ARAB ACADEMY FOR SCIENCE, TECHNOLOGY AND MARITIME TRANSPORT (AASTMT)

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LATTICE SCREENS FOR OFFICE BUILDINGS IN EGYPT, BETWEEN CLIMATIC AND PARAMETRIC DESIGN APPROACHES

A PARAMETRIC APROACH THAT PROMOTES INDOOR NATURAL LIGHT FOR WORKING SPACES IN EGYP

By

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I owe this research mainly to my grandfather, who kept guiding me to finish it, wish he could see it, and to my mentors who helped me finish it it’s been a long way and I could have done it without them

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Abstract

Daylight is a crucial element for indoor environment quality. Egypt is classified with a hot arid dry weather (Peel, 2007), on the other hand Egypt is classified with about 90% of clear sky (Yansane, 2011). Egypt is currently going through an energy crisis that results in power lagers during the day Therefore, buildings in Egypt should take into consideration natural illumination in buildings to decrease artificial illumination decreasing energy consumption.

Office buildings are one of the most building types that use energy (Hamza, 2008) , on the other hand users stay in the building for about 8 hours daily (Egyptian Government, 2011), thus Office buildings commonly use fully glazed façades to reflect a luxurious appearance and to maximize natural light at the expenses of high energy consumption due to cooling/heating. Lattice screens can improve the building efficiency while maintaining good natural lighting.

This research studies the impact of various lattice screens facing west on light quality on a prototypical office space in Egypt using parametric design. A traditional solution for light such as the *Mashrabiya, Qamarīyah* and *sudare* is taken as an inspiration for this study to generate different forms of perforated screens. The cases were analyzed using light simulation tool and sorted by a genetic algorithm to show best solutions offered by the design criteria. A methodology to achieve these objectives .The research provided a method of optimization for lattice screens using genetic algorithms and light simulation tools. The research showed the results of the best 50 cases offered by the criteria chosen by the researcher.

Chapter 1:

1. Research Framework

1.1. Introduction

Controlling the indoor environment quality within buildings has for long been a quest that architects have been seeking. There is a need for the creation of a better performing space, which meets the user needs, by using all the available historical and cultural resources. Though the current techniques proved for a time to meet the users' needs, they no longer satisfy their needs and preferences. The ongoing development of computer programs help architects to create and explore new geometries that they were not previously capable of performing. Hence, if the traditional systems for environmental controls, such as thermal massing and opening shading, Have not yet changed, the development in the scientific filed has changed in seeking better energy performance inside spaces.

The building envelope is essential in shielding, screening, and filtering the interior spaces from external harsh environmental factors, such as heat, glare, and pollution. Therefore, it should integrate most of the environmental solutions to create a building that copes with the surrounding environment. Office buildings are a common type of buildings where people occupy them for 8 hours daily. They usually use large surfaces of glass in order to reflect a luxurious appearance. Though glass façades provide a plentiful natural light penetration to the interior space, they are not preferred in hot arid climates when more light penetrates the envelope causing eyestrain with the possibility of solar heat gain. Accordingly, large amount of energy is needed to cool and maintain the quality of the indoor space.

This research explores the use of computer simulation and optimization in designing office buildings façades that provides an adequate environmental performance taking traditional *Mashrabiyas* into consideration. The visual appeal of the façade results from its geometric design which uses reputation pattern that is randomly generated with a parametric algorithm. Besides, the environmental factors are tested by using standard simulation programs optimization of this process; that is by the use of genetic algorithm those cycles through different designs to evaluate their environmental performance and select an optimum solution.

1.2. Research problem

Based on global warming threats, one of the main challenges for architects nowadays is to minimize building's energy consumption to and simultaneously maintain a satisfactory indoor environment. Most of the contemporary office buildings, which are built in Egypt, are not designed in accordance with their local environment leaving the building with large glazed surfaces that cause (Figure 1-1), vast energy consumption, Electrical bills and carbon emission. Among different building types, office buildings are considered the highest energy consumers (International Energy Agency, 2003) where people work for an average of 8 hours daily during the peak energy demand period (Egyptian Government, 2011). The reduction of artificial light and increasing the use of natural daylight is considered an effective strategy in designing energy efficient buildings.

East and West façades are considered the worst in terms of high heat gain due to low incidental solar angels. Accordingly, the resultant risk of potential glare and over illumination is high in them. Hence, it is essential to provide sufficient natural light for the interior space and eliminate the excessive illumination that occurs at the afternoon on these elevations of buildings. For that end, energy simulation programs can help in designing more efficient façades. However, the problem lies in how to optimize the design of screens for office building west façades based on indoor light quality.

The challenges, that architects face in designing west façades of fully glazed buildings, lie in the presence of many parameters, which need to be taken into consideration, such as glare, energy consumption, requirements of light, and, finally, the aesthetic value of the building. Many of these elements are not in direct relationship with each other such as glare and natural light, and energy consumption and natural illumination, in the building. Reaching an optimal lattice screen that provides sufficient light in the interior space.

Figure 1-1 office buildings in Cairo, Egypt with curtain wall façades facing west and south.

The building envelope integrates 80% of the environmental solution such as the thermal massing of the building, shading devices, and materials used in the façade (Hamza, 2008). These solutions are highly important in creating an efficient building that interacts with its surrounding environment. In hot arid climates such as that of Egypt, the envelope solutions, in most of the contemporary office buildings, are not designed with respect to their climate, such as constructed at the 90th street in new Cairo (Figure 1-1), which have large glazed surfaces facing west that lead to more energy consumption. The question which ensues is how to combine both the double skin envelopes and the smart geometries to the envelope of the office building to create a smart, efficient screen that serve better indoor light quality.

1.3. Research scope

This research tries to understand and clarify the effect of lattice screens on the indoor light quality for office buildings in Egypt. The effect of lattice screens on the quality of light distribution in the indoor spaces and how it promotes the usage of natural daylight in office buildings is a crucial keystone for designing such buildings. The research focuses on west facing glazed office building façades and the means to optimize the façade design with respect to traditional *Mashrabiyas.* The research integrates parametric modeling tools with environmental light simulation programs to reach a lattice screen that responds to location and the environmental conditions in Cairo.

1.4. Research Aim and Objectives

This research aims to integrate the parametric design process with an environmental design process in the design phase. The research takes into consideration the historical *Mashrabiyas*, a well-known element in the traditional Arabic architecture, as the core of the design problem. Then, trials are made to adjust the design of this element to the modern façades of the office buildings in Egypt. The research also aims to increase the amount of the active areas which provide the required amount of light for employees.

The objective of this research is to reach the optimum range in the office buildings to give the maximum required natural light and sketch the behavior of double skin façades. This is performed by using parametric modeling tools combined with genetic algorithms to optimize office building facades in Egypt. The aim is to reduce the energy consumption in office buildings from artificial light and increase the zones that depend mainly on natural illumination.

1.5. Methodology

The research is based on a quantitative simulation study that is based on a sequential process, of which the first step is an analysis of contemporary office buildings in Egypt. These buildings will be analyzed in accordance with their exposed building surface area and their envelope volumes to reach a prototypical room design that will be used for the subsequent parametric analysis. The second phase will be involved in the analysis of the envelope using a based comprehensive parametric analysis in order to predict the total solar radiation and the intensity of the falling light on each and every coordinate point of the envelope. These data will be transferred to a parameterization program that generates the population pattern on the envelope according to the predicted total solar radiation and the intensity of light. This generating step involves the repetition of basic shape modules on the façade in order to optimize the total solar radiation and the penetrating natural light, which are inversely proportional.

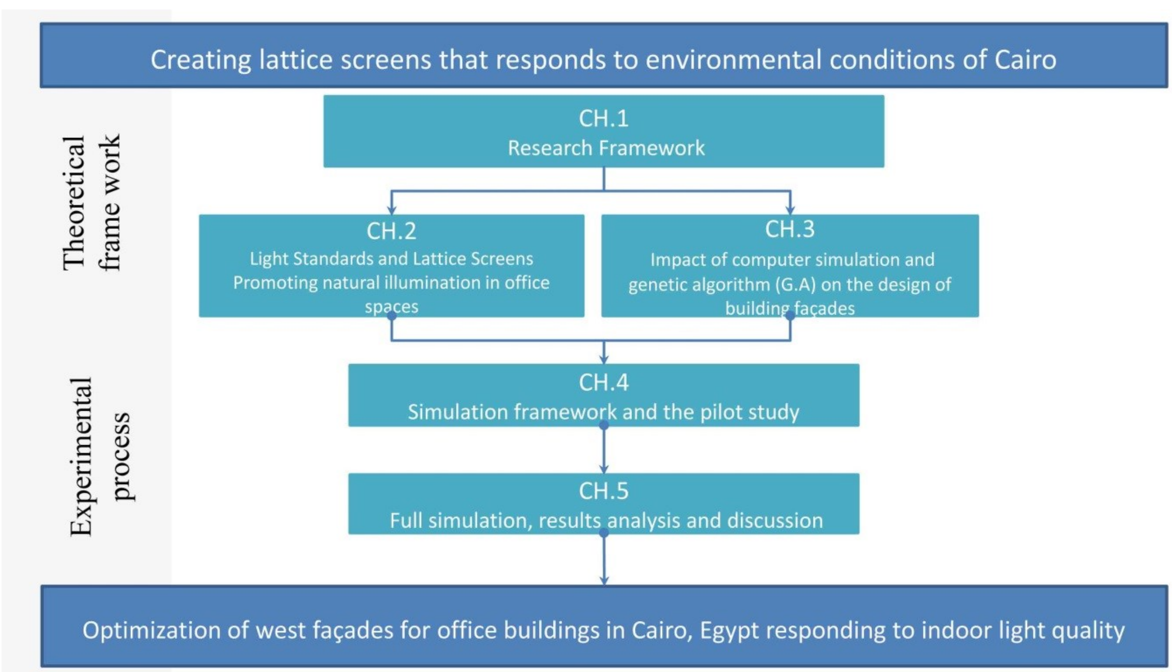


Figure 1-2 flow chart showing the research different phases and structure

The third step will be based on defining the parameters that will be generated to meet the challenge of the climatic adaptation of the envelope for Egypt. The parameters will take into consideration the traditional lattice screen in the Islamic era in Cairo known as the *mashrabiya*. Finally, analyzing and discussing the result and concluding the best range that generates a lattice screen responding to the light intensity in the interior space (Figure 1-2).

The modules will be generated responding to their parameters (scale of the modules and their rotation). These modules will be analyzed in each of these parameters to reach their optimum orientation in the corresponding façades. Besides, each interval of parameters will be analyzed and chosen to reach the optimum point.

1.6. Expected Outcome

The research is expected to show the relationship among the different parameters that affect the penetration of natural light through the west façade and, also, how to optimize the façade of this type of buildings to the climate of Egypt. The modules will be analyzed in each of these parameters to reach the optimum tilt angle of these modules in the corresponding façades. Besides, each interval of parameters will be analyzed and chosen to reach a good solution and extract from it the optimum zones and show them in a set of recommendation. Finally, a set of recommendations for architects should be given at the end of the research to suggest how to use this trend in the design process, and how it works in favor of creating efficient buildings.

1.7. Research Structure

The research is divided into six chapters. The first chapter aims to present the structure frame work and give a brief summary of the research. The second chapter begins by discussing office buildings and energy consumption, then moves to talking about the lattice façades, and, finally, shows office buildings in Egypt by discussing the Egyptian historical techniques to filter day light. The chapter then introduces light, expounds on the meanings of the quality of light, shading devices, and shows how they work. Then, it explains room geometries and shows how they affect light penetration, and, finally, expands on day light strategies and the tools, which are used to design day light in buildings. The third chapter defines parametric architecture, genetic algorithms, and the used tools and the reasons for the usage of these programs. The fourth chapter enrolls a pilot study where the base case and the parameters of the research are refined after the pilot simulation. Finally, the fifth chapter involves the full simulation of the research and discussion of the results. Finally, the sixth chapter concludes with suggestions of further recommendations for researchers (Figure 1-3).

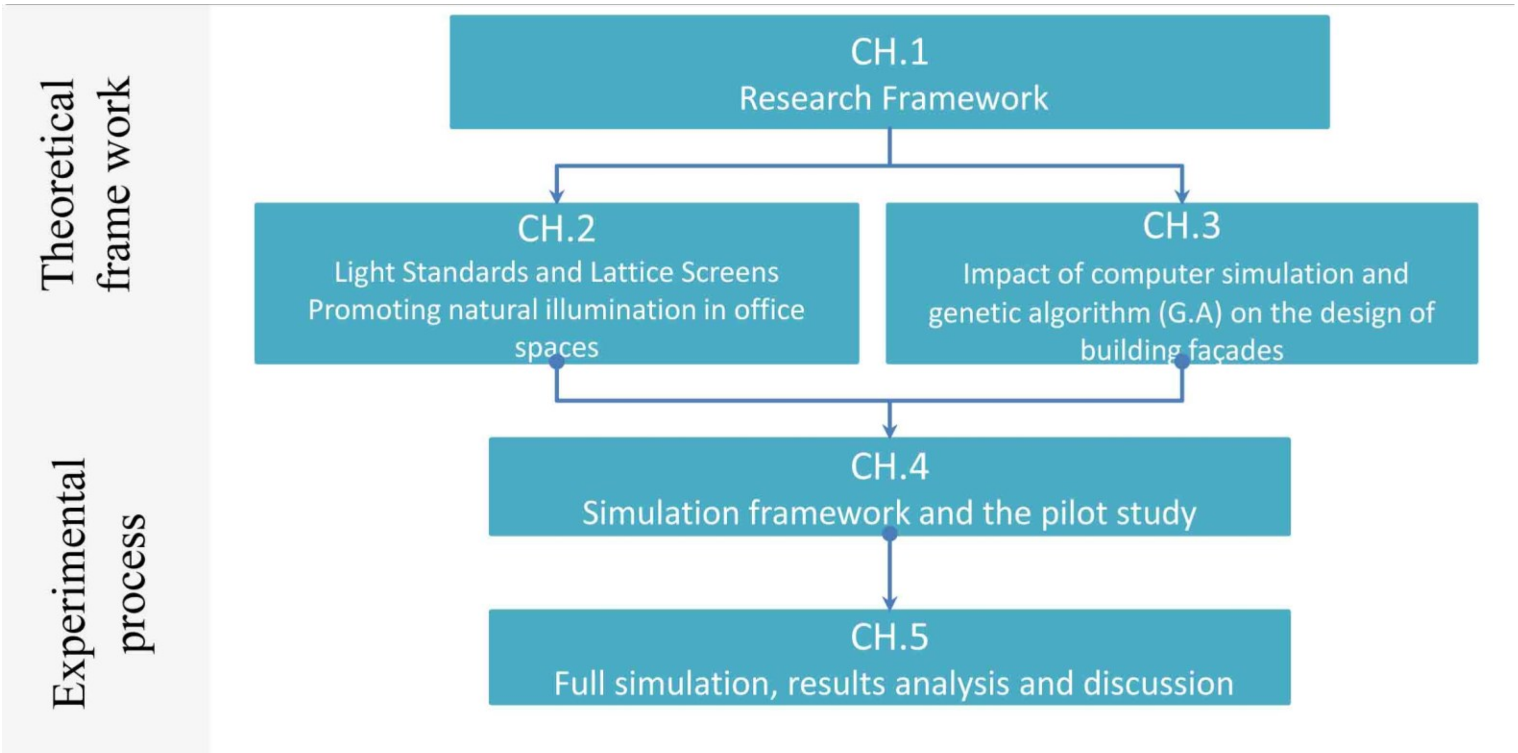


Figure 1-3 flow chart showing research structure

Chapter 2:

2. Daylight Quality for Office Spaces

2.1. Introduction

Architects have long been able to achieve successful environmental control techniques for ‘better’ performing spaces. They used all available resources—from cultural inspirations to whatever resources in their grasp—to create a better indoor quality; though, these techniques do not fit with the needs and preferences of today’s occupants as they were used to doing at a time. This is due to the unprecedented technological development and the design complexity. In other words, though the performance of these systems has not changed, other variables have changed such as the materials, used in construction technique, and modeling tools, that help in representing and simulating the indoor quality, which help in making better energy performance buildings.

Building façades are the main manipulators of environmental parameters. If designed efficiently, they should be capable of maintaining an adequate comfort level, by adjusting the impact of natural forces to interior spaces. The envelope’s functions include day lighting optimization, glare protection, acoustical barrier, natural ventilation, humidity adjustment, wind protection, visual contact, security and safety, and energy performance. Responsive façades are integrated facades that respond to the surrounding environmental changes. For a skin to have such an optimum quality is to maintain the quality of the indoor throughout the day (El-Sheikh & Gerber, 2011). On the other hand, such facades are expensive and such technologies are not common in Egypt.

This research focuses on static facades that are designed with harmony with the surrounding environment and maintain the indoor daylight quality for an office space in Egypt. This chapter focuses on the office building façades in Egypt and how shading screens are integrated and are inspired form the traditional *Mashrabiyas*.

2.2. Daylight quality in office spaces

Day-lighting mainly depends on the quantity of natural light that penetrates and illuminates the interior space. However, in some cases, the quantity of light that penetrates the space may cause over illumination at same spots generating potential glare. Hence, designers should take into consideration the quantity of the light entering the space, and light distribution within the designed spaces.

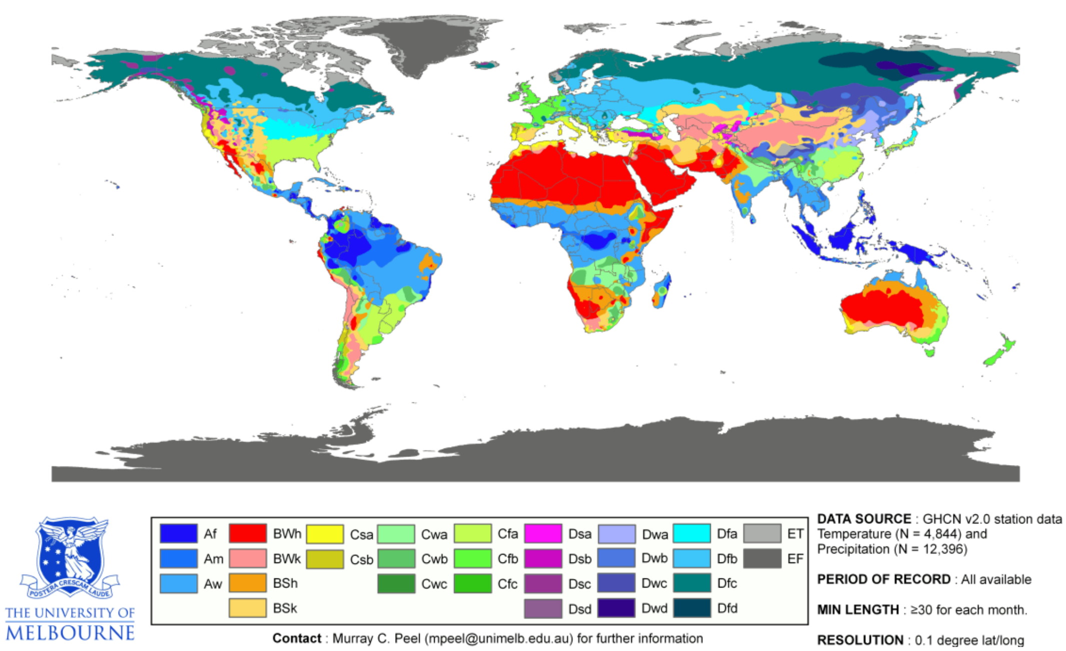


Figure 2-1 The classification of Köppen's climate world map (wikipedia, 2008)

On the other hand, office buildings in Egypt should be designed carefully as Egypt is considered a desert hot arid climate (Peel, 2007) according to Köppen’s climate map

(Figure 2-1).Office buildings in Egypt should take the environmental conditions into consideration as Egypt is characterized with about 90% of clear sky around the hole year (Yansane, 2011). Shielding and filtering the daylight entering the spaces, is important to create efficient buildings that satisfy the user needs and save energy. Therefore, architects should comply with light requirements within standards, which improve the daylight quality in the office buildings.

