Irradiance modeling and simulation of the Solar Chandelier.

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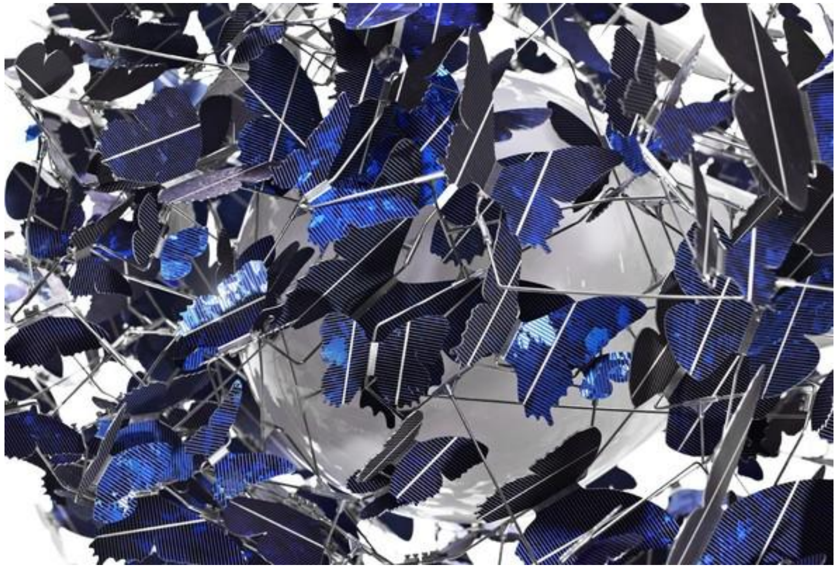
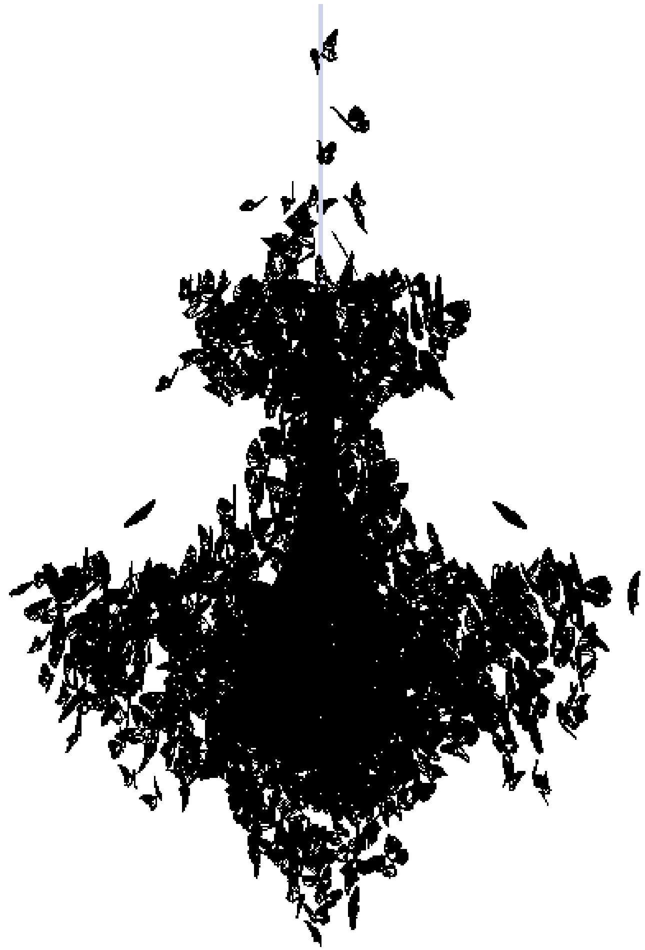


Preface.

This report is the culmination of many months of work on the Solar Chandelier project. It details the activities I undertook and the results of my bachelor assignment, which was to research, model and simulate the irradiance conditions of the Solar Chandelier. I would like to thank Angele Reinders, Jeroen Verhoeven and Kay van Mourik for their guidance and advice, and Sebastian Kettler and Rik de Konink for their company and support.



1. Summary.

In this report the results of the bachelor assignment ‘Irradiance modelling and simulation of the Solar Chandelier’ are presented. The goal of the assignment was to use software simulations to optimize the performance of the solar cells in the Solar Chandelier. With the simulation results the performance of the Solar Chandelier was analyzed and recommendations have been given with regards to the circuit design, modifications to the butterfly design and general recommendations for future owners.

First literature studies were performed to research the characteristics of the PV cells, irradiance and illuminance to gain a theoretical basis to build on. Next simulation software was studied and based on a set of requirements, which detail the needs of the simulation study, 3ds Max was chosen as simulation software. The simulation model used in 3ds Max was developed, including geometry, materials and settings. This involved a mix of practical experiments and literature study. Before beginning the simulations a study design was developed to limit the amount of experimental factors due to time constraints. The biggest effect of this was that only a single day could be simulated. The choice was made to pursue a worst case scenario by simulating the shortest day of the year in London. The simulation results showed that the Solar Chandelier generated little electricity under these circumstances and that is would not function autonomously. To improve the performance a bit another set of butterflies were made functional and the results of this decision simulated. Based on these results two minor modifications were made to the butterfly design and the results simulated. In addition 4 circuits were defined, in a design taking advantage of symmetry inherent in the Solar Chandelier and supporting various daylighting setups. Finally some recommendations are made for future owners of the Solar Chandelier, outlining in what kind of spaces the Solar Chandelier would perform best.

2. Introduction.

2.1 The Solar Chandelier project.

This bachelor assignment was part of the Solar Chandelier (SC) project that started in June 2009. This project was initiated by Demakersvan, an internationally renowned Dutch design studio based in Rotterdam. The SC is a large chandelier measuring over 1440 x 1440 x 1620 mm, powered by solar energy. Its design consists of a large opaque glass bulb which is surrounded by hundreds of Photovoltaic (PV) cells shaped into butterfly wings. A conceptual design, detailing the shape of the glass bulb and butterflies, and their placement was made by the studio. Both a real world model and a CAD model, made in Solid Works, were produced.

The SC was presented to the public during a showing of their collection in the London based Blain Southern Gallery in the second quarter of 2011. Twente University was contracted as a partner for the technical detailing of the design. Three separate bachelor assignments were formulated as part of the project, including the one detailed in this report: 'Irradiance modelling of the Solar Chandelier'.

2.2 Goals of the Bachelor assignment.

The goal of this assignment was to optimize the functioning of the PV cells in the SC. To this end the irradiance, or amount of energy the cells receive from daylight, and their energy output would have to be researched and simulated with software. Also the influences of the product environment and the configuration of the PV cells would have to be assessed. Based on the results an advice for the design of the electrical circuits of the PV Solar Chandelier will be given. Also recommendations for small modifications to the design will be given to optimize the energy yield. Finally guidelines will be formulated for future owners regarding the optimum environment for the SC.

2.3 Research questions.

To reach the goals of the Bachelor assignment, several key issues will have to be resolved. To this end the following research questions were formulated:

1. How do the solar butterflies in the SC work?
   1.1. What is the design of the solar butterflies in the SC?
   1.2. What influences the functional performance of the solar butterflies in the SC?

2. Which environmental factors influence irradiance?
   2.1. What is irradiance?
   2.2. What is illuminance?
   2.3. Which influence has the natural environment on the irradiance and illuminance?
   2.4. Which influence has the built environment on the irradiance on illuminance of the SC?
      2.4.1. In which environments will the SC be used?
      2.4.2. How do these environments influence the irradiance?

3. What advice would be given to future owners of the SC, with regards to the environments in which the SC could be used?

4. How will irradiance be simulated with software for this assignment?
    4.1. How is irradiance simulated in software?
    4.2. What are the requirements for selecting a software package to simulate irradiance for this bachelor assignment?
    4.3. Which software is best suitable for the simulations?

5. What is the energy yield of the Solar Chandelier?
    5.1. How is the energy yield determined?
    5.2. What is the energy yield in different seasons?

6. Which modifications can be made to the PV cell configuration to optimize the energy yield?

7. Based on the energy yield of the PV cells, how should the electrical circuits be designed?

These research questions were first formulated in the Plan van Aanpak, found in Appendix F. During the course of the assignment these were adapted to fit the information found in the literature and during the simulations.

2.4 Structure of the report.

To answer the research questions several studies have been carried out, detailed in individual chapters. In chapter three, the PV cell study, the characteristics and functioning of the PV cells are described. Chapter four contains the irradiance study, answering research questions 2 and 3. In chapter five, the simulation study, question 4 is answered. Chapter 6 contains the results of the simulations and as such answers question 5. Finally chapter seven details the modifications that can be made to the butterfly configuration and the configuration for the electrical circuits, answering research questions 6 and 7. Chapter 8 gives guidelines for future owners, based on the simulation results and the literature, answering question 3. And the final chapter 9 contains the conclusions.

3. PV cell study.

3.1 PV cells.

Functioning of PV cells.

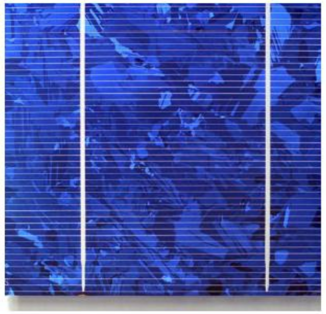
A solar cell is a device capable of generating electrical energy from light. Light consists of photons, small packets of energy whose energy depends on the frequency of the light. When a material is struck by light, the photons are absorbed and excite the electrons of the material to a higher energy state (Nelson, 2003, p.1). Usually the electrons quickly return to their normal state but the material of a solar cell has different properties. Solar Cells are constructed from a p and n-type semiconductor, which are materials through which electrons can travel. A p-type material has a shortage of electrons, and an n-type has a positive of electrons (Wikipedia [1], 2009). Because of the asymmetry caused by the n and p type material, excited electrons are pulled away before they can relax, creating a current. On the junction of the p and n type is the depletion zone, meaning there are no free electrons (Wikipedia [2], 2009). Its effect is that electricity in a solar cell can only flow in a single direction, making its functioning similar to that of a diode.

Characteristics of PV cells.

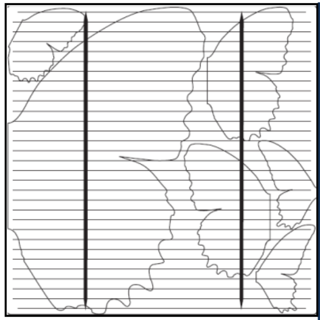
Nelson states that '*PV cells can be considered as a two terminal device which conducts like a diode in the dark and generates a photovoltage when charged by the sun*'. A basic unit of 100 cm^3 generates a voltage of 0,5 to 1 volt, dependent on the intensity of the incident light (Nelson, 2003, p.4). The power output of a cell is thus dependent on the amount of incident light, making shading a large problem (Hanitsch e.a., 2001, p.93).

3.2 Solar Butterflies.

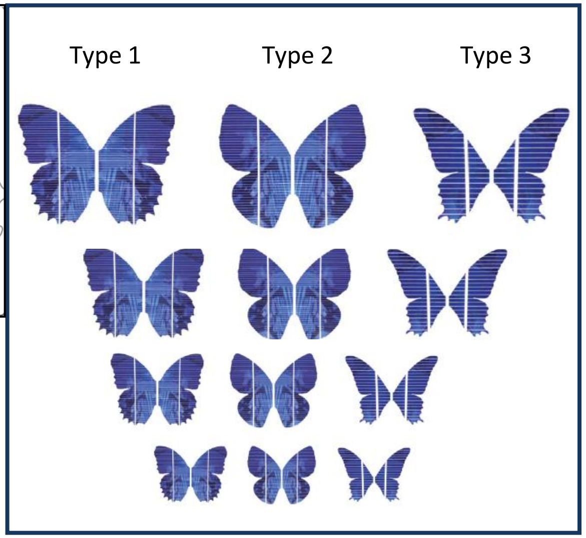
The solar cells used in the SC are multi crystalline units produced bij Sunways. These are cut in the shape of butterfly wings. There a three basic shapes, and each shape is used in four different sizes, A, B, C and D (with A the largest and D the smallest).



Picture 3.1: Used Sunway solar cell.



Picture 3.2: Cutting of cells



Picture 3.3: Overview of butterfly types and sizes

Based on recommendations made by Erik Hop, it was decided by Demakersvan that not all butterflies would be functioning PV cells. Only 1A,1B, 2A, 2B and 3A would be used, as it was expected that the smaller ones would not generate a large amount of power due to their size.

Performance of the Solar Butterflies.

Rik de Konink carried out tests during his bachelor assignment to assess the effects of cutting the solar cells into these shapes. A prototype of type 2A was made and outdoor measurements were performed. The results show that compared to the original cell the efficiency is the same. This means the cutting of the cells has no detrimental effect on the performance of the cells. Of all butterfly types 3A was shown to be the most efficient.

Next the influence of shading was researched. The power output of the cells is linearly dependent on the amount of shading. If $1/6^{th}$ of the cell is shaded completely, the power output drops by $1/6^{th}$. If a butterfly is completely shaded it has a detrimental effect on the performance of the circuit in which it is placed as it will start to act as a resistance (de Konink, 2009, p.9)

Finally the power output of butterfly 2A under different irradiances was determined; the results are shown in the table below. The irradiance of 1000 W/m^2 was measured outdoors; the irradiance of 31 W/m^2 was simulated in an experiment mimicking indoor conditions.

Measured irradiance	Output voltage	Output current	Output Power
1000 W/m^2	584 mV	4,51 A	2,634 W
31 W/m^2	485 mV	0,151 A	0,073 W

Table 3.1: Power output of 2A under different irradiances.

4. Irradiance study.

4.1 Introduction

The goal of this study is to gain insight on the properties of irradiance and the factors that can influence the amount of irradiance the Solar Chandelier will receive. First irradiance itself will be researched, secondly how the built environment affects it. Then possible environments for the SC will be identified and assessed how these would perform.

4.2 Irradiance and illuminance

4.2.1 Irradiance.

As was mentioned first in the introduction of this report, irradiance is the amount of energy an object receives as it is struck by light. It is expressed in Watt per square meter (W/m^2). The most important source of radiant energy on earth is the sun. The rate at which this radiant energy is output is called the radiant intensity.

As the energy travels through the earth's atmosphere it encounters clouds, rain or snow and pollution. This causes the light to reflect and refract and the two components of irradiance are formed; direct and diffuse irradiance. Also some of the energy is absorbed. The geographical location of the irradiated site is influential. On high latitudes, near the poles of the earth, the sunlight has to travel through a larger portion of the earth's atmosphere. As the radiation is scattered and absorbed to a larger degree, the resulting irradiance will have lower energy intensity (Riordan & Hulstrom, 1990, p. 1086). In case of northern Europe it is estimated that direct irradiance is 5 to 10 times stronger than diffuse irradiance (Baker & Steemers, 2002, p.40). There are also some spectral differences; diffuse light will contain a larger portion of shorter (blue) wavelengths if compared to direct light.

The local climate and weather conditions are also influential on the amount of diffusion. As the cloud cover increases the amount of diffuse irradiance will increase. On a clear day the diffuse irradiance amounts from 10 % up to 20% of the total irradiance (Kan, 2006, p.28). If the total irradiance only amounts to 30% of the maximum value it is likely to be completely diffuse (Kan, 2006, p.28).

In case of an indoor product as the Solar Chandelier the most likely sources of light will be the windows. A window can also be modeled as a radiant energy source. As the light hits the window it becomes a plane which emits light with a certain radiant intensity. The resulting energy field is called the radiant flux or power and is measured in watt or joule per second. As this radiant flux reaches an object the total received radiant flux per square meter is the irradiance. This means that the way the object's surface is positioned with respect to the window can influence the amount of irradiance received. In the case of the solar butterflies the angle with which the wings are positioned is an example. If the wings make a shallow angle the flux is distributed over a larger area than in the case of sharply angled butterfly wings, resulting in a lower local irradiance on the wings.

4.2.2 Illuminance.

Besides irradiance another commonly used way to define the amount of incident energy is the illuminance. The main difference is that the incident light is wavelength-weighted by the so called luminosity function (Wikipedia, 2009). This function describes the sensitivity of the human eye to different wavelengths of light, meaning a luminous flux only consists of light with the wavelengths which the human eye can see. This means the incident light is usually expressed in illuminance in situations where it is important to research what the human perception is. For example architects research the illuminance of the spaces in their designs to check their suitability for human occupation.
Luminance is measured in lux, the illuminance in lux per square meter.

4.3 Environments of the Solar Chandelier.

To assess the irradiance and the performance of the Solar Chandelier some extra research was needed about the environment it is expected to be used. As was shown in the earlier sections of this chapter, the environment is highly influential on the amount of irradiance that is received.

