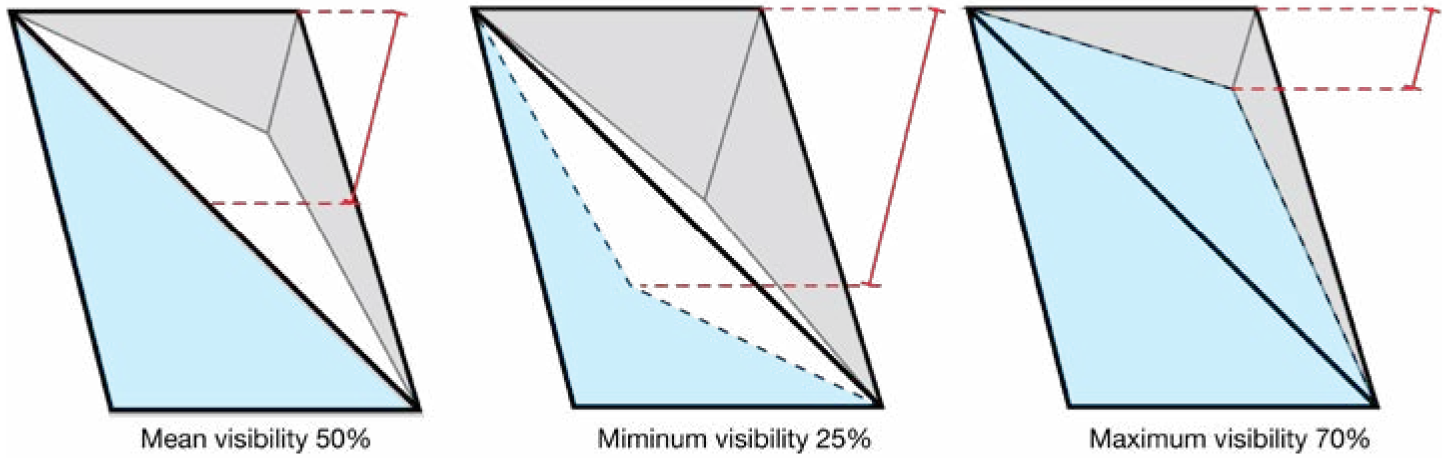


Figure 136. Visibility shade samples.

Regarding the geometric principles of the shading device, height variations of the tip of the awning are expected, and will need to have logic to control the variation that must be tackled through the parametric model.

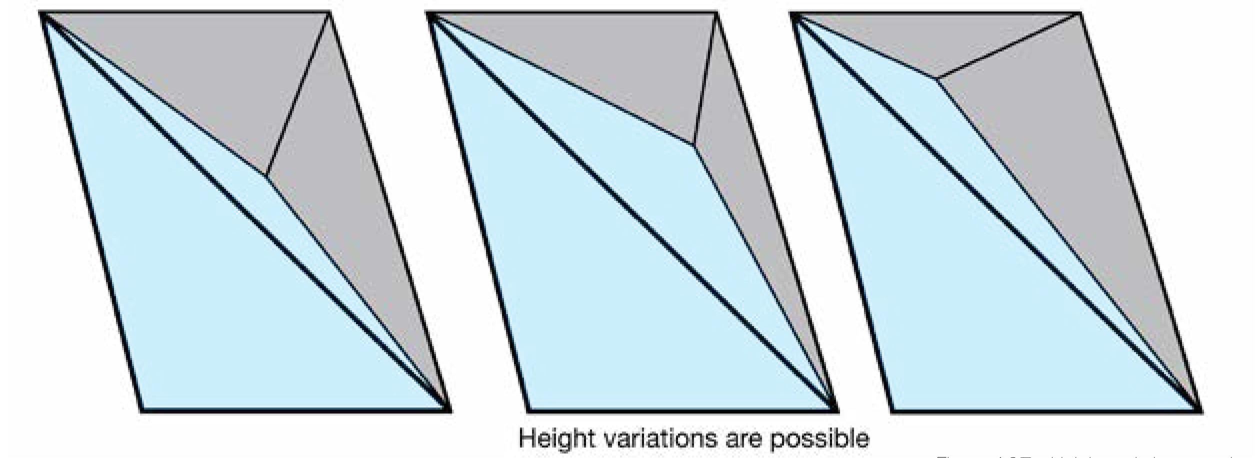


Figure 137. Height variation samples.

A. DESIGN - CONCEPTUAL SHADING DESIGN

Since it is already known that the shading devices are made of alluminum, another important element of the Objective Design Parameters for material has been established therefore a maximum and minimum length for the axis of the awning. The minimum will be set to 30cms and the maximum to 100m, giving the design the capability of always have at least a 30cms awning in every window module.

Figure 134(1). Facade sample awning.

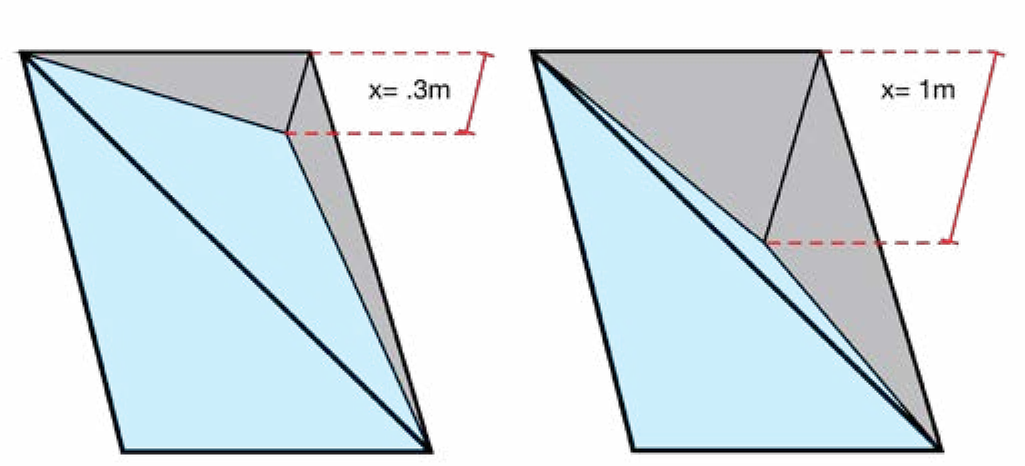


Figure 138. Amplitude variation samples.

According to the design of the building, the design strategic approach will be an additive due to the fact that the envelope where the shading devices are located will be a second skin to the building, as it is shown in figure 131.

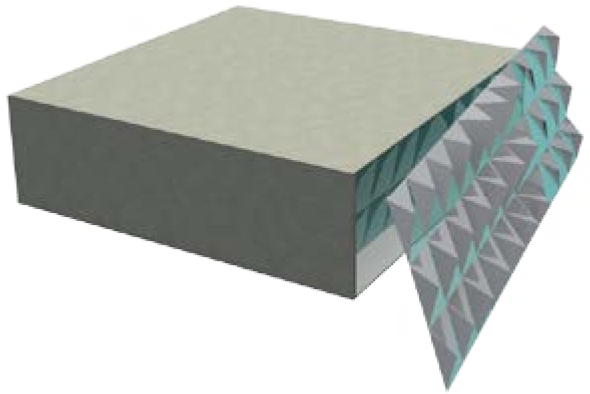


Figure 139. Sample room with second skin shading.

A. DESIGN - PARAMETRIZED SHADING DESIGN

In order to parametrize the shading design, following a logic that relates to one of the indicators in this case Daylight Factor is needed. A solution is found in relating the parametric model of the building to the projection of the surfaces of the Tergenza dome (figure 140) that have a direct influence over the glassed surface of the analysed room in question.

The resulted projected points are “Vectorial Pull Points” (figure 141) that have the capability of controlling and modifying the permutations of the shading devices according to the position of the point as it is shown in figure 142 for point 0, for point 8 and for point 12.

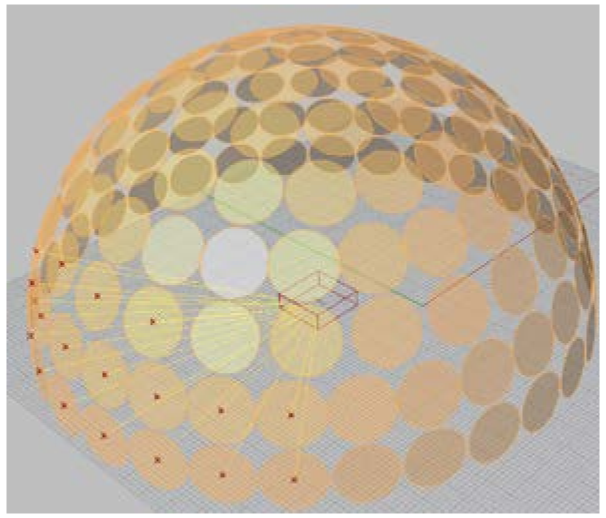


Figure 140. Tergenza dome with dome light patches.

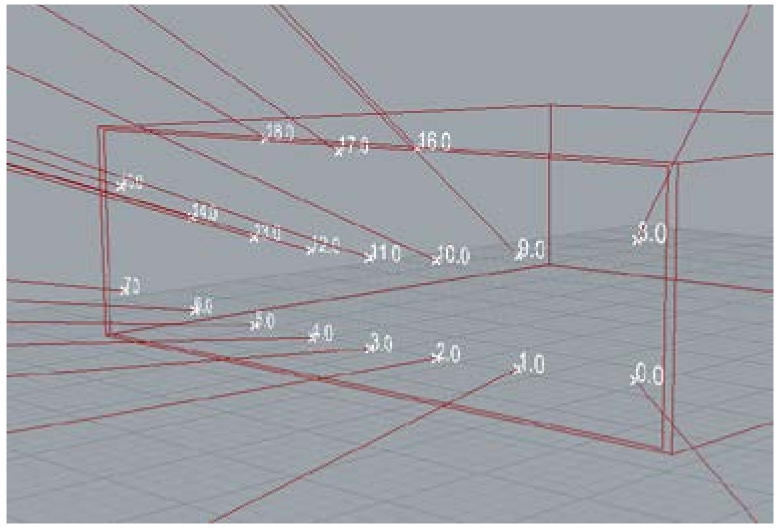


Figure 141. Resulting projected points.

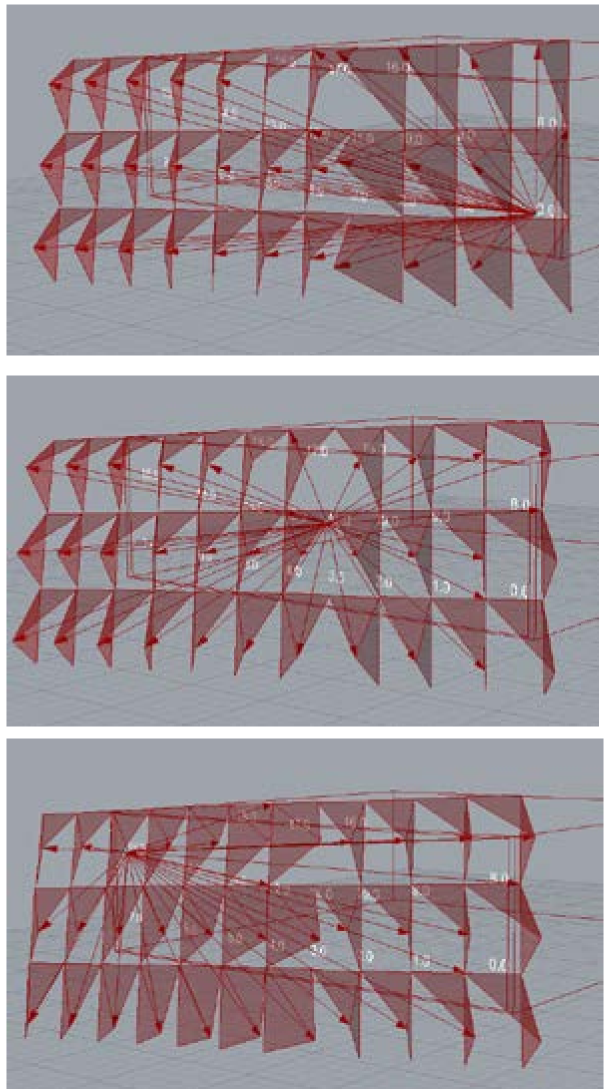


Figure 142. Shading design iteration samples.

A. DESIGN - PARAMETRIZED SHADING DESIGN

With the use of the Vectorial Pull Points a wide range of results are generated, therefore it is needed since the conceptual stage of shading designs to set dimensions that will control the growth or scaling of the shading device. In case of this project the maximum and minimum lengths for a shading device have been set into .3m and 1m as mentioned previously.

In order to have a bigger control of the growth of the shading devices the use of the parameter Amplitude, which will determine the control of the maximum height that the tip of the awning can grow (figure, 143), in the project the length of the amplitude has been set also from .3m to 1m in order to prevent the use generation of flat panels (flat = 0 height) . With the use of this parameter it is possible to reduce the modules into a fixed number of variations as seen in figure 144, where the the nuber of variations of the amplitude can be has been fixed to 4.

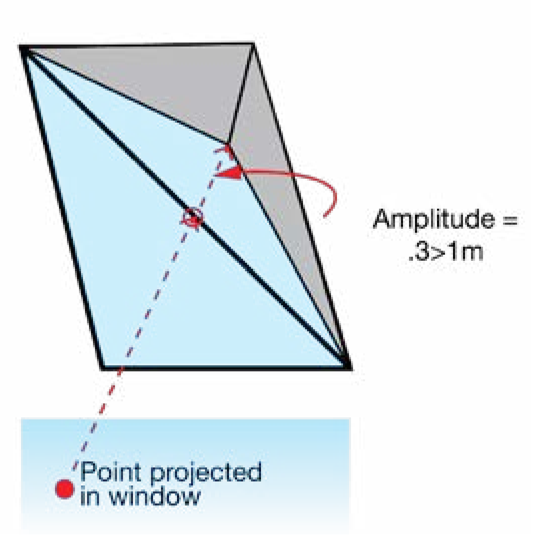


Figure 143. Amplitude limit variations.