2.2.1. Light Requirements in Office Buildings

The usage of daylight is considered an effective way to reduce the dependence on artificial lighting for buildings. There are two main ways to quantify the light intensity at a certain point in the space: illuminance and the daylight factor. Daylight factor is the ratio of internal light level to external light level (Burberry, 1997), while illuminance is the total luminous flux that is incident on the surface per unit area (Azza & John, 2006).

The daylight factor approach is considered to be lacking realism in its calculations as it measures a ratio of the penetrating light from the dome of sky illumination which is an around figure value (Burberry, 1997), while the illuminance method is considered to be more effective as it measures the absolute illuminance value for a specific time of the year, or a full year average on the working plane. This approach is called “climate–based” (Azza & John, 2006).

To measure daylight in office spaces, some requirements should be stated in this section. Measuring daylight in office spaces depend on something called a threshold that defines the optimum daylight intensity, which is defined as (500 lux) (Burberry, 1997). On the other hand, daylight is not a constant value as there is an effective range of light intensity that lies between (100-2000 lux) (Azza & John, 2006).

> *"It is worth noting that a number of studies have demonstrated that the ability of an employee to control to a degree the daylight and electric light directly around his or her work area has led to even better production and morale. This is because, while overall good lighting is important, individuals often have their own particular preferences for brightness and the angle from which light hits their work area." (Ander, 2003)*

Accordingly, the variation of daylight in the space is one of the requirements to improve the quality of light in the space that leads to the increase of the productivity of employees. Though useful, the daylight illuminance range, which falls between 100 lux and 2000 lux (Azza & John, 2006), is based on a comprehensive data review of field studies resulting from the occupant's behavior during daylight strategies. The useful daylight illuminance (UDI) scheme is applied to determine the ranges in relation to activities in the space. It was found that spaces that fall within the range of (100lux-2000 lux) are within the effective range of illumination, whereas, ranges below 100lux are insufficient as they fall short of the useful illumination range (Ander, 2003). Finally, the spaces that fall in the ranges above 2000 lux exceed the range of useful day-lighting and need filtering strategies to overcome the over illumination in the space which is known as potential glare (Azza & John, 2006).

Office spaces can be categorized into three zones of work: fine work is a work that needs concentration of these areas that need range of 750 to 1000 lux; medium work 500 to 700 lux which involves reading and writing; and, finally, casual work from 300 to 500 lux that involves using computer screens in work stations (Burberry, 1997).

Finally, it is concluded from this section that the effective ranges of the daylight is between 100 lux and 2000 lux. The ranges below that are considered to be effective according to the U.D.I (Azza & John, 2006) and the ranges above, as over illuminated spaces, are likely to cause visual or thermal discomfort and needs shielding.

2.2.2. Active Zones

As previously mentioned, the quality of the light that penetrates the space determines the activity of the space. Office buildings need a uniform illumination that ranges from 100 to 1000 lux (Azza & John, 2006). Light that enters the space varies in its intensity leaving inactive spaces. The challenge in office spaces is to acquire the desired light increasing the active space. Active spaces are the spaces that depend mainly on the natural illumination (Department of Energy, 2000). Luminance method is used in architectural buildings to measure the quality of the light in the space, identify its intensity, and predict the potential glare as mentioned in the U.D.I (Azza & John, 2006). Potential glare is the potential of a surface to cause glare due to difference between bright and dim surfaces (Ander, 2003).

Filtering the day light entering the space seems to be the answer to the problem of the over illumination of space, the answer lies in how to increase the active space. Parametric tools combined with environmental tools can optimize the designer of lattice screens to meet the environmental criteria for designers nowadays. The calculation should consider the sky condition and the geographical data of the location (Azza & John, 2006), e.g. latitude, longitude, overcast sky. Calculating the illumination in a space can be defined either by calculation sheets, that determine the amount of illumination in the space, or by using computer tools, that predict the distribution of light in the space. The problem with these methods is that the solutions are always conventional, while today's architects and users seek non-conventional solutions. On the other hand, architects try to use non-conventional tools to increase the daylight penetration in the building. The problem is how to increase the daylight penetration by increasing the active areas, decreasing the excessive illumination, caused by the large surfaces of glass in the office buildings, and decreasing the glare.

2.2.3. Glare in Office Buildings

Providing sufficient illuminance values in the indoor space is not the only aim of efficient daylighting design. Maintaining the quality of the working atmosphere is the main issue of day-lighting design. On the other hand, glare or excessive lighting is mainly defined as the high difference, and contrast, form the illumination of the working plane surface. Glare is one of the main phenomena that cause eye strain and visual discomfort for the users of the space Figure 2-2, which needs to be addressed in buildings (Ander, 2003).

Figure 2-2 typical glare in office spaces that causes visual discomfort (L.C.A, 2012)

To improve the quality of the visual environment in the space, the contrast between the foreground and the background should be taken into consideration. Excessive contrast in the space may cause users eye strain and disrupt the eye's ability to either perceive details or distinguish objects. Hence, it is important to make sure that glare conditions are minimized and the large difference in illumination is kept under control (El-Sheikh & Gerber, 2011).

Glare is not an issue of design. It is critical only when certain illumination and vision circumstances occur. On the other hand, over illumination and difference in the contrast within the space should be kept to minimum to eliminate potentials of glare occurring. Finally, glare is a subjective phenomenon and as such it is difficult to quantify (Ander, 2003).

2.3.Daylight Strategies

Different tactics are applied to buildings to assure the quality of illumination for office buildings such as side lighting and top lighting. Side lighting techniques use the wall plane of the building as the void or the window plane. Side lighting provides illumination for horizontal planes and working surfaces (Figure 2-3). A disadvantage of side lighting is that it may cause glare because of the contrast between the light and shade of the surrounding planes. Glare is an important element to be taken into consideration ant it may affect the quality of the space and cause discomfort for the users in the space (Reinhart & Walkenhorst, 2001).

Vertical windows have been used since the beginning of time to introduce natural light to space.

Figure 2-3 Vertical window section and picture of the green building source arch daily

Vertical windows on the vertical planes create a connection between indoor and outdoor. They give the light beam more planes to reflect upon. In designing vertical windows, some parameters should be taken into consideration. One of these parameters is the size of the window; larger windows provide more light in the space. It is highly recommended to calculate the amount of Light needed and then make an opening to prevent the space form potential glare. Second one is to avoid the small openings placed on solid walls as they create discomfort to users due to the high contrast between the surface of the wall and the window.

A third one is the clearstory light which provides side lighting for the space. Clearstory light characterized with sill high above the eye horizon and it is below the ceiling level. The main advantage of clearstory is that it provides light to the space in a wider distribution and reduces the brightness level. Clearstory light proved to be an excellent light for vertical and horizontal

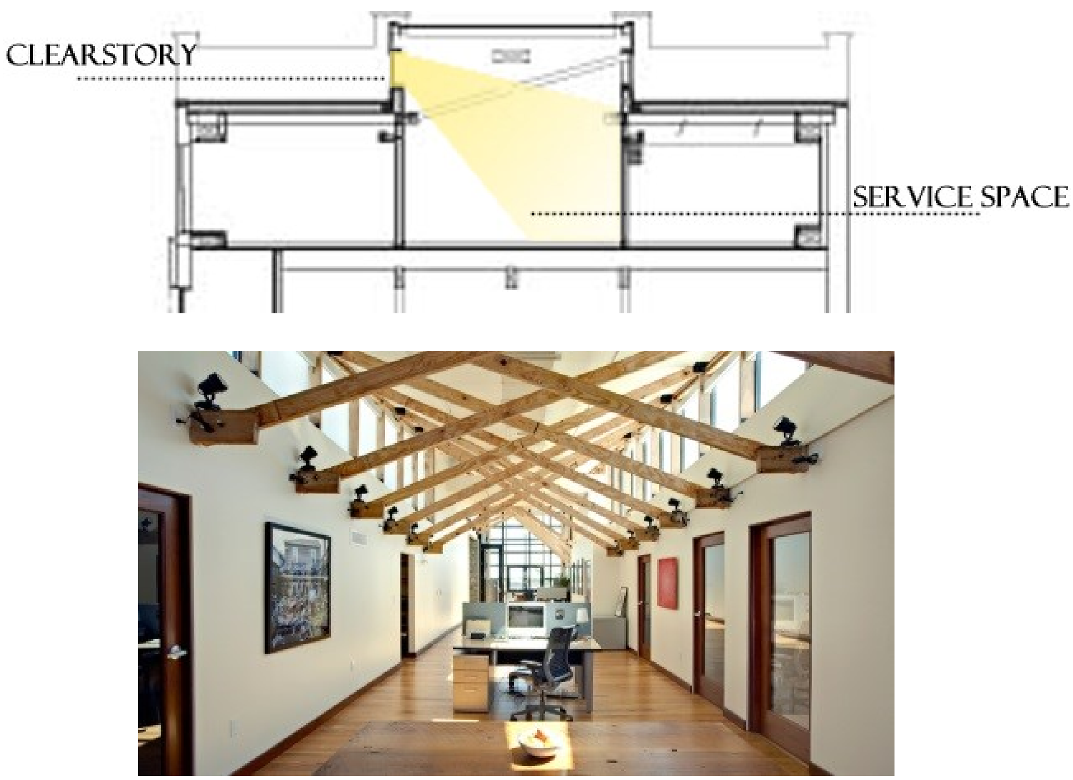


Figure 2-4 Clearstory light in plan and section source (arch daily adapted by researcher)

planes (Figure 2-4) as it provided deeper penetration of light into the space. Clearstory light is a perfect light for gym halls, libraries, museums, and circulation spaces.

A fourth one is the top lighting. Top lighting is a strategy where the ceiling plane is used as the provider of light. This concept of openings always provides the space with distributed patterns of light. Top lightings have different characteristics from those, which come from side lighting, as the quality of light varies significantly by the type of the transparent or translucent material used in the opening or the placement (Ander, 2003). One of the advantages of top light is that it can introduce light to strategic areas. It is often used to illuminate the top floor; however, the penetration of direct solar radiation should be controlled and taken into consideration as it may cause user discomfort (Figure 2-5).

Figure 2-5 Top light in the National Gallery of Canada by Moshi Safdei source (Ander, 2003)

Sky light is one of the types of top light. It is a glazed roof opening, which is paralleled or tilted to the roof. The layout and the spacing of skylights in the roof determine the light pattern that enters the space. Atrium light is another type of top light but it can stretch from the upper to the ground levels. It provides stable uniform source of light that deep buildings can rely on.

2.4.Direct Sunlight

Direct sunlight is one of the main reasons for the poor visibility and discomfort because of its excessive lighting and brightness that strains the eye. Daylight quality is not about making bigger openings or glazing curtain walls; the aperture or the opening should be controlled and light beams should be measured to assure the quality of the natural light in the space (Ander, 2003).

Direct solar beams are one of the main causes of potential glare (Figure 2-6); the difference in

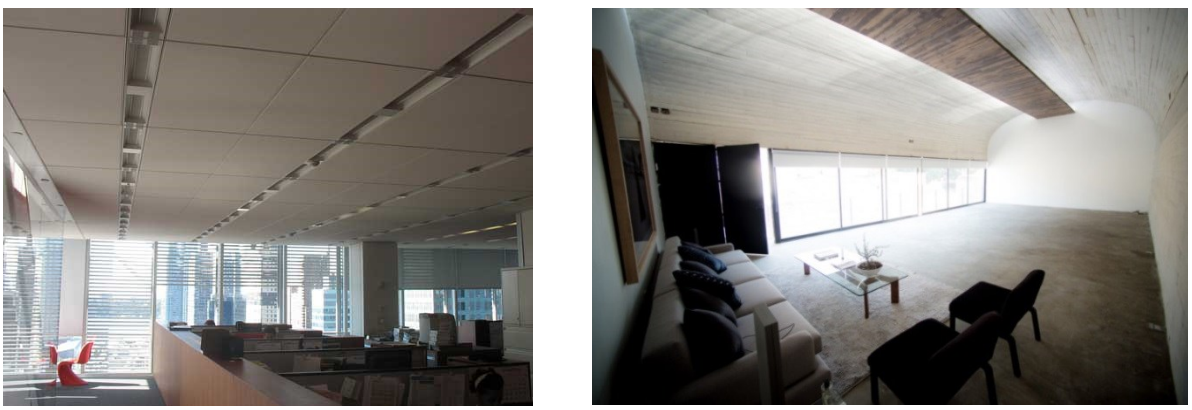


Figure 2-6 Rebollar Complex source (ArchiNet, 2013)

the brightness and the large contrast between light and shade cause discomfort in the space.

However, diffused light is preferred in the space as it allows soft transitions between light and shaded spaces. On the other hand, direct solar radiation creates a pattern that helps the employers to feel connected to the outer world and gives them a sense of time by the dynamic movement of the shade and daylight penetration in the space (Burberry, 1997). This should be considered in the design process to allow direct beam by studying its impact in the space. Diffused natural light is the best option for the space as it provides the users with the needed amount of light and the sense of time. Shading devices that filters the direct solar radiation seems to be the most effective solution. Shielding the openings and defusing the direct radiation is a combination that shading devices should provide.

2.4.1. Natural light and shading devices

Shading devices are used to reduce the impact of the direct solar radiation increases the heat loads gained by the building envelope. Shading devices are an element of design that has a function. Ignoring this function leads to greater energy consumption in space, while ignoring the design factor gives a building with bad aesthetical value.

Shading devices can be classified to two main categories: the first is a solar shading device that prevents solar beams from transferring heat loads to the interior space; the second is a shading device that prevents and refracts the direct solar beam into the interior space giving the space an indirect source of light. This second type is also known as solar harvesters.

Office spaces depend on natural light to improve the productivity of users and to reduce the amount of energy used. Good shading devices in office buildings should allow the penetration of light as well as prevent the direct solar radiation. As mentioned in Chapter 1,the problem of office spaces in Egypt that contemporary office buildings ignore the functional value and concentrate on the design value of shading devices or ignore the environment and make large areas of curtain walls.

Room depth is one of the main parameters that affect the light entering the space and its distribution. The amount of light penetrating the space depends mainly on the sill height of the window from the floor (Figure 2). Taller windows will allow the light to penetrate the space and refracting on the celling plane leading to the reflection of light into the space.

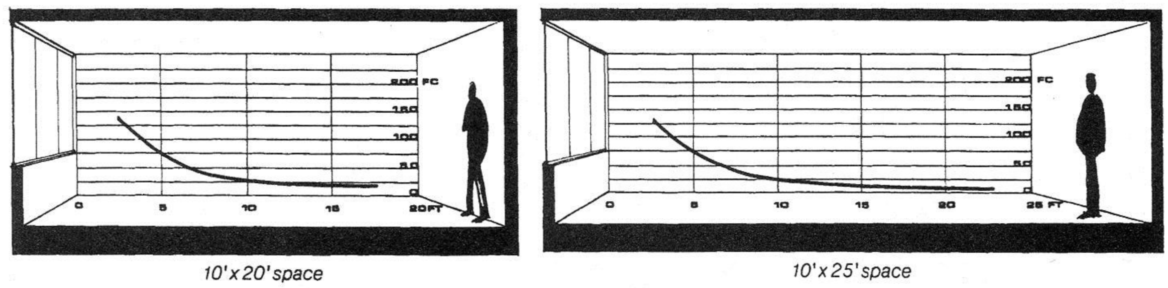


Figure 2 room depth and light penetration source (Ander, 2003)

The main parameters of the room geometry are length of the room and the width and the ceiling height. The optimum ratio of the room is always 1:2 or 1:2.5 (Ander, 2003). The window height is another factor that affects the penetration of light where the active daylight zone is to the ratio of 1:1.5 to 1:2 the window height (Ander, 2003). The mentioned parameters ignore the fact of the light reflection and refraction in space depend on the color of the walls and ceiling therefore using light colors in office spaces maximize the amount of light reflected increasing the active zones that depend on natural light

Shading devices are exterior elements that prevent or decrease the amount of direct solar radiation entering the space providing the interior space with indirect light. While, shading devices help to decrease direct solar radiation it will reduce the amount of light entering through the opening (Ander, 2003). On the other hand direct sunlight is not the only source for daylight illumination in space. Reflected light from the ground or other surfaces can be designed to harvest and project indirect sun rays into the space. (El-Sheikh & Gerber, 2011).

Shading devices can be divided into three categories horizontal louvers, vertical fins and lattice. Horizontal louvers are an effective strategy to block the direct sun light during the summer periods in south elevations when the sun angles are high and allowing for light penetration in the milder seasons where direct solar radiation is more bearable (Velasco et al., 2012)

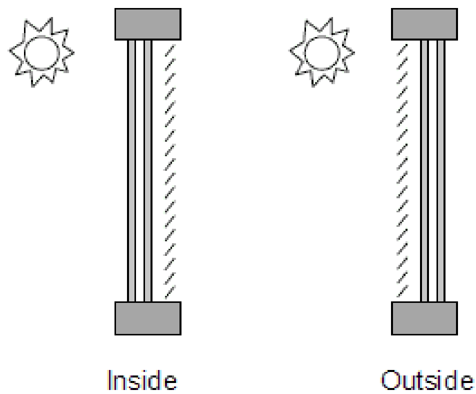


Figure 2-7 the different placement of the fins or louvers as interior or exterior element (Ander, 2003)

The second category is the vertical fins they are effective in the areas where the sun angles are too low with high penetration angles. Thus, vertical fins can be used to refract the direct beam to the interior space such as east and west. On the other hand these systems can be used as curtains in the interior space or as an architectural element (Figure 2-7)

The third category is combined shading (Figure 2-8) where there are vertical fins and horizontal louvers on the façade that is due to the big variation of the sun angle as the sun starts with a low angle then ends with a high angle. Thus, using that category of shading devices is effective in 45 degrees orientations such as east-west and south west. On the other hand, that type of shading device is known as the Egg-crate shading device (Gut & Ackerknecht, 1993)

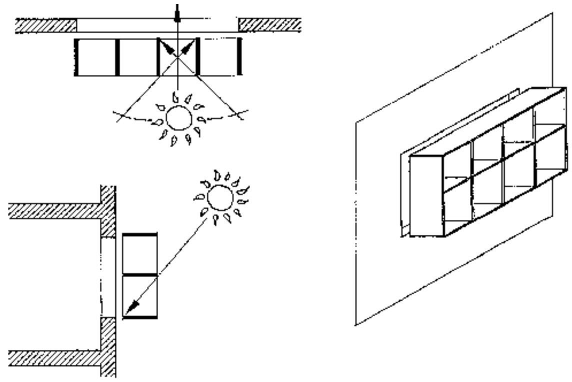


Figure 2-8 Egg-crate types may be used where only horizontal or vertical protection alone would not provide shade. It may be required on east to southeast and on west to southwest oriented surfaces. (Gut & Ackerknecht, 1993)

The final type is the lattice or the shading wall (Figure 2-9) is a projected wall or plane that filters the day light through fine opening these fine openings adjust the quality of light in the indoor space and eliminate the excessive light. Lattice was used in different traditional methods exist for reducing the effects of the sun's glare, such as lattices (*shīsh*, or *mashrabiya*), pierced screens (*qamarīyah*) as used at the Tāj-Mahal, or blinds of split bamboo as used in Japan (*sudare*) Figure 2-9, shades used outside the windows that are similar in effect to venetian blinds. (Britannica, 2013)

Figure 2-9 Different types of traditional lattice screens in Egypt mashrabiya (left) and Japan's sudare(right) (source (Satoh Blog , 2011))

Using the new tools that manipulate geometrical patterns lattice found a way into the modern architecture as it is an effective and it give the building its unique form and shape. On the other hand generating theses shapes with respect to the screen or lattice behavior to environment is an aspect that has been on top of researchers agenda the past few years (Kaplan, 2005)

Figure 2-10 picture showing the north façade of Feisal Islamic bank and it's lattice screen

Examples of lattice facades in Egypt can be seen in buildings like Feisal Islamic bank (Figure 2-10), in Cairo's downtown where the lattice screen is generated from Arabic calligraphy that is taken from Islamic statements. On the other hand, the *Feisal* bank plan is a triangular shaped plan that is vertically extruded decreasing the known numbers of facades in a building to 3 instead of 4. The building facades are facing north, south- east and west respectively. Finally, it can be found that the balconies are rotated towards the north east side to allow for morning light penetration to the working space of the bank.