As the SC is a large product, it is likely to be placed in large spaces. Demakersvan estimates it will be sold for about 30.000 euro's, making it a product for the upper segment of the market. 3 different kinds of future owners can be identified:

Public.
Modern art museums are already an important group of customers for Demakersvan. As the Solar Chandelier will also be displayed in a modern art

gallery, considering the kind of environments that would go with these customers would be valuable.

Private.

Demakersvan also indicated they want to sell the SC to private customers. Considering the high price it is estimated that these kinds of customers possess large residences with rooms of appropriate dimensions for the SC.

Corporate.

Many office buildings or commercial spaces such as malls and hotels could potentially house the Solar Chandelier. Especially in hotels the lobby is a space which would be appropriate. Many lobby designs include a piece of art or a chandelier as a focal point, an example can be seen to the right.

4.4 Built environment factors.

Literature describing the way the built environment affects the irradiance was scarce. Another approach had to be found to find the relevant information. Luckily in architecture, utilizing natural light inside buildings has become a increasingly important theme. By designing a good daylighting strategy for a building, a comfortable working environment for its users is assured and the energy efficiency of a building can also be improved (International Energy Agency (IEA), 2000, p.2-1). An overview of the factors that have to be accounted for during the design of a building to improve the use of daylight is provided in the table below.

Building	Room	Window	Daylighting system
Daylight availability - Latitude - Sunshine probability - Temperature Obstruction Building design scheme - Beam shaped - Courtyard/Atria - Block - Nucleus	Relation to adjacent spaces. - Autonomous - Borrowing light - Giving light - Interchanging light Fenestration - Unilateral, sidelight - Unilateral, top-light - Multilateral, sidelight - Multilateral, sidelight and top-light Proportion - Height to depth ratio	Design of facades and windows. - Single design - Multiple design - Division within windows. - Division between windows	Function of system(s) - Multiple functions - Glare, shading, redirection. - Glare, solar shading - Glare, redirection - Shading, redirection - Single function - Protection from glare. - Solar shading - Redirection - Other function

Table 4.1: Factors for daylight in buildings (IEA, 2000)[1]

A new overview of factors relevant to the Solar Chandelier was defined based on the above figure. This should make it easier to assess the factors of influence on the

[1] IEA, 2000. Daylight in Building. Berkeley: Lawrence Berkeley National Laboratory, page 2-1

[2] Lindsey,J.L., 1997. *Applied Illumination Engineering* (2nd edition). Lilburn, Georgia: Fairmont Press.

irradiation. Three levels were defined; the building, the room and the lighting system. Lighting systems also include sources of artificial lighting to account for all possible sources of light. Based on a literature study other new factors were added that influence the irradiance or illuminance. These, in addition to the 'original' factors, will be reviewed in the next paragraphs.

Building	Room	Lighting system
Location: - Latitude - Sunshine probability - Surrounding environment. Shape of the building	Relation to adjacent spaces: - Autonomous - Borrowing light - Giving light - Interchanging light Proportions of the room - Length-depth ratio - Glazing-flooring area ratio - Glazing-reflecting area ratio Orientation to the sun Interior decoration	Type of light system - Daylight - Artificial light Light system design - Composition - Design - Placement Function of light system - Glare protection - Heat protection - Shading - Redirection Spectrum altering

Table 4.2: Factors for the irradiance and illuminance of the SC.

Building.

The location of the building affects the irradiance in multiple ways. As mentioned earlier in section 4.1 the higher the latitude of the location, the lower the expected average irradiance as the proportion of diffuse light increases. Diffuse light is however isotropic, meaning it is uniform in all directions. Therefore the contribution on vertical surfaces will relatively increase, and as a result the difference between total irradiance on north-oriented and south-oriented surfaces will be reduced (Kan, 2006, p.28). In spite of the largely diffuse conditions it is however recommended for northern Europe to orient the glazing of the buildings to the south to profit from the available direct sunlight (Baker & Steemer, 2002, p.63).

Also of importance is the direct environment of the building. Nearby situated buildings can severely limit the amount of incident light. To protect the right to daylight legislation was introduced which defines the degree to which buildings may affect each others daylighting (Wilson & Brotas, 2001, p.28). However, in urban environments nearby buildings may also form a means of extra usable daylight caused by their reflection of light. This does require the use of lightly coloured, strongly reflecting building materials (Baker & Steemers, 2002, p.40).

Room.

The size of the radiant flux of a room is not only dependent on the radiant intensity but also on the available area of fenestration. How far the light penetrates is dependent on a few factors. The direct and diffuse components quickly decrease as the distance to the window increases. The room itself however creates a third component, consisting of light reflected by the room or objects in it. This component remains nearly constant (Baker & Steemers, 2002, p.70). The placement of the windows, the amount of available reflective surfaces and the reflective properties of the materials all influence how strongly the light is reflected.

The ceiling is the principal surface when it comes to further reflecting the light. The depth with which the daylight penetrates the room is dependent on the height of the window. A higher window allows the daylight to hit the ceiling and consequently be reflected further into the room (Kubie et. al., 2002, p.150). A rule of thumb is that the depth of penetration amounts to twice the distance from the top of the window till the floor (Baker & Steemers, 2002, p.70). It is however important that no profiles running parallel to the window are present on the ceiling. The can cause shadows or reflect light back to the window (Baker & Steemer, 2002, p.70)

In rooms where the width of the space does not amount to more than twice the distance between the floor and ceiling, the sidewalls can also play an important role. They can also be struck directly by the incident sunlight, but lightly coloured and smooth walls are necessary to aid reflections.

A special case are atria. These are big, open, high spaces with a glass roof, mostly found in big buildings. The purpose of an atrium is to introduce extra daylight in a building and connect adjacent spaces to the outside world (Calcagni & Parancini, 2004, p.669). The amount of daylight it receives depends on the type of glazing used for the roof and its orientation to the sun. Most interesting is however how much of the light reaches the floor and spaces adjacent to the atrium. Similarly to other types of rooms, this is mainly through internal reflections. However, in the case of an atrium the light must be reflected initially vertically instead of horizontal. The best design strategy is to increase the amount of reflecting surface as one transverses down the atrium. This way the amount of daylight on the top floors is limited and the lower levels receive more because of the enlarged white walls on the upper floors (Calcagni & Parancini, 2004, p.673)

Finally it is important if a room is autonomous or if it is connected to other spaces. If a space also provides light to other rooms the irradiance will be lower if compared to the autonomous situation. The amount of incident light stays the same; it is however distributed over much larger surface.

Lighting system.

The most important function of a light system is to light a room such that it's suitable for its users and their activities. In the figure below recommended illuminances are listed for each kind of activity.

Type of activity	Lux
Public spaces with dark surroundings	20-30-50
Simple orientation for short temporary visits	50-75-100
Working space where visual tasks are only occasionally performed	100-150-200
Performance of visual tasks of high contrast or large size	200-300-500
Performance of visual tasks of medium contrast of small size	500-750-1000
Performance of visual tasks of low contrast or very small size	1000-1500-2000
Performance of visual tasks of low contrast and very small size over a prolonged period	2000-3000-5000
Performance of very prolonged and exacting visual tasks	5000-7500-10000
Performance of very special visual tasks of extremely low contrast and small size	10000-15000-20000

Table 4.3: Recommended illuminances for generic tasks (Lindsey, 1997)[2]

The amount of lux that is needed for a task depends on the age of a person, the reflection rate of the present surfaces and the speed and accuracy with which it must be performed (Lindsey, 1997, p.239). Generally in a room which is only lighted by daylight the daylight factor must be at least 5%. This means the illuminance in a

[2] Lindsey,J.L., 1997. *Applied Illumination Engineering* (2nd edition). Lilburn, Georgia: Fairmont Press.

room must amount at least to 5% of the illuminance outside. If artificial light is used the average daylight factor may be 2% (CIBSE, 2002, p.29)

Most light systems applied in buildings consist of both daylight and artificial light. The use of daylight is nowadays preferable, also in warmer climates, as it can reduce the energy consumption of a building. There is however a marked difference in the way daylight is applied in buildings on high or low latitudes.
On high latitudes, where the sky is frequently clouded and direct sunlight has a lower intensity, large amounts of fenestration can be used. Frequently seen are large roof lights and glass walls, but these must still be used in conjunction with some shading systems. Roof lights are constructed from diffusing glass to protect the interior from direct sun rays, for glass facades variable shading systems must be used as the light is only too strong during certain times of the day or during some seasons. Using drapes reduces the amount of light entering a room with 68%, open blinds with 62% and closed blinds even with 94%. On low latitudes the angle of incidence of the sun is very small; meaning the direct sunlight on east and west oriented windows is very strong (Li et. al., 2004, p.922). A small window or roof light, which could be combined with a system to transport light, is enough lit a room homogeneously (Baker & Steemers, 2002, p.40). Here, historically the most important function of daylighting systems was to provide shade and protect from the heat. Users of variable shading systems however have the tendency to over-compensate, making it frequently necessary in office buildings to use artificial lighting. This makes it necessary to introduce more daylight in buildings to reduce the energy consumption. Frequently used are small roof lights combined with daylight distributing systems to transport light to rooms. Another option is the use of specially coated glass which protects from the heat but allows light to pass through (Li et. al., 2004, p.922).

Artificial light systems are usually used if a insufficient amount of daylight is available. But it can also be used in the case more control is needed over the spectrum and the intensity of the light in the room. Museums avoid exposing light sensitive objects such as paintings to daylight as UV light can damage them (Cassar, 1995, p.88).

5. Irradiance and illuminance simulation study.

5.1 Introduction.

The goal of this study is to gain knowledge about the technology with which irradiance and illuminance can be simulated and measured. First the modelling of irradiance and illuminance is researched, next the applied methods in software to compute and render irradiation and luminance.

Suitable software for the expected simulations is also investigated. Based on a list of requirements one or multiple programmes are chosen and a detailed analysis is made of the needed information and input for the simulations. Finally a detailed design for the simulations is made.

5.2 Modelling irradiance and illuminance.

In chapter 4 the properties of irradiance and luminance were discussed. For this project it is desired to generate indoor solar irradiance data on various inclined surfaces, the butterflies. Systematic long-term measurements are regarded as the best way to collect data (Li & Cheung, 2005, p.171), but would be impossible to undertake within the scope of this project. Simulation of irradiance on sloped surfaces in software is the next best option. In chapter 4 the properties of irradiation and luminance were discussed. Irradiance (and illuminance) consists of three components: direct, global and diffuse irradiation. To simulate these properties, software utilizes mathematical models.

For the calculation of irradiance on sloped surfaces two basic approaches can be found: predicting the solar irradiance on inclined surfaces using horizontal irradiation data or calculating the diffuse irradiance on a plane by integrating the radiance distribution generated by a sky radiance model (Li & Cheung, 2005, p.170).

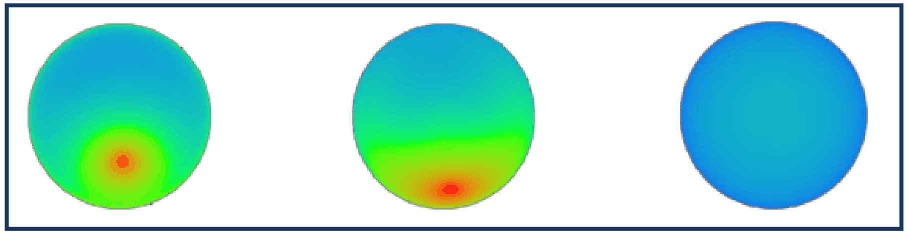
Luminance can be modelled with a sky luminance distribution model used in conjunction with a direct beam illuminance (Perez et al. 1990, p.284).

A very quick review of the possible software options for the simulations has shown four models are the most commonly used. For irradiation the Perez point-source model and the Perez all-weather model. And for illuminance the Perez all-weather model and the CIE model.

5.2.1 CIE model

The Commission Internationale de l'eclairage (CIE) is an international non-profit organization devoted to advancing knowledge and providing standardisation to improve the lighted environment. It is recognized by ISO as an standardization body. As such the CIE has published standards which define exterior daylight conditions, namely the CIE Sky model (Darula & Kittler, 2002, p.1).

The CIE Sky model consists of a series of standard sky luminance distribution models, which model skies under a wide range of occurrences. This varies from overcast to clear skies, with or without sunlight (Darula & Kittler, 2002, p.1). All the different sky conditions are arranged in 15 sky types, 5 for clear skies, 5 for overcast skies and 5 for partly overcast skies (Kobav & Biziak, 2003).



Picture 5.1: The CIE clear sky **Picture 5.2: The CIE partly cloudy sky** **Picture 5.3:The CIE overcast sky**

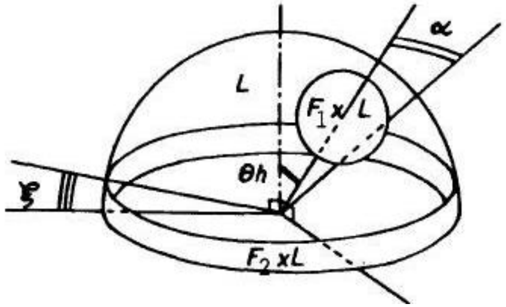
5.2.2. Perez models.

As mentioned earlier two approaches exist to predict irradiance on a tilted surface. Predictions based on horizontal irradiation data or the radiance distribution generated by a sky radiance model. The two Perez models each represent one of these approaches, the point-source model the first, the all-weather model the second.

Perez point-source model.

The Perez point-source model (Perez), also known as the anisotropic hourly diffuse radiation model for sloping surfaces, consists of three elements:

1) A geometrical representation of the sky dome.
2) A parametric representation of the insolation (average irradiation) conditions
3) A statistical component linking the two (Perez et al., 1986, p.481)



Picture 5.4: Perez sky model.

The sky dome is divided in three different regions. Two of these regions, the one near the horizon and the circumsolar one, account for anisotropic effects observed in the atmosphere. Namely horizontal brightening due to multiple scattering and Rayleigh scattering in the atmosphere, and the circumsolar brightening which is caused by forward scattering of aerosols. Two coefficients set the radiance magnitude in the two anisotropic regions relatively to that in the main portion of the dome. The magnitude of these coefficients depends on the normal incidence direct irradiance, horizontal diffuse irradiance and the solar zenith angle (Perez et al., 1986, p. 482).

Through a small change to the model formulation the Perez model can also be used to calculate illumination at an inclined surface (Perez et al., 1990, p.282).

Perez all-weather model.

In the Perez all-weather model (Perez AWM) skylight is treated as a non-uniform light source whose intensity and angular distribution pattern varies as a function of three insolation (average irradiation) conditions, namely solar elevation, sky clearness and brightness (Perez et al., 1993, p.235). The model is designed to use hourly or shorter time step global and direct irradiance to predict sky luminance angular distribution. As mentioned earlier, to calculate daylight penetration in any environment a direct sunlight should be used in addition to the sky luminance angular distribution modelled by Perez AWM.

The model itself is a generalization of the CIE standard clear-sky formula. Its formula includes 5 coefficients that can be adjusted to account for the luminance distributions under all-weather conditions, ranging from totally overcast to very clear (Li& Cheung, 2005, p. 178). They account for the relative effects of forward scattering, backscattering, multiple scattering and air mass on luminance distribution and are treated as a function of the three insolation condition parameters. The model accounts for most mean anisotropic effects, but not random, one-of-kind cloud effects (Perez et al., 1993, p. 243)

5.2.3. Implications of model selection.

Perez vs. Perez AWM

The performance of both varies when predicting the diffuse irradiance on inclined surfaces. For a small tilted angle of 22.3° it was shown that Perez shows the best overall performance. It has a better predictive ability under overcast conditions than under non-overcast conditions, Perez AWM exhibits the reverse behaviour (Li & Cheung, 2005, p. 184).

The relative RMS errors of the AWM model are larger than for the Perez model. This is however to be expected because of the high variability that may occur in a confined region of the sky dome for all but extremely clear and dark overcast conditions (Perez et al., 1990, p. 284)

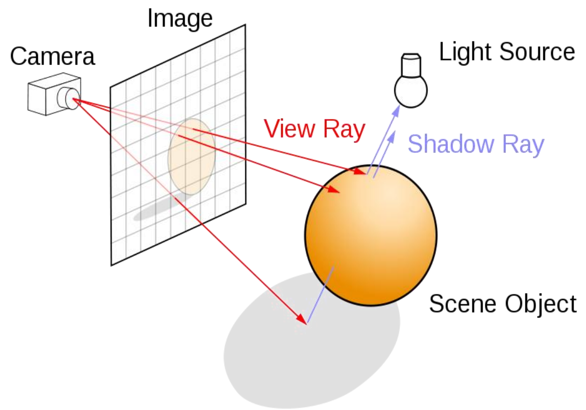
CIE vs. Perez AWM

Lam, et al. (1997) researched the divergence of luminance predictions based on various sky models relative to each other. The CIE and Perez AWM showed great similarity in their overall trend for predictions, but their absolute predictions diverged. The Perez AWM has a smaller Mean Relative Error of -4% to the -14% of the CIE model, with standard deviations that are about the same. It is shown the Perez AWM outperforms the CIE model.