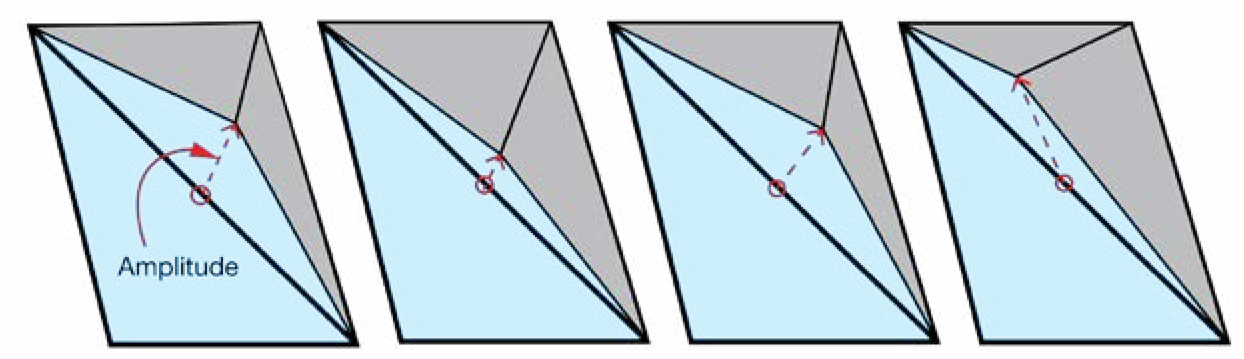


Figure 144. Amplitude variation samples.

B. SIMULATION - DAYLIGHT SIMULATION

The daylight simulation is the tool that will be used in order to retrieve the results for average Daylight Factor and Usable Area, to obtain accurate results a suitable Radiance Material profile for an office with the following configuration has been used:

Glass= Low-e Argon glass: TVis_.714
Shading= Aluminum: .900,.880,.880,.800
Walls= Gypsum: 255,255,255
Floor= Parquet: .309, .165, .083, .03, .1
Roof= Gypsum: 255,255,255

B. SIMULATION - ENERGY SIMULATION

Through the energy simulation the results for the G-Value decrease and the total prevented energy in the system will be retrieved, in order to have accurate results a suitable Energy Plus material profile for a construction of an office building, the following configuration according to the ASHARAE climate zone (1-A) has been set as the following:

Glass= Alum2 Frame, XLowEArg
Shading= Aluminum_.900,.880,.880,.800
Walls :ASHRAE 90.1-2004 EXTWALL MASS CLIMATEZONE 1-2
Floor :ASHRAE 90.1-2004 ATTICFLOOR CLIMATEZONE 1-5
Roof :ASHRAE 90.1-2004 EXTROOF IEAD CLIMATEZONE 1-4

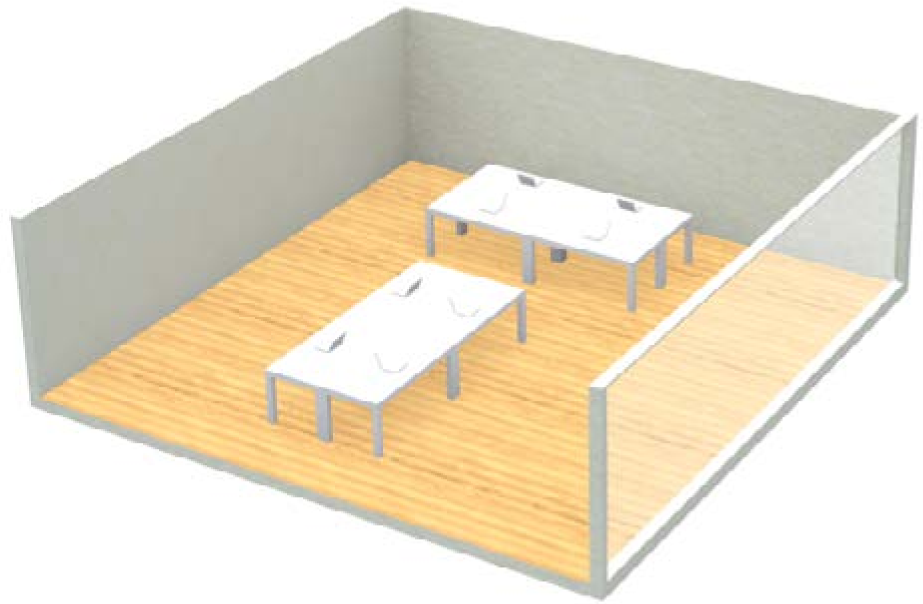


Figure 132 (1).

C. OPTIMIZATION

The optimization process from the parametric environment is executed with D-Exp and the ESTECO GH (in case of this project) Component, which bridges the parametric model to the optimization process.

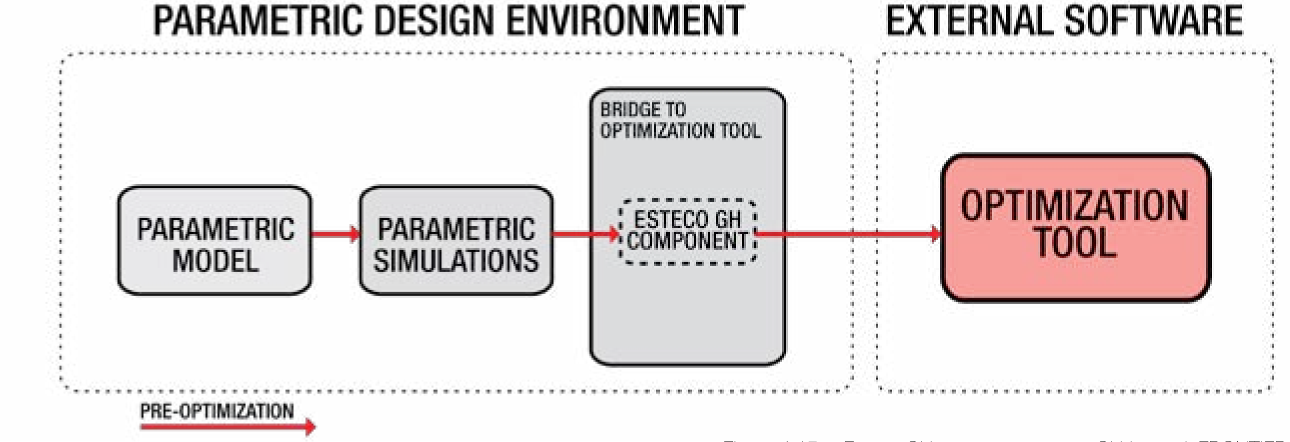


Figure 145. Esteco GH component to run GH in modeFRONTIER.

Through the optimization tool the design parameters and objectives will be set. The parametric definition model for the shading device is carefully structured to have the least amount of parameters controlling the modelling, which for this project is only one, Amplitude. Maximizing Daylight factor, Minimizing G-Value and Maxmizing the useful area are the design objectives taken in account in this project. (figure 146)

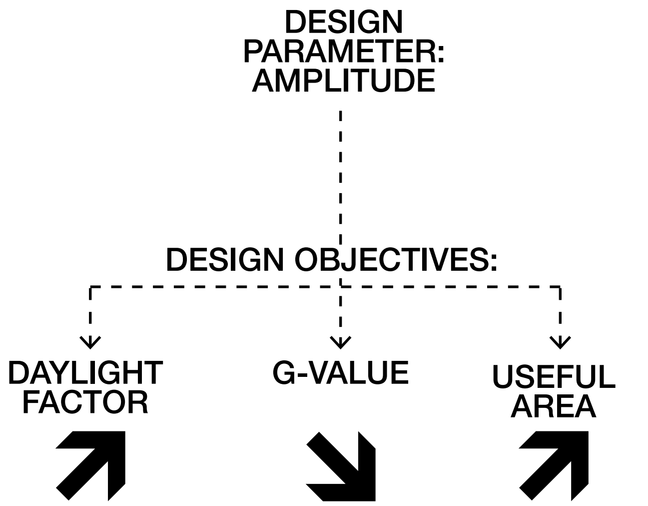
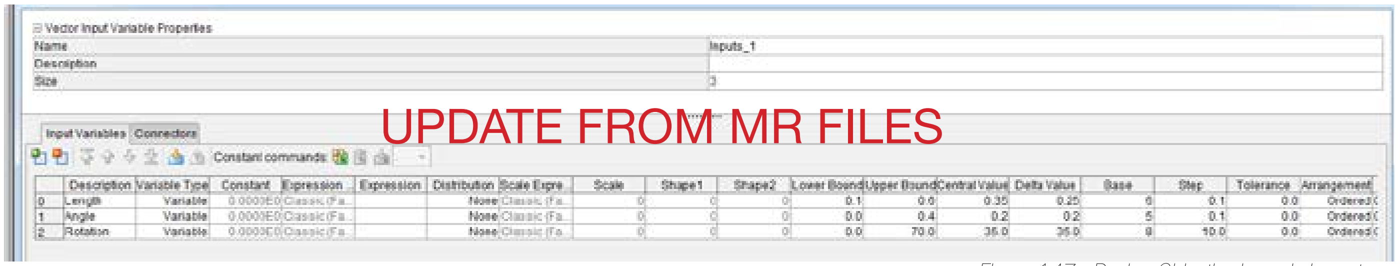


Figure 146. Optimization map for case study.

Before the optimization begins, the limits for the design parameters in this case: Amplitude .3<1m in order for the tool to calculate results within the desired values. Also a the desired amount of samples is determined, which has been set to 100, as it is shown in figure 147, and 148.



Vector Input Variable Properties

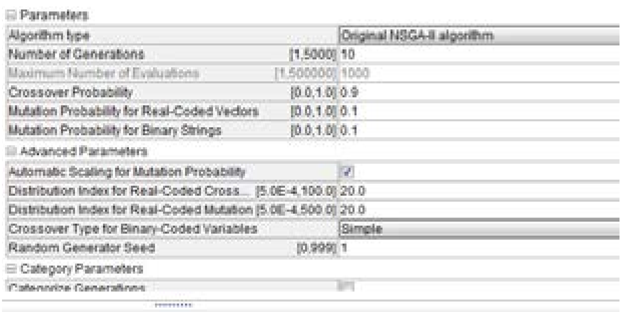
Name	Inputs_1
Description	
Size	3

Input Variables | Connectors

Constant commands:

	Description	Variable Type	Constant	Expression	Expression	Distribution	Scale Expre	Scale	Shape1	Shape2	Lower Bound	Upper Bound	Central Value	Delta Value	Base	Step	Tolerance	Arrangement
0	Length	Variable	0.0000E0	Classic (Fa...		None	Classic (Fa...	0	0	0	0.1	0.6	0.35	0.25	6	0.1	0.0	Ordered
1	Angle	Variable	0.0000E0	Classic (Fa...		None	Classic (Fa...	0	0	0	0.0	0.4	0.2	0.2	5	0.1	0.0	Ordered
2	Rotation	Variable	0.0000E0	Classic (Fa...		None	Classic (Fa...	0	0	0	0.0	70.0	35.0	35.0	8	10.0	0.0	Ordered

Figure 147. Design Objective boundaries set-up.



Parameters

Algorithm type		Original NSGA-II algorithm
Number of Generations	[1,5000]	10
Maximum Number of Evaluations	[1,500000]	1000
Crossover Probability	[0.0,1.0]	0.9
Mutation Probability for Real-Coded Vectors	[0.0,1.0]	0.1
Mutation Probability for Binary Strings	[0.0,1.0]	0.1

Advanced Parameters

Automatic Scaling for Mutation Probability		✓
Distribution Index for Real-Coded Cross...	[5.0E-4,100.0]	20.0
Distribution Index for Real-Coded Mutation	[5.0E-4,500.0]	20.0
Crossover Type for Binary-Coded Variables		Simple
Random Generator Seed	[0,999]	1

Category Parameters

Categorize Generations

Figure 148. Result sample configuration.

From the optimized results for the office, the only results that will be taken into account for the project are the ones that are Pareto and Real, meaning that they belong to the Pareto front and are feasible according to the established design results.

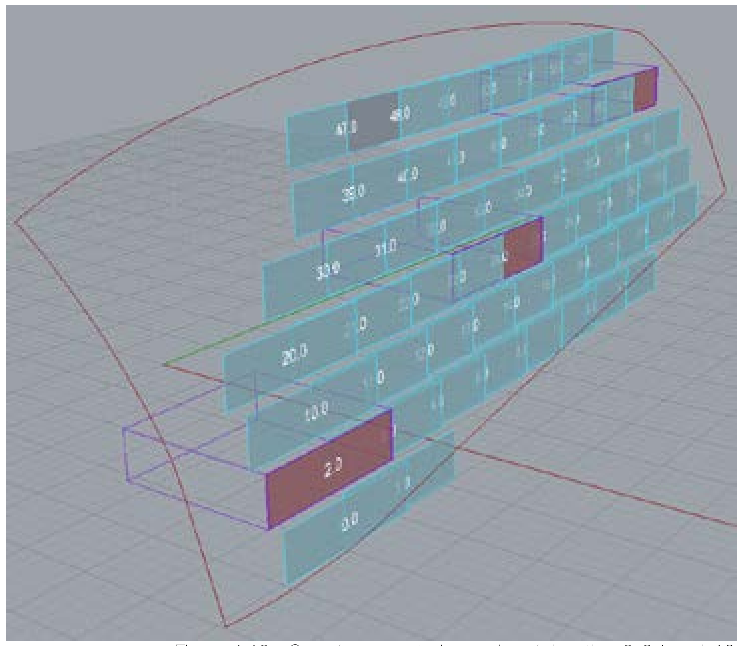
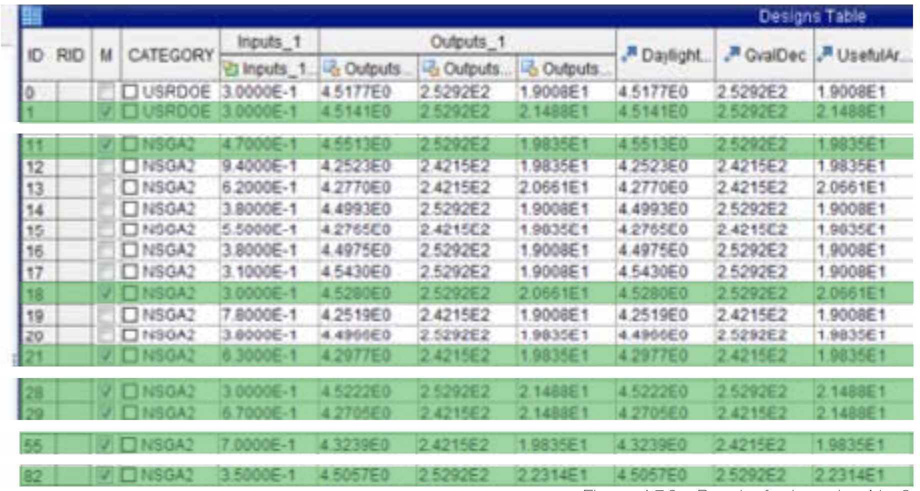


Figure 149. Sample rooms to be analysed, location 2,24 and 46.