The problem of lattice is shown in (Figure 2-10), as the screen faces the north elevation with no direct solar beam on the façade. On the other hand, the openings of the lattice are the same in the three facades of the building which means that the building lattice is designed for an aesthetic purpose not an environmental one. This means that these types of buildings need a different paradigm to make these buildings more efficient. Using daylight simulation tools can help predict the behavior of light hat penetrates these screens. Accordingly the design criteria of lattice screen should be rely more on the environmental aspect and the light quality in the interior spaces not the aesthetic value of the façade. The next section will discuss the different simulation tool used by architects to predict the light intensity in buildings and how they performed in relation to real time measurements.

2.4.2. Daylight Simulation Tools

Daylight is an important feature in the building that's why computer simulations nowadays provide accurate result to help designer taking into consideration the amount of day light needed in the interior spaces. Computer simulations provide accurate results and visualization of spaces that gives designers guide lines and decide the parameters of day light. Accordingly, there are programs that simulate light and its behavior in building. The three main light simulation tools are *Radiance, Superlite* and *3Ds Max*.

a. Radiance

There are many computer simulation tools for daylight analysis the most popular and accurate program is *radiance*. *Radiance* is a program developed by Lawrence Berkeley national laboratory at the Berkeley University in California and is funded by the U.S department of energy to help in the creation of Energy efficient buildings (Department of Energy, 2000) .

Radiance uses ray tracing methodology to predict and sketch accurately the behavior of light beams in the architectural spaces the program uses geometry that is modeled on a various platform of computer modeling tools these geometries are then updated with their materials, colors and the type of widows used in the same orientation of the real building the a mathematical physical algorithm is calculated in the space predicting the behavior of the light in the interior space. (Larson & Shakespeare, 1998)

The idea of having a model that simulate the behavior of light without having to build the space physically hast only helped designer to make better and more energy-efficient buildings but it also helped researchers to place guide lines.

Rendered images are the final output of the program these images appear on the screen the image has the amount of light in each pixel so by the mouse you can place and choose any point and get the data out of it also the calculations can be sent to an excel file or any other program using a *txt* file format.

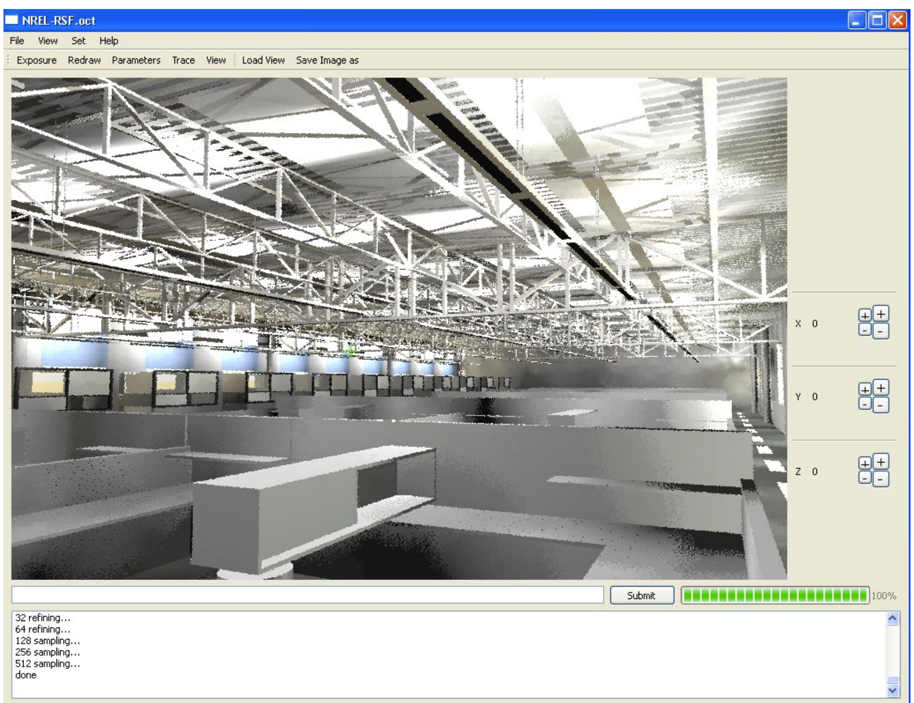


Figure 2-11 The User Interface for Radiance and render in process source (NREL, 2005)

Radiance is also available as a plugin for a wide spectrum of computer program like *Ecotect* (Ecotect, 2001), *Energy Plus* (Design Builder, 2005) and *Rhino* (Rhino, 2012) these programs run *radiance* through their user interface which is friendlier for the user of these program as it's in the program interface helping them in research or design.

Radiance can be used at any point in the design process it only needs the light source to render and calculate the matrix that is imbedded in the images shown on computer screens the more accurate the data given to *radiance* the more accurate the image will get e.g. define the texture or the color of the materials used in the model (Figure 2-12). Finally radiance is considered the to be the most resalable and accurate program to simulate light intensity for interior spaces

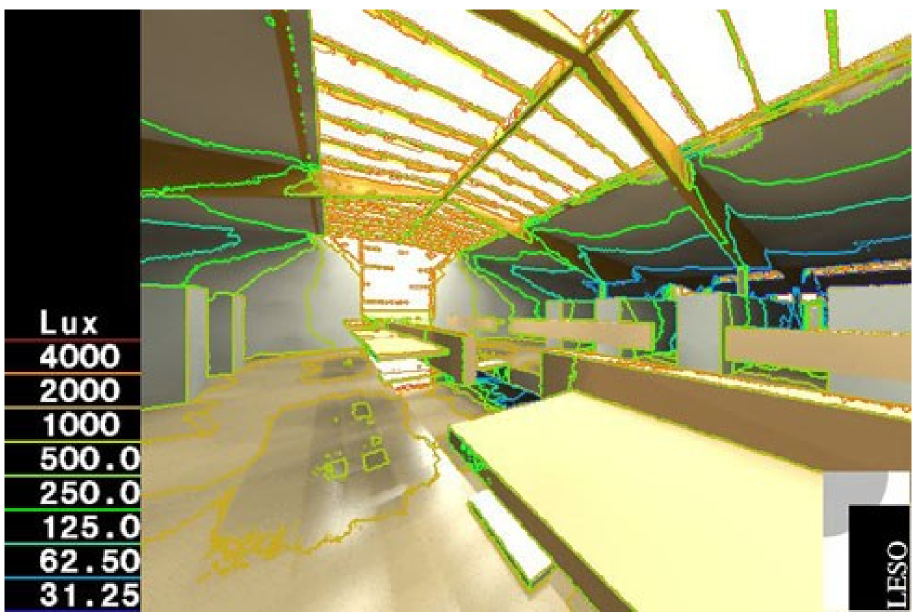


Figure 2-12 The outcome Picture from Radiance showing the contours of illumination Courtesy of Berkeley lab (source (University Of Minnesota, 2002))

b. Superlite

Superlite is relatively new program that is used to predict the illuminance in buildings. The program was developed by M, Jaime at the *Berkeley* research lab. the program is used to address the needs to accurately measure the geometrically complex openings in buildings the program uses complex geometric form system that is able to predict illumination levels the program allows users to measure complex room geometries in complicated building forms such as T-shaped rooms with a frame structured building with the internal partitions taken into consideration (Jaime et al., 2010)

The program also has the capability to measure daylight from diffused sources such as sky and ground planes the amount of light that is diffused from glazed window glass also can be either clear or translucent glass or shading devices (Ander, 2003)

The environmental data for the program can be defined by three steps the first one is by allowing the user to enter the appropriate sky conditions (clear sky, over cast, uniform) the second option is provide the geographical information for the plot and the time bracket of the study the third step involves the solar location bracket under the sky conditions given to the computer (Jaime et al., 2010)

Superlite adopts a very detailed point by point calculation for a day and time .the simulation is fully depended on the three interties entered in the beginning of the program the more accurate the simulation get the more time it takes to finish the analysis of the space (Jaime et al., 2010)

Like *Radiance* the program is not user friendly in its raw form the geometry is defined by coordinate system not a geometrical method the input to the program a list of numbers for the geometry the are ne second party plug ins for the program which makes the program less popular than *radiance* and the data entry for the program is relatively hard to get

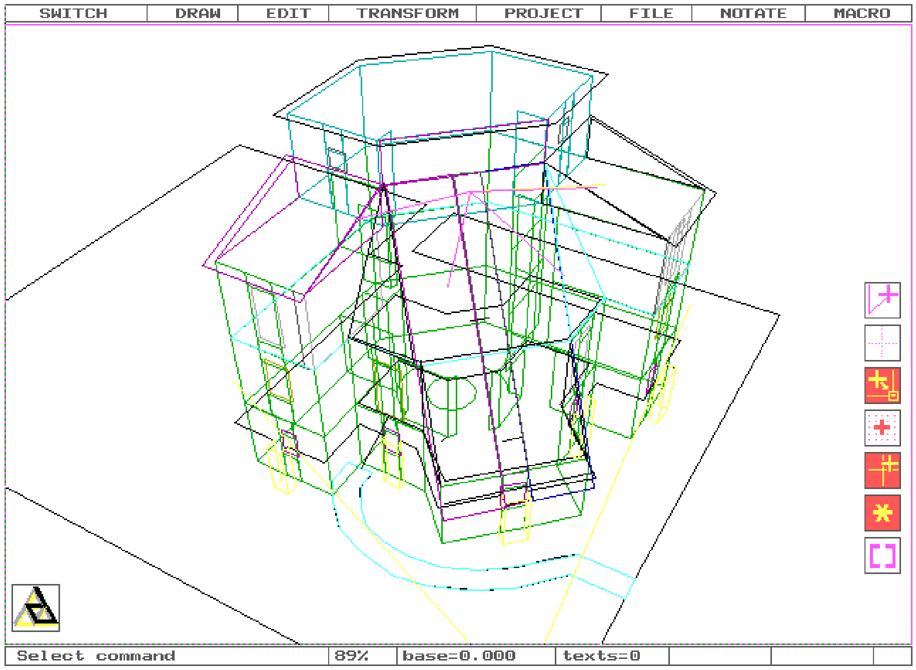


Figure 2-13 Superlite user interface showing the planes that constructs the interior spaces for the light simulation and the direction of the sun source (Lawrence Berkeley Laboratory, 1996)

One of the main limitations of the program is that all assumes that all reflecting surfaces is perfectly diffusing the light beams with may affect the accuracy of the results. Another drawback of the program is that it considers the light entering the room to be uniform so in the case of cloudy skies the beams should vary in magnitude of their fluxes however these limitations are not of great concern for a normal daylight studies however the program is new and it is evolving each year to satisfy users (Ander, 2003)

Superlite is only in a beta version and *Lawrence Berkeley lab* and there is no more news of the program to be released soon thought little research was made with *Superlite*. On the other hand, *Berkeley* lab focused on development of *Radiance* and stopped the development of *Superlight*. (Lawrence Berkeley Laboratory, 1996)

c. 3d Studio max (3DS MAX).

Mainly a modeling program developed by Autodesk *3Ds Max* has an embedded exposure functionality feature it enables the program to analyze and simulate the sky conditions, sun and artificial light in a rendered scene (Landry & Breton, 2008). It is an important program that simulates and helps the architects to analyze and visualize the light intensity in the interior and exterior spaces on the condition of accurate data entry of sun and light position with their luminance intensities. There are several aspects that ought to be taken into considerations while preparing a model to be analyzed *in 3Ds Max*, first the ground plane and the color of the ground plane and its reflective value, second textures of the ground plane and last the position and the altitude of the sun rays. If the user doesn't have a precise model with identified textures, color and materials about the building and the buildings surrounding it then the results are incorrect as it allows more rays to bounce from the ground floor plane into the building. The data entry in *3Ds Max* is the problem where there are many aspects to be taken into consideration. (Brooker, 2008)

3Ds Max has some limitations in light simulation; to begin with materials that use radiance material library exported from the *optics 5* database ignore the angular dependency so visualization may appear brighter than it is in the physical world, on the other hand the difference between the *optics 5* library and the *R.G.B* library of *3D*s *Max* approximate the light spectrum conducted by the *3Ds Max.* Therefor light simulations are done by R.G.B colors and its library drawbacks. Therefore *3Ds Max* has proven to be reliable for architects as a modeling tool .meanwhile importing the radiance library into 3Ds Max causes errors in the results. Hence it is not commonly used as a light simulating tool for architects. (Landry & Breton, 2008)

2.5.Concluding Summary

Natural illumination in interior spaces is not only by placing large openings or by creating deeper light penetration. Natural illumination is about analyzing the activities that happen in the space and trying to achieve the corresponding illumination that fits the space needs. Using shading devices is important to filter day light as they eliminate the direct sun beam and allow indirect reflected beams to enter the space. Accordingly potential glare should be taken into consideration as shading devices result in difference in the day light factor causing eyestrain. Meanwhile filtering the daylight is crucial in office spaces by means of vertical gardens or perforated panels. On the other hand curtains may be used as an interior solution for daylight filtering. The room geometry plays a major role in illumination of the space as the depth of the light penetrating the space depend on the height of the window and the plans that reflect the direct light beams into the space. There are a lot of strategies to illuminate the space side lighting is one of the oldest and efficient ways of allowing daylight to enter the space. Side lighting uses the wall planes as the window planes allowing light to enter this technique should take the solar altitude and latitude in relation to its orientation so as to decrease the direct solar rays that enters the space. On the other hand top light is another way to illuminate the space using the ceiling or roof plane as the widow plane this strategy allows light to top floors and in some cases architects were able to use them as the main illuminating source for some spaces like gyms and galleries i.e. spaces that do not need a lot of illumination. Meanwhile top light should be used carefully as it is exposed to the direct solar radiation causing unwanted heat transfer to the space .hence using translucent materials or double glazed glass is preferred in top lights. Meanwhile the integration of artificial light and natural light should be taken into consideration.

3. Parametric Design of Building Façades

3.1. Introduction

Recent developments in Computer Aided Drafting and Design (CADD) tools enabled architects to create and visualize new forms that previously were difficult to create. Generating geometry through mathematical equations and building algorithms that create the building is the new trend in architectural design. Parametric architecture is in need of a bigger frame work that links the building form and interior spaces to the building users instead of relying on the form (Meredith, 2008).

Parametric design is about extracting parameters that affects the design and use them to alter the building form or special organization circulation. These key elements alter the users experience and the building form (Schumacher, 2009). Most of architects nowadays are accused of being formalistic and ignore key aspects of design that should drive the design process (Meredith, 2008). Hence, architects are focused nowadays to create environment efficient buildings using parametric tools to try and merge the gap between form and functionality of building.

This chapter deals with the terms related to parametric architecture and the use of it in architectural design field and how to link them to the environmental parameters. On the other hand, it deals with the term of genetic algorithms and its link to the new approaches of architectural design. Accordingly, linking the environmental parameters to the program and use them as the design generator. Finally, showing the tools used for parametric architecture and the way to integrate them together and how to optimize results to reach solid findings in architectural design

3.2. Parametricism an Emerging Style

This section discusses parametric design and how it is used in different approaches such as , simulation and model making it also shows the weakness within the practice nowadays of parametric architecture and how it lacks some reason as it is accused of being an approach that greats good looking building rather than functional buildings . (Meredith, 2008)

Parametricism and the use of its techniques have created a new style in Architecture, Urban Design as well as Spatial Design that values form over function (Schumacher, 2009).

"It is an emerging style that is based on advanced computational design and digital animation techniques to create digital visualizations and designs. Its latest modifications are based on advanced parametric design systems and scripting techniques that create fluid forms. Parametricism as a style has been developed over the last 15 years and is now gaining control within avant-garde architecture. Styles are characterized to represent cycles of innovation that gather the design research efforts together. It succeeds modernist architecture as a new long wave of systematic innovation. The style finally closes the transitional period of uncertainty that was caused by the crisis of modernism that was marked by a series of short lived episodes including Postmodernism, De-constructivism, and Minimalism". (Schumacher, 2008).

Architectural filed is always seeking to create new complex forms and pushing the boundaries of design the program manipulate parameters that are defined by the architect to create complex geometries enabling them to explore new forms . Styles represent cycles of innovation, gathering the design research efforts into a collective endeavor. Stable self-identity is here as much a necessary precondition of evolution as it is in the case of organic life (Meredith, 2008).

The use of parametric tools helped architects to explore and create new geometrical patterns that gave the building its unique shape and form. On the other hand, using these tools to simulate and make these patterns respond to the environment is taking parametric architecture to a new framework that merges environmental buildings with complex forms that adapts to environment

3.3. Parametric architecture

Computers enable architects to calculate complex mathematical formulas, complicated equations introducing a whole new family of shapes, curved topologies, splines, and surfaces. Nevertheless, these tools offer relations and dependencies between points, curves and surfaces embedding fixed or variable parameters. Smart geometries are associated with parametric environment, which has been developed in the car industry and Aeronautic industry ending by the aero architecture (Kilian, 2006)

Parametric Architecture is a term that is used by architects nowadays it is the architecture that takes the design form into consideration creating certain parameters that bound the form creating new solution for the spatial experience and the structure of the space see (Figure 3-1) (Meredith, 2008).the forms crated are sophisticated that computer aided manufacturing programs are integrated in the software to in constructing them. The architectural use parametric tools has been superficial and skin-deep the frame work constructing these buildings need to be more wider as introducing parameters of functionality and environmental use to make these form more efficient (Meredith, 2008)

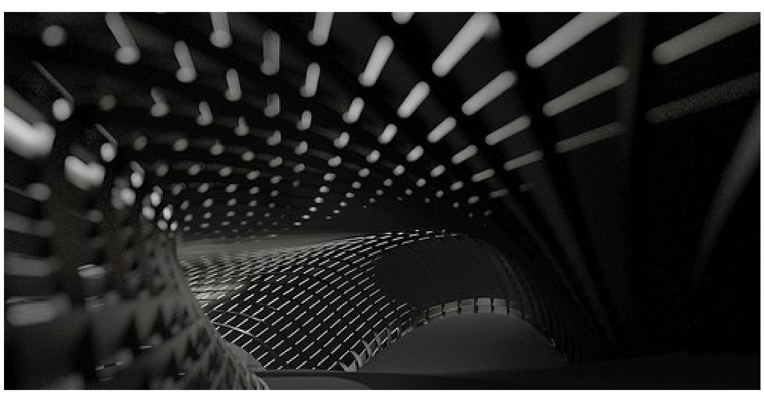


Figure 3-1 space definition using parametric tools source Flickr

Parametric architecture has so far, and skin deep .the problems within the current practice are accused of formalism. Lately parametric design is trying to adapt to multiple design criteria to reach a solution that fits the need thus most of its products are based upon the post visual effects and the form of the building and the visual complexities it creates. (Meredith, 2008).