5.3 Software technology for simulating irradiation.

Besides the models for calculating the irradiance en luminance software packages have to utilize techniques to generate the images physically correctly. A number of technologies have been developed to render images, however not all of them are suitable for the simulations. This section will give a short overview of the technologies which are capable of simulating a wide variety of optical effects in a physically correct way.

The first suitable technology is ray tracing. McMahon & Browne (1998, pp.114) state that "it comprises a series of algorithms which generate images by considering the path of a ray of light arriving at each pixel in the screen. The path is traced to the points where it meets surfaces in the screen. It can be used to identify visible surfaces, or it may allow shadows, reflection and refraction to be considered by calculating the surface intensity at the intersection points from three contributions: the local colour due to the illumination of the surface by direct and ambient light, a contribution from the reflection of a ray coming



Picture 5.5: Depiction of Ray Tracing

from reflection direction, and a contribution from a transmitted ray coming from a refraction direction , if the surface is translucent. The path of each refracted and reflected ray is traced to further intersections, and the process is continued for a predetermined number of levels of intersections.”

As can be seen in picture 5.5, the rays are cast away from the camera and not into the camera as would happen in the real world. This ‘backward’ method may at first seem counterintuitive but is however more efficient as the forward method (calculating first the light paths in the scene and then use the ones that intersect with the image plane of the camera to build the picture). This is because the majority of the traced light paths in a forward traced scene never make it to the camera (Wikipedia, 2009).

However in the case of light simulations the ray tracing algorithms do not have all the required capabilities. It is not enough to have the capabilities to trace the light paths through a scene into the camera, it is also necessary to be able to simulate ray casting from a light source. To this end other technologies have been developed, which in software are used in conjunction with backwards ray tracing algorithms, namely global illumination and photon mapping.

Global illumination is the general name for a group of algorithms which can not only account for light from direct light sources but also reflected or refracted light from other objects in the scene (Wikipedia, 2009).

Photon mapping is a global illumination algorithm often used in light simulations, because is it capable of rendering spectrally. This means the light in the scene is modelled with real wavelengths, or more specifically; photons with the correct amount of energy. The light source in a scene emits photons which meet the objects in a scene and eventually become lost or absorbed. The results are recorded into a so called photon map. Once the photon map for the whole scene has been made it is used to estimate the radiance of every pixel in the output image (Wikipedia, 2009).

5.4 Software.

Selecting a software package suited to the expected activities within this Bachelor assignment is critical. Different packages offer different features to carry out irradiance or illuminance simulations, which could impact the shape and reliability of the results heavily. A study was carried out on prospective software packages and their capabilities. Based on its results and the bachelor PVA (Appendix E) a list of requirements was made. A comparison of the capabilities and the suitability of the programs was made to select the best software for the project.

5.4.1 Light simulation software

Radiance

Radiance is a widely used, UNIX based, program for light simulations. It is used both as a scientific and a professional tool. The program is capable of rendering both irradiance and illuminance and is extensively validated. Perez, Perez AWM and CIE can be used. It offers a library of surface material types which all can be adapted and tuned according to need. Radiance can also handle large amounts of complicated geometry which can be imported directly from some CAD programs or, in the case of Solid Works, through conversion to a compatible format.

The program requires a lot of skill to use, as the interface is mostly command based or complicated control files have to be made to automate the process. The program uses a backward ray tracer to compute the direct component of the irradiation and an algorithm closely resembling the radiosity method to determine the indirect irradiation.

Daysim

Daysim is a program aimed at the building industry and used to carry out daylight simulations. It utilized the Perez AWM. It is based on Radiance package, and cannot be used without a Radiance installation as it uses for example the Radiance materials in its simulations. It differs from Radiance in the sense that is was developed to enable professionals to quickly carry out indoor illuminance simulations under many different sky conditions in a way Radiance isn't able to (Reinhardt, 2009, p.12).

The program requires as input the scene geometry (with no editing capabilities), weather data files, electric lighting system data and user behavior. As output dynamic daylight autonomy data (the amount of time a certain level of light can be reached through daylight), electric lightning consumption data and daylight illuminance data for buildings can be generated.

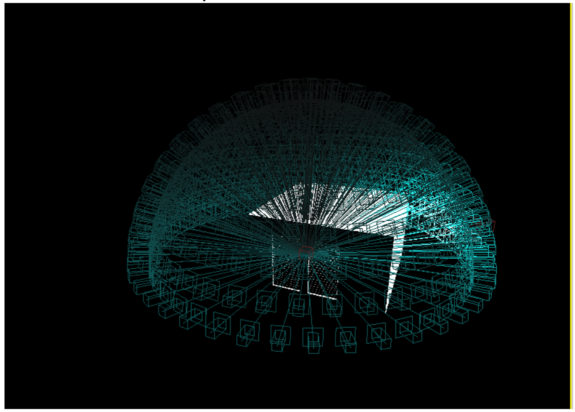
3ds Max 2009

3ds Max 2009 is a commercial software package from Autodesk, and is geared towards producing high quality renderings. It offers extensive facilities to model and edit geometry and multiple methods to model, simulate and visualize light. Not all types of render methods produce reliable results for light simulations, as some are more geared towards producing aesthetically pleasing pictures. 3ds Max is however only capable of rendering illuminance, using the CIE or Perez AWM model. When the software was researched in 2009 only one study was available to validate the results. Some research was done as to the possibilities to adapt 3ds Max to render irradiance. A correspondence with Philip Breton, an expert on 3ds Max and author of articles referenced in this report, revealed that during the rendering process a radiometric light shader applies a transformation that makes the light perceptually based instead of true-physics based. This means that the entire calculation process in 3ds Max makes assumptions which could not be changed without rewriting a lot of the core functions of 3ds Max. To obtain irradiation, the results of a 3ds Max simulation would have to be converted.

Like the software discussed earlier, 3ds Max also offers a library of materials which can be adapted to suit the needs of the simulations. CAD geometry can be imported directly or through a conversion. The program is quite complicated to use, but was used previously at the University Twente to carry out light simulations so a manual is available. Finally the program also uses a backward raytracer, called mental ray, to carry out physics-based simulations.

3ds Max 2009 with 3D-PV plugin.

As mentioned in the section above, 3ds Max was used previously at the UT. Tools were developed to tailor 3ds Max 9 to the needs of light simulation. Fortunately these remain compatible with 3ds Max 2009. The 3D-PV was a tool developed to enable irradiation simulations to be carried out (Reinders, 2009, p.1). It consists of a hemisphere built up out of discrete sky elements, which together describe a solid angle distribution of irradiation (Reich et al., unknown, p.2). Each element is modelled as a direct light source in 3ds Max, and so the incident irradiation on a scene is generated. Also any desired number of sky elements is possible. (Reich et al., unknown, p.2) As input the tool requires text files which define the solid angle distribution of the irradiation.



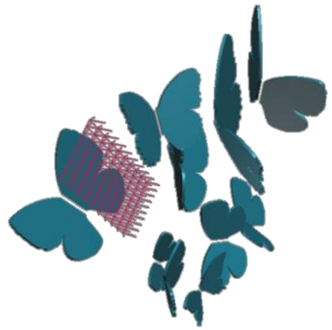
Picture 5.6: Visualization of 3D-PV tool.

The generating of the text files is complex, and would require outside assistance from the University of Utrecht. Currently only data for irradiation distribution of Utrecht on a summer day is available.

Utilizing the 3ds Max Mental Ray render engine and the render function 'Render to light map' the results are displayed in TARGA images, in which the RGB values of the pixels of the image represent a specific irradiation value. Through a second tool developed by the university the program is capable of reading these values and displaying them.

3ds Max 2009 design

This is a special edition of 3ds Max geared towards the architecture industry. It contains a functionality called 'Exposure', which offers specialized tools for lighting analysis. It uses the same materials and lights for the simulations, it offers however an extra CIE sky, the partly cloudy CIE sky. Exposure consists of a tool which checks if the simulation model is sound before rendering it, and has light meters are used to measure light levels locally in the scene.



Picture 5.7: A light meter in a scene

5.4.2 Software requirements

Based on the software analysis and the bachelor "Plan van Aanpak" a list of requirements was formulated for the light simulation software.

- The Solid Works model that was made by the Demakersvan can be imported in the program.
- The program is able to simulate photo metrically correct:
  - Daylight for different geographical locations.
  - Daylight for different seasons.
  - Materials.
- The program is able to measure the results of the simulation and display the results.
- The results of the software are validated.
- The software can be easily learned within the given time.

5.4.3 Selection of software.

Based on the earlier analysis of the software features and the requirements a choice was made. Radiance and Daysim were first eliminated.

Radiance is an extensively validated programme with all the required features. It is however not easily learned and complicated to use. It was determined that in the scope of this Bachelor Project there simply wasn't enough time to learn to use the software. Daysim was ultimately not selected because its design as a tool for building analysis meant there was not a perfect fit for this project. The irradiation could not be measured locally enough for any practical application with the Solar Chandelier model.

The choice between 3ds Max and 3ds Max design was however more complicated. Design offers the Exposure feature, with the earlier mentioned light meters. It also offers an extra CIE sky, the partially overcast CIE sky. However, for the Design version of 3ds Max an additional investment would have to be made as it is not used by the university. The necessity of using 3ds Max Design for the simulations therefore had to be assessed.

The light meters of 3ds Max Design offer an extra opportunity to measure illumination locally. It is possible to calculate the illuminance only for the light meters and export the generated data into Excel. It is however arguable if the light meters would be an improvement on the 'regular' method of rendering the TARGA images. Using the light meters requires a lot of work on the 3ds Max model, as they would all have to be positioned manually. Given the potentially large amount of PV cells that would have to be analyzed this could become a time consuming process.

The extra CIE sky offered could generate useful information, enriching the understanding of the behaviour of the SC under different conditions. However the required information on different conditions could also be generated without the use of this additional sky model.

Based on these considerations the additional investment required for 3ds Max Design is not warranted for this project. The 3ds Max 2009 satisfies the requirements perfectly. The 3D-PV tool will also not be used. As only data is available on the weather conditions in Utrecht on a summer day it does not fulfil the requirements.

5.5 Simulation modelling.

The CAD model of the Solar Chandelier and its environment play a very important part in the simulations. The accuracy of the definition of the geometry used has a strong influence on the quality of the simulations and subsequent calculations. In this chapter the research and the subsequent definition of the geometry for the simulations will be described.

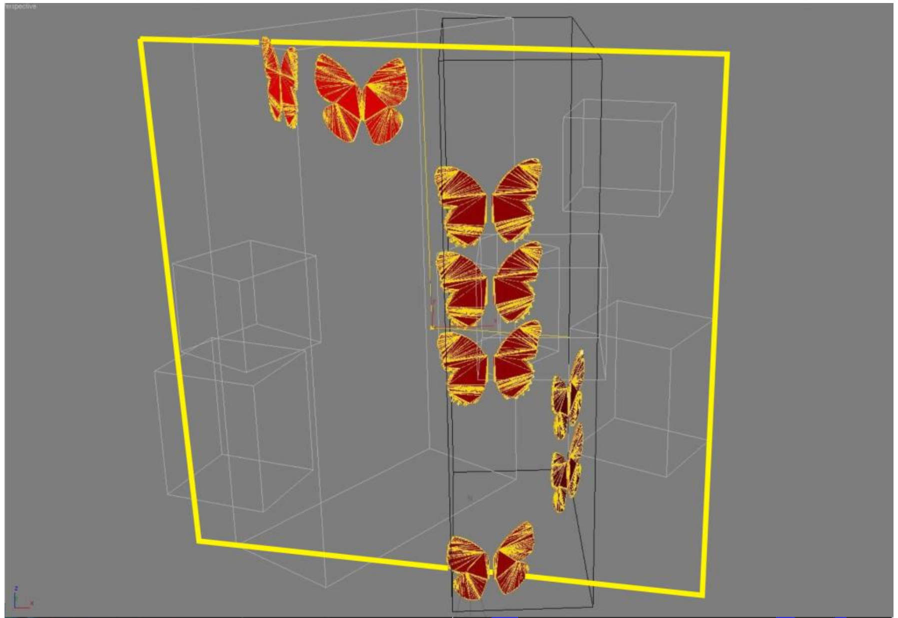
5.5.1 Simulating illuminance in 3ds Max.

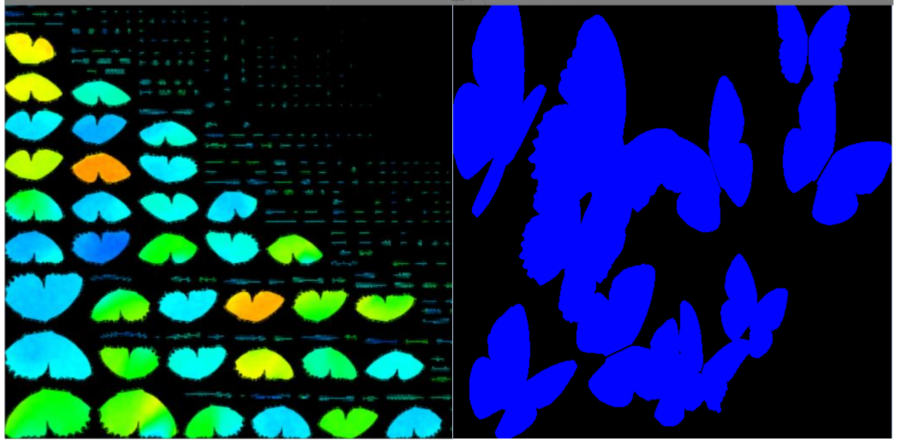
In order to match the simulation modelling to the capabilities of 3ds Max, the way it simulates illuminance and the shape of the simulation results were researched. The tools and simulation guide that were developed earlier at the UT for 3ds Max 9 were also reviewed. Though the tools remain compatible with 3ds Max 2009, the simulation guide turned out to be out of date as 3ds Max 2009 has better capabilities for simulating and rendering illumination.

In 3ds Max the simulations take place in a scene, an environment containing all the objects needed for the simulations and defined by the user. The basic components of a scene for an illuminance simulation are the light source and the geometry on which the light is projected. Also part of the setup process are the settings controlling the simulation. These will be discussed in detail in section 5.5.3.
To simulate sunlight 3ds Max uses a daylight system which must be added to the scene. This system models the intensity and orientation of the light that the scene receives from the sun and sky. Direct sunlight is modelled as a directional light source and can be found in the scene, diffuse daylight is however modelled as an environmental light source and is not directly visible in the scene (Reinhardt e.a. (2), 2008, p.4).
The geometry in the scene must resemble the real-world situation as closely as possible or the simulation will not produce reliable results. Not only the object which is to be illuminated has to modelled, but also the environment in which it is placed. Next each object in the scene has to be assigned a material. Each material can be fully designed by the user or chosen from a database offered by the program. Another important part of setting up an illuminance simulation is determining the shape of its results. These have to be defined before the simulation starts, as these determine which calculations the software has to make when it is carrying out the simulations.

To obtain the illuminance on an object a functionality called ‘rendering to texture’ is used. If a scene is rendered with this function, 3ds Max only calculates the illumination on a pre-selected surfaces in the scene.

To be able to do this, several steps need to be followed. First UVW maps, which are essentially sets of coordinates, need to be generated for the surfaces for which the illuminance needs to be calculated. This can be done with the ‘Unwrap UVW’ menu which offers options to manually or automatically map. The automatic mapping method ‘Flatten mapping’ was used. This method flattens the geometry of the SC, ensuring all the wing surfaces are projected flatly onto a surface. The amount of geometry that is flattened remains under the control of the user, as the surfaces which are to be mapped can be manually pre-selected.





Picture 5.1 (above): Applying an UVW map to selected surfaces.

Picture 5.2 (below): Simulation results of a flattened (l) and not flattened(r) UVW mapping.

These maps are then used to align a texture map to the surface of the object (Murdock, 2007, p. 597), a process called texture baking. A texture map is essentially a calculation of a specific type of behaviour of the surface. If a Lighting Map is used as a texture map, the way the surface reflects light is calculated. The texture map has a size of 512x512 pixels.

After the SC is mapped and texture baked, the illuminance on its surfaces can be obtained through the 'rendering to texture function'. 3ds Max is capable of producing pictures of these lighting maps. The generated Maps are 512 by 512 pixels and are in the TARGA file format. In these pictures the RGB values of the pixels represent a certain illuminance. Through a tool, developed earlier for research at the University Twente, these values can be directly read from the pictures.