At location No.2 (Down-left corner in facade), results are the following: 1, 18, 21,28, 29, 55 and 82.

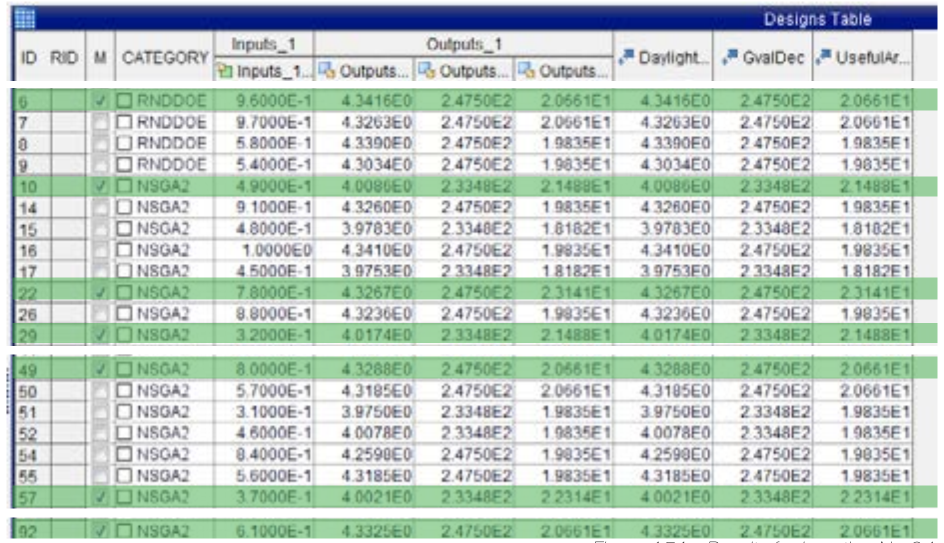


Designs Table

ID	RID	M	CATEGORY	Inputs_1	Outputs_1			Daylight...	GvalDec	UsefulAr...
				Inputs_1...	Outputs...	Outputs...	Outputs...			
0			USRDOE	3.0000E-1	4.5177E0	2.5292E2	1.9008E1	4.5177E0	2.5292E2	1.9008E1
1		✓	USRDOE	3.0000E-1	4.5141E0	2.5292E2	2.1488E1	4.5141E0	2.5292E2	2.1488E1
11		✓	NSGA2	4.7000E-1	4.5513E0	2.5292E2	1.9835E1	4.5513E0	2.5292E2	1.9835E1
12			NSGA2	9.4000E-1	4.2523E0	2.4215E2	1.9835E1	4.2523E0	2.4215E2	1.9835E1
13			NSGA2	6.2000E-1	4.2770E0	2.4215E2	2.0661E1	4.2770E0	2.4215E2	2.0661E1
14			NSGA2	3.8000E-1	4.4993E0	2.5292E2	1.9008E1	4.4993E0	2.5292E2	1.9008E1
15			NSGA2	5.5000E-1	4.2765E0	2.4215E2	1.9835E1	4.2765E0	2.4215E2	1.9835E1
16			NSGA2	3.8000E-1	4.4975E0	2.5292E2	1.9008E1	4.4975E0	2.5292E2	1.9008E1
17			NSGA2	3.1000E-1	4.5430E0	2.5292E2	1.9008E1	4.5430E0	2.5292E2	1.9008E1
18		✓	NSGA2	3.0000E-1	4.5280E0	2.5292E2	2.0661E1	4.5280E0	2.5292E2	2.0661E1
19			NSGA2	7.8000E-1	4.2519E0	2.4215E2	1.9008E1	4.2519E0	2.4215E2	1.9008E1
20			NSGA2	3.6000E-1	4.4966E0	2.5292E2	1.9835E1	4.4966E0	2.5292E2	1.9835E1
21		✓	NSGA2	6.3000E-1	4.2977E0	2.4215E2	1.9835E1	4.2977E0	2.4215E2	1.9835E1
28		✓	NSGA2	3.0000E-1	4.5222E0	2.5292E2	2.1488E1	4.5222E0	2.5292E2	2.1488E1
29		✓	NSGA2	6.7000E-1	4.2705E0	2.4215E2	2.1488E1	4.2705E0	2.4215E2	2.1488E1
55		✓	NSGA2	7.0000E-1	4.3239E0	2.4215E2	1.9835E1	4.3239E0	2.4215E2	1.9835E1
82		✓	NSGA2	3.5000E-1	4.5057E0	2.5292E2	2.2314E1	4.5057E0	2.5292E2	2.2314E1

Figure 150. Results for Location No.2.

At location No.24 (Center), results are the following: 6,10, 22, 29, 49, 57 and 92.



Designs Table

ID	RID	M	CATEGORY	Inputs_1	Outputs_1			Daylight...	GvalDec	UsefulAr...
				Inputs_1...	Outputs...	Outputs...	Outputs...			
6		✓	RNDDOE	9.6000E-1	4.3416E0	2.4750E2	2.0661E1	4.3416E0	2.4750E2	2.0661E1
7			RNDDOE	9.7000E-1	4.3263E0	2.4750E2	2.0661E1	4.3263E0	2.4750E2	2.0661E1
8			RNDDOE	5.8000E-1	4.3390E0	2.4750E2	1.9835E1	4.3390E0	2.4750E2	1.9835E1
9			RNDDOE	5.4000E-1	4.3034E0	2.4750E2	1.9835E1	4.3034E0	2.4750E2	1.9835E1
10		✓	NSGA2	4.9000E-1	4.0086E0	2.3348E2	2.1488E1	4.0086E0	2.3348E2	2.1488E1
14			NSGA2	9.1000E-1	4.3260E0	2.4750E2	1.9835E1	4.3260E0	2.4750E2	1.9835E1
15			NSGA2	4.8000E-1	3.9783E0	2.3348E2	1.8182E1	3.9783E0	2.3348E2	1.8182E1
16			NSGA2	1.0000E0	4.3410E0	2.4750E2	1.9835E1	4.3410E0	2.4750E2	1.9835E1
17			NSGA2	4.5000E-1	3.9753E0	2.3348E2	1.8182E1	3.9753E0	2.3348E2	1.8182E1
22		✓	NSGA2	7.8000E-1	4.3267E0	2.4750E2	2.3141E1	4.3267E0	2.4750E2	2.3141E1
26			NSGA2	8.8000E-1	4.3236E0	2.4750E2	1.9835E1	4.3236E0	2.4750E2	1.9835E1
29		✓	NSGA2	3.2000E-1	4.0174E0	2.3348E2	2.1488E1	4.0174E0	2.3348E2	2.1488E1
49		✓	NSGA2	8.0000E-1	4.3288E0	2.4750E2	2.0661E1	4.3288E0	2.4750E2	2.0661E1
50			NSGA2	5.7000E-1	4.3185E0	2.4750E2	2.0661E1	4.3185E0	2.4750E2	2.0661E1
51			NSGA2	3.1000E-1	3.9750E0	2.3348E2	1.9835E1	3.9750E0	2.3348E2	1.9835E1
52			NSGA2	4.6000E-1	4.0078E0	2.3348E2	1.9835E1	4.0078E0	2.3348E2	1.9835E1
54			NSGA2	8.4000E-1	4.2598E0	2.4750E2	1.9835E1	4.2598E0	2.4750E2	1.9835E1
55			NSGA2	5.6000E-1	4.3185E0	2.4750E2	1.9835E1	4.3185E0	2.4750E2	1.9835E1
57		✓	NSGA2	3.7000E-1	4.0021E0	2.3348E2	2.2314E1	4.0021E0	2.3348E2	2.2314E1
92		✓	NSGA2	6.1000E-1	4.3325E0	2.4750E2	2.0661E1	4.3325E0	2.4750E2	2.0661E1

Figure 151. Results for Location No.24.

At location No.46 (Center), results are the following: 19, 29, 31, 44 and 74.

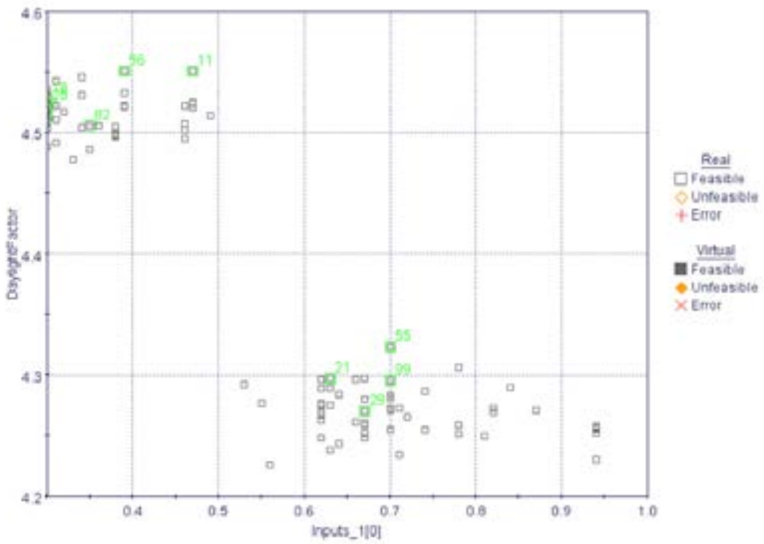
Designs Table

ID	RID	M	CATEGORY	Inputs_1	Outputs_1			Daylight...	GvalDec	UsefulAr...
				Inputs_1...	Outputs...	Outputs...	Outputs...			
19		✓	NSGA2	7.8000E-1	3.3918E0	2.1016E2	2.3140E1	3.3918E0	2.1016E2	2.3140E1
21			NSGA2	9.5000E-1	3.3612E0	2.1016E2	1.9008E1	3.3612E0	2.1016E2	1.9008E1
22			NSGA2	4.2000E-1	2.9380E0	1.9132E2	1.5702E1	2.9380E0	1.9132E2	1.5702E1
29		✓	NSGA2	3.4000E-1	2.9645E0	1.9132E2	1.7355E1	2.9645E0	1.9132E2	1.7355E1
31		✓	NSGA2	5.0000E-1	2.9626E0	1.9132E2	1.9008E1	2.9626E0	1.9132E2	1.9008E1
44		✓	NSGA2	7.0000E-1	3.4046E0	2.1016E2	1.9835E1	3.4046E0	2.1016E2	1.9835E1
74		✓	NSGA2	3.5000E-1	2.9585E0	1.9132E2	1.9835E1	2.9585E0	1.9132E2	1.9835E1

Figure 152. Results for Location No.46.

With the use of informative tools such as Scatter Charts (Pareto Front), Scattered Matrix, Relative Strength graphs along with the result tables it becomes easier to determine which optimized results will be taken into consideration for assessment through the use of visual tools. This first selection could be considered as part of the Level 1 of assessment.

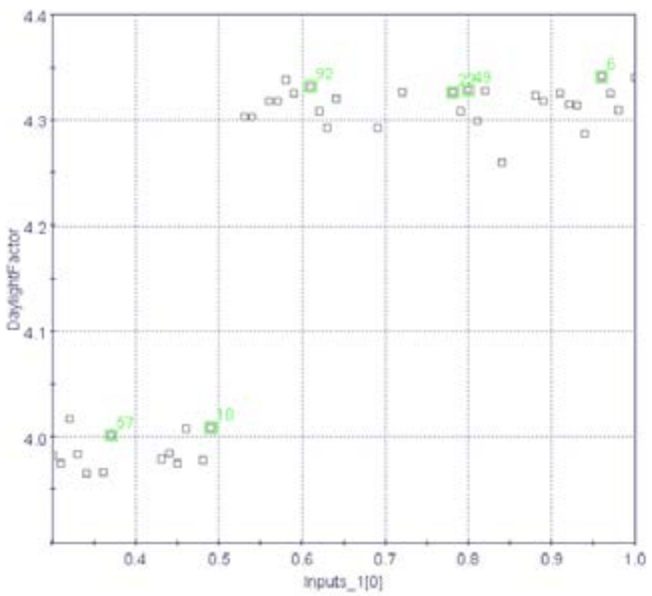
In the following catter charts it is visible that in location 2 and 24, is where the daylight factor achieved in the highest levels, since the most highly rated of the optimized results above 4%, whereas in location 46, the results do not surpass the 3.4%.