Parametric tools allowed architects to explore new geometries that architects were not able to explore before it pushed the architect in creating unique forms that helped in the architectural industries. In 2001 partnership between Practice, Research and Academia, formed by members of the world's leading architectural and engineering practices and educational institutions called smart geometry was founded. The new generations of designers, engineers and architects, mathematics and algorithms are becoming as natural as pen and pencil. Smart geometry promotes the emergence of this new paradigm in which digital designers and craftsmen are able to intelligently exploit the combination of digital and physical media to take projects from design right through to production (Rutten, 2010).

The problem with the current practice of architecture is that it lacks the integration between the form and the surrounding environment (Meredith, 2008). Little integration has been made to combine the approach of parametric design with the climatic design to reach more efficient buildings. (Figure 3-2).

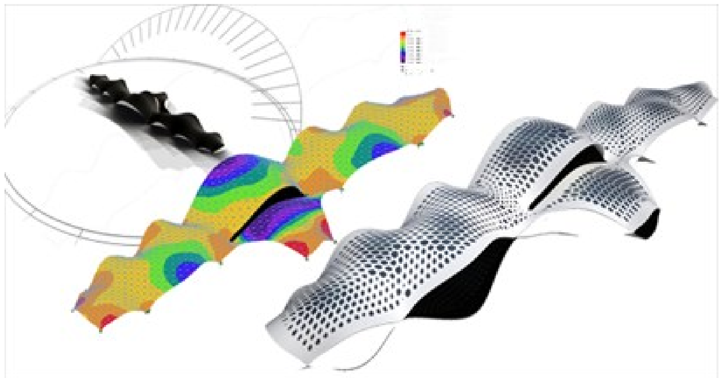


Figure 3-2 integration of environmental tools and parametric tools source grasshopper3d.com

Parametric design tools used surface for modeling and populates modules on these surfaces. These modules can then be transformed to shading unites openings and for the massing of the building. On the other hand, recently architects have been calculating these modules to determine the size and the position of openings in the building creating the fenestration or the shading wall to the building (Terzidis, 2006)

The introduction of a new method of thinking is needed to integrate the climatic design with the parametric design to try and optimize the building to save more energy and materials in the building construction. As parametric architecture is based upon algorithms introducing more parameters to the algorithm will lead to the creation of a new plugins that helps architects to perform faster such as *Diva* (Diva, 2012) that imports the radiance library to grasshopper helping architects to simulate and analyze the geometries created in rhino and optimizing them using *Galapagos* (Rhino, 2012)and *Diva*. (Diva, 2012)

Using parametric modeling tools are strong to transform and generate geometry. Accordingly, they are used to generate forms that respond to parameters that are defined by the architect. On the other hand, using environmental analysis tools con be effective in optimizing such geometries. Hence, integrating these techniques together create unique forms and types of lattice that respond to the environment (Kaplan, 2005).

3.4. Genetic Algorithms (GA) as Design Aids

. The introduction of the genetic algorithm was a break through that helped architects as well as many other disciplines to find more solid and efficient solutions. A genetic algorithm is composed of *genomes*, *generations* and a *fitness equation*. The *genomes* are the no of the different solutions generated by the different parameters, *generations* are a set of a fixed no of genomes and their behavior to the *fitness equation*, the fitness equation is the datum where the algorithm chooses the best genomes accordingly. Genetic algorithms are very useful to optimize solutions for equation with multiple parameters and variation of solutions

GA are effective if integrated in the design process. GA can be used in finding good and efficient architectural solutions in the design phase; they are used nowadays to find unconventional solutions for different design criteria, such as building forms (Figure 3-3) façade shading and daylight harvesting. GA was shown to be effective in presenting new solutions to optimize light penetration and shading (Jaime et al., 2010).

The main benefit of the evolutionary solving process in a genetic algorithm is that it enables the designer to adopt a holistic approach, taking into account many different aspects influencing the performance of a façade. One Another limitation of GA is that the generated solutions are picked randomly, which may result in skipping some cases that may have been beneficial. This can be avoided, to some extent, by forcing the algorithm to use more generations (Rutten, 2010).

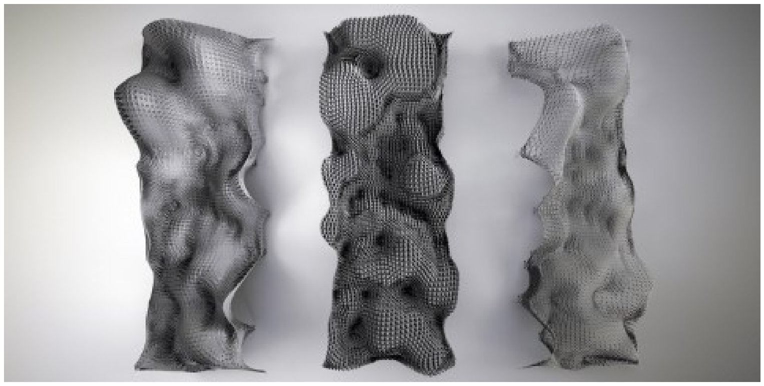


Figure 3-3 Genetic algorithms and their use in architecture source (Pugnale, 2008)

While GA are effective in the design process they have a major drawback which; GA can consume too much time and processing to reach a solution that architects do not have during the design process phase the question lies with how to reduce the parameters and try to reduce the processing time to reach the best solution possible (Zemella et al., 2011).

3.4.1. Introduction to GA

Computer simulations based on Darwinian theories known as GA where developed by John Holland at the University of Michigan and nowadays many interests have been directed towards using the GA. They are applied as a search engine to help researcher from different disciplines to reach optimization and try to reach enhanced solutions (Rutten, 2010).

There are two types of solvers in the genetic algorithm the first depends on the survival of the fittest of the genomes selected it's based on the Darwinian theory and it is called the evolutionary solver .the other type is annealing solvers optimization problems using a probabilistic search algorithm that mimics the physical process of annealing, in which a material is heated and then the temperature is slowly lowered to decrease defects, thus minimizing the system energy. By analogy, each time of a simulated annealing algorithm seeks to improve the current minimum by slowly reducing the extent of the search.

In this research GA will be used to optimize a solution between the geometry generation and the natural indoor lighting levels .this research focuses on how the double skin façade will affect the natural light levels in the interior space and choose (Rutten, 2010).

3.4.2. Advantages and disadvantages of GA

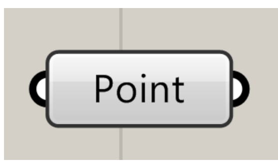
Using GA helps in finding solutions with a wide spectrum of probabilities. GA solves Problems with multiple solutions. GA it gives the opportunity to solve the structure and parameter solution at the same time. It solves the problem with a chromosome that is mated or mutated with different genomes to reach a solution.GA definitions can be easily transferred to models and existing simulations in different programs

Like other artificial intelligence techniques, the genetic algorithm cannot assure constant optimization response times. Even more, the difference between the shortest and the longest optimization response time is much larger than with conventional gradient methods. This unfortunate genetic algorithm property limits the G.A' use in real time applications. There is no absolute assurance that a genetic algorithm will find a global optimum. It happens very often when the populations have a lot of subjects. (Rutten, 2010)

3.4.3. Tools used for parametric design and GA

A. *Grasshopper (G.H)*

One of the programs that play a major role in parametric design is *Rhino* (Rhino, 2012)and *GH* (Grasshopper, 2010) for the geometry generation Rhino is 3-D modeling software was developed by *Robert McNeel & Associates* and it targeted Architects and designers from different fields as it compatible with the CAD/CAM. *GH* is a plug in for *Rhino* that enables architects to use scripting language with a visual interface the script is called a definition the definition is consisted of batteries of containers that contains information referenced from rhino geometry or operators that operate on generated or referenced geometries (Figure 3-4).



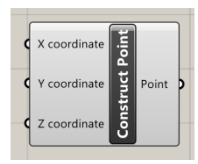


Figure 3-4 Containers and operators in grasshopper

The definition is build up by connecting batteries together this type of modeling tool break the ordinary boundaries and help architects explore new geometries that are generated from mathematical formulas or algorithms.

The definition in grasshopper has two main functions and they are the creation of base geometry and the generation of the parameter that built the cases. On the other hand there are lots of third party plugins such as *Diva* (Diva, 2012) for *G.H* a plug in that analyzes the generated geometries through exporting the data to *Radiance* (Larson & Shakespeare, 1998) or *Energy Plus* (Department of Energy, 2000) libraries .*Diva* analyzes generated geometries and calculate their thermal and illumination behaviors (Figure 3-5). The illumination operator uses *Radiance* in the light analysis where the thermal operator uses *Energy-plus* for thermal analysis, though this research focuses only on light analysis

Figure 3-5 Diva thermal and light components

B. Generative components (G.C)

Generative Components G.C. (Bentley, 2011) is a parametric platform developed by Bentley systems Inc. used by architects to help them visualize and explore new geometries. It automates the deign process and produces alternatives for the design. *GC* enhances the relationship between the design components and the abstract ideas created by architects' imagination. *GC* as a parametric modeling tool enables architects to take control over the object attributes and the associative network between objects and each other. Design the construction sequence of the model and use it to manage and explain the setup of design that helps and facilitates the integration between *CAD* and modeling software (Bentley, 2005).

GC is being used by many of today's design firms to embrace and enhance the creativity for these firms. *GC* is used by leading architects and engineers around the world like *Arup, Foster + partners, HOK and Morphosis.* However, there are main drawbacks to *GC* that makes it less popular than *GH* the learning curve of this software is longer than that of *GH*. It is not as flexible as *GH* when it comes to modification of generated geometries (ArchiNet, 2013). Also the lack of variety in third party plugins in *GH* that saves scripting problems to researchers to reach desired forms and geometries.

C. *Genetic Algorithms GA* **Tools**

As it was mentioned before genetic algorithms are form of artificial intelligence that adopts the selection theory process in problem solving using them helps the user to explore all possibilities (Shiffman, 2012) .

One of the programs that have an integrated genetic algorithm solver is *GH* called *Galapagos*. *Galapagos* works by two inputs the first is the spectrum of possibilities defined in *GH* the second step is a fitness equation that measures and evaluates the geometry Figure 3-6. The setting window of the tab need the number of the genomes in each generation and the fitness value weather it needs to be minimized or maximized

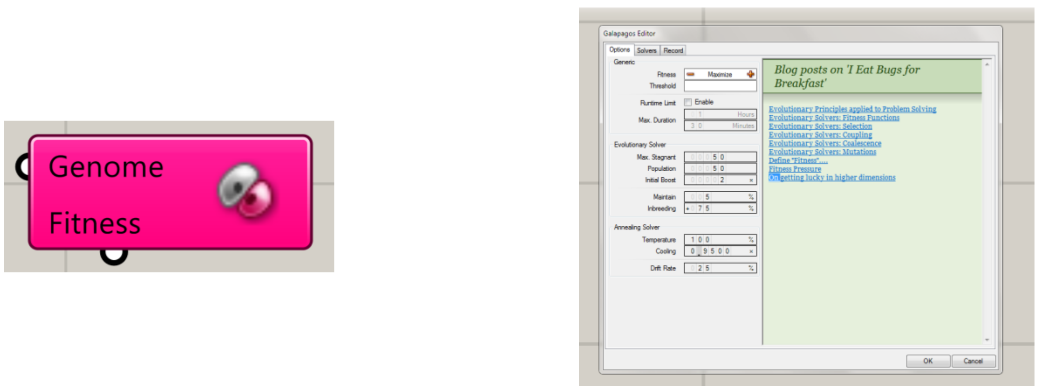


Figure 3-6 Galapagos operator and setting window in Grasshopper

Programs like processing by Ben Fry is one of the widely used programming languages gives the opportunity to write the logic of the *GA* but it is not commonly used by architects as programming languages are hard to learn (processing, 2007) . On the other hand visual programming languages like *GH* give the opportunity to use a *GA* component called *Galapagos* it has the option to use the Darwinian or the annealing solvers to assess the parameters and reach a solid finding.

Finally, the parametric modeling tools are basically based on scripting and identifying parameters to the computer to create forms that respond to a problem. That problem can be something that has to do with environment or any other quantifiable problem. On the other hand, social or behavioral problems are out of the scripting league as it's something that cannot be quantified. Hence, these tools are effective to simulate environmental aspects and generate geometries and patterns that respond to it.

3.5.Concluding summary

Parametric Architecture is an emerging style that has been ganging momentum over the past few years. Parametric design programs enabled architects to explore, visualize and fabricate new geometries. Meanwhile the integration of these programs are giving users the edge in design as the architect can define the parameters of the building Cleary and the building is shaped respecting those parameters. On the other hand GA is effective in finding solution from a big spectrum of choices.

The use of parametric modeling so far has been superficial and architects are being accused of formalism. Integration of simulation, environmental analysis, parametric modeling and genetic algorithms can be used to generated and optimize lattice screens for office buildings based on their environmental performance

The need of integration the parametric tools with environmental analysis tool are crucial as we have just scratched the surface of the abilities of such programs. Accordingly, architects are seeking to create forms nowadays that respond to parameters creating an intelligent form that responds to the users comfort and the surrounding environment. On the other hand using such techniques enables architects to expand their intelligence and create a non-conventional form that fits their criteria

The next chapter describes the pilot simulation that an algorithm definition that integrates environmental, parametric and genetic algorithms to test the behavior of lattice screens with respect to light in a west facing façade of an office building located in Egypt

4. Research Design pilot study

4.1.Introduction

This section describes a pilot study for a west facing façade screen to analyze the outcome data and validate the proposed algorithmic definition. The study will use a prototypical room of an office space. The results will help to identify and diagnose the definition for the main simulation to conduct the pilot study some of the parameters will be used as constants to decrease the simulation time.

In this research an algorithm definition will be used to generate the base geometry and the screen through the previous parameters using *Rhino* (Rhino, 2012) and *Grasshopper* (Grasshopper, 2010). The design criteria take the *arabesque* pattern of the *Mashrabiyas* into consideration. The cases will be generated and tested through the proposed days in different hours using *RADIANCE* (Larson & Shakespeare, 1998)through *DIVA* (Reinhart & Walkenhorst, 2001), cases will be chosen through a genetic algorithm using *Galapagos* (Rutten, 2010) a genetic algorithm imbedded in grasshopper the final cases are compared to the base case and validation cases to discuss the results. The data produced from the study will be analyzed to show the charts that will be used in the final simulation. Charts will be drawn using.

4.2.Base case

To conduct a pilot study the bounding condition and constants of the study should be stated and recognized. Therefore the study is bounded by climatic and geometrical parameters first the climatic conditions , the experiment studies the different time laps of the working hours in the day each two hours from 9 am to 5 pm in the weather of Cairo, Egypt the study is conducted on four days in the hole year The four days are 21^{st} of June, 21^{st} of December ,21^{st} of March and the 21^{st} of September to represent the days where the solar angle is at its maximum (summer), minimum (winter) and the two days of the equinox . The conducted study is experimented on a west facing façade of an office building

In order to evaluate the impact of the proposed double skin on the internal light quality, the research a west-facing prototypical office space measuring 4x6 meters with a height of 3 meters (Figure 4-1). These dimensions represent an average span structural grid that can hold 3 workstations. The depth of the space is set at twice the height of the window (Ander, 2003). The distance between the perforated screen and the curtain all is 0.6 meters, which is considered a minimum distance for a maintenance catwalk. The curtain wall consists of a double-glazed window with low-emissivity coating, and the inner room surfaces are chosen as typical smooth light paints increasing the reflectivity of the horizontal and vertical planes in the space.

The analysis grid is placed at the height of 0.9 meters the (height of the working plane), and constructed of modules 20x20cm. The number of the bounces of the light rays is set at four bounces.

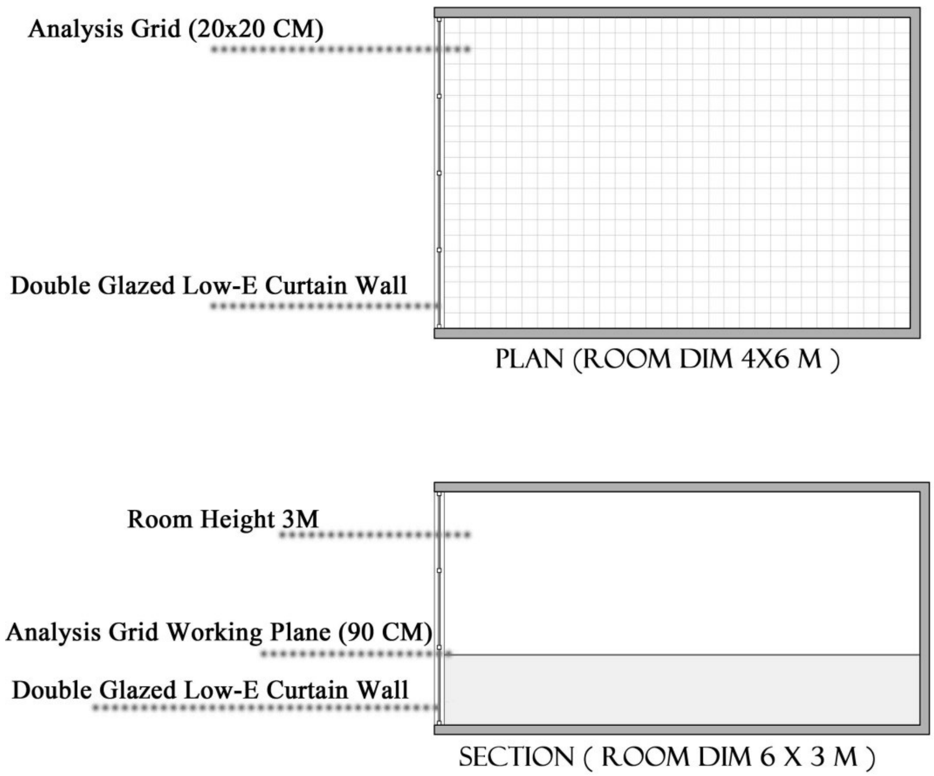


Figure 4-1 base case plan and section source researcher

The materials used in the room is masonry walls with thickness of 12 cm with light grey plaster of reflectivity of 65% the roof is define as white gypsum boards to help increasing the reflectivity of the surfaces in the space.