5.5.2. Modelling the simulation scene.

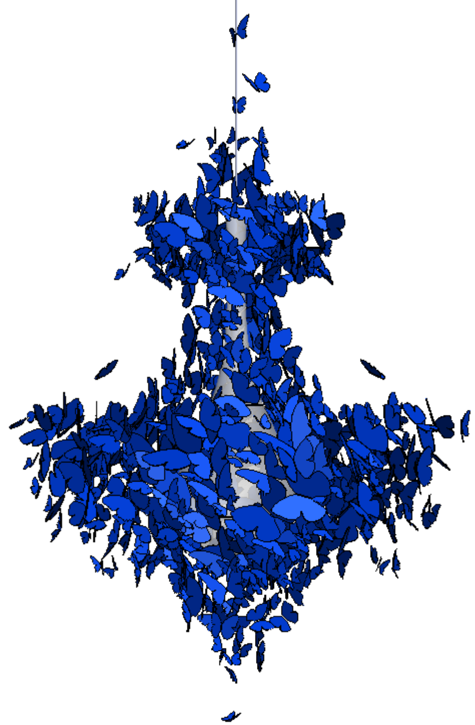
The simulations require a model of the Solar Chandelier and an approximation of a typical environment for the product. The best way to define and build this geometry was researched.

Selecting the Solar Chandelier 3ds Max model.

As the surfaces of the Solar Chandelier model in 3ds Max directly influence the texture mapping, its geometry greatly influences the quality, shape and amount of results. Based on recommendations by Erik Hop, Demakersvan had decided early on in the project to restrict the amount of functioning PV cells to types 1A, 1B, 2A, 2B and 3A. Amounting to 102 butterflies in total. With 102 functioning solar butterflies, and consequently 204 separate PV cells the biggest challenge was to design a way to generate illuminance data for each cell while keeping the amount of needed simulations small. The limited size of the TARGA pictures was an important constraint, meaning the legibility of the results had to be balanced against the need to include as many butterflies in a picture as possible to reduce the needed amount of pictures. Further considerations were the fidelity of the results with respect to the SW model and if the data could be used to develop theory on the influence of the orientation of butterflies on their energy yield.

To this end 2 different options were developed for the modelling of the Solar Chandelier in 3ds Max. The first was to reduce the geometry drastically by creating a new model for the Solar Chandelier, instead of using the Solid Works model that was supplied by Demakersvan. The PV's are arranged in grids, and placed under different angles. Shade is created by a shell placed around the grids, again varying per butterfly.
The second option was to directly use the model made by Demakersvan. Demakersvan wants the final physical product to resemble this model as much as possible, making it an excellent basis to use for producing directly applicable results for the company.

For this reason the second option was chosen. The first option offered a lot more opportunity to directly research parameters such as the amount of shade and placement angles and their effects on the energy yield. Using these results to give an estimate on the performance of the PV cells in the actual model was however judged to be very complicated. Unknowns such as the expected amount of shade would have to be estimated per butterfly in order to apply the results. This would leave a large margin for error and made it questionable if the results would be valuable for Demakersvan. Using the SW model as a basis for the simulations ensures the results will resemble the real world circumstances for the eventual physical product as closely as possible.

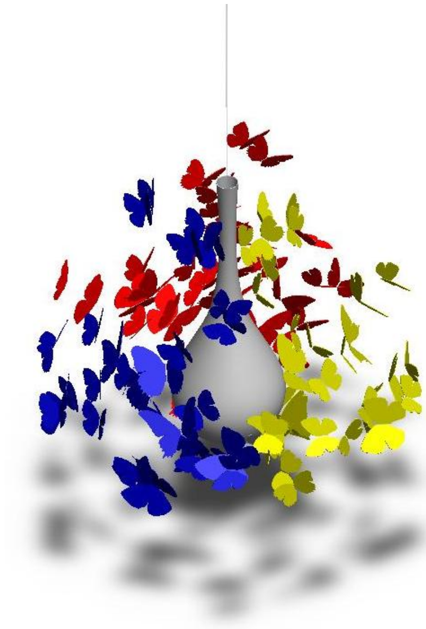


Picture 5.3: Solid Works model of SC.

Constructing the Solar Chandelier 3ds Max model.

The original CAD model of the Solar Chandelier was created by Demakersvan Demakersvan in Solid Works. As 3ds Max is not compatible with Solid Works the model has to be converted into a file format which is compatible with both packages. Most suitable was the STL file format (Stereolithograhy). It describes only the surface geometry of an 3D object, without any other common attributes such as colour or texture (Wikipedia, 2009). Also to successfully convert the model into STL format changes had to be made to the geometry of the butterfly wings. They were originally constructed as planes but had to be replaced by extrusions based on the same drawings. The resulting butterfly wings have a thickness of 2mm.

After the STL model was imported into the 3ds Max scene it was converted into a mesh, making editing possible. The 102 functioning butterflies were sorted into 9 groups, each converted to a separate object in the scene to make separate UVW mapping of each group possible. Utilizing the symmetry present in the Solar Chandelier model it was divided into 3 sections of 120 degrees. Each section contains 3 groups of butterflies.



Picture 5.4 (left): Solidworks model divided into three sections.

Picture 5.5 (right): Section divided into three groups.

The sections and their content:

Name	*Amount of butterflies*
Front 1	9
Front 2	13
Front 3	13
Left 1	9
Left 2	12
Left 3	13
Right 1	9
Right 2	13
Right 3	13

For a detailed overview of the content of each section see Appendix A.

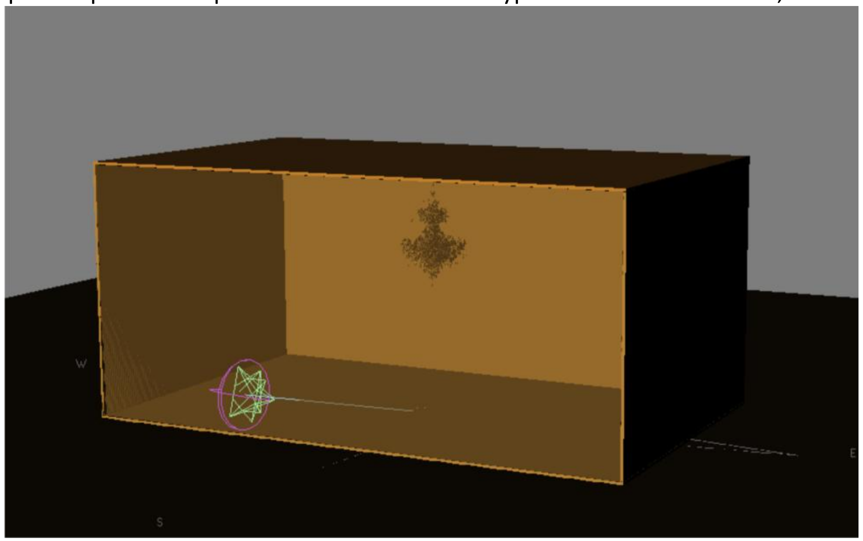
Defining the material of the Solar Chandelier.

The final part of the defining of the SC model in 3ds Max is designing its material. Different options were considered. The first was to model the material as an absolute absorber of light, eliminating internal reflections. It could possibly have been valuable to see how much of an impact internal reflections have on the received illuminance. Testing however showed using this material gave bad results. For example the TARGA file would show the left wing of the same butterfly receiving the maximum amount of illuminance and the right wings the minimum amount(and vice versa).

The next option was to model the material of the used PV cells as closely as possible. This was however quite complicated. First the material of the used cells is multi-crystalline, meaning it is a non-homogeneous material with locally differing reflection rates. Secondly PV cells are treated to reflect as little light as possible (Nelson, 2003, p.4). The PV cells in the SC will be treated with a protective coating, with unknown reflective properties. However as de Konink (2009, p.13) has shown, the application of this coating increases the efficiency of the PV cells slightly. This could point to a further reduction of the rate of reflection. In the end a homogeneous material was

made with a reflection rate of 30%. The number was chosen on a review of a few articles on the reflection of PV cells.
This material was definedin 3ds Max. To ensure correct simulation, a generic photometric 3ds Max material was used and adapted to the specific needs for this simulation. This type, compassing a few categories of materials are the only ones which guarantee a photometric correct simulation.

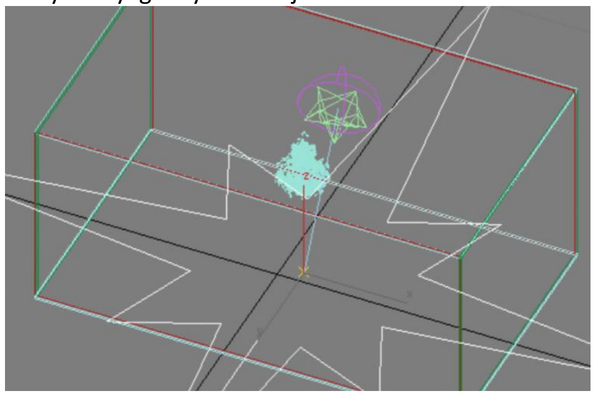
Environment geometry.
Essential parts of the environment are the building containing the SC model and its surroundings. As was shown in the environment study, other nearby buildings and the ground can have a great effect on the amount of light a building receives. The surrounding build environment is however such a complicated parameter, as it is quite impossible to predict which would be a typical situation for the SC, that in this case it was not modelled. For the ground recommendations of Landry and Breton (2008, p. 2) were followed, meaning a large ground plane of 30 by 30 metres was modelled in 3ds Max on which the building was placed.



picture 5.6: Simulation environment model.

The design on the building is based on that of a gallery of museum hall. A large rectangular space of 10 by 6 meters and 5 meters high was modelled. To light the room one of the sidewalls is modelled entirely as glass. Though spectrum absorbing glass is frequently used in museum environments, it will not be modelled in this case. This allows the room to double as a large space in a private residence. The room was entirely constructed in 3ds Max, with separate objects for the walls, flour, ceiling and glass.

Lastly a Daylight system object was added to the scene. Direct sunlight is modelled as a directional light source and can be found in the scene, diffuse daylight is however modelled as an environmental light source and not directly visible. Much attention was given to the positioning of all the components of the scene, as gaps or intersecting geometry have a detrimental effect on the results of the simulations.



Picture 5.7: Scene with daylight system.

Environment Materials.

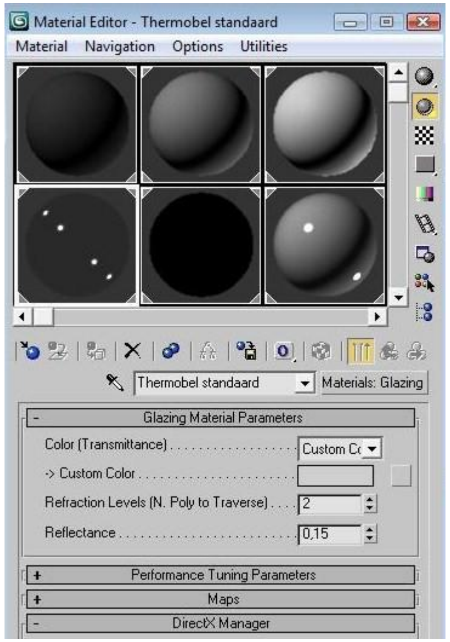
Again in order to guarantee the physical correctness of the simulations, only photometric materials from the 3ds Max Design library can be used (Reinhardt et. al, 2008, p. 8). Their properties are based on measurements derived from real world experiments. A wide range of materials is available, from concrete to wood, and from metal to glass.

To mimic typical ground conditions, the ground plane material was modelled as a diffuse material with an RGB colour of 0.2, 0,2, 0.2, as recommended by Landry and Breton (2008, p.2). This creates a ground plane with a diffuse reflectance of 20 %.For the walls and the ceiling of the building a Wall paint material was used with a flat surface finish and a roller as application method. The floor was modelled as a wood, with a satin varnish.

The modelling of glass required some extra consideration. Whereas with other materials it is enough to model the geometry simply as a volume and assign a material, the transparency of glass demands some more thought. For 3ds Max two different kinds of approaches can be used. In the case of multiple glass panes, the individual panes could be modelled with the correct thickness and positioned. However, to account for all the effects an extra function in 3ds Max would have to be enabled if a physical correct simulation is required. This function, Caustics, simulates the bright glowing lines that are caused when light is reflected or refracted multiple times before it hits a surface (Dualheights, 2007). It also accounts for the attenuation, the gradual loss of intensity that occurs when light transverses a glass volume. Caustics is a very computationally intensive function and can considerably affect render times (Landry & Breton, 2008, p. 5).

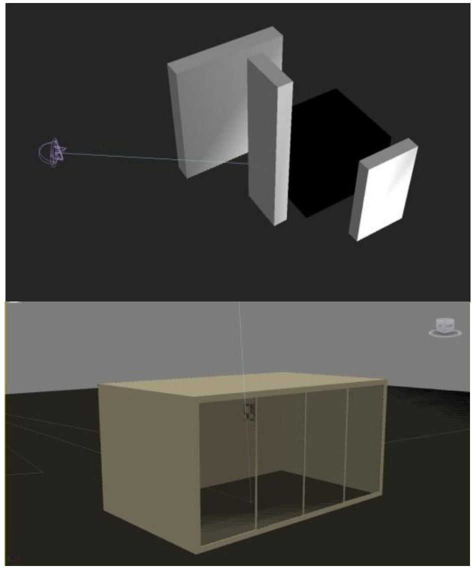
If such a high degree of accuracy is not required, it is recommended to model all the glass panes together in a single volume. The volume will act as a gel filter, without internal attenuation and refraction of the transversing light rays (Landry & Breton, 2008, pp. 5-6). This eliminates the need for enabling the Caustics functionality. In the case of the SC, in which such localized effects as caustics will have little to no effect on the amount of irradiation received on the butterflies, modelling glass as a volume will be sufficient.

The Promaterial Glazing material was used. Its settings were based on the specifications of Themobel double glazing with a RGB of 0.81, 0.81, 0,81, 2 refraction levels and a reflectance of 15%.



Picture 5.8: Screenshot of used glazing material

5.5.3 Simulation settings.



Picture 5.9: the two test environments.

The next step was to determine which settings have to be used during the simulations. Two test environments were created, one with simple and one with complex geometry. Starting with the simple one, consisting of a ground plane with concrete pillars on it, tests were carried out to determine which settings produced satisfactory results. The testing process also provided an opportunity to practice with complicated functions such as the UVW mapping. The results were next tested with the complex scene, which matched the environment that would be used in the simulations but with a simpler SC model. With these tests the settings were refined and an estimate was made of the time needed to carry out the simulations. A short overview of the most important settings for the simulations:

Daylight system:

Daylight parameters	• Sunlight: mr Sun • Skylight: mr Sky • Position: Weather data file for London Gatwick, for December 21th 8.00-16.00 and June 21th 5.00-21.00
Mr Sky Parameters	• Set ground color to RGB: 0,0,0 (black) • Sky model: Perez All Weather
Mr Advanced Parameters	Aerial Perspective off

By choosing these settings for the daylight system a simulation based on the Perez AWM is possible. As Demakersvan preferred to obtain the results for a specific site, London, the EPW files were selected as to set the parameters for the daylight system. They contain the typical environmental conditions for a specific site and are based on years of measured data, making it possible to simulate hourly the conditions for London on any date.

The Aerial Perspective function should be off and the ground colour (not to be confused with the ground plane) set to black for any quantitative lighting analysis (Reinhardt e.a. (2), 2008, p.6).

Render setup:

Renderer	• Sampling Quality: Set Frame buffer type to Floating Point (32-bit)
	• Rendering Algorithms:
	    ○ Max. Trace Depth: 6
	    ○ Max. Reflections: 6
	    ○ Max. Refractions: 6

Indirect Illumination	Final Gather: • Enable • Precision preset: high • Diffuse bounces: 6 • Caustics & Global illumination off

These setting heavily influence the accuracy and time with which each frame is rendered. By increasing the number of calculated reflections, refractions, diffuse bounces and trace depth the quality increases. When values higher than 6 were used, the render times increased dramatically while the results only deviated 2% from the ones generated by using lower settings. As it was anticipated that many renders would have to be carried out the chosen setting are a compromise, resulting in a render time of approximately 1,5 hour per frame.