Scatter chart position No. 2

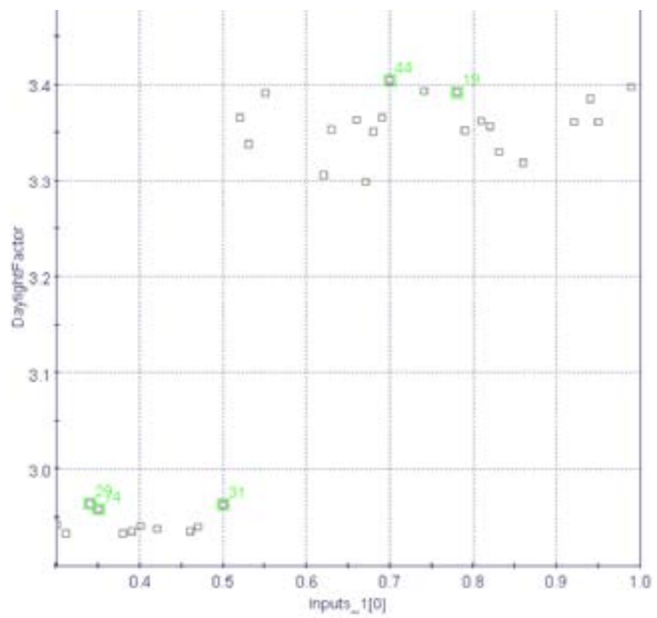
Figure 153.

Figure 153. Pareto front Design Objective vs Daylight Factor. Location 2.
Figure 154. Pareto front Design Objective vs Daylight Factor. Location 24.
Figure 155. Pareto front Design Objective vs Daylight Factor. Location 46.



Scatter chart position No. 24

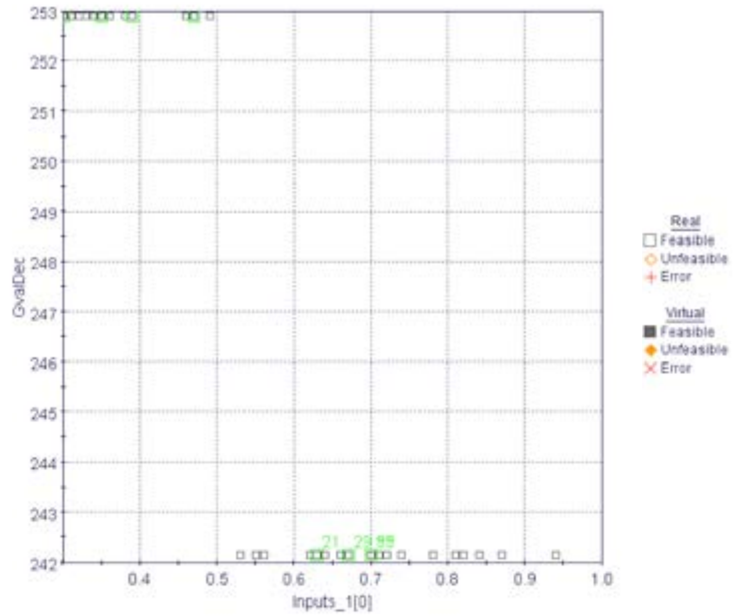
Figure 154.



Scatter chart position No. 46

Figure 155.

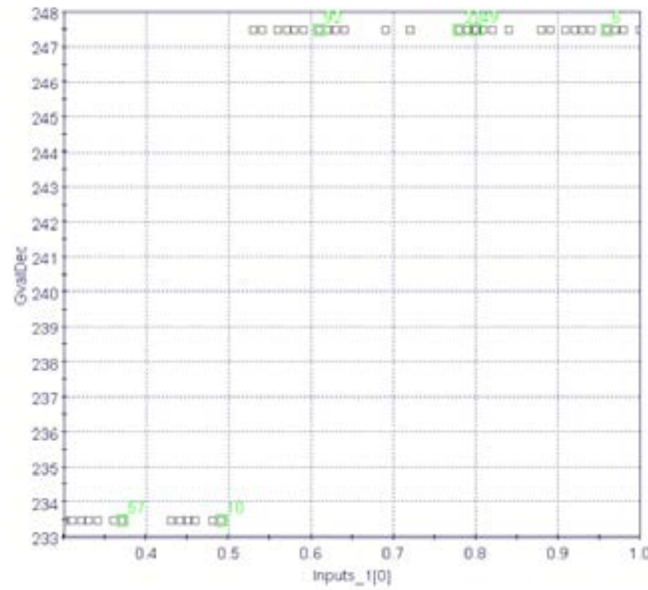
In the Scatter charts for G-Value decreasing, it can be noticed that the results for position 46, has the least contribution for this design objective since the top values are close to the 211KW/m2hr., whilst the results for position No.2 and No.24 gave the highest rates of G-Value contribution, the optimized results for position No. 2 has the highest values with results above the 250 KW/m2hr and above 246 KW/m2hr for position No. 24.



Scatter chart position No. 2

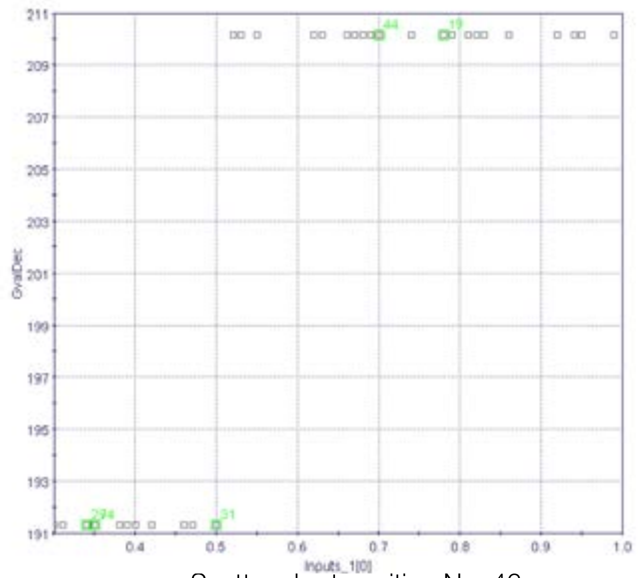
Figure 156.

Figure 156. Pareto front Design Objective vs G-Value reduction. Location 2.
Figure 157. Pareto front Design Objective vs G-Value reduction. Location 24.
Figure 158. Pareto front Design Objective vs G-Value reduction Location 46.



Scatter chart position No. 24

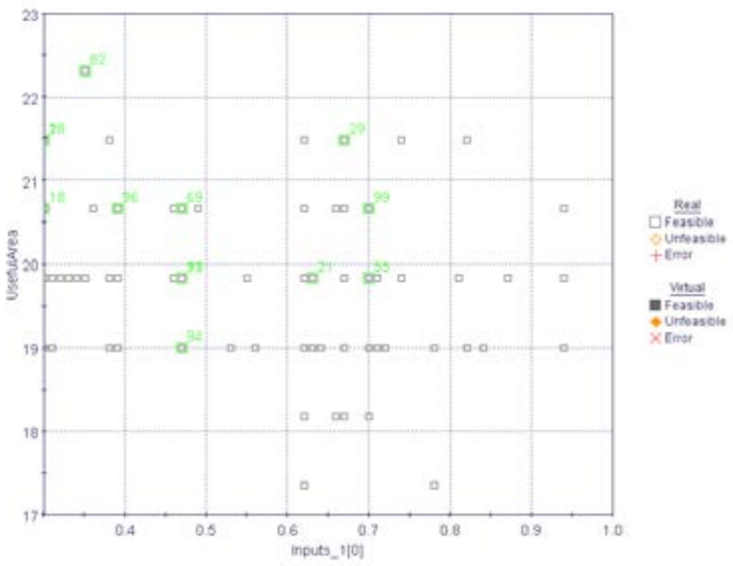
Figure 157.



Scatter chart position No. 46

Figure 158.

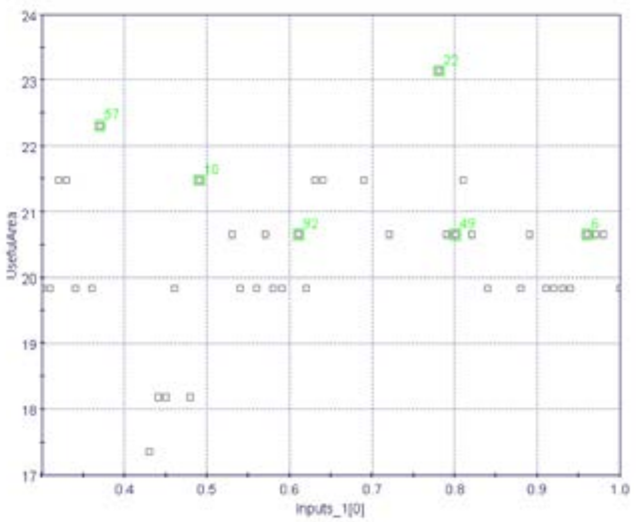
In the Scatter charts for Useful, the results for all positions are ranged between 19m2 to 23m2. Making the results very similar in all cases given that the office space of the analysed room is of 100m2, none of the results seem to be above a moderate range never larger than the 25%.



Scatter chart position No. 2

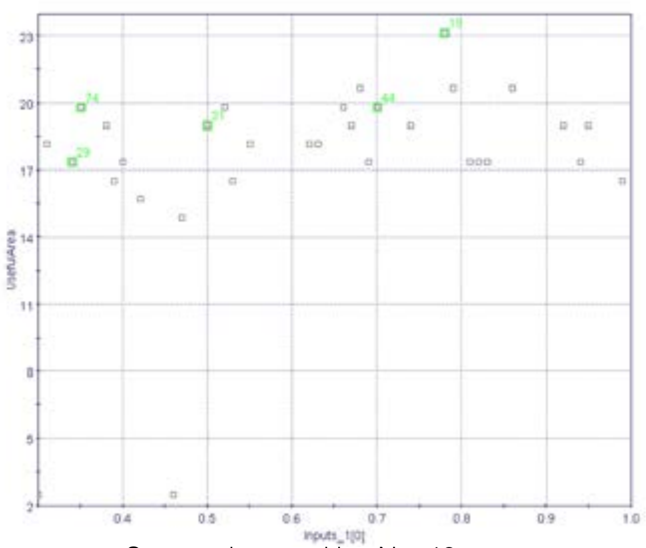
Figure 159.

Figure 159. Pareto front Design Objective vs Useful Area. Location 2.
Figure 160. Pareto front Design Objective vs Useful Area. Location 24.
Figure 161. Pareto front Design Objective vs Useful Area. Location 46.



Scatter chart position No. 24

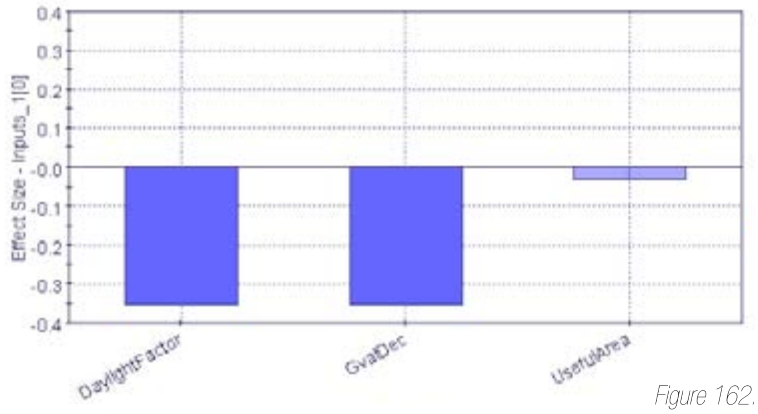
Figure 160.



Scatter chart position No. 46

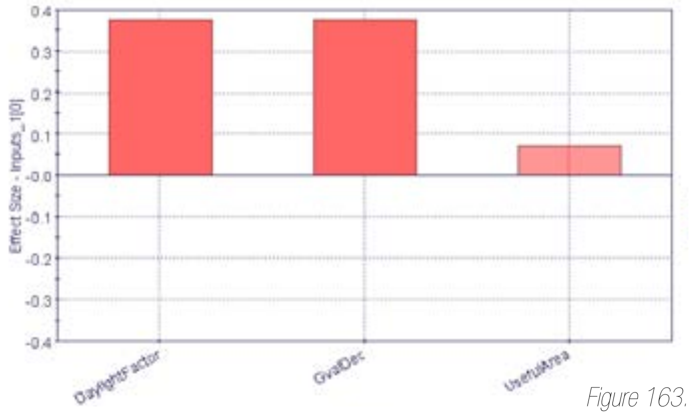
Figure 161.

While observing the Relative Strength charts it is visible that in location 24 and 46, is where there is major influence of the design parameter on the three design objectives occurs. From the charts it is deducted that the results of position 2 have the least amount of useful area in comparison with position 24 and 46.



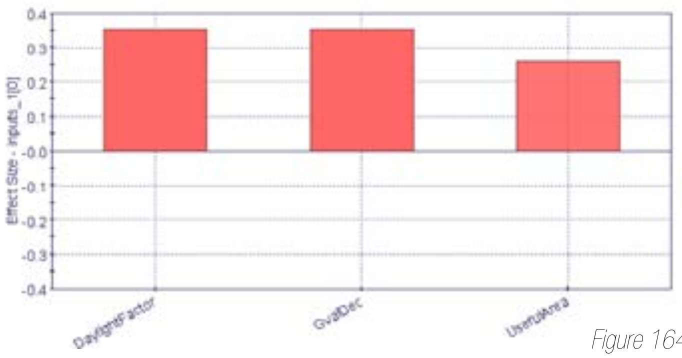
Relative strength chart for position No. 2

Figure 162.



Relative strength chart for position No. 24

Figure 163.



Relative strength chart for position No.46

Figure 164.

Figure 162. Relative strength graph for position No. 2.
Figure 163 Relative strength graph for position No. 24.
Figure 164. Relative strength graph for position No. 46.

At this point of the analysis it can be concluded that, the results for position No. 2 will be discarded due to the low performance on the objective for Useful Area. Although the performance position No. 2 for Daylight factor and G-Value performance is comparable with position No. 24, where position No.46 performs with the lowest rates, but within the admitted values for Daylight Factor.

Therefore the results that will be taken into account for a visual assessment purposes will be the ones with highest Useful Area values for position No. 24 and No. 46. Visual assessment methods such will help determine through the 3-D model which is the most convenient room to locate the office and the best option for optimized set of shading devices. In conclusion the results that best cope with the design objectives are: Result 22 of position No. 24 and result 19 of position No.46.