Genetic algorithm is used to conduct a search for the best skin parameters throughout the year, in a certain sky condition. The genetic algorithm searches the definition for an optimal solution under certain criteria and conditions. These parameters vary from users and their desired illumination levels to externally-reflected Daylighting components. Changes in any of these parameters triggered the system to run and find an optimal configuration for the skin to maintain the desired luminous environment. Hence, the effective range of 700 to 200 lux will be taken with a datum line for the optimal illumination 500lux.

4.3. Parameters and Cases

The lattice screen (perforated screen) is envisioned as a grid of rectangular modules. The different parameters of these modules include the width (w), height (h) and incremental rotation angle (ϴ). As seen from the outside of the building, the bottom-left module starts with zero-rotation. Then, the module directly above it is rotated, and so on, until the top of the first column of the grid is reached. At this point the rotation is applied to the next column of grid, starting from its bottom. This results in a repetitive pattern, similar in principle to a traditional wooden screen (Table 4-1). Different values of the perforated screen's parameters.

Table 4-1 Parameters of the repetitive modules of the lattice screen (perforated screen)

Parameter	No of Cases	Possible Values
w	5	10, 20, 25, 40, 50 cm
h	6	10, 15, 20, 25, 30, 50 cm
ϴ	18	10°, 20°, 30°, ...180° *around an inclined rotation axis (1, 1, 1) at center of module*
Total	540	

A total of 540 different cases were simulated to determine the illumination level inside the office space. An analysis grid, where the illumination levels are measured, is placed 0.9 meters above ground with a resolution of 0.2x0.2 meters. Each generated screen undergoes lighting simulation 18 times as described later. The typical weather data file of Egypt is used in all simulations (U.S Depatmen of Energy, 2012).

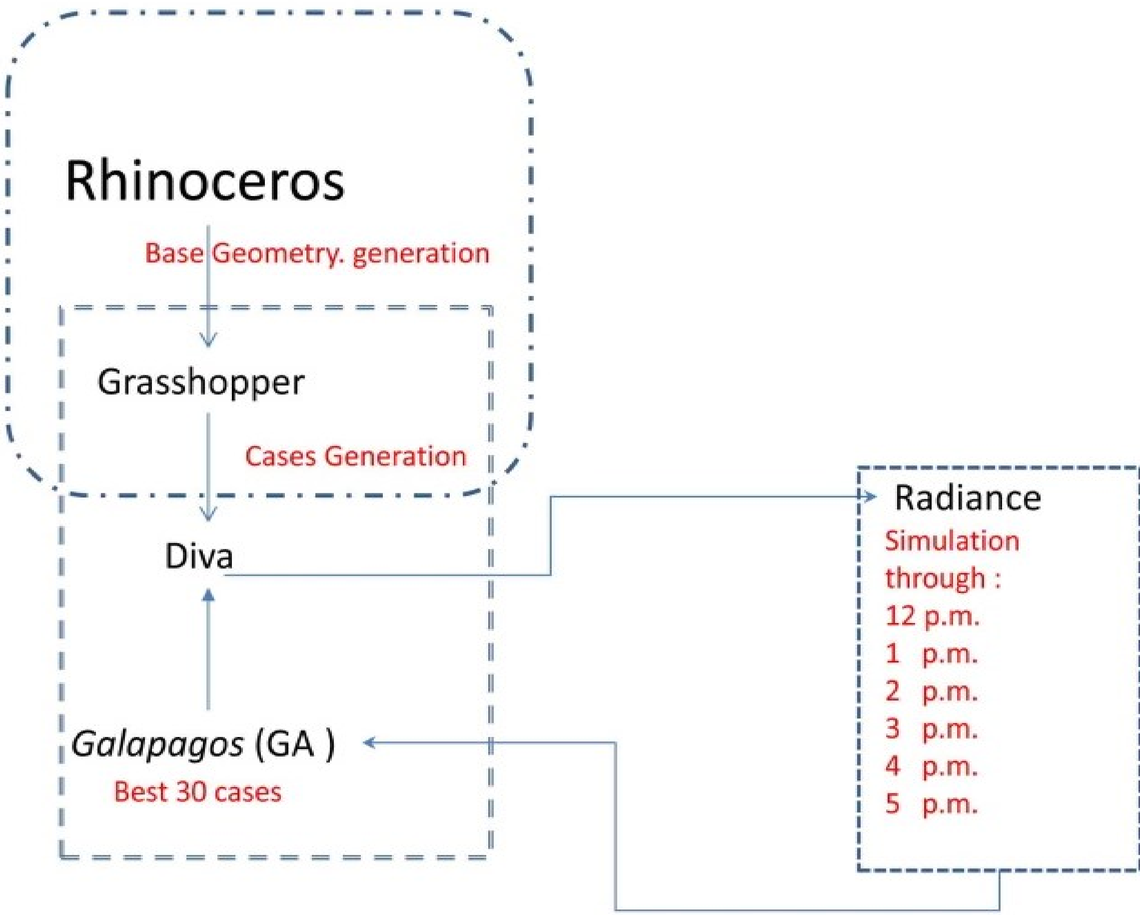


Figure 4-2 Flow chart of the simulation showing the consecutive phases under taken on the lattice screen

The role of the genetic algorithm and its fitness equation is to simultaneously help in the choosing the cases that helps in the penetration of light preventing over illumination in the space. Therefore, a square fitness equation is added to evaluate the illumination of each screen creating a fitness coefficient. The equation tries to minimize the gap and transitions of light trying to reach the optimal illumination which is 500lux.finally, the algorithm will arrange the cases according to their fitness coefficient using the flowing equation:

$$\boldsymbol{F} = \boldsymbol{\Sigma}\,(\boldsymbol{Measured\ illuminance} - \boldsymbol{Desired\ illuminance})^{2} \qquad \textit{Equation 1}$$

The equation measures each illumination value in the analysis grid and subtracts the desired illumination from it then squares the results. On the other hand, each squared value will be added creating a fitness coefficient (F) that resembles the amount of deviation of the proposed lattice screen finally, the GA attempts to find an optimum solution that minimizes the value of the fitness coefficient (F).

The measured illumination is that for the 18 simulation grids mentioned above, while the desired illumination for office space is considered to be 500 lux (Burberry, 1997). This fitness equation places penalties on illumination levels that depart from the desired level, keeping the transitions between the readings as smooth as possible in order to avoid glare. Finally, it is easy to change any of the parameters given and re Conduct the study to fulfill the new requirements. After the simulation process finishes, the best case is validated against another case with a similar rotation angle while changing the size of the modules.

4.4.Simulation methodology

Reviewing the tools section in the previous chapters it becomes more essential to declare the tools used in the simulation process. Therefore this research uses *Rhino 5 the beta version* (Rhino, 2012) the modeling tool for N.U.R.B.S., *Grasshopper v0.9* (Grasshopper, 2010) as the parametric design tool as it is becoming more popular between architects as well and it is a free user friendly software compared to other software as it was mentioned in section 3.4.3 . On the other hand the proposed definition uses *Diva* (Diva, 2012)*,* a plugin for grasshopper that uses *Radiance* for light simulation. *DIVA* for *Grasshopper* has a user-friendly interface, which one uses to choose the type of lighting test, sky condition, solar date and time, and desired illuminance range. Within the context of this study, the “lighting test” was set to “illuminance values,” for the calculation of illuminance nodes evenly distributed over the working plane.

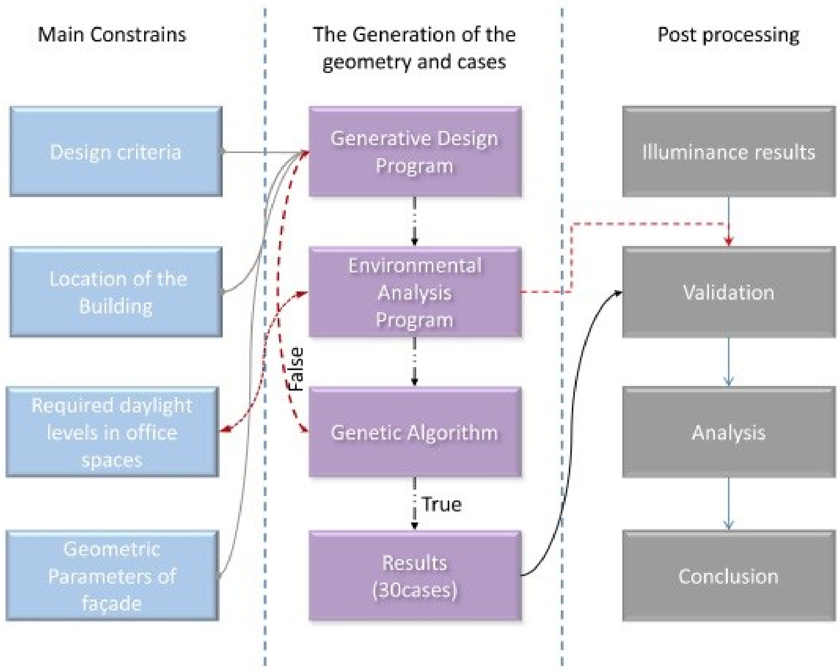


Figure 4-3 Flow chart of the simulation and algorithm procedures

The research adopts simulation methodology is assembled through an algorithm that is represented by a *Grasshopper* definition that all the previous parameters into consideration the algorithm can be divided into three part the first part involves the main constraints that contain the design criteria ,location of the building , required daylight in the space and the geometric parameters of the façade. The second part is where the simulation takes process with the grasshopper definition and its steps the final part involves the post processing of the data gathered from the simulation software. The algorithm shows the relation between the components in the three parts with each other and how the data is entered and exchanged from one part to the other part it shown in (Figure 4-3) that visually represents the algorithm and the steps taken to reach a finding for a lattice Screen that fits in the climate of Egypt and filters the daylight of office buildings to increase the area of active spaces

4.4.1. The definition and algorithm of simulation

The flowchart in the (Figure 4-3) describes the different parts of the simulation. The first phase of the flowchart involves the constant parameters that were described earlier in this chapter concerning the dates and the location of the building the required illumination inside the space and the dimensions of the façade, room and the lattice screen and the constant parameters that were mentioned in (Figure 4-1) and (Table 4-1)

The second phase of the flow chart mainly concerns about the *Grasshopper/ DIVA* definition that conducts the simulation study the definition is composed out of several parts these parts are integrated into the genetic algorithm component *Galapagos*. The first part of the definition involves the geometry generation of the base case geometry the definition starts by constructing the points that creates the boundary of the surfaces of the base geometry and constructing the skin and the distance between the inner and the outer screen preparing the geometry to be manipulated (Figure 4-4) in the next part to apply the design criteria adopted by the research that takes the traditional *Mashrabiya* into consideration through the *Arabesque* pattern.

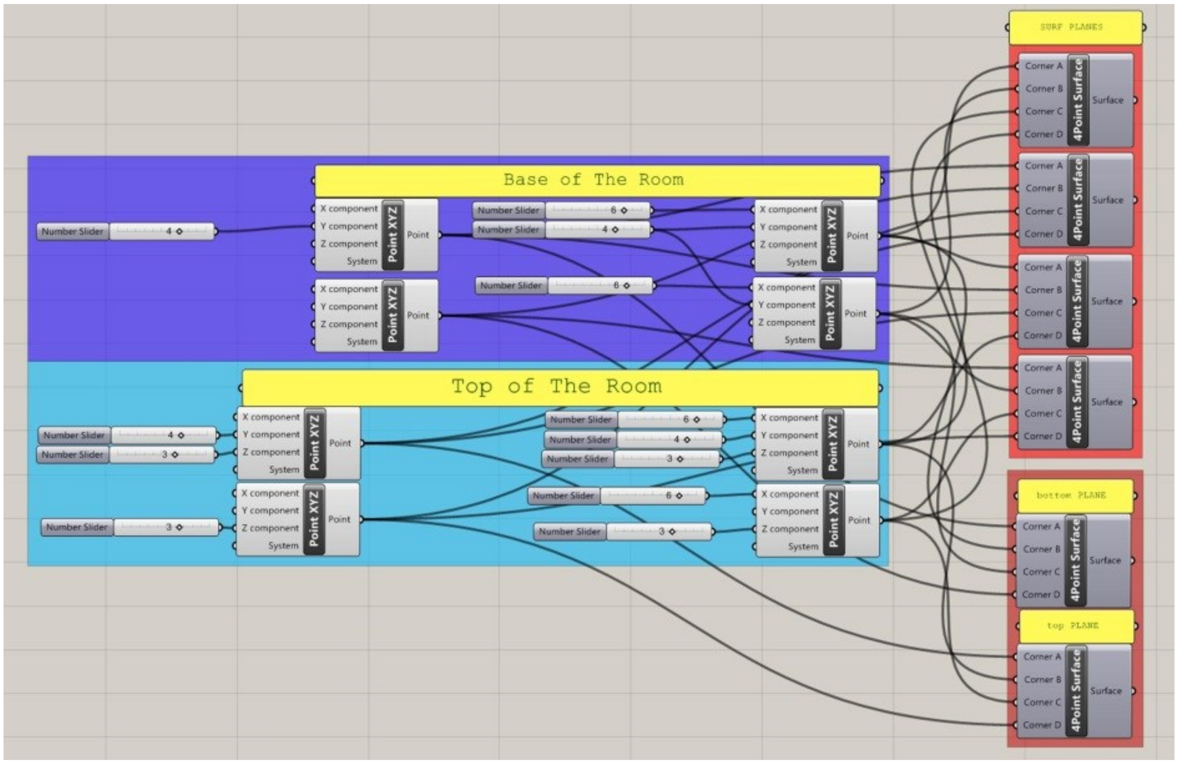


Figure 4-4 The first part of the definition that generates the base case geometry.

The second part of the definition is the part where the cases are generated and the base geometry of the module is populated on the screen surface. The modules geometry is determined by an operator that determines their length and width these modules are then rotated about a three dimensional (3D) axis determined by the researcher which is (1, 1, 1) (Figure 4-5).

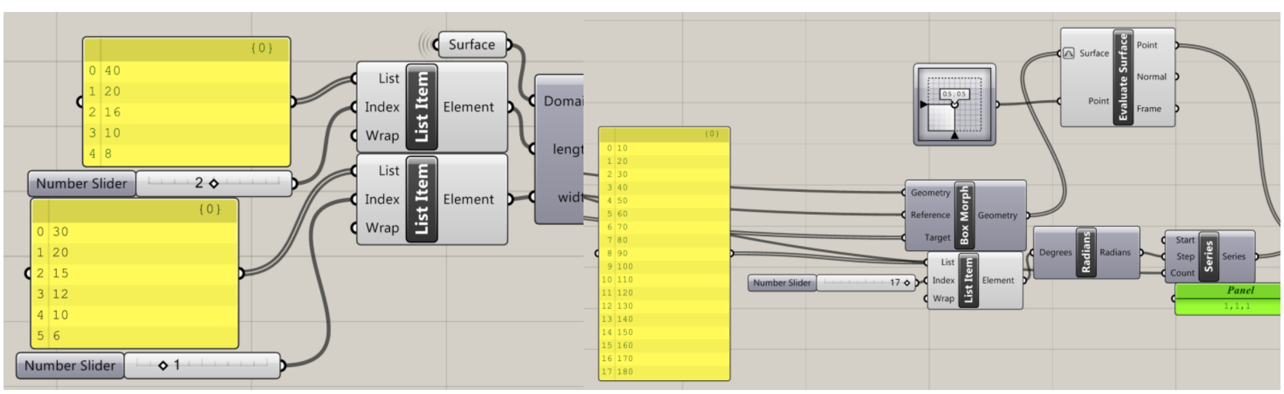


Figure 4-5 GH rotation and the surface division components

The next step is to construct the analysis grid by dividing the surface into modules of 20x20 cm. on the other hand the midpoint of each module is determined to perform the calculation on it (Figure 4-6). Accordingly the materials of each plane is chosen to prepare the geometry for the final stage of data entry which is setting the light simulating operator to begin the pilot simulation phase (Figure 3-5) .

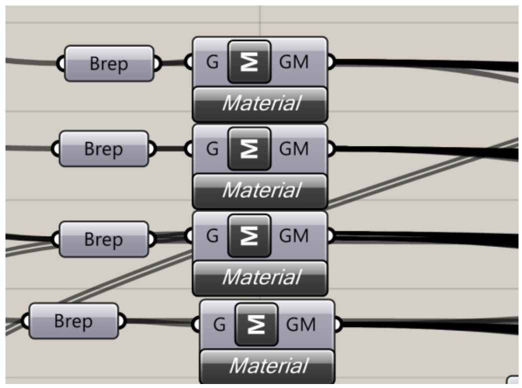


Figure 4-6 The analysis grid and the material operators

The pre-final stage before simulation is to define the fitness equation (Equation 1) that the GA component will perform the evaluation on and finally connecting the parameter sliders and the fitness equation sliders to the *Galapagos* component and start the simulation. The next section will involve the results of the pilot simulation process. The flow of the cases can be seen in the flow chart in Figure 4-7

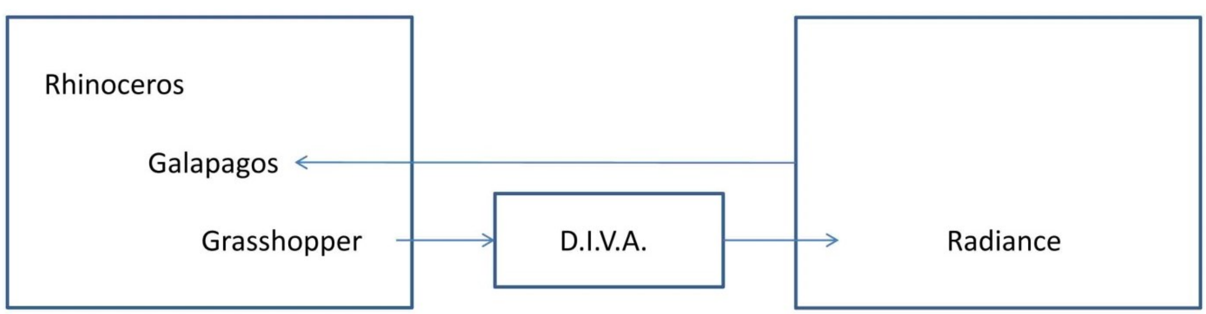


Figure 4-7 Flowchart for the case algorithm

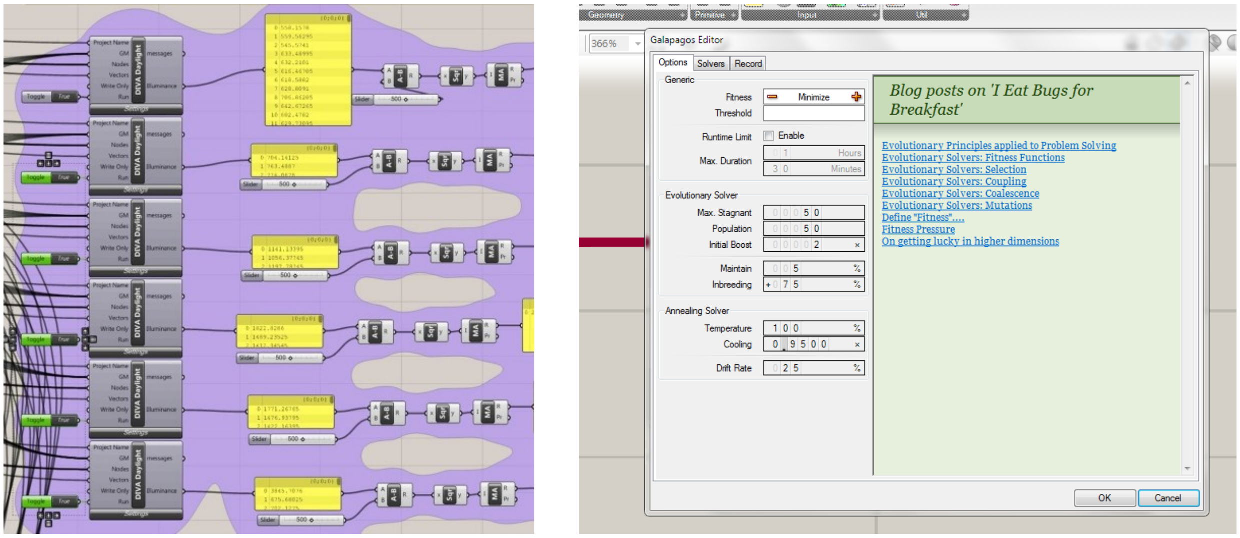


Figure 4-8 The fitness equation and the Galapagos settinsg window

To decrease the time of simulation the results from the equinox in September are used twice to decrease the number of runs per case to 18 runs instead of 24, as the results in March will be similar to the results in September (Table 4-2)

Table 4-2 No of runs and the simulation dates and time

Date	No of runs	Time of simulation
21st Sep/ 21st march	6	12 p.m. ,1 p.m. ,2 p.m. ,3 p.m. ,4 p.m. and 5 p.m.
21st Dec	6	12 p.m. ,1 p.m. ,2 p.m. ,3 p.m. ,4 p.m. and 5 p.m.
21st June	6	12 p.m. ,1 p.m. ,2 p.m. ,3 p.m. ,4 p.m. and 5 p.m.
21st March	6	12 p.m. ,1 p.m. ,2 p.m. ,3 p.m. ,4 p.m. and 5 p.m.
Total	24	

4.5. Results

The simulation process took 8 days and 18 hours to complete 50 generation with a population of 30 genomes. The combinations of parameters for the best 30 cases, as selected by the genetic algorithm, are shown in (Table 4-3) in an ascending order based on the fitness coefficient. These values show the amount of deviation from the desired illumination level (500 lux). The best generated case is presented first with least fitness coefficient (0.52) (; its perforated screen consists of repetitive square modules of 10x10 cm, with an incremental rotation angle of 180° around the rotation vector (1, 1, 1) (Figure 4-9).