Environment and effects:

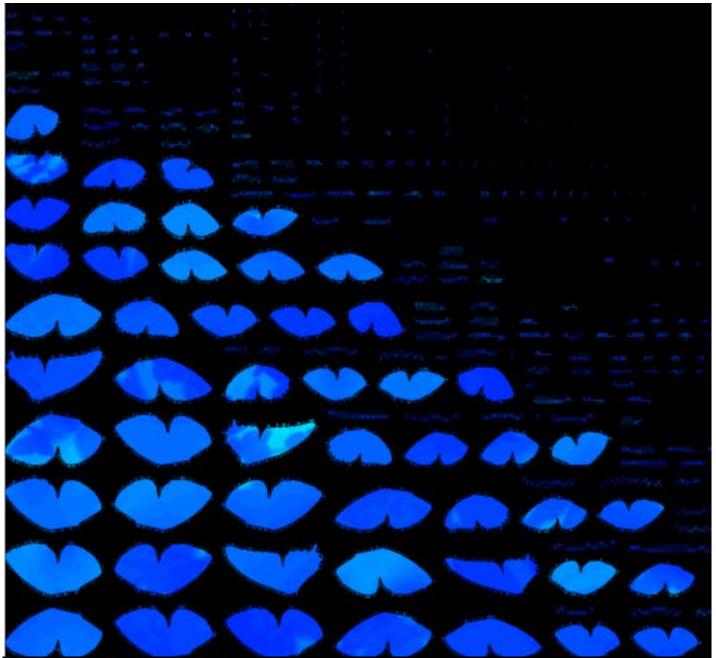
Exposure control	Set to Pseudo Colour Exposure Control • Min:0 lux, Max: value determined with low quality test renderings. • Display type: Illuminance, Coloured and Linear • Physical scale: 1500

for

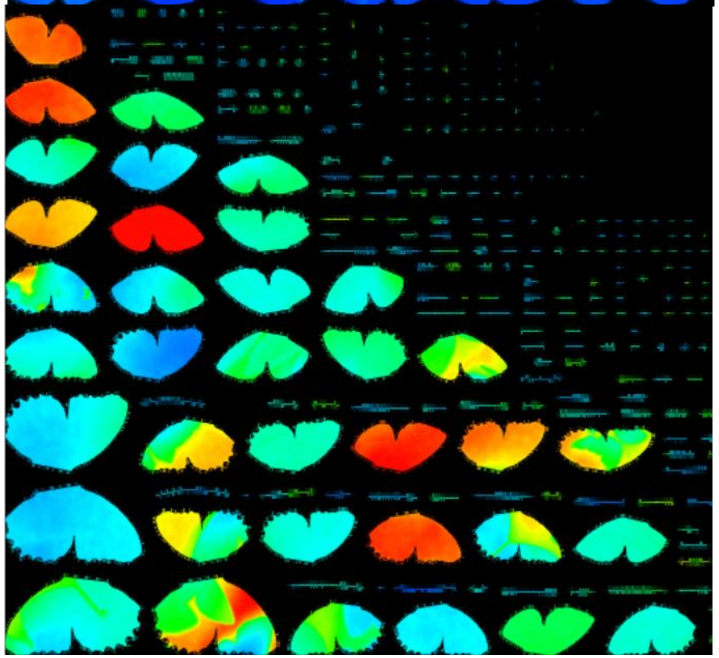
Exposure control sets the range of the information rendered in the picture. If set to display illuminance with colour in a linear way, it relates a specific RGB value of a pixel in the rendered picture to a certain illuminance value. The colour ranges from blue for the lower values to red for the higher values. Setting the range correctly is crucial. If taken too small, parts of the picture with higher illuminance values will be displayed incorrectly. If the range is set too large, legibility will become a problem because the image will suffer from low contrast, making it hard to distinguish between the different areas.

As exposure control is set before the picture is rendered the only way to correct mistakes is to render a new picture with different settings. To avoid these problems the correct range for each frame is researched by carrying out test renders with lower render settings.

For a detailed overview of the correct settings and procedures to be used when rendering please see Appendix B.



Picture 5.10: Results with a too large range exposure control



Picture 5.11: Results with a good range for exposure control

6. Simulations.

6.1 Study design.

Due to the high amount of functioning PV cells in the Solar Chandelier the amount of parameters in the study had to be set carefully to keep the amount of work reasonable. As mentioned earlier, the SC was divided in 9 sections, each requiring a full set of renders.

Demakersvan required information on the individual performance of butterflies under differing conditions. Initially it was planned to simulate the performance of the SC in two differing geographical locations, London and Riyadh, under summer

Location	Season	Environment	Hours	SC zones	Total
London	winter	Hall	8	9	72
London	summer	Hall	16	9	144
Riyadh	winter	Hall	10	9	90
Riyadh	summer	Hall	14	9	126

Figure 6.1: Overview of required frames.

and winter conditions. However as can be seen in the figure above, this resulted in a very large amount of frames which needed to be rendered.

As each frame required 1,5 hour to render and had to be analyzed later on, it was decided to reduce the amount of parameters.

Location	Season	Section	Frames
London	winter	Front 1	8
London	winter	Front 2	8
London	winter	Front 3	8
London	winter	Right 1	8
London	winter	Right 2	8
London	winter	Right 3	8
London	winter	Left 1	8
London	winter	Left 2	8
London	winter	Left 3	8

Only London will be considered in this study, and only for the winter the full set of simulations will be produced.

Overview of the simulation and calculation process.

First, for each section a series of test renders was made to determine the appropriate exposure control range (explained earlier in section 5.5.3). Because a very high level of accuracy was not necessary for these pictures low setting were used, resulting in very fast render times of only 10 minutes per picture.

After the correct exposure control settings were determined the frames were rendered using 3 fast pc systems. This setup enabled parallel rendering, reducing the total amount of time which had to be spent rendering.

Next, each rendered frame had to be analyzed. A 3ds Max script, made by Hugo de Wit, was used to read out the results. With this script a TARGA image is loaded in a new window. If the user then moves the pointer over the picture, the script reads the RGB values on that location and converts them to a certain illuminance value. Depending on the way the wings were illuminated and shaded a maximum of 4 illuminance values were recorded, along with their estimated areas. This resulted in an estimate of the average illuminance for each wing per frame. These values were used to calculate the average hourly illuminance.

Next the average irradiance was calculated by converting the illuminance using a luminous efficacy. Based on calculations and real world measurement carried out by Erik Hop in Enschede, a conversion factor was determined of 130 lm/W. The areas of each wing type were also estimated, taking into account that not the full area of the wing will generate electricity. Finally to calculate the energy yield of the cells a formula was used from the work of Erik Hop. The effiency is LOG(I / CF)*0.06; where I is the average illuminance on the plane and CF is the conversion factor for illuminance to radiance.

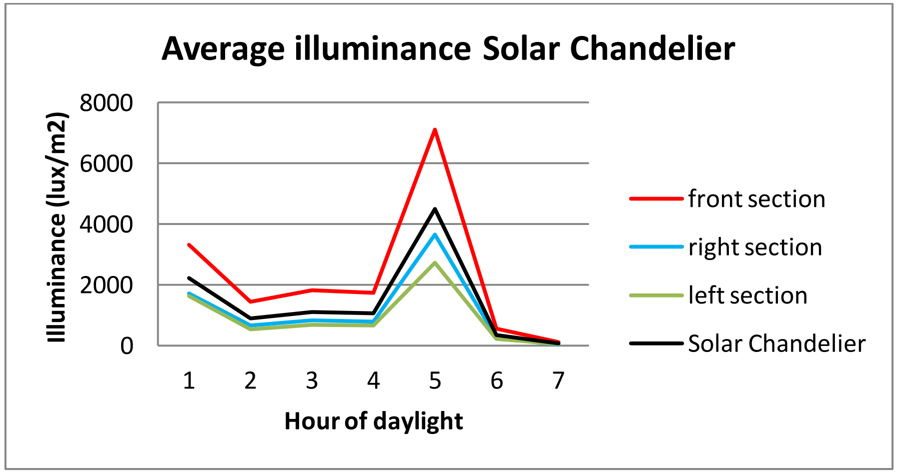
6.2 Results.

The full results of the simulations can be found Appendix C.

A summarization:

Average energy output of the SC per day (W/h)

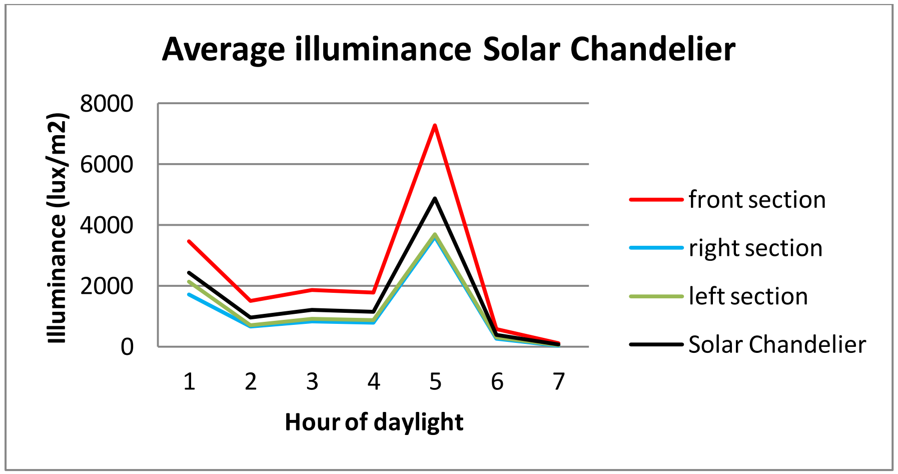
	front section	right section	left section
group 1	0,75	0,23	0,32
group 2	0,8	0,39	0,34
group 3	1,7	0,59	0,66
total SC	5,78	(W/H)	



These first results indicated the energy output of the butterflies would be very limited. It was decided the rethink a choice made by Erik Hop in an earlier stage of the project, and see if connecting the 3B butterflies would be worthwhile. Connecting these would add 30 functioning butterflies to the SC. Another set of simulations were carried out with the following results:

Energy output of the SC per day (W/h) – 3B connected

	front section	right section	left section
group 1	0,75	0,23	0,32
group 2	0,80	0,39	0,34
group 3	1,70	0,59	0,66
group 3B	0,6	0,18	0,21
total SC	6,77	(W/H)	
increase %	17%		



The simulations indicate that having the 3B butterflies functional is a valuable option to pursue. Under the same conditions 17% more energy output was generated by the SC. This was also reflected in the data on the average illuminance of the butterflies, with the average of the SC and the left section improving. Based on these results the decision was made to 'connect' the 3B's.

Discussion of the results.

While the simulations and calculations yielded a lot of data, the accuracy of the data is quite a big issue. Not only are there some sources of uncertainty, also many approximations were made which influence how well the results approximate reality. A list:

- The 3ds Max illuminance calculation
  - The approximation of the materials
  - The approximation of the illuminance
  - Only run for one location, London.
  - Perez All Weather Model
  - Weather data files
- The estimation of the illuminance of the wings
  - Estimation of an average illuminance
  - Estimation of the effective area
- The calculation of the irradiance of the wings
  - Use of an conversion factor determined for Enschede
- The calculation of the power output
  - Based on average illumination, effects of shadows are not accounted for.

It is very difficult to estimate the magnitude of the error. In a study by Reinhardt (2009) over 60% of the 3ds Max 2009 simulations fall within a plus/minor error band of 25%. The study did not measure the irradiance on such a complex object as the SC, so it is highly unlikely the results are directly applicable. Additionally studies have also shown that the Perez model also has its limits, it has troubles predicting irradiances just after sunrise and before sunset. Already mentioned in section 5.2.3 was that it also has a mean relative error of -4% in illuminance calculations.

Taking into account the number of sources of error and some of the magnitudes mentioned above, an error of 40-50% in the results does not seem unlikely. This means the results of the simulations should be taken as a general indication of the performance of the butterflies.

7. Configuration modifications and circuit design.

7.1 Configuration modifications

Based on the results of the simulations recommendations could be made on the placement of the solar butterflies to improve the performance of the Solar Chandelier. Large modifications were however not possible as Demakersvan did not want to compromise the aesthetics of the SC design. Finally the only modifications made were to replace some small butterfly's which received on average much light, by a larger type. This resulted in 2 new butterflies: 2B 251 and 2B 254.

7.2 Circuit design

Another goal of the simulations was to base the design of the circuits of the SC on the results of the simulations. This process was greatly impacted by the work of Sebastian Kettler and Rik de Konink on the SC project. Several decisions were made as to the electronic design of the SC. To counter the detrimental effects of shadowing the best solution is to connect the butterflies in parallel. This would however result in a large amount of wiring, which is not desirable because Demakersvan wanted a frame with little visual impact. The decision was made to make the frame electricity conducting, eliminating the need for any wiring. Several sections will be isolated, creating groups of serially connected butterflies. Each group will have a bypass diode, meaning that if a series contains too many shaded butterflies the whole section will be knocked out. This was done to counter the detrimental effects of a fully shaded PV cell, which acts as a resistance. Both PV cells of a single butterfly will be parallel connected to the frame. In addition the battery which is charged by the butterflies requires 12 Volts. Measurement carried out by Rik de Konink showed that under a irradiance of 31 W/m^2 butterfly 2A generates 485 mV. Based on this information design circuits had to be defined. The most important considerations:

- Link similarly performing cells together as serially connected PV cells perform with the current of the weakest performing cell in the chain.
- Avoid connecting butterflies which can become fully shaded.
- Link enough butterflies to reach the required voltage of 12 V.

The last point formed the biggest constraint in defining the circuits. Based on the data provided by Rik de Konink and the simulations in which the average irradiance of the front section during the winter is 18 W/m^2 an considerable amount of butterflies need to be linked together. As no measurements were carried out for irradiances lower than 31 W/m^2 or for the other butterfly types and sizes, the optimum amount of connected cells was very difficult to determine.

7.3 Circuit design advice.

Similarly to the simulation model, the SC is divided into three similar sections of 120 degrees. This means that in the case of a single window, for an optimum performance the SC must be positioned with a section fully facing the window. However as the simulation results indicated lighting from a single side seems to be insufficient, so if the room has windows on multiple sides the design would be able to profit from this.

In total 4 circuits will be formed. 1 in each section containing 28 (29 in the front section because of an unique butterfly) of the best performing butterflies. The fourth circuit runs through all three sections and contains the 28 most poorly performing butterflies. For the actual contents of the circuits see Appendix D.

8. Guidelines for future owners.

8.1 Introduction.

Demakersvan asked that some guidelines were formulated to advise future owners of the Solar Chandelier on the right environment of the product. An advice was written based on the insights gained from the environment study.

8.2 Guidelines for future owners.

The environment in which the Solar Chandelier is placed has a large influence on the performance of the solar cells. To optimize the performance of the Solar Chandelier, it is important that the space in which it is placed possesses at least a few of the following characteristics.

The solar cells in the chandelier need a considerable amount of daylight to function. Minimally required is a room which possesses a single wall with several large windows or a glass wall. A room with large surfaces of glazing in multiple walls or a roof light is the best environment for the Solar Chandelier.

The Solar Chandelier highly profits from exposure to direct sunlight, which penetrates a room twice the distance found between the top of the windows and the floor. If a room possesses windows which are 3,5 meters high, the Solar Chandelier could be hung up to 7 meters from the window and still profit from direct daylight. The intensity of the received light however quickly decreases as the distance between the window and the Solar Chandelier increases, so if the design of the room allows for it hang it well within range of the widows.

The decoration of the room is also influential. Ideal are smooth, lightly coloured walls and ceiling. White coloured walls are preferable. Profiles or beams spanning the ceiling severely reduce the reflection of light in the room itself, so if possible avoid hanging the Solar Chandelier in a room with such a ceiling.

A short overview of the most important points:

- At least a single wall of the room must contain large areas of glazing.
- If possible hang the Solar Chandelier within reach of the windows to profit from direct sunlight.
- If possible hang the Solar Chandelier in a room with smooth, lightly coloured walls and ceiling.

9. Conclusions

The conclusions of this research:

1. *How do the solar butterflies in the SC work?*

   1.1. *What is the design of the solar butterflies in the SC?*

The solar butterflies used in the SC are of three different types, each consisting of 4 different sizes named A, B,C and D. Initially only 1A, 1B, 2A, 2B and 3A would be functional, but based on the simulation results 3B were added.
Each functional butterfly consists of two parallel connected multi-crystalline PV cells, cut in the shape of butterfly wings.

   1.2. *What influences the functional performance of the solar butterflies?*

PV cells show the behavior of a diode when they are in the dark, making shading a large problem. Research by de Konink showed that the power output if the cells used for the solar butterflies is linearly dependent on the amount of shading.
The intensity of the received irradiance on the PV cells is also of great importance. De Konink's work also showed that under an irradiance of 1000 W/ m^2 the output power of a 2A butterfly was 2,634 W and under 31 W/ m^2 (which is nearer to the conditions encountered during the simulations) the output power was only 0,073 W.
Influences on the amount of received irradiance (and thus on the performance of the solar butterflies) are further examined in research question 2.

2. *Which factors influence the amount of irradiance and illuminance the SC receives?*

   2.1. *What is irradiance?*

Irradiance is the amount of energy an object receives when it is struck by light and expressed as Watt per square meter. The most important source of radiant energy is the sun.

   2.2. *What is illuminance?*

Iluminance is another way to define the amount of incident energy on surfaces. In this case the incident light is wave-length weighted in such a way that a luminous flux only consists of light with the wavelengths the human eye can see. Incident light is usually expressed in illuminance in situations where it is important what the human perception of the light is.