Result 22 at No.24:	Result 19 at No.46:
Daylight factor: 4.32 avg. %	Daylight factor: 3.39 avg. %
G-val reduction: 0.71	G-val reduction: 0.60
Useful Area: 23.14 m2	Useful Area: 23.14 m2

D. VISUALIZATION - Optimized Design Exploration

At this point of the analysis it can be concluded that, the results for position No. 2 will be discarded due to the low performance on the objective for Useful Area. Although the performance position No. 2 for Daylight factor and G-Value performance is comparable with position No. 24, where position No.46 performs with the lowest rates, but within the admitted values for Daylight Factor.

Therefore the results that will be taken into account for the assessment in Virtual Reality will be the ones with highest Useful Area values for Result 22 of position No. 24 and result 19 of position No.46.

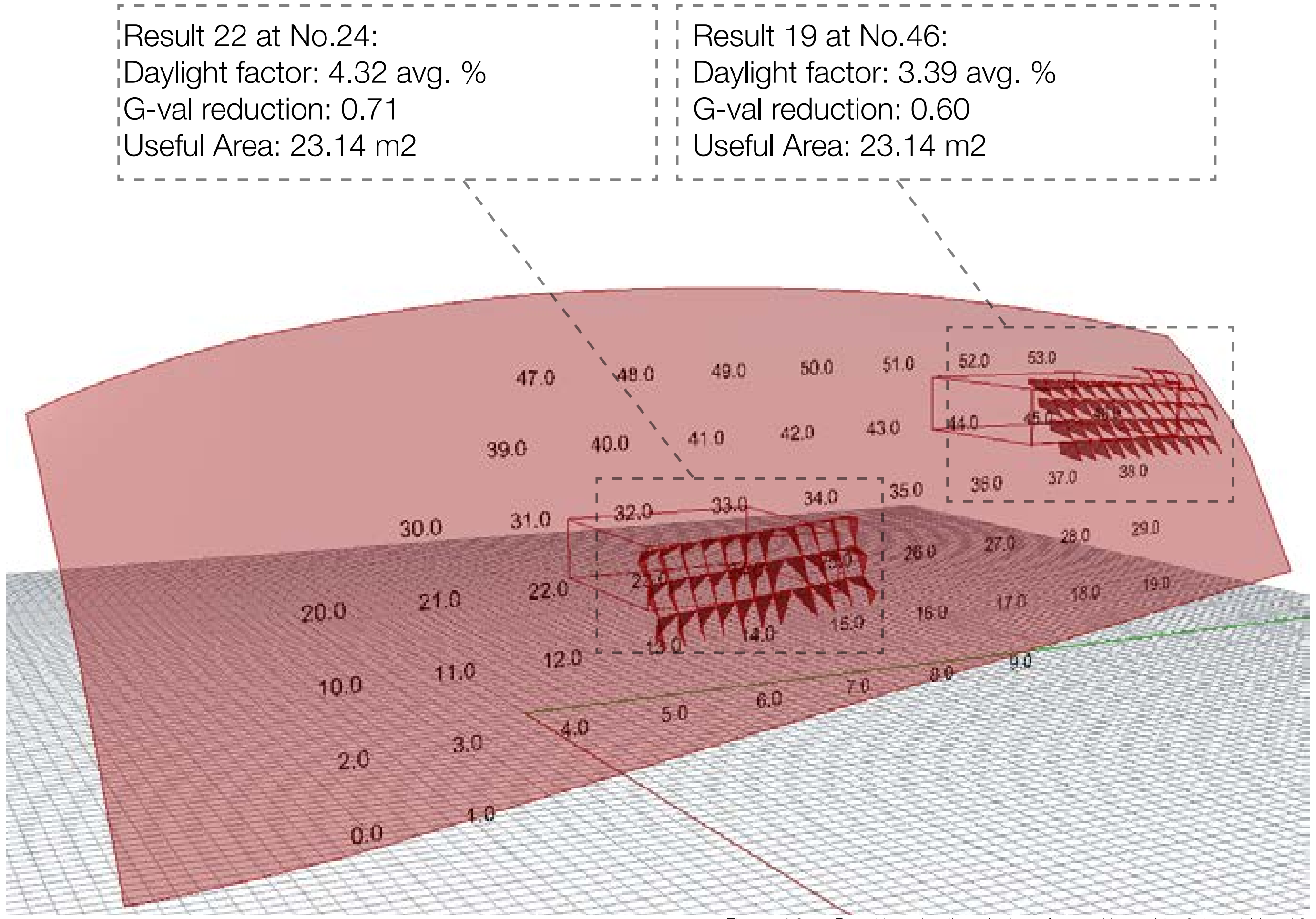
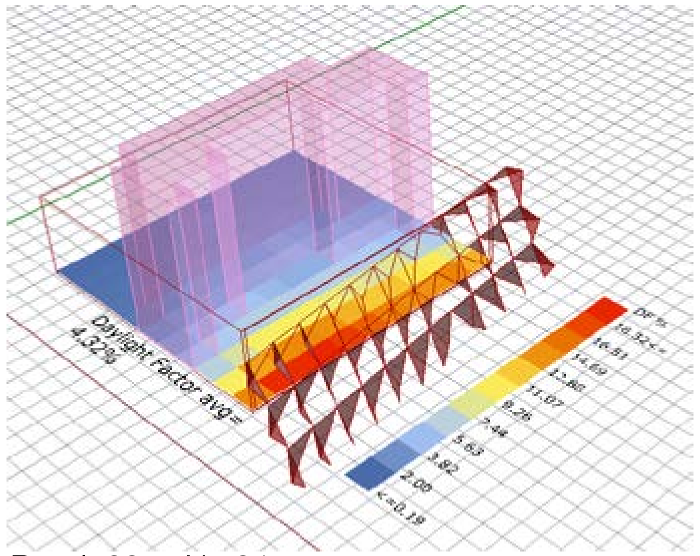


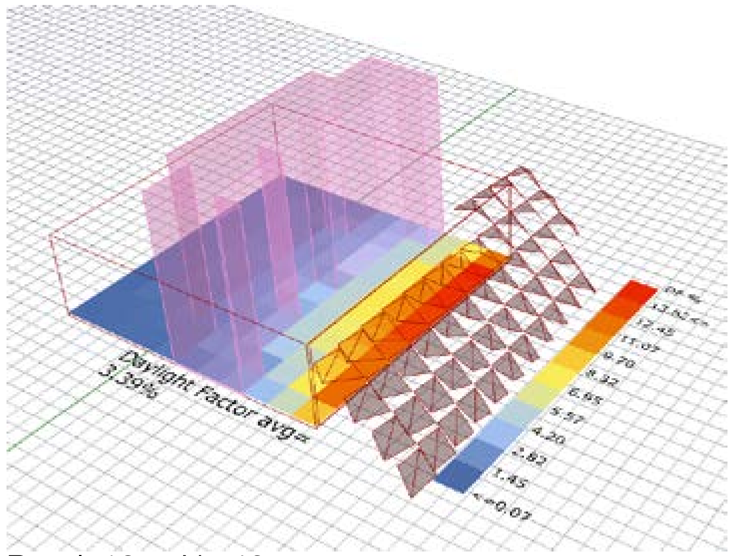
Figure 165. Resulting shading devices for positions No,24 and No. 46.

As it is noticed both useful areas remain, similar both at 23m2 although the area for Result 19 shows a better even distribution of light, although the daylight factor average value is lower than Result 22



Result 22 at No.24.

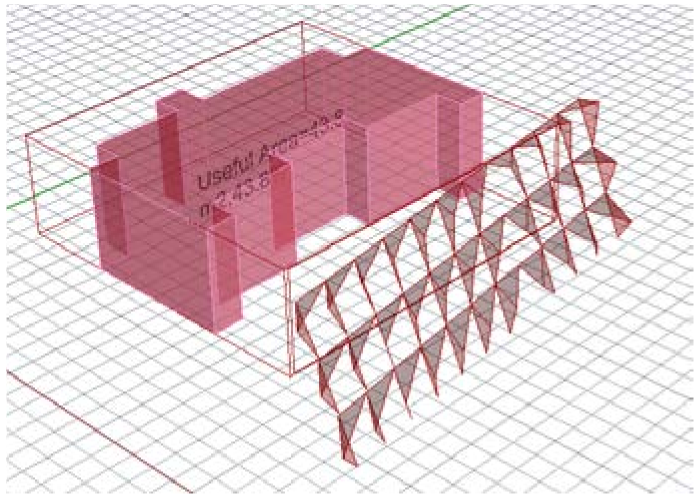
Figure 166. 3-D representation result for Daylight Factor Position 24.



Result 19 at No.46:

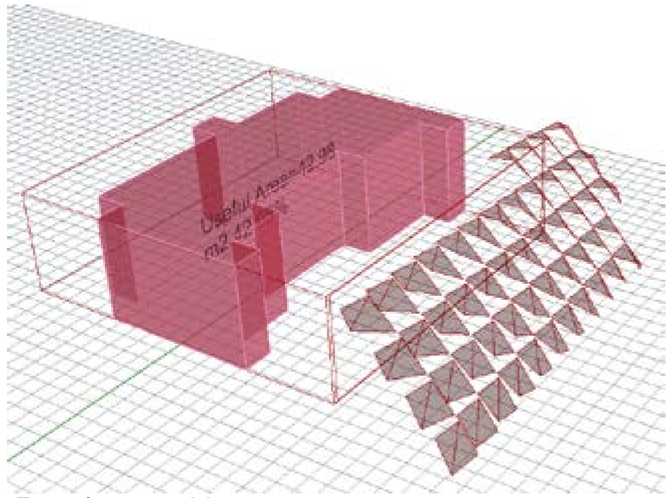
Figure 167. 3-D representation result for Daylight Factor Position 46.

Also if the Daylight Factor admitted admits a lower limit to 1 instead of 2, taking into consideration the desired need for shading over light in a tropical climate as happens in Singapore, regardless the fact of possible use of artificial daylight, the usable area will grow to 43.8% for result 22, and 42.98%% for result 19.



Result 22 at No.24.

Figure 168. 3-D representation result for Useful Area Position 24.

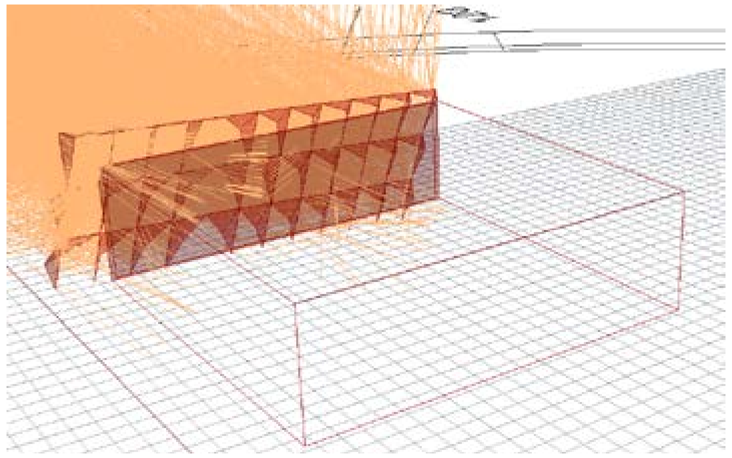


Result 19 at No.46:

Figure 169. 3-D representation result for Useful Area Position 46.

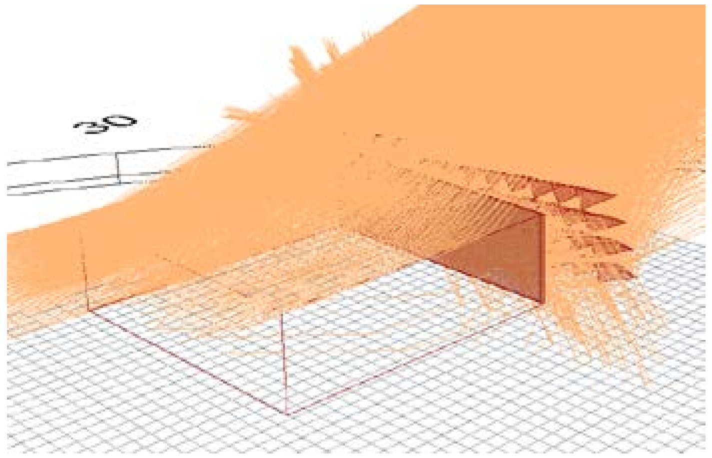
The G-Value reduction, also the design for result 22 with 0.71, is more appealing since with a difference of .1 (10%) more effective that the 0.60 of result 46.

When tested for ray-tracing result 22 has results better while blocking the incoming solar gain as it is visible from the images below.



Result 22 at No.24.

Figure 170. 3-D representation result for G-Value Reduction Position 24.



Result 19 at No.46:

Figure 171. 3-D representation result for G-Value Reduction Position 46.

The parameters taken into account for the Single Node panoramas where the following:

1. Position of the camera at center of the room
2. Height for point of view at 1.78mts

It is possible to make a quick assessment to the relation of the relation of the view towards the external environment through a use of an static in image and from a single point of view that result 22 and 19, design 22 shows a bigger amount of view to the exterior, while known results from the parametric model are displayed and confirmed.

Figure 172. Panoramic view interior result 22 at No.24.