Table 4-3 The pilot simulation results:30cases of the final genration

NO	W	H	Θ	F	NO	W	H	Θ	F	NO	W	H	Θ	F
1	10	10	180	0.5179	11	10	15	140	1.0331	21	10	15	90	1.0952
2	10	15	180	0.6168	12	10	10	170	1.0532	22	10	15	120	1.1013
3	10	20	160	0.9948	13	20	25	160	1.0572	23	10	15	80	1.113
4	20	30	130	0.9901	14	25	25	160	1.0625	24	10	10	110	1.1252
5	10	20	170	1.0103	15	10	20	150	1.0641	25	10	15	100	1.1321
6	20	25	60	1.0128	16	20	15	140	1.0698	26	10	10	140	1.1335
7	10	30	90	1.0179	17	10	10	90	1.0701	27	10	15	160	1.1382
8	20	10	110	1.0245	18	10	10	130	1.0756	28	20	25	50	1.1396
9	40	20	80	1.0289	19	10	10	140	1.0798	29	20	20	170	1.1425
10	10	20	120	1.0321	20	10	10	80	1.0824	30	10	10	160	1.4231

It can be seen from the results that the selected 30 cases, with least discrepancy in illumination level around 500 lux, use small modules; only three cases have modules exceeding 25 cm. In addition, nearly all the incremental angles are between 80°-180°; only 2 cases are below 80°. Thus, smaller modules with large incremental rotational angles seem to be more preferable than larger ones with small angles.

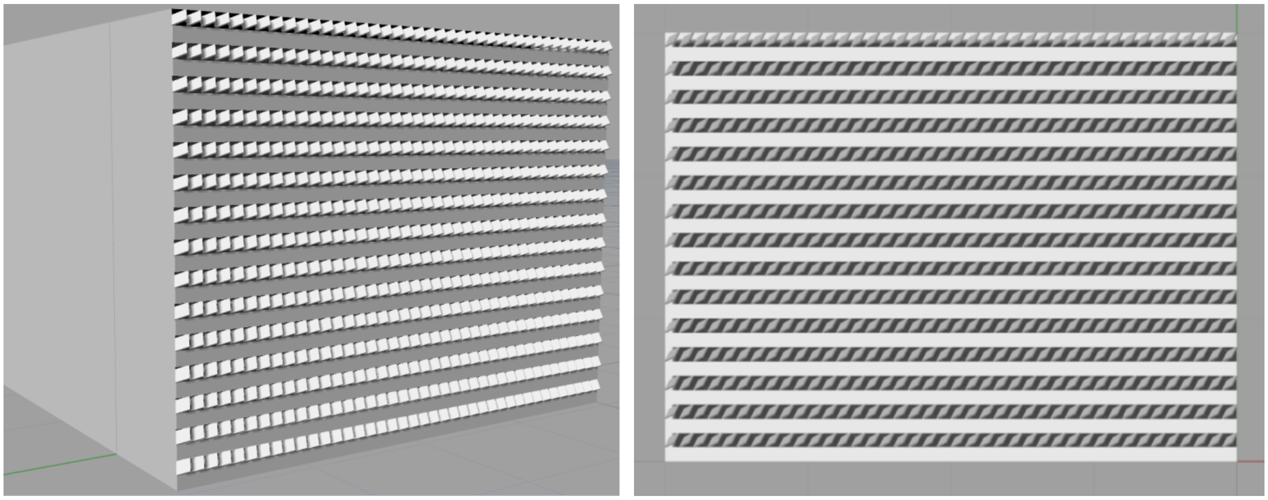


Figure 4-9 Best chosen case from the pilot study

By comparing the simulation results of the best generated case against those of the base case (without a screen), light level distribution of the best generated case showed that 74% of the room area is supplied with acceptable illumination level (300-500 lux) within the 6 simulated hours and the 3 selected days. On the other hand, just 54% of the room area of the base case is supplied with acceptable illumination level (see Figure 4-10 and Figure 4-11).

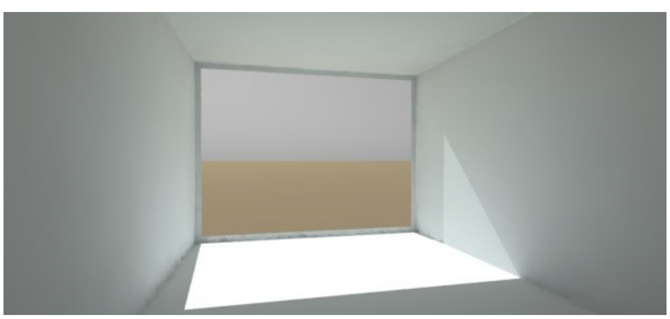


Figure 4-10 Base case 21st June at 4 o'clock

Figure 4-11 betst generated case21st June at 4 o'clock

By analyzing the illumination levels at different hours of the day, natural light penetrates more deeply inside the space of the base case, as expected, with a risk of potential glare at late working hours, especially in winter days. The results of the base case showed that solar radiation penetrates inside the space starting from 2 pm. On the other hand, the generated case delayed this problem two more hours with fine scattered solar spots as shown in (Figure 4-11).

In order to understand the impact of module size on the distribution of light levels, a validation case is generated with reference to the best generated case, where the size of the modules is increased keeping the same incremental rotation angle. The validation case with large modules provided a fitness coefficient value of 1.14101. The large repetitive modules cause more potential glare, which affects the fitness coefficient value (see Figure 4-12 and Figure 4-13).

The definition took the time of the day where the sun is direct on the façade so the definition tended to close the modules this problem may be due to ignoring the time of the day when the sun is not directional on the façade from 9 am till 12 pm.

Although the total number of cases is 540, the genetic algorithm simulated 1500 cases to reach the selected optimal solutions. This wasted more time than necessary because genetic algorithms are suited toward solving problems with very large search spaces. In our future research, we will expand our search space by employing more parameters with finer steps in the final simulation.

Figure 4-12 Top case - 21st of march at 4 o'clock

Figure 4-13 Large modules - 21st of march at 4 o'clock

4.6. Concluding summary

The pilot simulation presents initial findings for the research about design optimization of the light filtering screens (lattice screens) on west-facing façades in order to maintain acceptable illumination levels within a prototypical office space. Based on the presented simulation results, it was concluded that an effective design of the west façade could increase the potential use of daylight in indoor spaces. The use of the fitness function helps in providing smooth light ranges that decreases the risk of potential glare. Accordingly, perforated screens with repetitive modules, inspired by the traditional *Mashrabiya*, improved the distribution of acceptable indoor illumination level from 54% to 78%compared to the base case. The proposed skin delayed the periods of solar penetration and potential glare; the space achieved acceptable indoor illumination level from 12 pm to 4 pm.

The proposed skin increased the areas of the active zone on the space without the support of artificial light though it was facing the western elevation and most of the louvers were directed toward the south. The perforated screen delayed the sun penetration to the space creating potential glare to 2 hours giving the indoor space an active working hours from 9 till 4 (one hour before the employees departure time).

Using a genetic algorithm definition, the best 30 alternatives of the perforated screen and their parameters were presented. Perforated screens with small repetitive modules and large incremental rotational angles were chosen by the algorithm as they diffuse more light and increase acceptable daylight levels in the space. The used parameters and genetic algorithm need further refinement as they failed to give conclusive results and consumed more time than expected.

The pilot study showed that perforated screens with repetitive modules derived from the traditional *Mashrabiya* are effective in west elevations. More refined analysis grid, more values for module parameters, and different rotation axis are to be tested in the full simulation process in order to reach more efficient solutions. The recommendations given by the pilot case will help reaching a solid finding in the full simulation in the next chapter

5. Simulation Results and Optimal Designs

5.1. Introduction

This chapter deals with the full simulation of the research in the previous chapter a pilot study was conducted to evaluate the definition and to refine the definition to assure that the results are valid. The simulation process has been refined based on the results of the pilot study (chapter 4) and its recommendations

This chapter will show the refinements made to the algorithm of the pilot case and the final simulation stage. To implement the recommendations from the pilot study some research should be conducted to reach an optimum result that fits within the algorithm without wasting time of processing. The pilot study recommendations stated three main recommendations the first was the analysis grid spacing where the problem with large analysis grid and small modules was that the areas with high contrast where not easy to be represented .therefore finer spacing in the analysis grid should be chosen carefully to verify the results from the simulation, then working on increasing the cases by defining the missing axes that were omitted in the pilot study and finally introducing hours were the sun is not incident on the façade

5.2. Refinement of Parameters

The definition needed some refinements as it was stated in the pilot study. To refine the analysis grid a study was conducted to reach the proper resolution for the grid. Therefore three grids where constructed a grid with 15x15 cm, 10x10 cm and 5x5 cm on the best case by the pilot study (Figure 5-1). The three grids were simulated on the 21st of July to test the analysis grid at 2 pm. It was found that the 5 cm grid had the best resolution but it took long calculation period (6 minutes per case). On the other hand the 15 cm grid failed to detect the gaps between different contrasts. Hence, the 10 cm grid showed the gaps successfully and took a reasonable time for simulating the case (4 minutes per run). Therefore the 10 cm was chosen for the final simulation process.

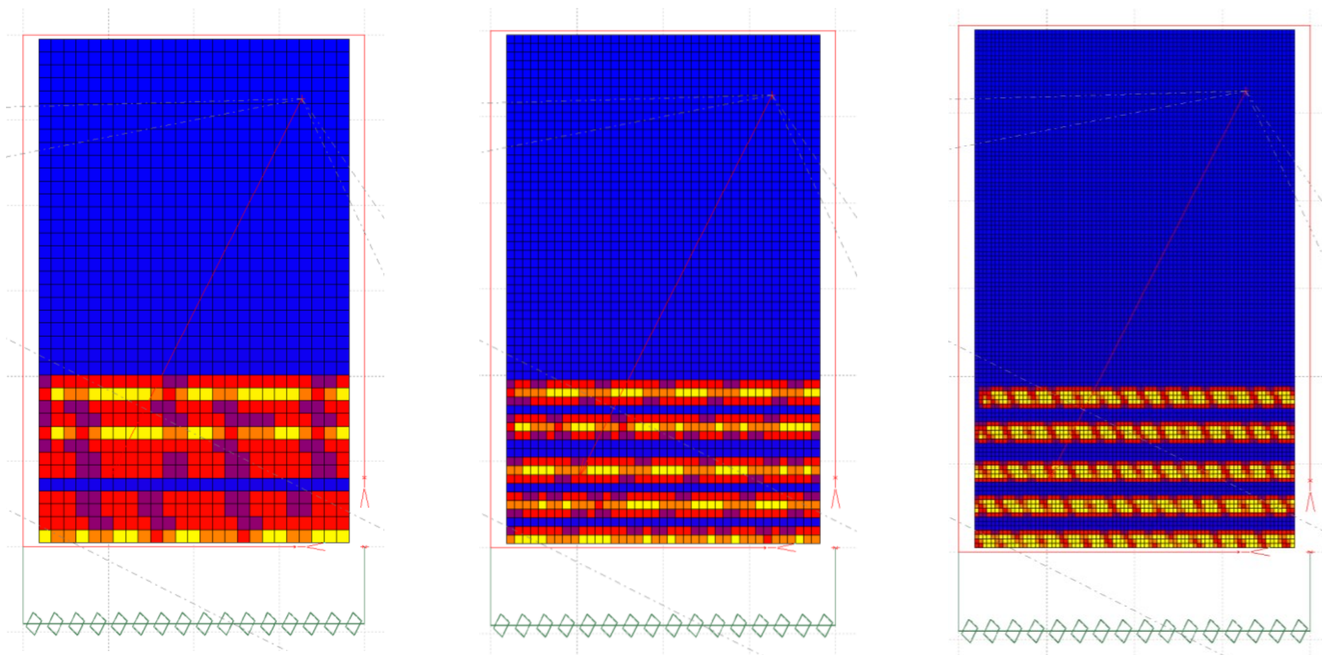


Figure 5-1 The tested analysis grids 15,10 and 5 cm the medium sized grid proved to be the most efficient

The next step involves the cases in the pilot study were few for the algorithm to choose from, the pilot study had 540 case. The final simulation cases are 9720 cases where in the pilot study the rotation axis was (1,1,1) in the full simulation 17 rotation axis were used (Table 5-1).

Table 5-1 Showing the axis used for the final simulation process

Axis (X,Y,Z) respectively					
(0,0,1)	(0,1,1)	(1,1,1)	(0,0,-1)	(0,-1,-1)	(-1,-1,-1)
(1,0,0)	(1,1,0)	(1,0,1)	(1,0,0)	(1,-1,0)	(1,0,-1)
(-1,0,0)	(-1,-1,0)	(-1,0,-1)	(-1,1,0)	(-1,0,1)	

The genetic algorithm in the pilot study was set to find 30 genomes in each generation increasing the genomes in one generation was made in the full simulation to reach 50 genomes if the simulation did not stop its own as it is recommended by *David Rutten* developer of grasshopper (Rutten, 2010). The final step in refining the definition is to change the time of the simulation using 9am, 11am, 1pm, 3pm and 5pm in the *Diva* component,this step makes the perforated screen valid throughout the day.

5.3. Full Simulation Results

The simulation process took 14 days and 14 hours to complete 84 generation with a population of 50 genomes (Table 5-2Figure 5-2). The combinations of parameters for the best 50 cases, as selected by the genetic algorithm, are shown in an ascending order based on the fitness coefficient. These values show the amount of deviation from the desired illumination level (500 lux) (Table 5-2). The best generated case is presented first with least fitness coefficient (0.051); its perforated screen consists of repetitive square modules of 25x15 cm, with an incremental rotation angle of 180 degrees around the rotation vector (-1, -1, 1)(Figure 5-3).

Table 5-2 Refinements of the parameters in the full simulation as compared with the pilot study

Parameters	Pilot study	Full simulation
Rotation Axis	Only one axis (1,1,1)	17 axis (Table 5-1)
No of genomes	30	50
Simulation hours	12, 1, 2, 3, 4, 5pm	9am, 11am, 1pm, 3pm, 5pm
No of generations	40	86

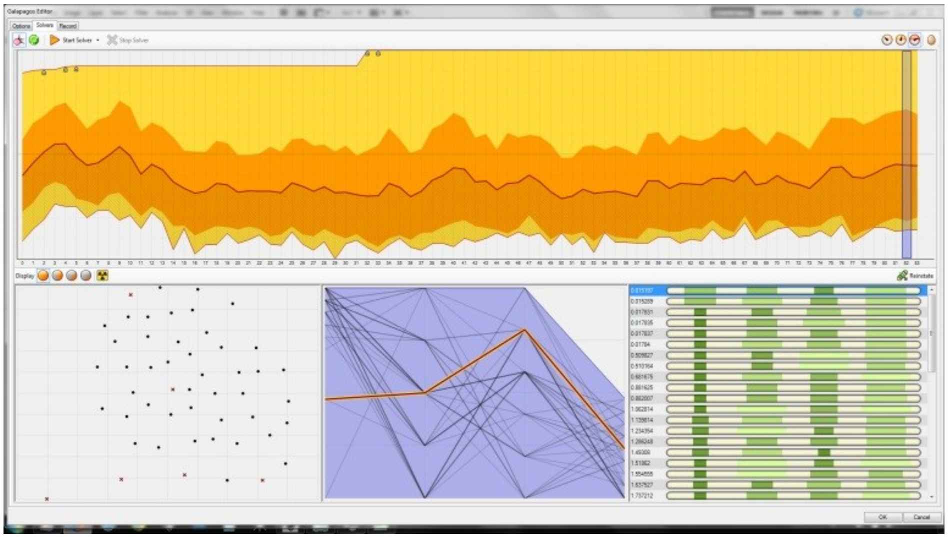


Figure 5-2 Simulation Generations in Galapagos

It can be seen from the results (Table 5-3) that the best 30 cases from the 50 genomes chosen by the program, with least discrepancy of illumination level around the 500 lux optimal illumination level.