   2.3. *Which influence has the natural environment on the irradiance and illuminance?*

As the energy travels from the sun through the earth's atmosphere it is scattered by clouds, rain or pollution, forming a diffuse irradiance. Some of the energy is also absorbed, causing spectral differences. Diffuse light contains a larger portion of blue. The geographical location of the irradiated site influences the length the energy has to travel through the atmosphere. The nearer to the poles, the more the energy is scattered and absorbed.

   2.4. *Which influence has the built environment on the irradiance and illuminance of the SC?*

      2.4.1. *In which environments will the SC be used?*

The SC is meant for indoor use. As it is not a small object, and expected to be quite expensive, the SC would be hung in larger spaces. Possible environments could be museums or gallery halls, large private rooms or large commercial spaces.

2.4.2. How do these environments influence the irradiance?

As little literature was available about the effect of the built environment on irradiance, other fields had to be examined. Based on literature found about utilizing natural daylight in architecture a specific set of factors was developed for the SC:

Building	**Room**	**Lighting system**
Location: - Latitude - Sunshine probability - Surrounding environment. Shape of the building	Relation to adjacent spaces: - Autonomous - Borrowing light - Giving light - Interchanging light Proportions of the room - Length-depth ratio - Glazing-flooring area ratio - Glazing-reflecting area ratio Orientation to the sun Interior decoration	Type of light system - Daylight - Artificial light Light system design - Composition - Design - Placement Function of light system - Glare protection - Heat protection - Shading - Redirection Spectrum altering

3. *What advice would be given to future owners of the SC, with regards to the environments in which the SC could be used?*

A list of factors was developed that influence the irradiance and illuminance received on the SC. These were based on literature about utilizing daylight in building design. Based on these factors and the simulation results the following advice is given:

- At least a single wall of the room must contain large areas of glazing.
- If possible hang the Solar Chandelier within reach of the windows to profit from direct sunlight.
- If possible hang the Solar Chandelier in a room with smooth, lightly coloured walls and ceiling.

4. *How will irradiance be simulated with software for this assignment?*

4.1. How is irradiance simulated in software?

This question was answered in two parts. First modeling methods used in software of irradiance and illuminance were analyzed, namely the CIE model, Perez point-source model and Perez all-weather model. In the case of simulation irradiance the Perez point-source model predicts best under overcast conditions, the Perez all-weather model under non-overcast conditions. In the case of illuminance the Perez all-weather model outperforms the CIE model, showing a smaller relative mean error. Next techniques utilized in software packaged to photometrically correctly simulate irrandiance and illuminance were examined. Ray tracing, global illumination and photon mapping are the techniques mentioned and also part of the software package used in the simulations.

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4.2. What are the requirements for selecting a software package to simulate irradiance for this bachelor assignment?

The requirements for the simulation software:

- ✓ The Solid Works model of the SC can be imported
- ✓ Software is able to simulate photo metrically correct:
  - Daylight for different geographical locations

- Daylight for different seasons
- Materials

✓ Software is able to measure and display the results

✓ Software is validated

✓ Software can be easily learned

4.3. Which software is best suitable for the simulations?

Several packages were analyzed with regards to their suitability for the assignment. Radiance and Daysim were the only packages considered that were directly capable of simulation irradiance. Radiance however was too difficult to learn within such a short time and Daysim was too much geared towards building light analysis.
Finally 3ds Max and a special version, 3ds Max Design, were considered. Both are only capable of simulating illuminance, meaning the results have to be converted to irradiance. 3ds Max Design offered light meters which locally measuring illuminance, but with so many butterflies to analyze this tool would have meant a lot of extra work as it needs to be positioned over each surface. 3ds Max was selected in the end, as 3ds Max design required an additional investment and seemed to offer little extra advantage.

5. What is the energy yield of the Solar Chandelier?

5.1. How is the energy yield determined?

To determine the energy yield of the SC images are rendered containing the hourly received amount of illuminance on each wing. As the data cannot be readily read from the images, the actual illuminance has to be estimated per wing. From this, using a conversion factor which is location specific, the average hourly irradiance can be calculated. Finally a formula calculates the energy yield, using the hourly irradiance and estimated areas of the wing that will generate electricity.

5.2. What is the energy yield in different seasons?

Due to the time and effort needed to obtain the energy yield of the SC during a single day it was not possible within the scope of this Bachelor Assignment to analyze different seasons. The worst case scenario was pursued, the energy yield of the SC on the shortest day of the year, namely the 21st of December. Under these circumstances the energy yield was 5,77 W/h per day.

6. Which modifications can be made to the PV cell configuration to optimize the energy yield?

Based on the first simulation results, the recommendation was made to also connect the 3B butterflies. A separate simulation was run to calculate the resulting in a 17,2% increase of energy output under the simulated conditions.
In addition 2 small butterflies were replaced with 2B butterflies, 2B 251 and 2B 254, because these received a lot of light. Further modifications were not possible as Demakersvan did not want to compromise the design of the SC.

7. Based on the energy yield of the PV cells, how can the electrical circuits be designed?

4 circuits were designed. The SC is divided in three nearly identical sections, each containing a circuit of 28 or 29 butterflies. This takes advantage of inherent symmetries present in the SC design, and enables the SC to profit from lighting from different sides. The fourth circuit contains the 28 most poorly performing butterflies

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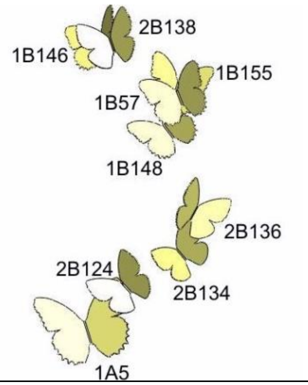
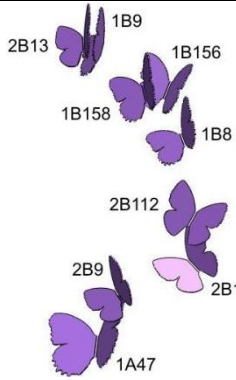
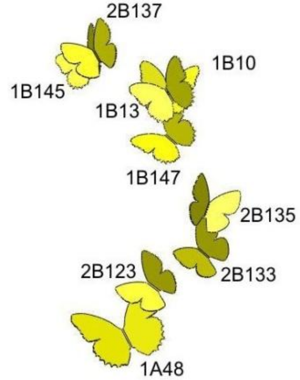
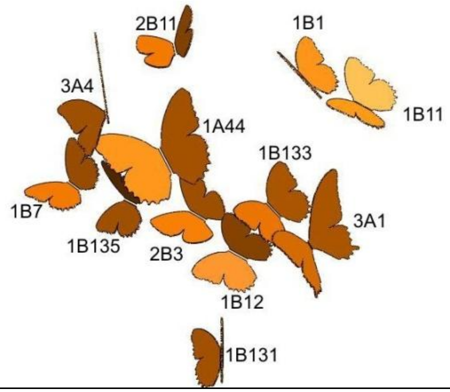
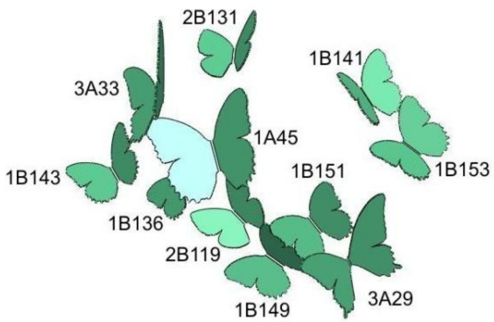
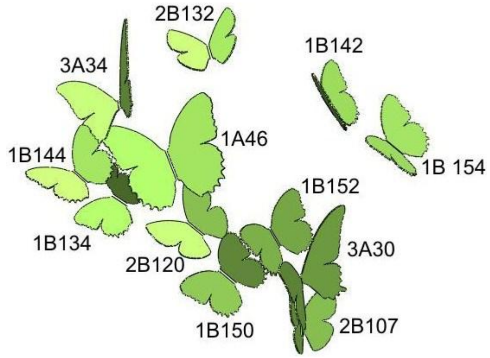
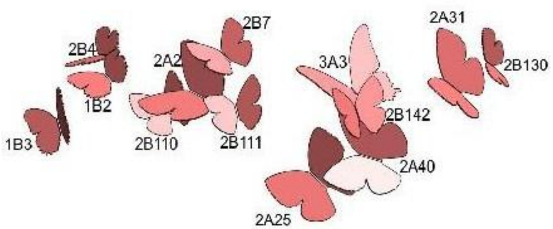
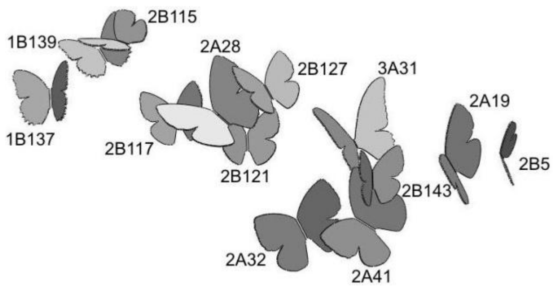
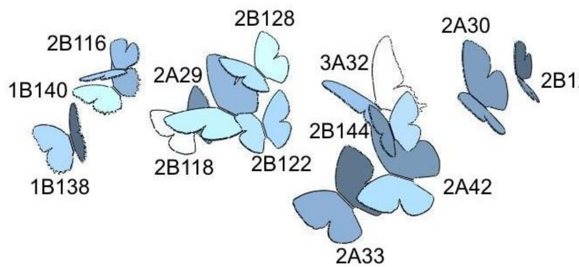
Appendix A: Solar Chandelier: contents of sections.

	Front section	Left section	Right section
1			
2			
3			

Appendix B: Rendering procedure and settings.

Daylight system

Create > Systems > Daylight system

Daylight parameters	• Sunlight: mr Sun • Skylight: mr Sky • Position: Weather data file, follow setup, match frames timeline
Mr Sky Parameters	• Set ground colour to RGB: 0,0,0 (black) • Sky model: Perez All Weather
Mr Sky Advanced Parameters	Aerial Perspective off

Objects

Ground material	Pro material generic, set diffuse colour to RGB: 0.2, 0.2, 0.2
SC material	Pro material Plastic/Vinyl • RGB: 0.4, 0.4, 0.4 • Type: Plastic (Solid) • Surface Finish: Polished • Surface bumps: None
Wall material	Pro material Wall Paint: • RGB: 0.7, 0.7, 0.7 • Surface finish: Flat • Application Method: Roller
Floor material	A&D Satin Varnished Wood: • default values
Glass	Type: Simple double glazing (Thermobel) 4mm pane +12 mm space + 4 mm pane, or 20 mm box. Box modelling will be used in the simulations. Pro materials Glazing: • RGB: 0.81, 0.81, 0.81 • Refraction levels: 2 • Reflectance:0.15

Be very careful when placing objects in the scene, they should be aligned perfectly with no openings.

UVW mapping

Select object for which an UVW map is to be generated.	
Using Modifier list add Unwrap UVW, select Face	
Parameters edit	Select
Mapping	Select Flatten mapping, experiment with settings
Tools	Pack UVs, standard settings

Render setup

Common	Time Output: set appropriate amount of frames

Renderer	• Sampling Quality: Set Frame buffer type to Floating Point (32-bit)
	• Rendering Algorithms:
	  ○ Max. Trace Depth: 6
	  ○ Max. Reflections: 6
	  ○ Max. Refractions: 6

Indirect Illumination	Final Gather: • Enable • Precision preset: high • Diffuse bounces: 6 • Caustics & Global illumination off

Environment and effects:

Exposure control	Set to Pseudo Colour Exposure Control • Min:0, Max: value determined with low quality test renderings. • Display type: Illuminance, Coloured and Linear • Physical scale: 1500

Render to texture

Objects to bake	• Select object • Mapping coordinates: use existing channel 1
Output	• Add lighting map, 512x512 pixels

Appendix C: Simulation results.

C1: Example of a simulation result and calculation.

Below screenshots can be seen of a section of the Excel worksheet which was used to record the illuminance values of the wing sections, and calculate the average illuminance, average irradiance and average energy output per hour of each wing. The worksheet was too big to be fully included in the appendices. It will be included with the digital version of the report.

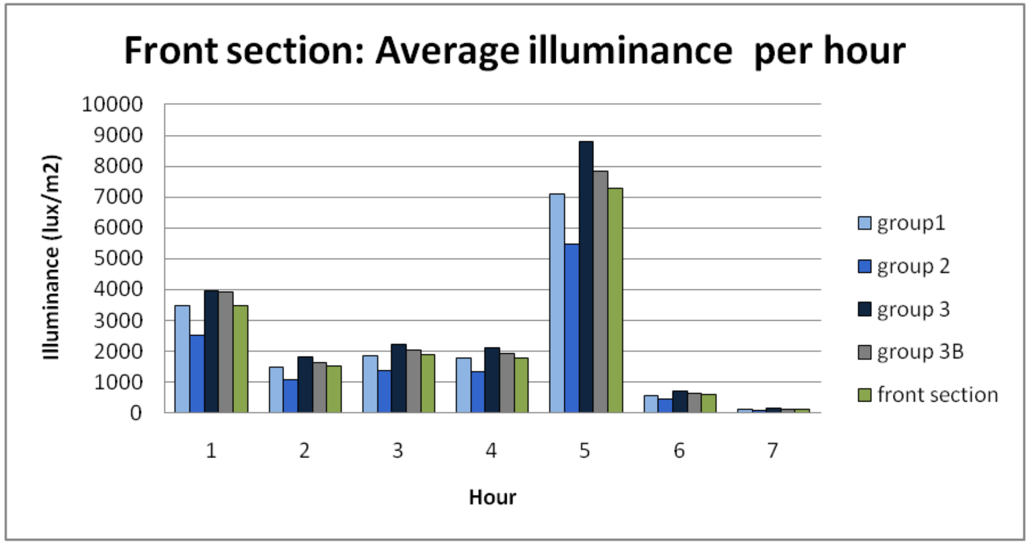
Summaries of the results for each wing can be found in appendix C2 to C4.

		1A 5L			1A 5R	
Frame 1 (8.00-9.00)		lux/m2	area		lux/m2	area
	area 1	4105	0,7		2294	0,15
	area 2	2510	0,3		2529	0,35
	area 3				2607	0,2
	area 4				1731	0,3
	average illuminance	3626,5			2269,95	
Frame 2 (9.00-10.00)		lux/m2	area		lux/m2	area
	area 1	1461	0,85		1947	0,1
	area 2	1023	0,15		1620	0,6
	area 3				1379	0,1
	area 4				615	0,2
	average illuminance	1395,3			1427,6	
Frame 3 (10.00-11.00)		lux/m2	area		lux/m2	area
	area 1	2014	0,1		2449	0,25
	area 2	1476	0,7		2158	0,5
	area 3	1841	0,2		1411	0,1
	area 4				802	0,15
	average illuminance	1602,8			1952,65	
Frame 4 (11.00-12.00)		lux/m2	area		lux/m2	area
	area 1	1773	0,1		2308	0,25
	area 2	1414	0,8		2002	0,35
	area 3	1182	0,1		1752	0,3
	area 4				773	0,1
	average illuminance	1426,7			1880,6	

		1A 5L			1A 5R	
Frame 5 (12.00-13.00)		lux/m2	area		lux/m2	area
	area 1	5666	0,1		10870	0,25
	area 2	3502	0,6		9371	0,15
	area 3	2724	0,3		4971	0,4
	area 4				3343	0,2
	average illuminance	3485			6780,15	
Frame 6 (13.00-14.00)		lux/m2	area		lux/m2	area
	area 1	512	0,05		750	0,2
	area 2	460	0,65		620	0,6
	area 3	353	0,3		443	0,1
	area 4				235	0,1
	average illuminance	430,5			589,8	
Frame 7 (14.00-15.00)		lux/m2	area		lux/m2	area
	area 1	94	1		141	0,2
	area 2				120	0,4
	area 3				110	0,3
	area 4				57	0,1
	average illuminance	94			114,9	
		1A 5L			1A 5R	
average illuminance (lux/m2)		1722,971			2145,093	
avarage irradiance (W/m2)		13,25363			16,50071	
irradiance divided by wing area		0,117016			0,145685	
energy output of wing (W/h)		0,00788			0,010642	

C2: Front section.