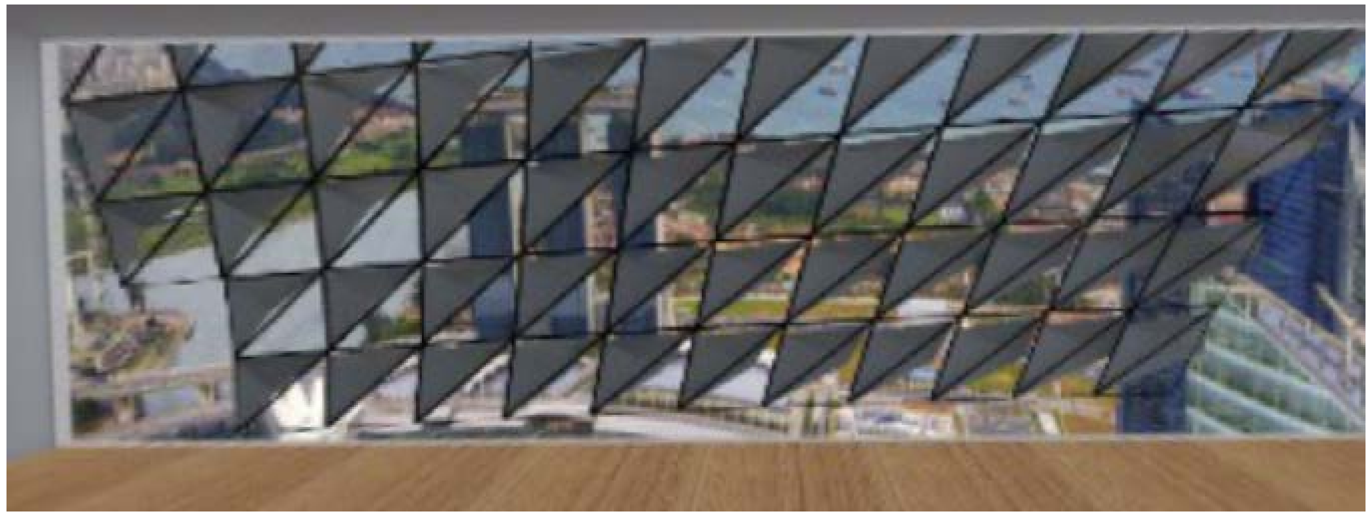


Figure 173. 3-D representation result for G-Value Reduction Position 46.

D. VISUALIZATION - Optimized Design Exploration

With the use Virtual Reality it was possible determine through exploration the 3-D model which is the most convenient room to locate the office and the best option for optimized set of shading devices. The design decision is now also driven by the following factors:

1. The relation of the view towards the external environment, in 1:1 scale.
2. Exploration of the shading devices and their visual effects to the interior in 1:1 scale.
3. Outcome of the modification of the shading design.

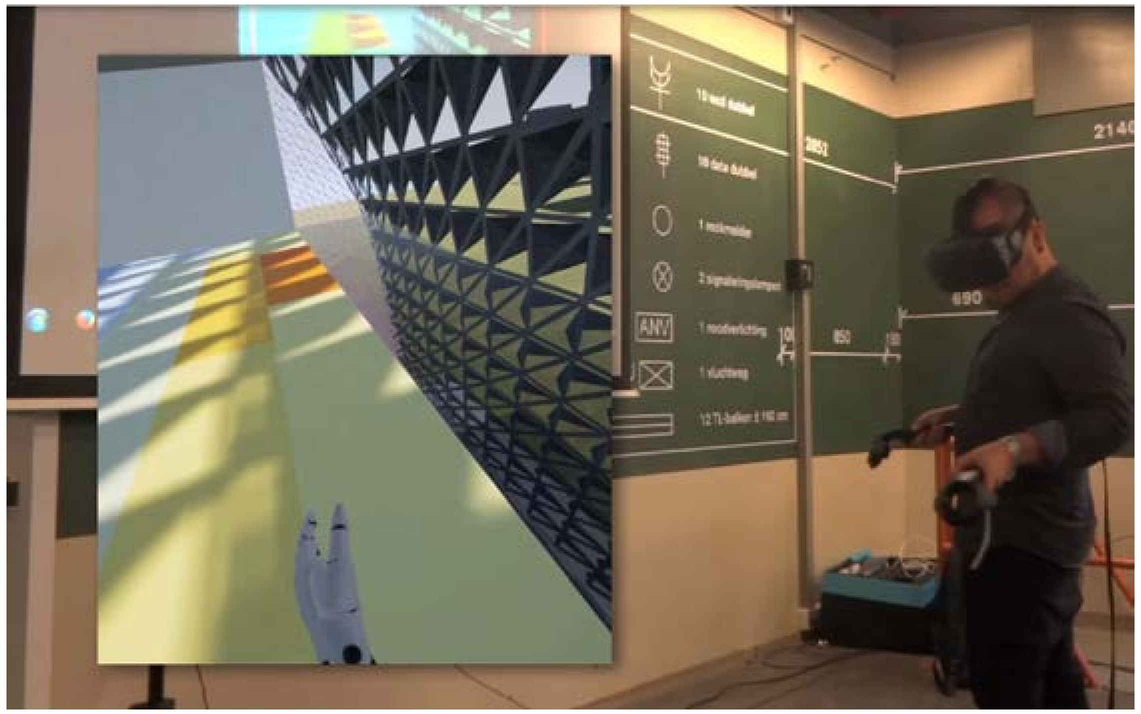


Figure 174. VR simulation environment in use.

E. ASSESSMENT - Satisfying Design

At this moment both results have presented differences but still have been able to perform according to the design expectations of the indicators:

1. Average Daylight Factor between 2% and 5%
2. Existence of a usable area within the desired Daylight Factor values
3. Decrease of the G-Value
4. Better views to the exterior.

It must be mentioned that the usable area was expected to perform better without taking into account the specified environmental needs of the site and make a possible consideration to lower the admitted Daylight factor levels by 1%.

Through the Static panorama VR it can also be notices that both shading designs do not conflict to the view to the exterior making both designs admissible.

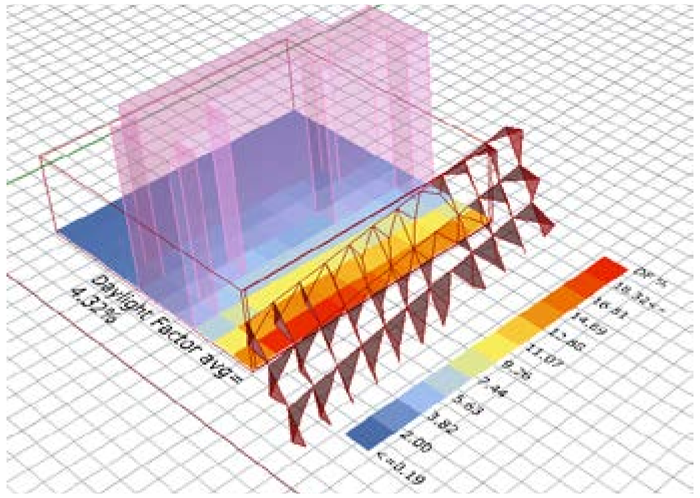
E. ASSESSMENT - Decission Making

Taking into account only the numerical values for the indicators main, the result can be determined as satisfying, since for daylight factor the average stand within the desired and recommended values. Although a certain degree of dissatisfaction must be mentioned due to that fact that in order to an acceptable useful area, higher that 25%, the admitted values de decreased, but as it was mentioned previously in some cases due to environmental conditions adapting the indicators to the context will be necessary.

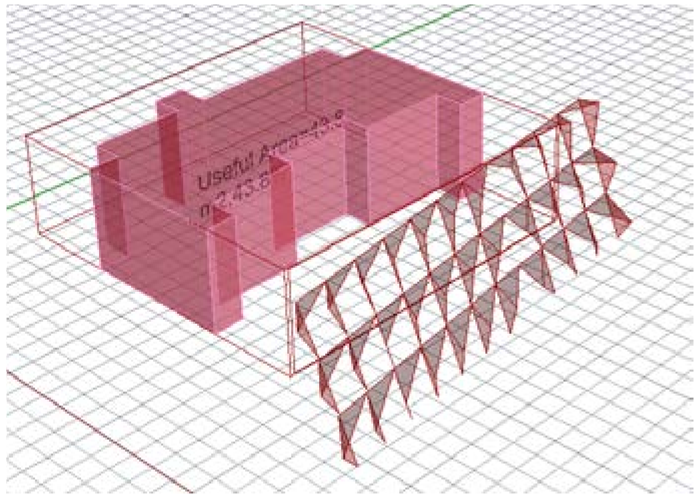
In conclusion the chosen design will be Result 22 at No.24 after the post optimization process, due to that fact that copes better with the indicators giving values of:

Daylight factor: 4.32 avg. %
G-val reduction: 2.47 Kw/m2 hr
Useful Area: 23.14 m2 when DF= 2% to 5%

When visualising the results into the parametric visual environment the useful area results in a more unified distribution of daylight, which makes it easier for modulation and comparison with possible layouts.



Result 22 at No.24, Daylight Factor and Usable Area.
Figure 166 (1).



Result 22 at No.24, Maximized Useful Area.
Figure 168(1).

Due to the position of the room the shading devices from result 22 offer a clearer view to the exterior, allow more natural daylight and cast less shadows making a clearer room which is more appealing for a working space

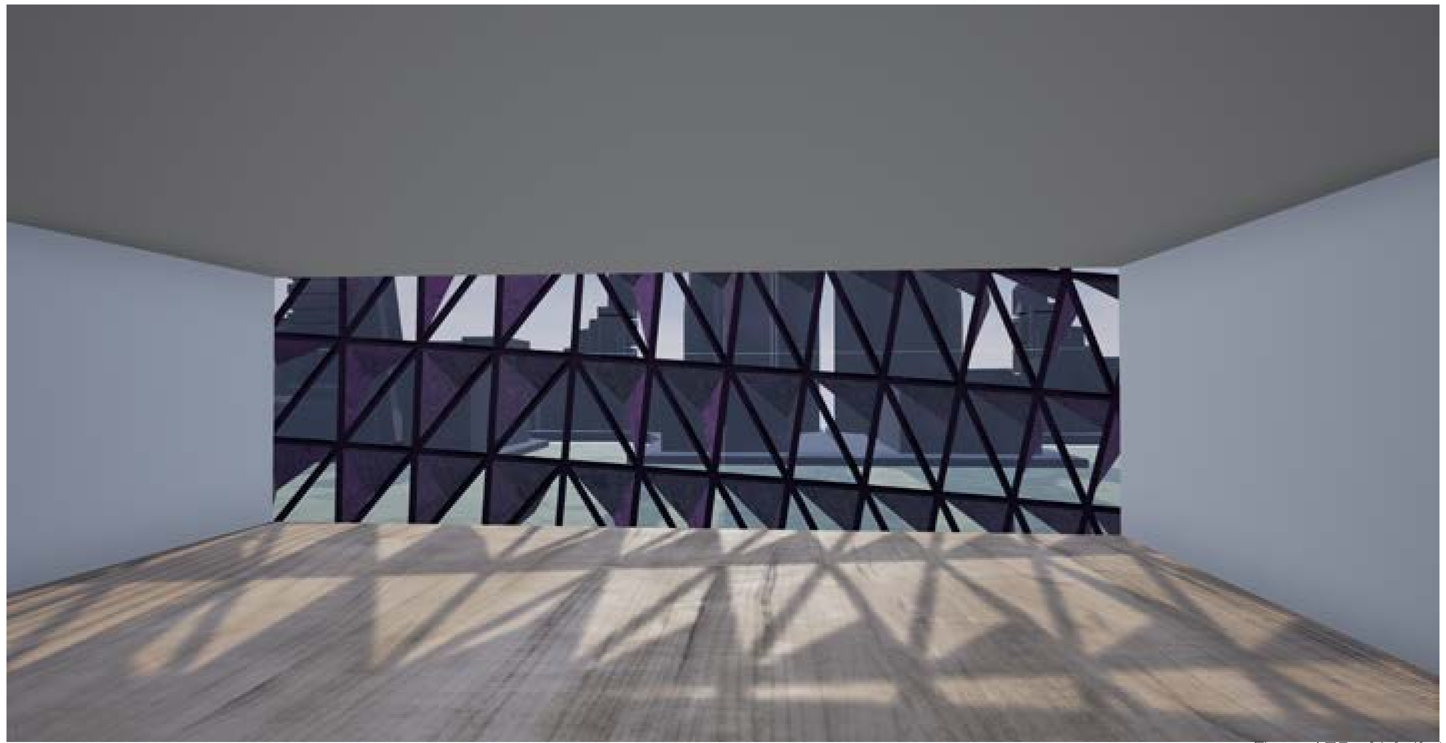


Figure 175 . fdsfsdfsd

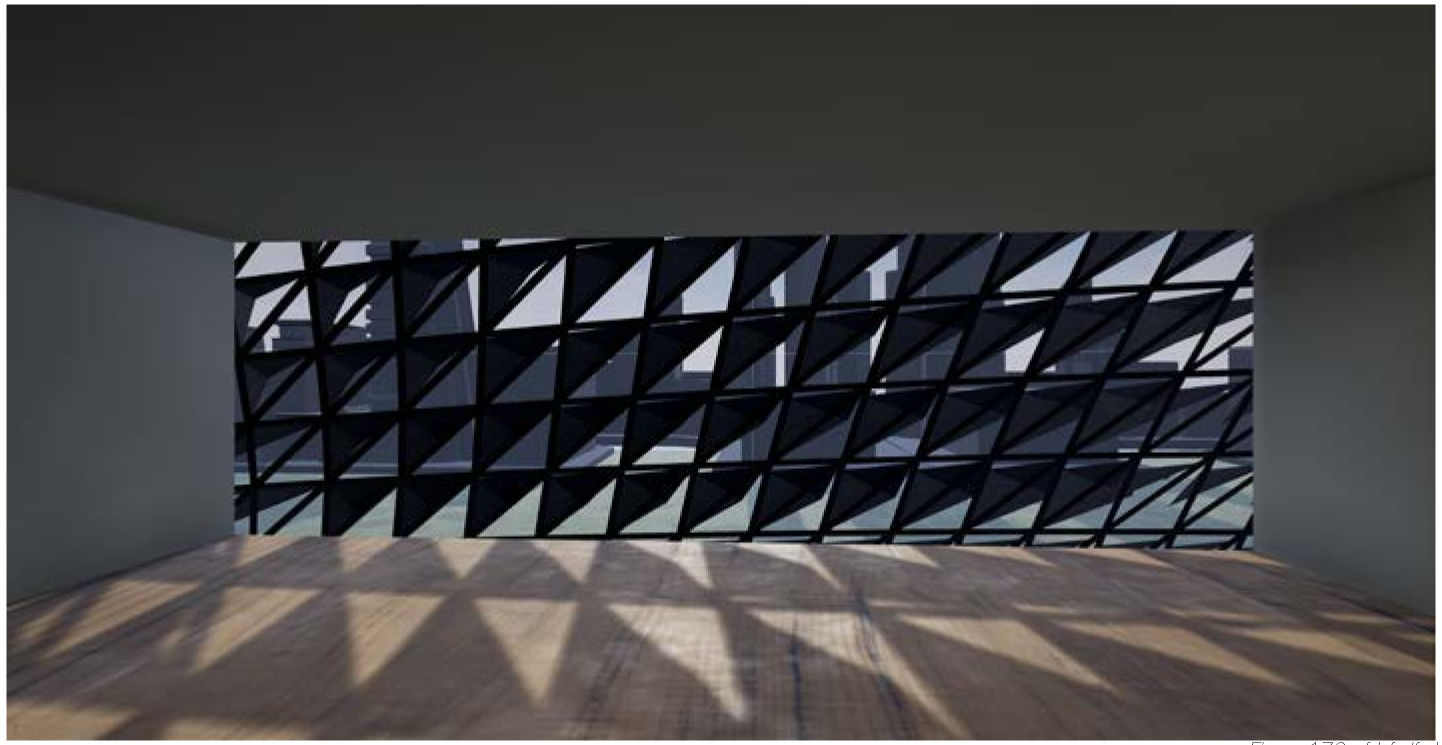


Figure 176 . fdsfsdfsd

When driven through Virtual Reality it is determined that position 22 in the best design due to best performance for the design objectives, after both exploring the design results in terms of:

1. The relation of the view towards the external environment, in 1:1 scale.
2. Exploration of the shading devices and their visual effects to the interior in 1:1 scale.
3. Outcome of the different shading results from multiple indicators.