Table 5-3 Final results table

NO	W	H	ϴ	Axis	F
1	25	15	180	(-1,-1,1)	0.0151
2	20	20	180	(-1,1,-1)	0.0152
3	10	15	180	(-1,1,-1)	0.017831
4	10	10	180	(-1,1,-1)	0.017835
5	50	10	180	(-1,0,-1)	0.017837
6	25	20	160	(-1,0,0)	0.5
7	40	15	180	(-1,0,-1)	0.51
8	20	30	170	(-1,0,0)	0.68
9	20	15	180	(-1,1,-1)	0.88
10	40	20	180	(-1,0,-1)	1.06
11	40	20	140	(-1,0,1)	1.13
12	20	10	180	(-1,1,-1)	1.25
13	50	10	170	(-1,0,0)	1.49
14	10	15	180	(-1,1,0)	1.665
15	10	30	180	(-1,1,0)	1.671
16	10	30	80	(-1,-1,0)	1.672
17	25	30	160	(-1,-1,-1)	1.701
18	50	15	170	(-1,0,1)	1.801
19	20	15	170	(-1,1,-1)	1.831
20	20	25	150	(-1,-1,-1)	1.839
21	25	30	180	(-1,-1,-1)	1.865
22	25	30	150	(-1,-1,-1)	1.883
23	40	30	180	(-1,-1,-1)	1.9077
24	25	25	180	(-1,-1,0)	1.922
25	40	10	180	(-1,-1,-1)	1.954
26	20	30	160	(-1,-1,-1)	1.977
27	25	25	170	(-1,-1,-1)	1.99
28	25	30	90	(-1,0,0)	2.01
29	25	20	170	(-1,1,-1)	2.03
30	20	20	180	(-1,-1,0)	2.06
31	20	15	170	(-1,1,0)	2.09
32	40	25	150	(-1,1,-1)	2.125
33	40	20	170	(-1,-1,-1)	2.156
34	20	30	170	(-1,1,-1)	2.164
35	50	50	140	(-1,0,-1)	2.239
36	25	25	170	(-1,0,0)	2.2397
37	10	25	170	(-1,0,-1)	2.26
38	25	10	170	(-1,0,0)	2.27
39	50	25	140	(-1,1,-1)	2.31
40	50	10	160	(-1,0,-1)	2.33
41	20	15	90	(-1,-1,1)	2.386
42	10	50	10	(-1,-1,-1)	2.398
43	10	30	10	(-1,1,0)	2.407
44	50	50	20	(-1,1,0)	2.439
45	20	50	10	(-1,1,0)	2.44
46	50	10	50	(-1,-1,0)	2.45
47	50	25	50	(-1,-1,-1)	2.48
48	20	50	70	(-1,0,1)	2.5
49	10	50	50	(-1,1,-1)	2.531
50	50	15	20	(-1,-1,-1)	2.533

1. Provides small modules.
2. 180 ◦ rotation angles seems to be preferable among most of the 50 cases (this results in a screen of alternating closed and semi-open rows
3. The values of the fitness coefficient, in the first five cases are smaller than the values that were generated from the pilot study as a result of introducing new axis.
4. The generated cases from the full simulation provided lss deviation from the desired lux range (500lux)
5. There was no change in the time of the penetration of the direct solar radiation (2 pm)

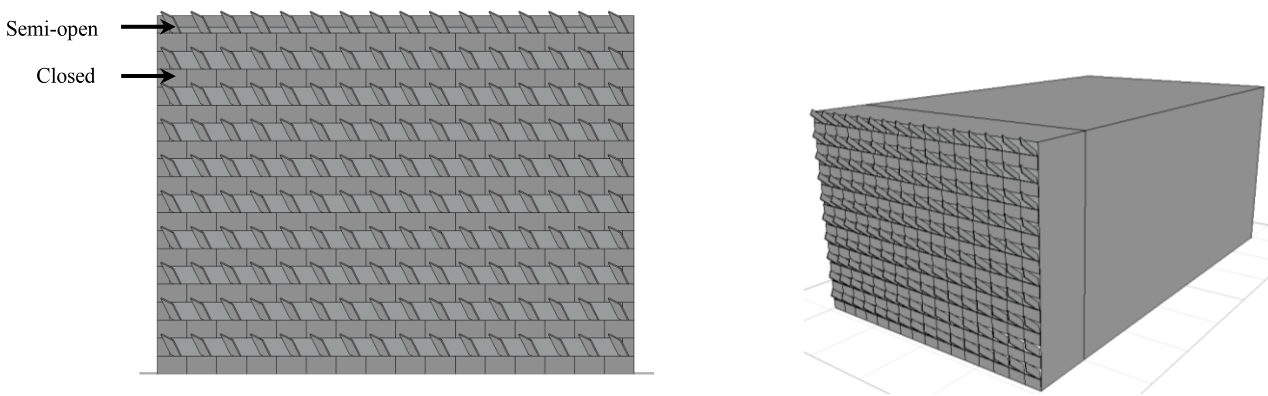


Figure 5-3 Best chosen case by the genetic algorithm (front and perspective views)

The best chosen case as mentioned before has the dimensions of 15x25 cm and 50% of the louvers are closed the other half is facing the north side with a rotation angle180 along the three main axis the X, Y and Z axis has the opposite orientation of the best Chosen case of the pilot study Figure 5-3

5.4. Discussion

The simulation result showed some findings that will help optimizing a western double skin façade in Egypt. Maintaining acceptable light quality in the prototypical; office space was the main aim of the research. Based on the simulation it was shown that using parametric tool integrated with environmental analysis tool could merge and decrease the gap between the conceptual design and the environmental analysis phase in the design process. On the other hand using lattice screens based on the historical mashrabiya leads to improve the areas that depend mainly on natural light (active spaces). As it was mentioned Egypt is considered to be one of the wealthiest countries in term of sunlight 325 days of clear sky (Yansane, 2011) . Accordingly the potential of using naturally illuminated spaces in Egypt is high .on the other hand over illumination and potential glare create functional and environmental problems. Therefore

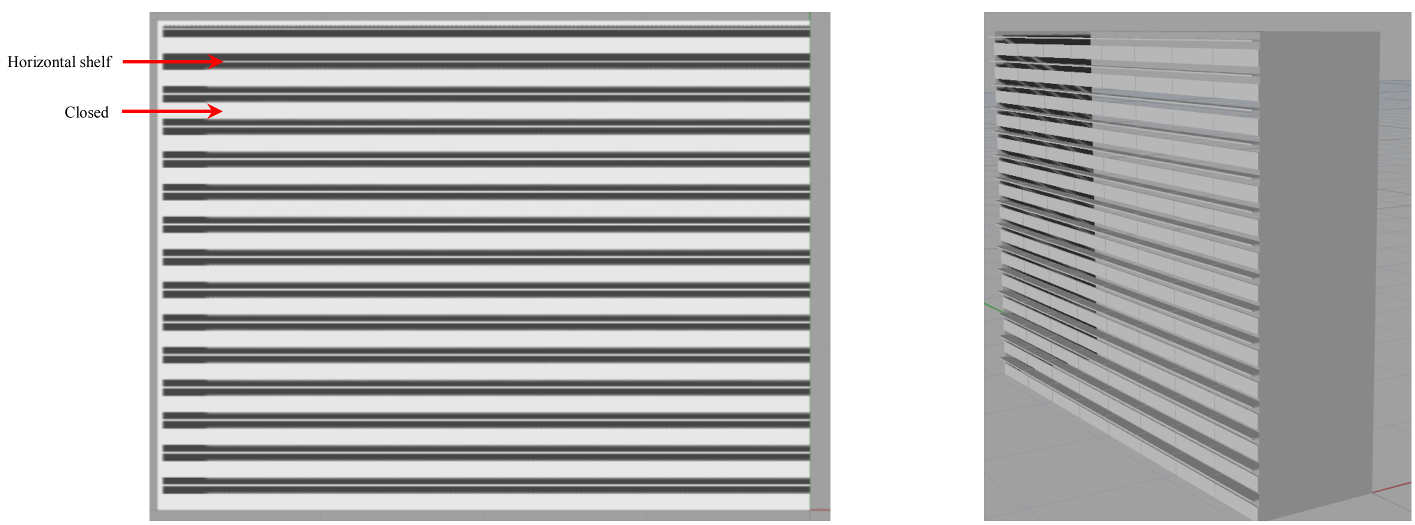


Figure 5-4 case no 5 in the simulation process.

The usage of perforated screen that adopts a similar logic to the arabesque pattern can improve the quality of light in the interior space.

It can be seen from the results that the selected 50 cases, with least discrepancy in illumination level around 500 lux, provide small modules; 16 cases with modules exceeding 25 cm exist. In addition, nearly all the incremental angles are between 80-180 degrees; only 9 cases are below 80 degrees. Thus, smaller modules with large incremental rotational angles seem to be more preferable than larger ones with small angles. On the other hand it can be seen from Table 5-3 that case 5 had the width of 50 cm and the height of 10cm with the incremental angle of 180° from the case it can be seen the perforated skin provides small openings that filters the daylight Figure 5-4.

Although the modules are large (50 x 10 cm), they are arranged in a pattern that filters sunlight effectively buy providing a row of a horizontal shelf and anther closed row consecutively

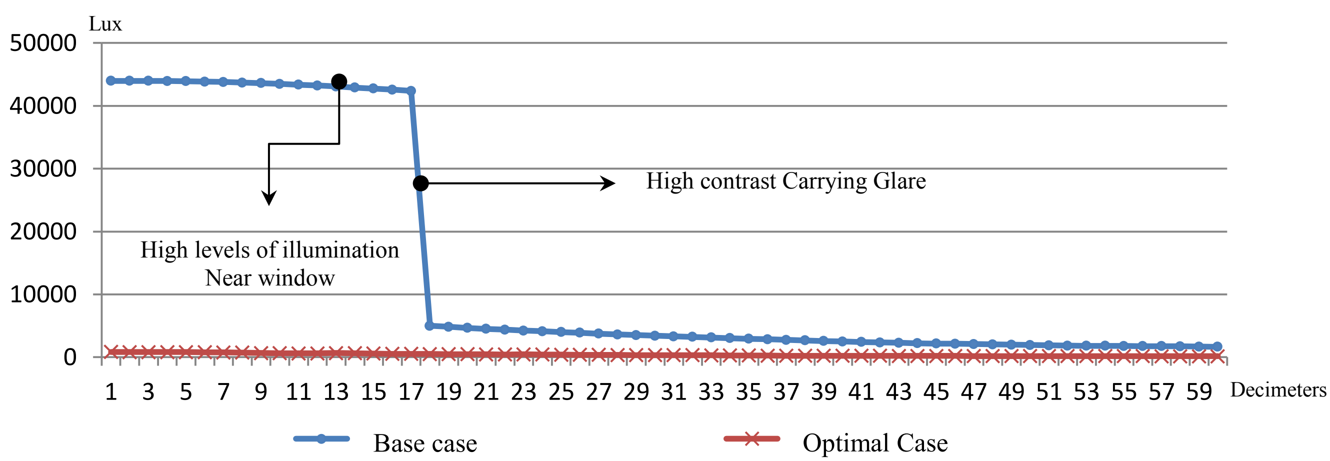


Figure 5-5 chart of illumination at 2 o'clock in the middle of the room between the bas case and the optimal

The results of the simulation showed that using perforated skin improved the light quality of the space during the period of incident sun rays, where the base case scored illumination levels at 2 pm of over 40000 lux the perforated screen scored about 850 lux. It is shown in (Figure 5-5) that there is high contrast in the base case in the area of incident radiation and the rest of the room; accordingly there is high potential for glare that will lead to closing the blinds and using artificial light to avoid eyestrain. On the other hand, the optimal case showed smooth transition between the contrasts of light with maximum illumination of 847 lux and minim of 150 lux (Figure 5-6)

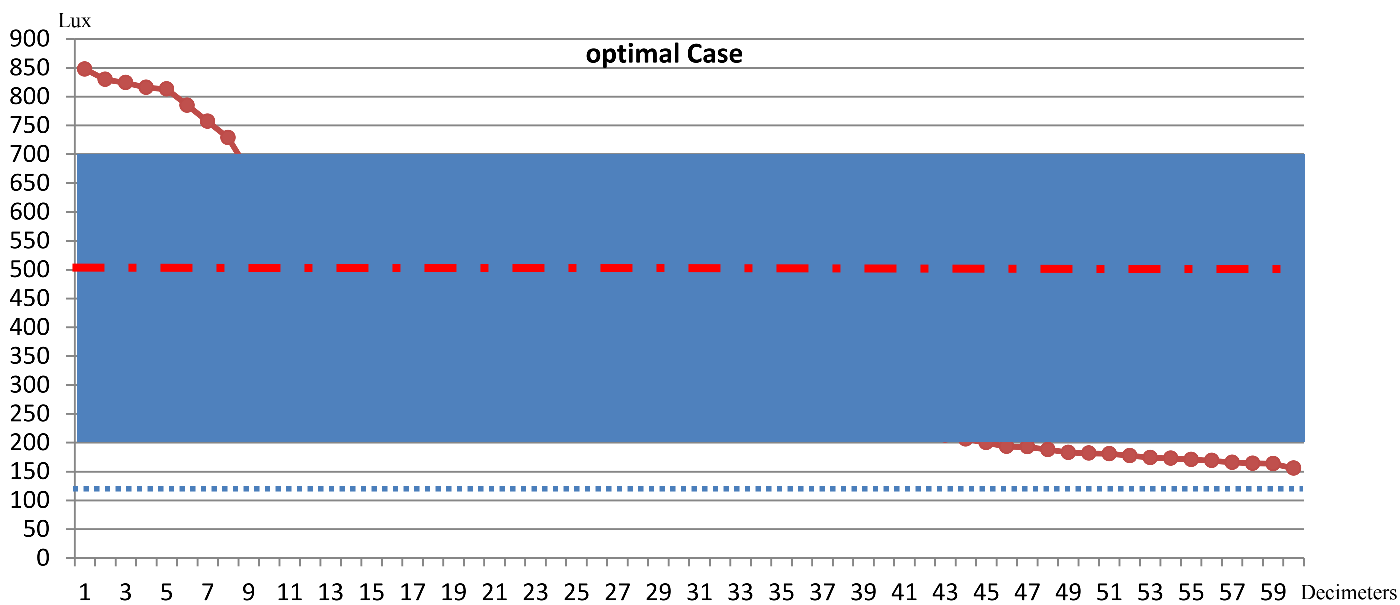


Figure 5-6 the illumination chart of the optimal case(cross section with window at the left hand side)

The perforated screen delayed the light penetration from pm till 4 pm (one hour before employees' departure time) by analyzing the illumination in different time of the day we find that the best chosen case has an active area of light by 75% and the rest is within the acceptable ranges (Figure 5-6), on the other hand the base case has an active area of 20% and 40% of area that falls in the over illumination ranges and the rest is within the acceptable amount of illumination. On the other hand all the room fell in the range of 115 to 1500 lux the 115 lux is defined in the Figure 5-5 by the blue dotted line showing the datum of the dimmed zone, it can also be seen in the chart that the amount of deviation from the desired lux range in the office space 500 lux falls in the acceptable range as it increased the active area that fell between the desired useful daylight zone (700-200 lux) (Nabil & Mardaljevic, 2006)

.Comparing the best case from the pilot study with the best case from the full simulation it can be found that in the base case 55% of the space fell in the range between the 200 to 700 lux the active area while in the best chosen case this area was increased to 75% of the space. On the other hand according to (Nabil & Mardaljevic, 2006) it can be noticed from the chart in Figure 5-7 that simulation case shows less deviation than that of the pilot case from the desired illumination 500 lux and that describes the variation between the 2 fitness coefficient which is 0.015 to the simulation case and 0.51 to the pilot case. The fitness coefficient showed that it succeeded in finding a case that provides minimum deviation from the desired lux range and it increased the area of active zones in the office spaces

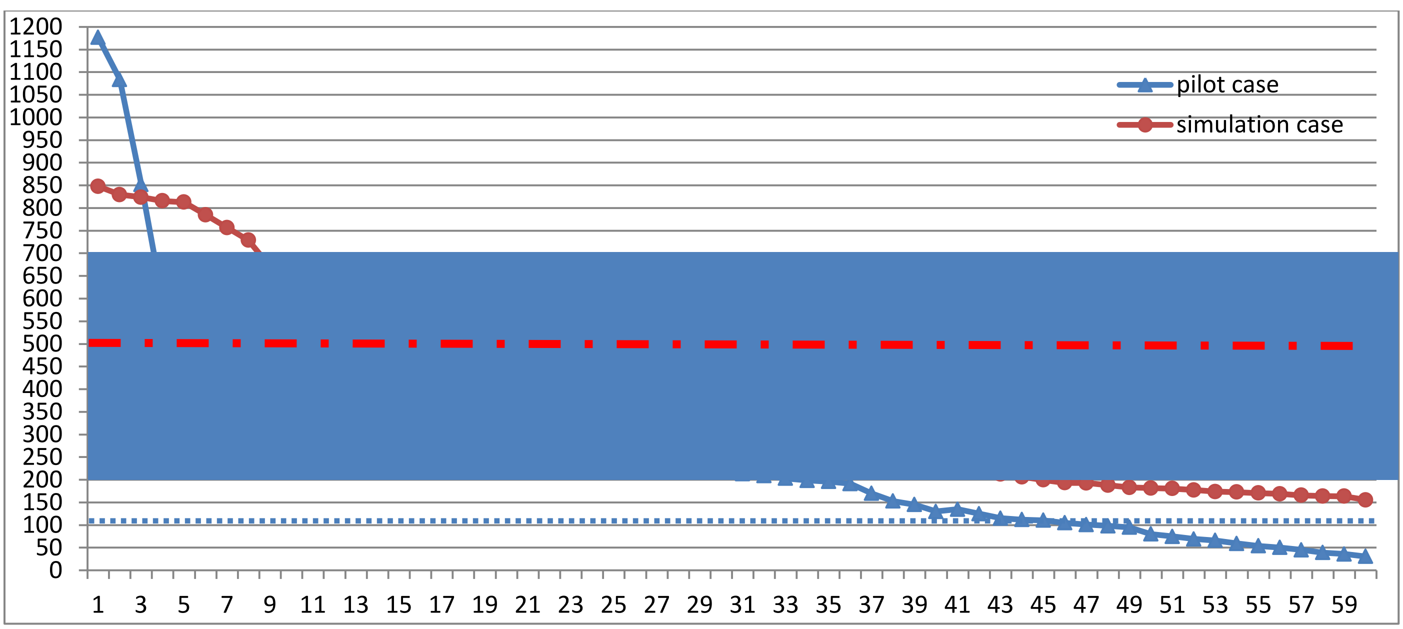


Figure 5-7 chart comparing the pilot and the simulation best cases

Finally, the best chosen case will be compared to the generated case from Ecotect. The comparison aims to find the performance of the normal used cases in Egypt to the new generated case and compare their performance by their fitness coefficient. Comparing the two cases it was found that at 4 pm the optimal case performance was better than that of the normal shading case (Figure 5-8).