GROUP 1	**1A 5L**	**1A 5R**	**1B 146L**	**1B 146R**	**1B 148L**	**1B 148R**	**1B 155L**	**1B 155R**	**1B 157L**	**1B 157R**	**2B 124L**	**2B 124R**	**2B 134L**	**2B 134R**	**2B 136L**	**2B 136R**	**2B 138L**	**2B 138R**								
average illuminance (lux/m2)	1722,971	2145,093	2436,5	1706,479	2225,329	1733,086	1285,379	1529,043	1810,807	1945,021	3654,557	3717	1931,436	2583,221	2150	3360,857	2978,571	3071,286								
average irradiance (W/m2)	13,25363	16,50071	18,74231	13,12676	17,11791	13,33143	9,887527	11,76187	13,92929	14,9617	28,11198	28,59231	14,8572	19,87093	16,53846	25,85275	22,91209	23,62527								
energy output of wing (W/h)	0,00788	0,010642	0,006126	0,003769	0,005422	0,003851	0,002527	0,003233	0,004092	0,004514	0,009089	0,009291	0,003885	0,005756	0,004497	0,008148	0,006953	0,00724								
average energy output per hour (W/h)	0,106917																									
energy output group 1 per day (W/h)	0,748419																									
GROUP 2	**1A 44L**	**1A 44R**	**1B 1L**	**1B 1R**	**1B 7L**	**1B 7R**	**1B 11L**	**1B 11R**	**1B 12L**	**1B 12R**	**1B 131L**	**1B 131R**	**1B 133L**	**1B 133R**	**1B 135L**	**1B 135R**	**2B 3L**	**2B 3R**	**2B 11L**	**2B 11R**	**2B 126L**	**2B 126R**	**3A 1L**	**3A 1R**	**3A 4L**	**3A 4R**
average illuminance (lux/m2)	1863,371	1379,143	1078,357	2248,207	3483,336	2116,707	1637,3	2001,707	2034,121	1525,379	2616,15	2024,714	1547,964	1584,736	1288,579	1143,371	1640,971	1684,279	2525,957	2130,764	791,1286	1159,507	1478,764	1179,536	2111,114	1412,35
average irradiance (W/m2)	14,33363	10,60879	8,295055	17,2939	26,79489	16,28236	12,59462	15,39775	15,64709	11,73368	20,12423	15,57473	11,90742	12,19027	9,912143	8,795165	12,62286	12,95599	19,43044	16,39049	6,085604	8,919286	11,37511	9,073352	16,23934	10,86423
energy output of wing (W/h)	0,00878	0,005764	0,001957	0,005498	0,009826	0,005067	0,003558	0,004695	0,004799	0,003222	0,006737	0,004769	0,00329	0,0034	0,002536	0,002133	0,003102	0,003216	0,005586	0,004442	0,001065	0,001891	0,004245	0,003071	0,006947	0,003978
average energy output per hour (W/h)	0,113576																									
energy output group 2 per day (W/h)	0,795033																									
GROUP 3	**1B 2L**	**1B 2R**	**1B 3L**	**1B 3R**	**2A 2L**	**2A 2R**	**2A 25L**	**2A 25R**	**2A 31L**	**2A 31R**	**2A 40L**	**2A 40R**	**2B 4L**	**2B 4R**	**2B 7L**	**2B 7R**	**2B 110L**	**2B 110R**	**2B 111L**	**2B 111R**	**2B 130L**	**2B 130R**	**2B 142L**	**2B 142R**	**3A 3L**	**3A 3R**
average illuminance (lux/m2)	2548,029	2127,614	3601,093	2136,743	3035,25	2288,593	3213,986	2872,3	2135,971	2380,679	3983,686	3068,196	1964,143	2544,686	3378,714	3748,229	2415,464	1938,429	2835,857	2636,314	2067,114	2644,429	3137	4299,2	2562,079	3476,657
average irradiance (W/m2)	19,60022	16,36626	27,70071	16,43648	23,34808	17,60456	24,72297	22,09462	16,43055	18,31291	30,64374	23,60151	15,10879	19,57451	25,99011	28,83253	18,58049	14,91099	21,81429	20,27934	15,90088	20,34176	24,13077	33,07077	19,7083	26,74352
energy output of wing (W/h)	0,006504	0,005102	0,010261	0,005132	0,015487	0,010631	0,016697	0,014399	0,009683	0,011211	0,022081	0,015709	0,003976	0,005642	0,008205	0,009392	0,005262	0,003905	0,006517	0,005915	0,004263	0,005939	0,007445	0,011213	0,009017	0,013489
average energy output per hour (W/h)	0,243076																									
energy output group 3 per day (W/h)	1,701533																									
3B'S	**3B 2L**	**3B 2R**	**3B 3L**	**3B 3R**	**3B 13L**	**3B 13R**	**3B 105L**	**3B 105R**	**3B 133L**	**3B 133R**	**3B 134L**	**3B 134R**	**3B 147L**	**3B 147R**	**3B 153L**	**3B 153R**	**3B 155L**	**3B 155R**	**3B 157L**	**3B 157R**						
average illuminance (lux/m2)	4204,121	2655,664	4196,65	3128,514	1962,486	2172,964	3250,743	2412,421	4073,286	4045,814	2121,6	1950,764	1823,436	3116,486	1940,121	2452,829	1265,257	2221,479	1725,443	1012,386						
average irradiance (W/m2)	32,3394	20,42819	32,28192	24,06549	15,09604	16,71511	25,00571	18,55709	31,33297	31,12165	16,32	15,00588	14,02643	23,97297	14,92401	18,86791	9,732747	17,0883	13,27264	7,787582						
energy output of wing (W/h)	0,007848	0,004302	0,00783	0,005344	0,002861	0,003286	0,005619	0,003784	0,007535	0,007469	0,003181	0,002837	0,002586	0,005317	0,002816	0,003869	0,001546	0,003386	0,002396	0,001116						
average energy output per hour (W/h)	0,084927																									
energy output 3B's per day (W/h)	0,594489																									



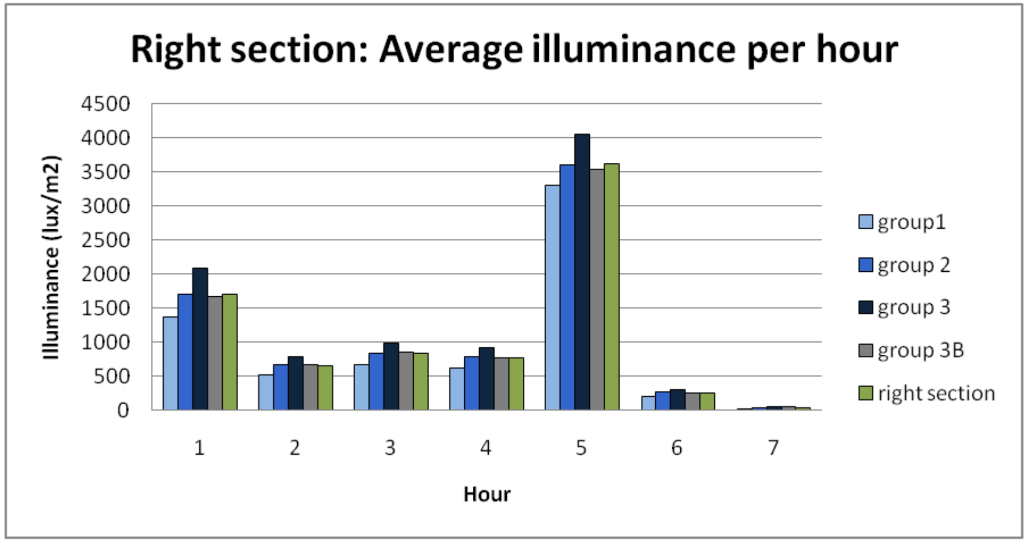
C3: Right section.

GROUP 1	1A 48L	1A 48R	1B 10L	1B 10R	1B 13L	1B 13R	1B 145L	1B 145R	1B 147L	1B 147R	2B 123L	2B 123R	2B 133L	2B 133R	2B 135L	2B 135R	2B 137L	2B 137R
average illuminance (lux/m2)	1064,057	941,3429	735,8214	661,4857	874,8857	1044,721	1029,364	1779,521	820,3929	917,4286	783,7143	1043,986	726,6286	888,7643	1167,8	936,2571	758,8571	1144,107
average irradiance (W/m2)	8,185055	7,241099	5,660165	5,088352	6,72989	8,036319	7,918187	13,68863	6,310714	7,057143	6,028571	8,030659	5,589451	6,836648	8,983077	7,201978	5,837363	8,800824
energy output of wing (W/h)	0,003959	0,003298	0,001094	0,000923	0,001431	0,001868	0,001827	0,003995	0,001297	0,001538	0,00105	0,001621	0,000932	0,001274	0,001911	0,001378	0,000998	0,001855
average energy output per hour (W/h)	0,032248																	
energy output group 1 per day (W/h)	0,225737																	

GROUP 2	1A 46L	1A 46R	1B 134L	1B 134R	1B 142L	1B 142R	1B 144L	1B 144R	1B 150L	1B 150R	1B 152L	1B 152R	1B 154L	1B 154R	2B 107L	2B 107R	2B 120L	2B 120R	2B 132L	2B 132R	3A 30L	3A 30R	3A 34L	3A 34R
average illuminance (lux/m2)	931,5429	931,75	1494,071	1429,586	663,8571	671,5714	1052,429	1491,529	1120,971	1184	1016,73	1094,364	923,8	1053,629	1111,486	1161,364	1000,914	1058,65	707,5143	1366,6	1336,551	1106,021	934,3643	2269,779
average irradiance (W/m2)	7,165714	7,167308	11,49286	10,99681	5,106593	5,165934	8,095604	11,4733	8,622857	9,10769	7,82099	8,418187	7,106154	8,104835	8,54989	8,933571	7,699341	8,143462	5,442418	10,51231	10,28116	8,507857	7,187418	17,45984
energy output of wing (W/h)	0,003247	0,003248	0,00313	0,002941	0,000929	0,000946	0,001888	0,003122	0,002072	0,00224	0,00179	0,002	0,001554	0,001891	0,001778	0,001896	0,001523	0,001655	0,000894	0,002397	0,002322	0,001765	0,002176	0,007664
average energy output per hour (W/h)	0,055073																							
energy output group 2 per day (W/h)	0,385514																							

GROUP 3	1B 138L	1B 138R	1B 140L	1B 140R	2A 29L	2A 29R	2A 30L	2A 30R	2A 33L	2A 33R	2A 42L	2A 42R	2B 116L	2B 116R	2B 118L	2B 118R	2B 122L	2B 122R	2B 128L	2B 128R	2B 129L	2B 129R	2B 144L	2B 144R	3A 32L	3A 32R
average illuminance (lux/m2)	1750,286	2863,086	830,8786	1460,1	1236	1810,664	859,7714	1189,214	1270,143	1312,99	978,143	1233,093	1709,429	2430,8	1152,943	1644,479	888,9143	1070,643	703	1341,664	933	1501,857	1275,743	1129,029	742,6	880,1071
average irradiance (W/m2)	13,46374	22,02374	6,391374	11,23154	9,507692	13,92819	6,613626	9,147802	9,77033	10,0999	7,52418	9,48533	13,14945	18,69846	8,868791	12,64984	6,837802	8,235714	5,407692	10,32049	7,176923	11,55275	9,813407	8,684835	5,712308	6,770055
energy output of wing (W/h)	0,003904	0,007595	0,001322	0,00303	0,004508	0,007724	0,002631	0,004263	0,004689	0,00492	0,0032	0,004493	0,003283	0,005306	0,001876	0,003111	0,001274	0,001683	0,000885	0,002334	0,001371	0,002739	0,002172	0,001819	0,001528	0,001987
average energy output per hour (W/h)	0,083642																									
energy output group 3 per day (W/h)	0,585493																									

3B'S	3B 10L	3B 10R	3B 11L	3B 11R	3B 16L	3B 16R	3B 17L	3B 17R	3B 136L	3B 136R	3B 138L	3B 138R	3B 142L	3B 142R	3B 150L	3B 150R	3B 162L	3B 162 R	3B 164L	3B 164R
average illuminance (lux/m2)	605,0714	993,85	659,8071	864,7857	1240,2	1732,014	824,9	672,2071	1055,257	1131,34	1265,54	1589,057	1270,4	1265,321	939,0214	1339,4	1218,829	1474,657	955,2857	1302,6
average irradiance (W/m2)	4,654396	7,645	5,07544	6,652198	9,54	13,32319	6,345385	5,170824	8,117363	8,70264	9,73489	12,22352	9,772308	9,733242	7,223242	10,30308	9,375604	11,34352	7,348352	10,02
energy output of wing (W/h)	0,0005	0,001086	0,000576	0,00088	0,001502	0,002408	0,000818	0,000593	0,001187	0,00131	0,00155	0,002136	0,001555	0,001546	0,000997	0,001678	0,001465	0,001923	0,001023	0,001612
average energy output per hour (W/h)	0,026346																			
energy output 3B's per day (W/h)	0,184419																			



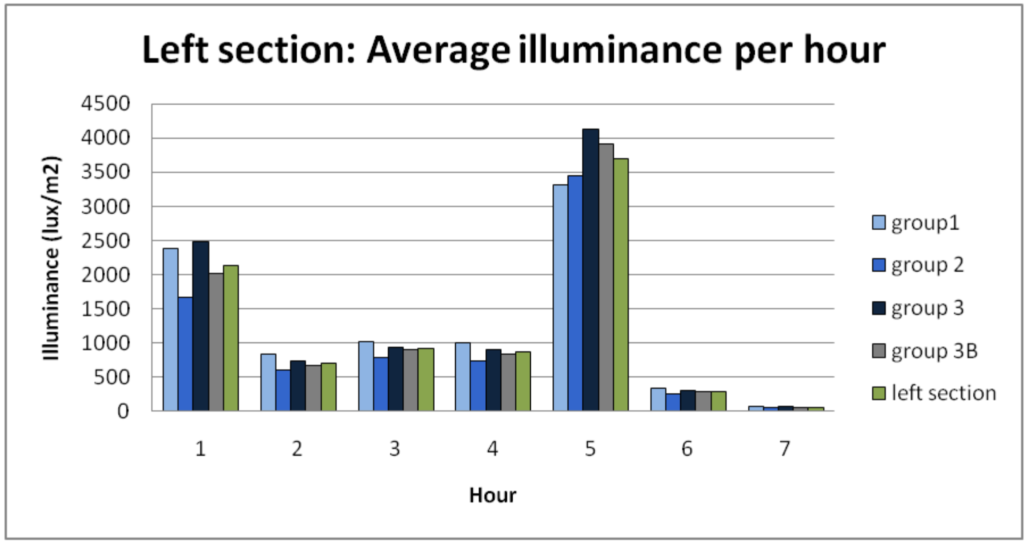
C4: Left section.

GROUP 1	1A 47L	1A 47R	1B 8L	1B 8R	1B 9L	1B 9R	1B 156L	1B 156R	1B 158L	1B 158R	2B 9L	2B 9R	2B 10L	2B 10R	2B 13L	2B 13R	2B 112L	2B 112R
average illuminance (lux/m2)	944,0286	895,0857	861,5643	1003,864	1095,6	1322,843	1011,193	968,1286	1233,671	1341,657	1173,636	1304,386	1888,243	1320,507	1084,179	1377,236	2602,514	1582,286
average irradiance (W/m2)	7,261758	6,885275	6,627418	7,722033	8,427692	10,17571	7,778407	7,447143	9,48978	10,32044	9,027967	10,03374	14,52495	10,15775	8,339835	10,59412	20,01934	12,17143
energy output of wing (W/h)	0,003312	0,003056	0,001398	0,00176	0,002003	0,002633	0,00178	0,001668	0,002382	0,002687	0,001925	0,002242	0,003767	0,002282	0,001714	0,002423	0,005814	0,002948
average energy output per hour (W/h)	0,045793																	
energy output group 1 per day (W/h)	0,320552																	

GROUP 2	1A 45L	1A 45R	1B 136L	1B 136R	1B 141L	1B 141R	1B 143L	1B 143R	1B 149L	1B 149R	1B 151L	1B 151R	1B 153L	1B 153R	2B 119L	2B 119R	2B 131L	2B 131R	3A 29L	3A 29R	3A 33L	3A 33R
average illuminance (lux/m2)	905,1071	1026,814	1075,221	1233,114	1372,564	911,2714	867,6143	1283	1089,921	1341,029	1079,607	1223,757	1074,214	839,8929	938,8571	1148,093	773,5143	923,7429	1463,679	1087,921	927,6214	1093,429
average irradiance (W/m2)	6,962363	7,898571	8,270934	9,485495	10,55819	7,00978	6,673956	9,869231	8,384011	10,3156	8,30467	9,413516	8,263187	6,460714	7,221978	8,831484	5,95011	7,105714	11,25907	8,368626	7,135549	8,410989
energy output of wing (W/h)	0,003108	0,003756	0,001949	0,00238	0,002775	0,001522	0,001413	0,00252	0,001988	0,002685	0,001961	0,002354	0,001946	0,001344	0,001384	0,001864	0,001028	0,00135	0,004184	0,002729	0,002152	0,002749
average energy output per hour (W/h)	0,049142																					
energy output group 2 per day (W/h)	0,343991																					