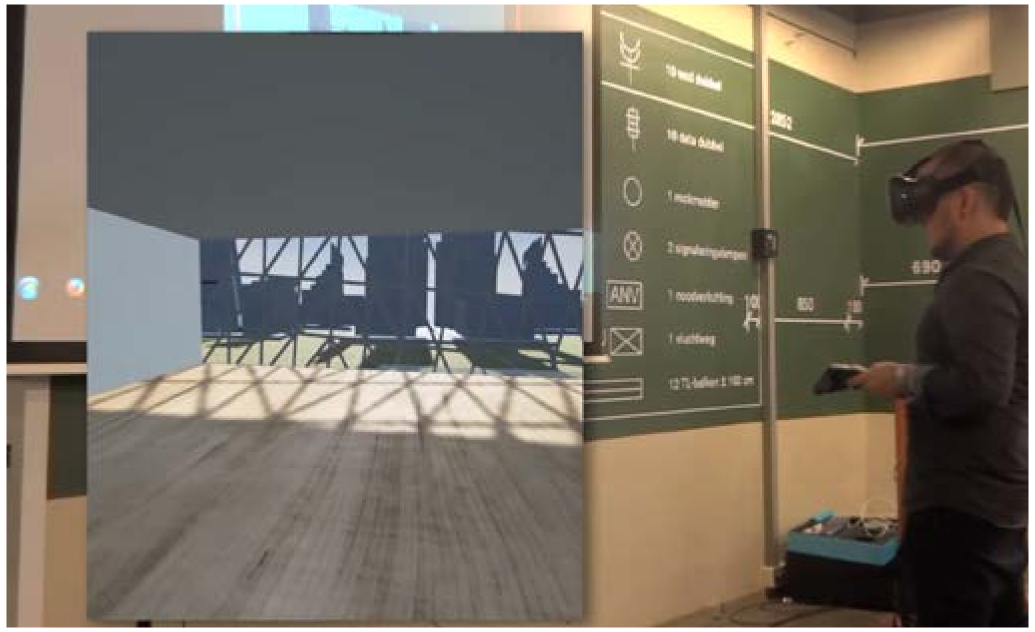


Figure 177. Relation of the view towards the external environment, in 1:1 scale.

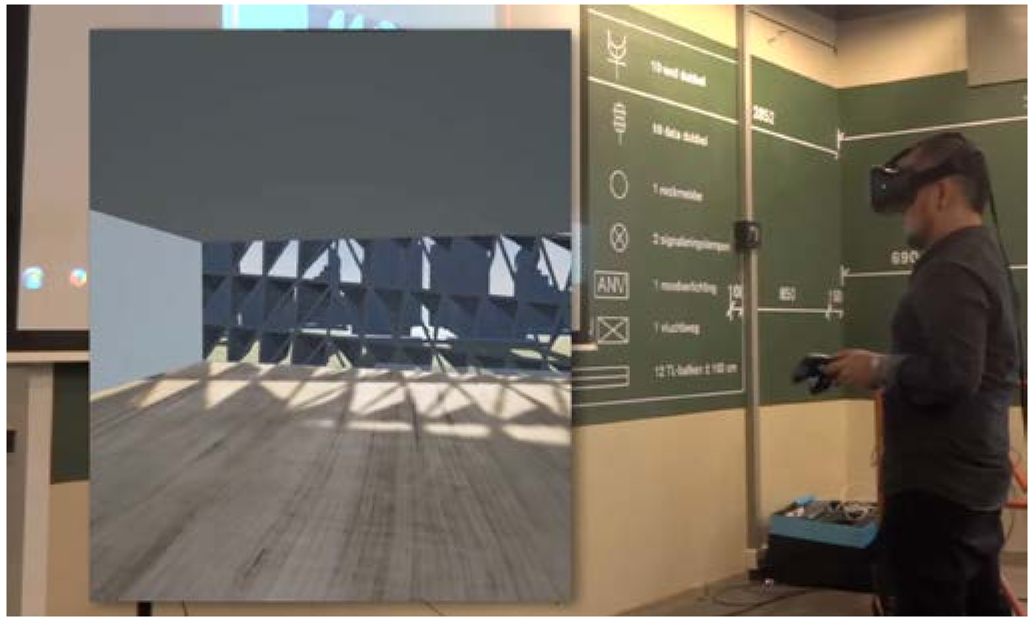


Figure 178. Exploration of the shading devices and their visual effects to the interior in 1:1 scale.

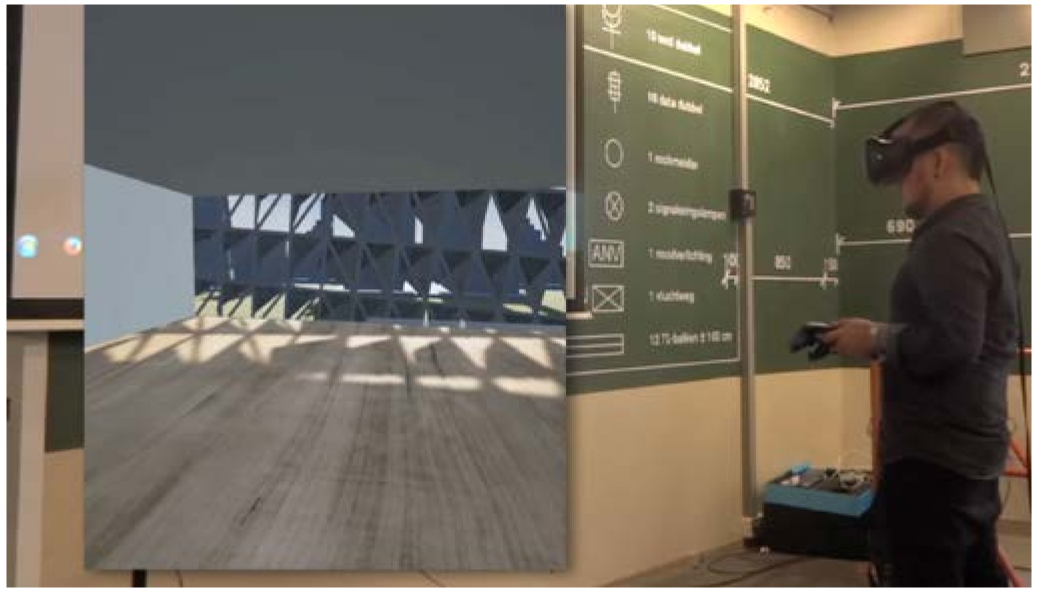


Figure 179. Exploration of the shading devices and their visual effects to the interior in 1:1 scale (1).

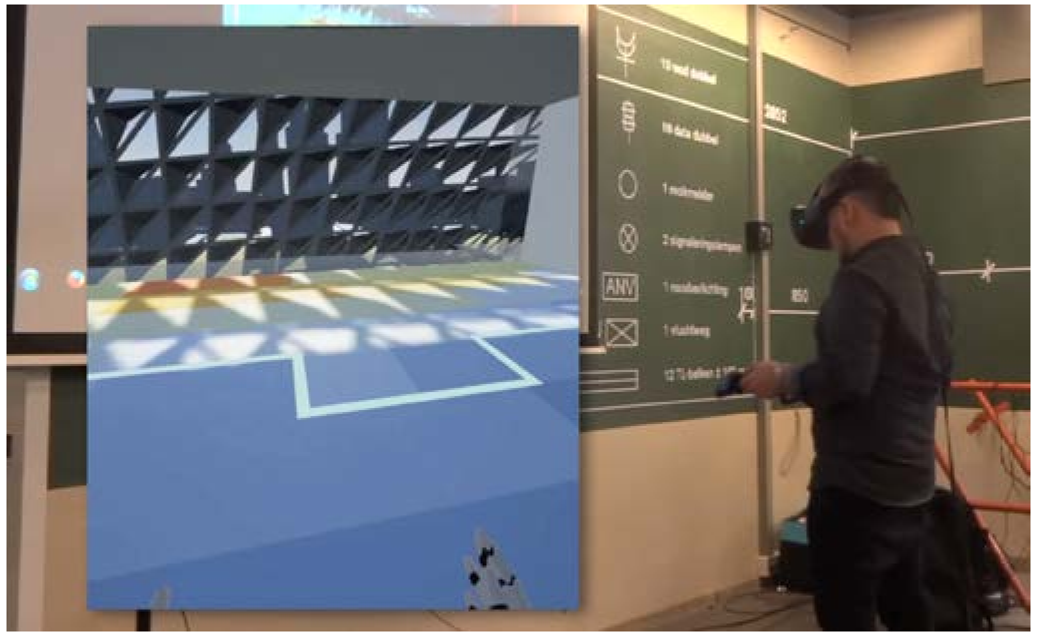


Figure 180. Outcome of the different shading results from multiple indicators at postion 46.

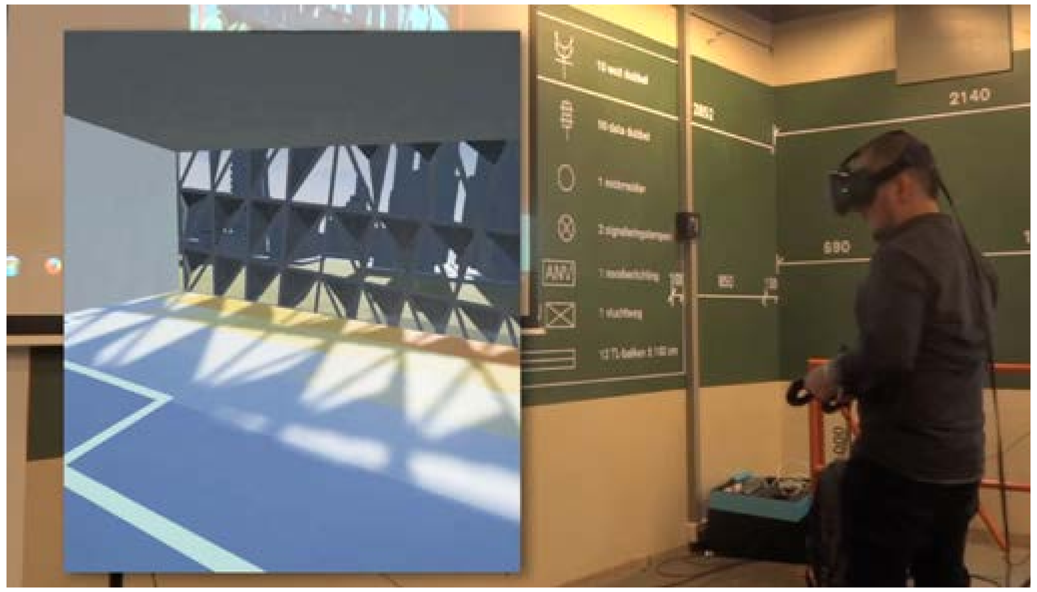


Figure 181. Outcome of the different shading results from multiple indicators at postion 24(1).

TOOL ANALYSIS APPENDIX

Tool	DIVA
Developers	Solemma
Platform	Rhino and Grasshopper
Software direct relation	Daysim, Radiance and Energy Plus
Where to learn from	http://diva4rhino.com/user-guide/getting-started/video-tutorials and http://web.mit.edu/sustainabledesignlab/projects/DIVATutorials/index.html http://diva4rhino.com/user-guide
Description (as from site)	DIVA-for-Rhino allows users to carry out a series of environmental performance evaluations of individual buildings and urban landscapes including Radiation Maps, Photorealistic Renderings, Climate-Based Daylighting Metrics, Annual and Individual Time Step Glare Analysis, LEED and CHPS Daylighting Compliance, and Single Thermal Zone Energy and Load Calculations.