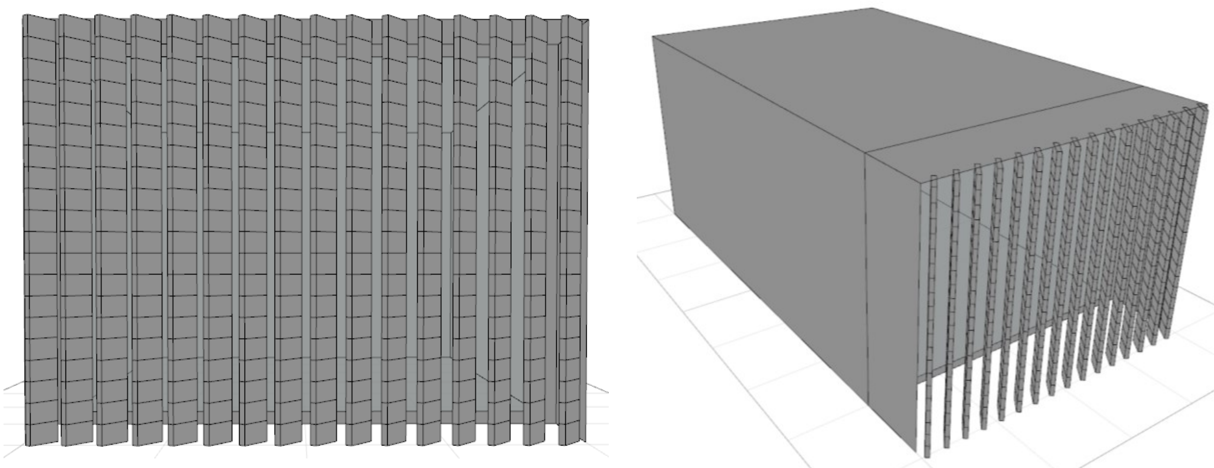


Figure 5-8 normal generated case from Ecotect (front and perspective views)

On the other hand, the normal shading case scored a 1.95 fitness coefficient while the optimal case scored a 0.015 making it better than the normal case. Accordingly, the genetic algorithm and its fitness equation proved to be effective to search and find a lattice screen that respond to the environment maximizing the usage of naturally illuminated spaces

From the chart that compares the normal case and the optimal case it can be seen that the optimal case from the algorithm it is shown its deviation from the desired lux range (500 lux) is less than that of the normal case decreasing the possibility of over illumination and potential glare. Finally, the square fitness equation proved to be very effective choosing a lattice screen that allows light to penetrate to space and eliminates the risk of over illumination and potential glare

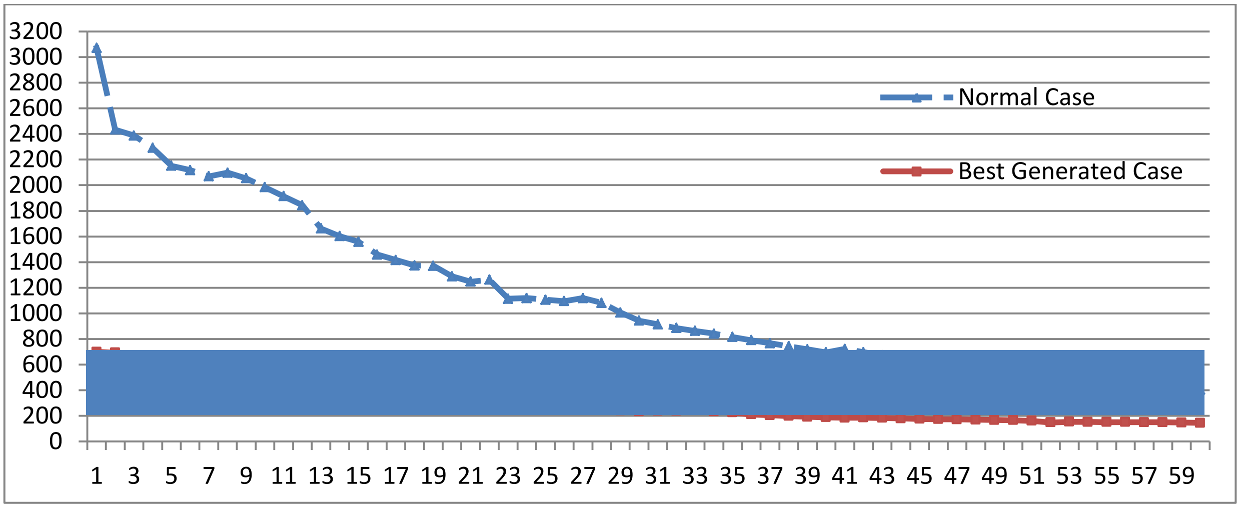


Figure 5-9 chart comparing the pilot and the simulation best cases

5.5. Concluding summary

Using perforated screens in the western façade inspired by the traditional *Mashrabiya* proved to have a positive impact on the quality of light in the interior spaces .accordingly it is highly recommended to use perforated walls in the western facades of office buildings in Egypt as it increases the quality of light and saves energy. Contemporary office buildings in Egypt use large areas of glass in the western façades of buildings which is one of the reasons of energy wastage. It was shown in this study that it is required to filter the day light in order to avoid over illumination of spaces. On the other hand the proposed skin showed that it increased the active zones in the prototypical room in an office space to 75% at the time of sun penetration to that of the base case.

Using computer simulation combined with genetic algorithms and parametric modeling tools helps architects to reach a solid finding concerning the quality of light in the interior spaces. The integration of parametric design tools for modeling and environmental analysis tools combined with genetic algorithms help in creating building that respond to the environment and saves energy. In the simulation process the fitness equation plays a primary role in finding the solution that designers search for. Accordingly the comparison between the best chosen cases from the pilot study and the simulation case shown a significant decrease in the fitness coefficient, it was shown in the charts that the amount of deviation in the best case was significantly better than that of the pilot case.

6. Conclusion and Further recommendation

6.1.Concluding Summary of the research

Office building are one of the main energy consumers, reducing the energy in office buildings should be taken into consideration form the conceptual design phase till construction. On the other hand, Most of contemporary office buildings in Egypt ignore the environment accordingly large amount of energy is wasted to maintain the quality of the indoor space. Parametric architecture is a new trend that has been gaining momentum over the past few years. Computer simulations are effective to help architects detect and solve problems of the building before the construction phase. Combining parametric modeling tools with computer environmental simulation can help architects create buildings that respond to the environment

Office buildings in Egypt use large areas of glass that lead to over illumination and discomfort of the user. Taking the orientation of the facades used as the window plane into consideration improve the quality of light in the indoor space and prevent user discomfort leading to better production and saving energy. East and west facing façades should be taken into consideration as they face the direct solar radiation from noon-time till sun set. Looking into the vernacular architecture can help architects find an solve problems that relate to the environment

Architects always display a design strategy to reach a solution for the problems facing them but there is a limit to the alternatives that architects can reach. Using parametric tools has proven to be of great use when it comes for design exploration. Parametric tools proved to be useful when it comes to optimization and setting conditions that alters the outcomes of the deign it helps in merging the gap between the conceptual design phases, it can help creating buildings that respond to the environment

This research adopts a simulation process to optimize the design of perforated screens for the west façades of office buildings in Egypt. The screen is assembled of small modules that are developed from the traditional *Mashrabiya*, as the facade is made out of low-e double glazed curtain wall to maximize the penetration of the light. The aim of the research is to find relation between the proposed parameters and each other to optimize the amount of light that enters the space increasing the active zones. The simulation process presented solid findings for the research about optimizing an outer-skin of a west-facing façade to maintain the quality of illumination in the indoor space. Based on the results of the research it was concluded that the integration between parametric modeling tools and computer simulation can increase the potential use of natural light in the indoor space. Using the square fitness equation helped in providing solution that decreased potential glare as that proved smooth ranges of light and prevented a huge difference in the contrast. Accordingly, perforated screens with repetitive modules, assembled as an outer skin and developed from the traditional *Mashrabiya*, improved the distribution of acceptable indoor illumination level from 40% to 75%. The proposed skin delayed the periods of solar penetration and potential glare; the space achieved acceptable indoor illumination level from 9 am to 4 pm.

The best chosen case increased the active zones that without the support of artificial light though it was facing the western elevation and most of the louvers were directed towards the north. The perforated screen delayed the sun penetration into the space creating potential glare to 2 hours given that the active time of the interior space is from 9am till 4pm (one hour before employees departure time) while the base case showed penetration from 2 o'clock

The usage of genetic algorithms combined with computer simulation helped reaching solid findings for the optimization of a western D.S.F in Egypt; the process is slow and may take several weeks according to the defined spectrum of the parameters chosen by the architect.

Genetic algorithms choose from these parameters creating genomes that create generations the number of genomes and generations can be defined by the architect according to the time available. In this research the generations where not chosen and the simulation process stopped by its own giving us the best 50 alternatives of the perforated screen and their parameters were presented. Perforated screens with small repetitive modules and large incremental rotational angles were chosen by the algorithm as they diffuse more light and increase acceptable daylight levels in the space.

A pilot study was conducted to verifying the definition and the fitness equation can help in optimizing the outer skin of office buildings in Egypt the simulation process showed some initial findings. The best chosen case in the pilot study showed increase in the active zones by 55% to that of the base case and the proposed skin succeeded in delaying the sun penetration. These finding showed some refinements to the full simulation. The simulation process refinements where taken into consideration and the simulation took 16days and 18 hours to reach best 50 cases. The best chosen case as mentioned before has the dimensions of 15x25 cm and 50% of the louvers are closed the other half is facing the north side with a rotation angle along the three main axis the X, Y and Z axis with the incremental angle of 180° which has the opposite orientation of the best chosen case of the pilot study. This case showed a fitness coefficient of 0.015 that showed smooth deviation in comparison to other cases from the desired illumination value 500 lux. The best case shoed that the definition and the fitness equation can help in reaching solutions that respond to the environment

Finally the research did not find any pattern or relation between the parameters that were chosen. On the other hand the simulation process proposed a methodology that will help in decreasing the time gap between the conceptual design and the environmental adaptation of buildings. Parametric design tools showed solid findings in improving the quality of light in office spaces using genetic algorithms. Genetic algorithms may take several weeks to reach a solution but by identifying the parameters of the research carefully time wastage could be avoided. The next section of this chapter deals with further recommendations for the research

6.2.Further Recommendations

By analyzing the results of the simulation it was found that the research proposed materials only for the sake of conducting the research, thus it is more likely that more research should be taken into consideration regarding the materials and their behavior to light reflection and refraction in the space. The research proposed square modules that acts as the louvers in the outer skin different shapes should be taken into consideration and porous modules should be tested. Sharp edges may not diffuse light as rounded edges so the edges of the louvers should be tested and taken into consideration in porous modules as well. This research deals with the light penetration and do not take daylight harvesting into consideration day light harvesting should be taken into consideration as it might increase the active zones in office spaces.

The shape of the modules should be tested to help in finding smooth transitions between light intensities to eliminate the possibility of potential glare as square modules result in high contrasts between light and shade zones. Accordingly the genetic algorithm should be tested on the modules and how they perform in the interior space

Bibliography

Ander, G.D., 2003. *Daylighting Performance and Design*. 2nd ed. United States Of America: John Wiley & Sons.

ArchiNet, 2013. *ArchiNet discussion Forum*. [Online] Available at: http://archinect.com/forum/thread/88049/gc-and-grasshopper-what-s-the-difference [Accessed 23 Augustus 2013].

Azza, N. & John, M., 2006. Useful daylight illuminance: a new paradigm for assessing daylight in buildings. *Energy and Buildings*, 38(7), pp.905-13.

BBRI, 2002. *Belgian Building Research Institute*. [Online] Available at: http://www.bbri.be/activefacades/index2.htm [Accessed 26 November 2012].

Bentley, 2005. *Bently Inc.* [Online] Bentely Systems Inc. Available at: http://ftp2.bentley.com/dist/collateral/Web/Building/GenerativeComponents/ProductDataSheet.pdf [Accessed 23 October 2013].

Bentley, 2011. *Bentley Systems, Incorporated*. [Online] Available at: http://www.bentley.com/en-US/promo/Generative+Components.htm [Accessed 20 May 2012].

Boubekri, M., 2008. *Daylighting, Architecture and Health*. First ed. London: Elsevier Ldt.

Britannica, 2013. *Britannica Encyclopaedia*. [Online] Available at: http://www.britannica.com/EBchecked/topic/79738/brise-soleil [Accessed 22 February 2014].

Burberry, P., 1997. *Mitchell`s Environment and Services*. london : Wesly Longman.

cookfox, 2013. *Archdaily*. [Online] Available at: http://www.archdaily.com/457436/300-lafayette-street-cookfox/ [Accessed 28 January 2014].

Department of Energy, 2000. *http://energy.gov/*. [Online] Available at: http://energy.gov/search/site/radiance [Accessed 13 March 2013].

Design Builder, 2005. *Design Builder*. [Online] Available at: http://www.designbuilder.co.uk/content/view/29/44/ [Accessed 23 May 2011].

Diva, 2012. *Diva4rhino*. [Online] Available at: http://diva4rhino.com/.

Ecotect, 2001. *Autodesk*. [Online] (2011) Available at: http://usa.autodesk.com/ecotect-analysis/ [Accessed 9 March 2011].

Egyptian Government, 2011. *Egyptian Government Services Portal*. [Online] Available at: http://www.egypt.gov.eg/english/laws/labour/ [Accessed 26 November 2011].

Electric power reasarch Institute of Palo Alto, California, 2008. *electric power research institute*. [Online] Available at: http://www.epri.com [Accessed 27 May 2011].

El-Sheikh, m. & Gerber, D., 2011. Building Skin Intelligence. In *Procedings of the 2011 ACADIA*. CALGARY, CANADA, 2011.

Elsherif, H., 2013. *Blogspot*. [Online] Available at: khushushban.blogspot.com [Accessed 20 July 2013].

EPRI, 2000. *electric power research institute of palo Alto California*. [Online] Available at: http://www.epri.com [Accessed 15 March 2012].

Etman, O., Tolba, O. & EzzEldine, S., 2013. Double-Skin Façades in Egypt between Parametric and Climatic Approaches. In *Proceedings of the 31st eCAADe Conference – Volume 1, Faculty of Architecture, Delft University of Technology*. Delft, The Netherlands, 2013.

Franta, G. & Anstead, K., 1994. Daylighting Offers Great Opportunities. *Specifier-Design Lab Specifier-Design Lab,* september. pp.40-43.

Grasshopper, 2010. *Grasshopper3d*. [Online] Available at: www.Grasshopper3d.com [Accessed 7 June 2011].

Gut, P. & Ackerknecht, D., 1993. Climate Responsive Building. In *Appropriate Building Construction in Tropical and Subtropical Regions*. 1st ed. Switzerland: SKAT. pp.100-20.

Hamza, N., 2008. Double versus single skin facades in hot arid areas. *Energy and Buildings*, 40(3), pp.240-48.

IESNA, 2000. *Illuminating Engeneering Society*. [Online] Available at: http://www.ies.org [Accessed 26 March 2012].

International Energy Agency, 2003. *I.E.A*. [Online] Available at: http://www.iea.org/ [Accessed 26 March 2011].

Jaime, M., Gagne, L. & andersen, M., 2010. Multi-objective facade optimization for daylighting desgin using a genetic algorithm. In *Proceedings of the 4TH national conference of IBPSA-USA sim buildings 2010*. New York, 2010.

Kaplan, C., 2005. Islamic star patterns from polygons in contact. In *Proceedings of Graphics Interface 2005*. Ontario, 2005. Canadian Human-Computer Communications Society.

Kilian, A., 2006. *Design Exploration through Bidirectional Modeling of Constraints*. Cambridge: MIT Press.

Kragh, M., 2000. Building Envelopes and Environmental Systems. In *Modern Façades of Office Buildings*. Delft, 2000. T.U Delft.

L.C.A, 2012. *lighting controls association*. [Online] Available at: http://lightingcontrolsassociation.org/uc-riverside-school-of-medicine-research-building-wins-ies-lighting-control-innovation-award-of-merit-2/ [Accessed 23 April 2013].

Landry, M. & Breton, P., 2008. *AutoDesk*. [Online] Available at: http://images.autodesk.com/adsk/files/3dsmax_advanced.pdf [Accessed 4 December 2013].

Larson, G.w. & Shakespeare, R., 1998. *Rendering With Radiance*. first ed. Morgan Kaufmann.

Lawrence Berkeley Laboratory, 1996. *ADELINE*. [Online] Available at: http://radsite.lbl.gov/adeline/features.html [Accessed 18 November 2012].

Meredith, M., 2008. *From control to desgin*. London: Verb Monograph.

Nabil, A. & Mardaljevic, j., 2006. Useful daylight illuminances : A replacement for daylight factor. *Energy and Buildings*, 38(7), pp.905-13.

Nayef, M., 2001. *saudi aramco world*. [Online] Available at: www.saudiaramcoworld.com [Accessed 5 October 2012].

NCR, 2004. *National Reasarch Council of Canda*. [Online] Available at: http://www.nrc-cnrc.gc.ca/eng/ [Accessed 16 May 2012].

NREL, 2005. *National Renewable Energy Laboratory*. [Online] (1.0) Available at: https://openstudio.nrel.gov/getting-started-developer/getting-started-radiance [Accessed 26 November 2012].

Oesterle, E., Lieb, R.-D. & Heusler, W., 2001. *Double Skin facades - integrated Planning*. Munich,Germany : Prestel Verlag.

Peel, 2007. Updated World Map of the Köppen-Geiger Climate classification. *Hydrology and earth system sciences*, pp.439-73.

Poirazis, H., 2004. ISBN:91-85147-02-8/ISSN:1651-8128 *Double Skin Facades for Office Buildings*. Lund: Lund University Lund Institute of Technology.

processing, 2007. *processing*. [Online] Available at: http://processing.org/ [Accessed 26 May 2012].

Reinhart, C. & Walkenhorst, O., 2001. Validation of dynamic RADIANCE-based daylight simulations for a test office with external blinds. *Energy and Buildings*, 33, pp.683-97.

Rhino, 2012. *rhino3d*. [Online] Available at: http://www.rhino3d.com/ [Accessed 26 Augustus 2012].

Rutten, D., 2010. *grasshopper 3d*. [Online] Available at: http://www.grasshopper3d.com/profiles/blogs/evolutionary-principles [Accessed 26 May 2011].

Satoh Blog , 2011. *Cool Japan*. [Online] Available at: http://satoh490625.blog50.fc2.com/blog-entry-847.html [Accessed 12 March 2012].

Schumacher, P., 2008. Parametricism Manfisto. In *11th Architecture Biennale*. Venice, 2008. Biennale.

Schumacher, P., 2009. Parametricism - A New Global Style for Architecture and Urban Design. *AD Architectural Design*, Vol 79.

Shiffman, D., 2012. The Evolution of Code. In S. Fry, ed. *The Nature of Code*. firts ed. California. pp.390-443.

Solarlux , 2011. *stylepark*. [Online] Available at: http://www.stylepark.com/en/architecture/double-skin-facade-concept/315266 [Accessed 14 June 2012].

Terzidis, K., 2006. *Algorithmic Architecture*. First ed. New York : Architectural Press.

U.S Depatmen of Energy, 2012. *Energy Plus*. [Online] Available at: http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data3.cfm/region=1_africa_wmo_region_1/country=EGY/cname=Egypt [Accessed 20 December 2012].

University Of Minnesota, 2002. *zeropluscampus*. [Online] Available at: http://zeropluscampus.umn.edu/tools/online_calculators.php [Accessed 26 March 2012].

Velasco, R., Brakke, A.P. & Tocancipa, F., 2012. Notes on the development of a parametric design process for a brise soleil system. In *Procedinfs of the 1st ecaade Regional International workshop*. london , 2012.

wikipedia, 2008. *wikipedia the free encyclopedia*. [Online] Available at: http://en.wikipedia.org/wiki/File:Koppen_World_Map_(retouched_version).png [Accessed 26 May 2011].

Wikipedia, 2007. *Wikipedia*. [Online] Available at: http://en.wikipedia.org/wiki/Avant-garde [Accessed 2 November 2011].

Yansane, A.M., 2011. *San Francisco State University*. [Online] Available at: http://userwww.sfsu.edu/ciotola/solar/asn_94nuclear.html [Accessed 15 March 2013].

Zemella, G., De March, D., Borrotti, M. & Poli, I., 2011. Optimised design of energy efficient building façades via Evolutionary Neural Networks. *Energy and Buildings*, 43(12), pp.3297-302.

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