Main Components

DIVA FOR RHINO				DIVA FOR GH		
LOCATION	***NODES***	***MATERIALS*** **Assing Materials** Daylight Materials	***METRICS*** Daylight Images Visualization, Timelapse, Radiation Map, Point-in-Time Glare and Anuual Glare	***DIVA Daylight*** Analysis grid	***DIVA Thermal*** Construction assembly	***Solar Tools*** Solar Envelope
Function description All .epw files must be downloaded and saved in DIVAs native folder.	*Function description* Subdivision for more accurate analysis and visualization pupurposes. The node grid can be applied to any Brep or Mesh never the less the subivision will be meshlike in similar form to a point cloud. (add example image)	*Function description* Materials can be assigned to the Rhino project´s layers for to the basic construction elements such as , includes floors ceilings, facades, grounds and different kinds of glazing, in a "basic" mode. More materials with physical properties can be added by the user. (add image of material palette)	*Function description* The purpose of this tools is to generate daylight efect images vased on the characteristics assigned to the model in terms of nodes, maerials and location. The user is able to set distinct paramters like sky condition, kind of camera used, date an tim and the size of the output image., In some of the menu advanced parameters (technical) are able to manipulate.	*Function description* Extracts data from a Mesh or Brep that will be tesaled in trainagles, which will derive in planar surfaces where the output will be a descomposicion of the mesh in Analysis Meshes, Nodes and Vectors.	*Function description* This tool allows the user to choose from the Default material from Diva for Rhino materials with their construction assembly. The user can also costumize its own Assembly by constuction element such as Slabs, Roofs, Wall and Patitions, select the amount of layers and the constriction material for this each layer. Previous construction sequence knowledge might be needed.	Function description From this tool the output resulting wil be a brep that defines the maximal buildable that will give the neighbors the specified minimal of sun over a determined period of time. The inputs for latitude have to be set manually.
		Thermal Materials *Function description* Materials can be assigned to the Diva´s output layers for to includes roof, ceiling, floor, wall, window, shading and adiabatic wall, the material list is short but more can be added with physical properties by the user. (add image of material palette)	Daylight Grid-Based Daylight Factor, Point-in-Time-Illuminance, Climate-Based and Radatio MAP	DIVA Daylight Anlysis *Function description* This tool helps to perform different sorts of analysis such as Solar Irradiation Nodes, Solar Irradation Imag, Daylight Factor, Illuminance, Climate Baed and Visualization, all of this anlysis have a pretedermined set of parameters to control a in a Windows environment. also they have different outputs according the selected simulation. Radiance parameter setting remain in the same level of technicality as Diva for Rhino. Some graphic outcomes of the tool like illumnance are directly visible on Rhino´s viewports. althogh other like Daylight are exported as a .TIFF image file to a predtermined folder.	Shade *Function description* Shade tools allows the plug-in of Breps to perform as shading elements, also inputs such as Solar and Visible refelctance, Transmittance, as well as a Glazed Fraction of the partition if any involded. Material knowledge for shade compostion might be needed.	Solar Fan Function description This tool will generate the oposite of the envelope since it will generate a brep that defines the volume that should not be blocked in order for the pace to recieve an specified ammount of solar acces. It is generally used for outodor spaces.
		Load IES File *Function description* Loading IES files, photometric (lighting files) for an accurate artifical light study.	*Function Description* The parameters for the daylight are set here are based on the Radiance simulation data. Glare (Lux/m2 and cd/m2) images can be retrieved from this tools. Climate based similations can be run according to and occupancy schedule and a target illuminance. Radioation analysis images can be obtained although they are based on the selected view on Rhino the image is produced as a .TIFF image in a separate foler. (add image)	Material *Function description* Lets the user input a brep or a mesh in to a material component from the generic deault material from the Diva for Rhino library as well as the ones created by the user in the in the Diva for Rhino tool.	Viper *Function description* Possibly the most important component in the Diva for GH tool, since with it the user can perform Thermal Anlysis from GH. The tool has a synthesized visual version of the component of the Thermal Single-Zon in the Rhino version, of course with the GH environment the are easier to edit directly from the component. The ouputss are the great advantage since it can offer plenty of different kind of date realted to enery consumption. The "graph" tools in GH allow the tool to be easy to read regarding and import as an image.	Solar Position Calculator Function description Generates a vector solar path from the .epw file which is selected from the settings button, the physical data regarding sun position such as Azimuth,. Altitude, Latitude, Longitud are outputed in the form of vectors that can be visible in the Rhino viewport with the aid of GH vector display component.
		Set LM-83 sDA Controls *Function description* Shading controls in this tool will help the used to make their results match from the ones from the Illuminating Engineering Society (IES) for Daylight Autonomy (sDA) anD Annual Sunlight Exposure (ASE), using a node based selection to control groups. Lux/m2 and cd/m2 can be added from analysis. (add image)	Thermal Single-Zone *Function Description* *A thermal analysis for a Single-Zone can be perdormed from this menu, occupant density, air changed and equipemnt power (W/m2) can be configured mnually. The heating, coolling can be configured and natural ventilation is presented as an On/Off option. (add image)*	Legend *Function description* Costumized legend without puts depending on the runned simulatio, it is directly related to representation on Rhino viewports. (add image)	Window Unit *Function description* The window unit tool allows the user to select the surfaces that will become the windows in the anlysis fro a brep iniput, and select glassing material from a defaul list, same as in the vonstruction assembly tool, other glassing material can be added as well as more glass layers up to 3, so the limit is triple glazzing.	
		Shading Controls No dynamic shading *Function description* No blinds or shading elements will be considered. Windows operate as voids. Conceptual dynamic shading *Function description* Perfroms an idealized blind syste without modelling the divide geometrically. Shading device is limited in their control in positioning, all blinds perform simultainously and perdorm the same action. Detailed dynamic shading *Function description* *This tool has two shding type modes, Mechanical ad Switchable (electrochromic). Mechanical is sabed on rotating elements and Switchable is based glazing that changes to opaque due to sunlight.*			Read Saved Thermal Resuls *Function description* The tool allows to read previously saved thermal results ran either in the Rhino or GH environment in order to continue the anlysis from the GH in case it´s needed. The metric button allows to add outputs that can help the user retrieve data regarding an specific simulation on GH. Reporting helps change de time lapse parameter from Annual to Hourly.	

Honey Bee is a free open source energy and daylight simulation plugin for Grasshopper. The plug-in is related to reliable energy data bases and simulators such as Radiance, Daysim, Energy Plus and Open studio, the tool allows designers to run energy simulations for to buildings of any scale in a multiple room bases with capability to work with any sort of surface.

HONEY BEE							
DAYLIGHT							
Honey Bee	Daylight Material	Daylight Sky	Daylight Recipe	Daylight Daylight	I_	Energy Material	Energy Schedule
Description	*Description*	*Description*	*Description*	*Description*	*Description*	*Description*	*Description*
The first component family in the Honeybee plug-in has six component sets. The first set containd the Honeybee/Honeybee which same as Ladybug starts running the simulator. The second set is for mass division which means sort of the decomposition of the analysed spaces. The third set is for creating the proper zones in which the building will be divided as well as the glazing areas and the adjancencies between spaces. The fourth set is complementary to the previos since it decomposed the zoned based on type or boundry condition. The fifth set are a components to label and assign attributes to surfaces and zones and check the zones are properly defined.	This component family contains all the components related to the Radiance Material library and it is divided into three sets. The first one to define opaque and glass materias, the second on is for setting, calling ad adding materials to the Raciance library. The final one is realted directly to especific Radiance materials realted to galls, metals, transluscent, opaque and mirror materials.	This component fmaily contains two sets, both for sky genetation data, speceficic knowledge might be neede to operate this tools.	This component family is related to Daysim ans Radiance directly and therefore has a strong relation to some of the features of Diva. It is integrated by three families the first is related to simulation based on test points, the tools are mostly directed to Daylight and Sky components. The last set of compnents has what is called Recipe for Dynamic Shading in advances and conceptual mode. As well as glare control and shading state based on test points, very similar to Diva.	This component family is build by six different tool sets all for thee visualization of daylight effect on a determined space., the first set has the two of the main features of Ladybug which are Glare analysis and Daylight simulation. The second set is about managing and importing RAD (Radiance) files. The third tool set is visualization of HDR to GIF images and False color representation which helps differenciate set glare levels in this case The fourth tool set is for file mamagement related to the light simulation. The fifth tool set contains components that are related to Daysim and focused on occupancy, shading with group sensors, electrical light use, occupancy and suer profiles. The sixth toolset is related to the final conversion of the files into visual presperentations, reading punctual data and simulation refinement.	This family only contains two tools, although very important ones. One related to building program and zone progrmas which will help determine the use of the building per building zones giving all of them their special determined characteristics in order to have a more accurate energy simulation.	This component family is related to the Energy Plus material library and edition, the first set of components is for extracting materials by characteristics such as constrution material, opaque and window material, as well as a search tool. The third set if for the management of the Energy plus material library. The last set is composed by components related for creating costum materials has the same materials as the first set with the difference of including materials for blinds, window ari gaps and air films with R-Value	This component family is based om compents from creating and managing schedules based on the Energy Plus library, which are helpful for defining the user behaviour in a building.

Tool	Lady Bug, Honey Bee and Human (complementary components)
Developers	Mostapha Sadeghipour Roudsari and Christopher Mackey
Platform	Grasshopper with Rhino as a Platform
Software direct relation	Rhino+GH, Radiance, Daysim, Energy Plus, Open Studio, Python and Human
Where to learn from	https://hydrashare.github.io/hydra/index.html?keywords=LBExampleFiles - Lady Bug repository https://hydrashare.github.io/hydra/index.html?keywords=HBExampleFiles - Honeybee repository https://www.youtube.com/user/chrismackey88/playlists https://www.youtube.com/user/MostaphaSad/playlists
Description	Lady bug is free and open source environmental plugin for Grasshopper to help Designer create an environmental-conscious architectural design. This plug-in in particular helps in the graphical presentation of weather data and comfort, and its directly related to the location which data its extracted from any .epw Weather Data files.

Main Components

LADY BUG						
Ladybug	Analyze Weather Data	Visualize Weather Data	Environmental Analysis	Extra	D_	WIP
Description	*Description*	*Description*	*Description*	*Description*	*Description*	*Description*
This component family has the propose of setting Ladybug beginning with the importing of an, the Ladybug/Ladybug will start running the simulator .epw file locally saved in our computer or downloading directly from Department of Energy website. The files can be related to the Köppen classification and also bringing into Grasshopper data from measurement tools to visualize with the LB and HB components.	This component family is divided into four groups, one about analysis period setting for analysis. The second one is for highest/lowest temperature and wind speed calculation. The third group helps the user generate comfort calculations, finally the fourth group can help set data for calculating heating and cooling hrs and also a clothing schedule based on outdoor air temperature.	The family for this component contains five different groups of tools, the first group includes components for generating data visualization from charts related to weather visualization such as adaptive comfort, of a psychometric chart. The second set contains tools to represent sky radiation through a certain period of time. The third set of components to visualizer sunlight, sky, radiation and interaction of radiation onto objects. The fourth set of components helps the user visualize features such as wind into a terrain and the wind rose which tells the direction of the wind on a specified location.	This component family is integrated by five different sets, the main idea of this component set is to visualize topics related to the environment of the site in question, the first set is the most basic and contains radiation and sunlight/hr analysis. The second set has components related to visibility and interaction such as bouncing from the sunlight on a surface. The next set helps the user to make evaluations on sun interaction related to shadow benefit and design and solar interaction such as solar fan and envelope.	Extra component set is very complex set of tools related to "scenario" configuration and unit conversion. The set in divided into five different sections, one related to north configuration, mesh color and hatching. The second set contains tools for passive strategies, activates and comfort parameters as well as real time radiation analysis. The third set is for view setting in order to capture the proper images for the data representation. The their and fourth sets are for data conversion (e.g. ºF to ºC or kW/mw to W/m2), shading parameters and the Ladybug Comfort Mannequin (one of the most singular features of this plugin)	The components in this family are for exporting Ladybug or Honeybee data and another component to look for updates on the plug-ins.	Wip component set has two different sets, one containing the possibility to generate a bioclimatic chart, a very innovative body characteristics component to help in the configuration for "Thermal comfort indices". The third tool in the set is a shadow generating study with outline curved represented in the Rhino model and finally two tools for shading masks related to the sky dome component.

Figure 182. Diva for Grasshopper analysis chart.

ENERGY				
Energy Zoning	Energy Energy	Energy Airsim	Update	WIP
Description	*Description*	*Description*	*Description*	*Description*
This componet family is integrated by two sets, the first set is for mamagent for loads, schedules, constructions and energy loads, the main function of this tools is to prepare the zones for energy analysis. The second set of tool is generating basic heating and cooling calculations such as adding an earthtube for ventliation, creating plenums, and also for zone edition in order to add surface, interior and underground constructions and adding glass.	This component family perhaps is one of the most complex and diversa in the Honeybee plug-in environment. It is intttegrated by seven sets of components, the first one if has two components one for running the Energy Plus simulation the other one to export to Open Studio. The second set includes tools related to Energy Plus such as shade generator and context surfaces. The third toolset contains for HVACS systems, air load parameters, Open Studio systems and the Honeybee Energy Plus geenetaror output .The fourth toolset is based on componets that help importing andreadind .idf and Energy Plus data. The fifth set includes zone representation tools for Energy Plus as well as shade benefit and optmizal shade creator. The sixth component set contains tools to help with the configuration of user paramters for features realted to microclimates, PMV, view factor and adaptive comfort. The seventh set has cmponents to represent results for balance temperature calculations, HVAC calculation results, energy balance and the Energy Plus parametric simulation controls for a determined period of time.	This componet family contains air management tools directly related to Open Studio software, the components simulate systems are for and handling, economizing, heating and coling, evaportive condensing, fans and mecheanical ventilaion.	Searches for Honeybee updates.	This component family is made up from six different tool sets. The first set of tools are for exporting the simulation results to graphical languaje formats as well as other readable formats that can work in other BIM related softwares. The second set includes some other system simulators from Open Studio such as cooling tower, water bolier and EIR chiller. The third set contains simulations for energy generating systems such simple current converter, PV generators and a wind turbine. The next one features tools for creating therm polygons and boundaries. The fifth set is for rotating, mirroring and moving Honeybee objects in the Rhino environment. The sixth set of tools has components for reading the energy genetaing system results and a cashflow visualizer that calculates the financial value of the energy savings.

Figure 183. Honeybee and Ladybug for Grasshopper analysis chart.

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