GROUP 3	1B 137L	1B 137R	1B 139L	1B 139R	2A 19L	2A 19R	2A 28L	2A 28R	2A 32L	2A 32R	2A 41L	2A 41R	2B 5L	2B 5R	2B 115L	2B 115R	2B 117L	2B 117R	2B 121L	2B 121R	2B 127L	2B 127R	2B 143L	2B 143R	3A 31L	3A 31R
average illuminance (lux/m2)	1330,857	1490	676,6857	1047,264	2087,314	1429,586	747,4286	1304,357	1244,986	1322,114	2955,271	1315,136	2774,871	2445	629,1143	1011,371	1156,35	1342,164	1017,743	1226,35	792,8857	1042,6	1944,7	1243,114	967,7214	909,9357
average irradiance (W/m2)	10,23736	11,46154	5,205275	8,055879	16,05626	10,99681	5,749451	10,03352	9,576813	10,17011	22,73286	10,11643	21,34516	18,80769	4,839341	7,77978	8,895	10,32434	7,828791	9,433462	6,099121	8,02	14,95923	9,562418	7,444011	6,999505
energy output of wing (W/h)	0,002656	0,003118	0,000958	0,001875	0,009385	0,005551	0,002117	0,004871	0,004556	0,004967	0,014952	0,004929	0,006331	0,005348	0,000739	0,001547	0,001884	0,002336	0,001561	0,002052	0,001069	0,001618	0,003922	0,002092	0,002293	0,00209
average energy output per hour (W/h)	0,094816																									
energy output group 3 per day (W/h)	0,663713																									

3B'S	3B 135L	3B 135R	3B 137L	3B 137R	3B 141L	3B 141R	3B 148L	3B 148R	3B 149L	3B 149R	3B 154L	3B 154R	3B 156L	3B 156R	3B 158L	3B 158R	3B 161L	3B 161R	3B 163L	3B 163R
average illuminance (lux/m2)	1054,3	1285,25	1262,436	1552,143	1569,3	1261,407	1396,586	1050,714	1611,743	1288,629	745,8571	939,1643	2337,379	1129,379	705,2857	883,4786	1205,807	1275,664	1014,257	1227,25
average irradiance (W/m2)	8,11	9,886538	9,711044	11,93956	12,07154	9,703132	10,74297	8,082418	12,39802	9,912527	5,737363	7,224341	17,97984	8,687527	5,425275	6,795989	9,27544	9,812802	7,801978	9,440385
energy output of wing (W/h)	0,001185	0,001581	0,001541	0,002067	0,002099	0,001539	0,001781	0,001179	0,002179	0,001587	0,0007	0,000997	0,003626	0,001311	0,00064	0,000909	0,001442	0,001564	0,001119	0,001479
average energy output per hour (W/h)	0,030527																			
energy output 3B's per day (W/h)	0,213692																			



C5: Substituting 2B for 2C.

		2B 251L		2B 251R		2B 254L		2B 254R	
Frame 1 (8.00-9.00)		lux/m2	area	lux/m2	area	lux/m2	area	lux/m2	area
	area 1	5117	0,8	5225	0,45	4901	1	6705	0,7
	area 2	4715	0,15	4635	0,4			5696	0,2
	area 3	2441	0,05	2598	0,05			2735	0,1
	area 4			1109	0,1				
	average illuminance	4922,9		4446,05		4901		6106,2	
Frame 2 (9.00-10.00)		lux/m2	area	lux/m2	area	lux/m2	area	lux/m2	area
	area 1	1529	0,85	1847	0,6	1611	1	2482	0,75
	area 2	1176	0,15	1545	0,2			1894	0,25
	area 3			1027	0,1				
	area 4			443	0,1				
	average illuminance	1476,05		1564,2		1611		2335	
Frame 3 (10.00-11.00)		lux/m2	area	lux/m2	area	lux/m2	area	lux/m2	area
	area 1	1850	0,95	2262	0,4	1941	1	3078	0,4
	area 2	1388	0,05	1929	0,5			2960	0,4
	area 3			927	0,05			2364	0,2
	area 4			560	0,05				
	average illuminance	1826,9		1943,65		1941		2888	
Frame 4 (11.00-12.00)		lux/m2	area	lux/m2	area	lux/m2	area	lux/m2	area
	area 1	1690	0,4	2086	0,45	1729	1	2803	0,15
	area 2	1650	0,4	1768	0,4			2721	0,6
	area 3	1392	0,2	1194	0,05			2254	0,25
	area 4			700	0,1				
	average illuminance	1614,4		1775,6		1729		2616,55	
		2B 251L		**2B 251R**		**2B 254L**		**2B 254R**	
Frame 5 (12.00-13.00)		lux/m2	area	lux/m2	area	lux/m2	area	lux/m2	area
	area 1	6764	0,4	9784	0,2	5558	1	11882	0,35
	area 2	6304	0,45	8000	0,35			9696	0,2
	area 3	5323	0,15	6058	0,225			9019	0,1
	area 4			5205	0,225			7892	0,35
	average illuminance	6340,85		7290,975		5558		9762	
Frame 6 (13.00-14.00)		lux/m2	area	lux/m2	area	lux/m2	area	lux/m2	area
	area 1	579	0,15	700	0,2	579	1	937	0,2
	area 2	544	0,7	640	0,35			898	0,6
	area 3	502	0,15	579	0,2			770	0,2
	area 4			396	0,25				
	average illuminance	542,95		578,8		579		880,2	
Frame 7 (14.00-15.00)		lux/m2	area	lux/m2	area	lux/m2	area	lux/m2	area
	area 1	103	1	138	0,2	115	1	173	0,65
	area 2			127	0,25			150	0,35
	area 3			115	0,3				
	area 4			92	0,25				
	average illuminance	103		116,85		115		164,95	
		2B 251L		**2B 251R**		**2B 254L**		**2B 254R**	
average illuminance (lux/m2)		2403,864		2530,875		2347,714		3536,129	
avarage irradiance (W/m2)		18,49126		19,46827		18,05934		27,20099	
irradiance divided by wing area		0,068769		0,072402		0,067163		0,10116	
energy output of wing (W/h)		0,005228		0,005601		0,005064		0,008707	

Appendix D: Circuit design.

front section	right section	left section
2B 138	2B 137	2B 13
3B 155	3B 17	3B 156
2B 151	2B 250	2B 145
2B 136	2B 135	2B 112
2B 124	2B 123	2B 9
1A 5	1A 48	1A 47
2B 11	2B 132	2B 131
3A 4	3A 34	3A 33
1B 2	1B 140	1B 139
2B 4	2B 116	2B 115
1B3	1B 138	1B 137
1B 7	1B 144	1B 143
1A 44	1A 46	1A 45
2A 2	2A 29	2A 28
2B 7	2B 128	2B 127
2B 111	2B 122	2B 121
3B 133	3B 164	3B 163
3B 2	3B 138	3B 137
3B 105	3B 162	3B 161
2A 25	2A 32	2A 42
3B 3	3B 136	3B 135
2A 40	2A 42	2A 41
2B 142	2B 144	2B 143
3A 3	3A 32	3A 31
2A 31	2A 30	2A 19
2B 130	2B 129	2B 5
2B 254	2B 253	2B 252
1B 131	3B 10	3B 148

Appendix E: Assignment Description.

Achtergrond project:
Demakersvan is een design studio die werkt op de grens van kunst en design. In deze context zijn we nu bezig met het realiseren van een solar chandelier voor een internationale design show in Londen. Om de innovatieve toepassing van zonnecellen op technisch vlak uit te werken zijn we een samenwerking aangegaan met de UT Twente, waarbij we ook jou als bachelor student willen betrekken.

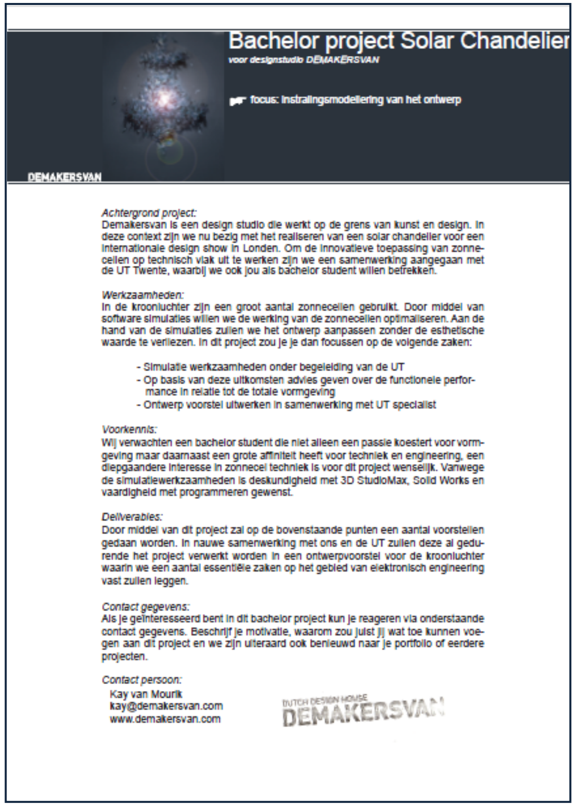
Werkzaamheden:
In de kroonluchter zijn een groot aantal zonnecellen gebruikt. Door middel van software simulaties willen we de werking van de zonnecellen optimaliseren. Aan de hand van de simulaties zullen we het ontwerp aanpassen zonder de esthetische waarde te verliezen. In dit project zou je je dan focussen op de volgende zaken:
- Simulatie werkzaamheden onder begeleiding van de UT
- Op basis van deze uitkomsten advies geven over de functionele performance in relatie tot de totale vormgeving
- Ontwerp voorstel uitwerken in samenwerking met UT specialist

Voorkennis:
Wij verwachten een bachelor student die niet alleen een passie koestert voor vormgeving maar daarnaast een grote affiniteit heeft voor techniek en engineering, een diepgaandere interesse in zonnecel techniek is voor dit project wenselijk. Vanwege
de simulatiewerkzaamheden is deskundigheid met 3D StudioMax, Solid Works en vaardigheid met programmeren gewenst.

Deliverables:
Door middel van dit project zal op de bovenstaande punten een aantal voorstellen gedaan worden. In nauwe samenwerking met ons en de UT zullen deze al gedurende het project verwerkt worden in een ontwerpvoorstel voor de kroonluchter waarin we een aantal essentiële zaken op het gebied van elektronisch engineering
vast zullen leggen.

Contact gegevens:
Als je geïnteresseerd bent in dit bachelor project kun je reageren via onderstaande contact gegevens. Beschrijf je motivatie, waarom zou juist jij wat toe kunnen voegen aan dit project en we zijn uiteraard ook benieuwd naar je portfolio of eerdere projecten.

Contact persoon:
Kay van Mourik
kay@demakersvan.com
www.demakersvan.com



Bachelor project Solar Chandelier
voor designstudio DEMAKERSVAN

focus: instralingsmodellering van het ontwerp

DEMAKERSVAN

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Contact persoon:
Kay van Mourik
kay@demakersvan.com
www.demakersvan.com

Appendix F: Plan van Aanpak

Anniek Braham, s0045160
Demakers van & Universiteit Twente
Begeleiders: Angele Reinders (UT) & Kay van Mourik (Demakersvan)

E1. Aanleiding.

Demakersvan is een designstudio die werkt op de grens van kunst en design. In deze context is de studio bezig met het realiseren van een solar chandelier voor een internationale designshow in Londen. Deze kroonluchter zal gaan bestaan uit een wolk van zonnecellen in de vorm van vlinders gegroepeerd om een glazen kelk. Om deze innovatieve toepassing van zonnecellen ook technisch te kunnen realiseren is de studio een samenwerkingsverband met de Universiteit Twente aangegaan. Namens de Universiteit zullen drie studenten middels bacheloropdrachten werken aan diverse aspecten van het ontwerp, namelijk de instralingsmodellering, ontwerpondersteuning en het ontwerpen van een experimentele opstelling. Dit plan van aanpak is voor de bacheloropdracht die zich richt op de instralingmodellering van de Solar Chandelier.

E2. Probleemverkenning

Actoranalyse

Doelstellingen van Demakersvan.

- De Solar Chandelier succesvol op de markt introduceren.
- De beoogde vormgeving van de Solar Chandelier kunnen realiseren.
- De Solar Chandelier technisch kunnen realiseren.
- Het ontwerp van de Solar Chandelier eind 2009 productierijp hebben.

Positie van Demakersvan.

Demakersvan is de bedenker en initiator van het Solar Chandelier project. Het heeft nu een conceptueel ontwerp gemaakt en is een samenwerking met de Universiteit Twente aangegaan om het product ook technisch te realiseren. Daarbij fungeert Demakersvan als afnemer van een uiteindelijk productierijp ontwerp. Tijdens het ontwerptraject fungeert Demakersvan zowel als opdrachtgever en als partner bij het nemen van ontwerpbeslissingen. Demakersvan is verantwoordelijk voor het leggen van de contacten en de afname van de benodigde producten en diensten bij toeleveranciers. Hierbij kan gedacht worden aan de toeleverancier van de zonnecellen, de bewerker van de zonnecellen en de leverancier van de lichtbronnen. Daarnaast onderhoudt de studio ook de contacten met de galerie in London waar het product mogelijk geëxposeerd zal worden.

Uiteindelijk zal de studio de Solar Chandelier op de markt brengen. Gezien de naar verwachting hoge aanschafprijs zal het een product worden voor een zeer exclusieve en kleine doelgroep. Hierbij wordt gedacht aan zowel gefortuneerde particulieren als bedrijven en instellingen.

Belangen van Demakersvan.
Demakersvan is een designstudio die met eerdere producten internationaal een goede naam heeft gevestigd. Als de studio de Solar Chandelier op de markt brengt zal deze aan een hoge standaard moeten voldoen om de goede reputatie niet op het spel te zetten. Dit houdt in dat de Solar Chandelier technisch goed moet functioneren. Daarnaast opereert Demakersvan in de kunstwereld, de technische uitwerking van de Solar Chandelier moet daarom geen afbreuk doen aan de vormgeving. Daarnaast moet dit project ook een winstgevend product voor de studio opleveren.

Demakersvan visie op het probleem.
Het Solar Chandelier project is voor Demakersvan een kans om een vernieuwende combinatie te realiseren tussen vormgeving en zonnecel technologie. Mits het technisch goed functioneert en mooi vormgegeven is, is het een kans om internationaal te reputatie verder te bevestigen en versterken.

Projectkader

Problemen die spelen.
Demakersvan heeft een conceptueel ontwerp ontwikkeld voor de Solar Chandelier. Daarbij zijn een aantal aspecten zoals de globale vormgeving van de kroonluchter, de vorm, materiaal en productie van de zonnecellen en de glazen kelk waarin de verlichting komt al verder doorontwikkeld. Ook is de precieze configuratie van zonnecellen al door de studio al vastgelegd in een fysiek model en een CAD-model. Om de Solar Chandelier echter technisch te kunnen realiseren moeten meerdere aspecten van het ontwerp nog nader onderzocht worden. Deze bacheloropdracht zal zich bezig houden met de optimalisatie van de werking van de zonnecellen. Hierbij spelen de volgende problemen:

- Nog niet bekend is de invloed van de omgeving op het functioneren van de Solar Chandelier.
- Het is onbekend of de huidige configuratie van de zonnecellen een goede performance biedt voor de Solar Chandelier.

Daarnaast mist de studio een handleiding die aan toekomstige klanten kan worden gegeven, waarin deze worden geadviseerd over de omstandigheden waarbinnen hun Solar Chandelier goed functioneert.

Achtergronden van de problemen.
Demakersvan kan niet zonder partners binnen de beoogde periode het Solar Chandelier project realiseren. De studio heeft niet de benodigde mankracht, tijd, technische kennis en werkplaats- en onderzoeksfaciliteiten om dit project tot een succes te kunnen maken.

Richtingen waarin oplossingen gezocht kunnen worden.
Het optimaliseren van de zonnecellen moet zo min mogelijk tijd, geld en moeite kosten. De beste optie hiervoor is het toepassen van software om verschillende simulaties te kunnen draaien. Hiervoor kan gebruik gemaakt worden van Solid Works om een model te bouwen. 3D Studio Max kan worden ingezet bij het doen van instralingssimulaties, waarbij binnen de universiteit ook nog een eigen ontwikkelde tool aanwezig is. De simulaties zouden zich moeten concentreren op het onderzoeken van de volgende aspecten:

- De energieopbrengst van de Solar Chandelier.
- De invloed van de omgeving op de energieopbrengst.
- De invloed van de configuratie van de zonnecellen op de energieopbrengst.

Vervolgens zou met de resultaten de volgende activiteiten ondernomen moeten worden:

- Een configuratie-advies voor de zonnecellen ontwikkelen waarbij de energieopbrengst geoptimaliseerd wordt.
- Een configuratie advies ontwikkelen waarbij het optimaliseren van de energieopbrengst niet ten koste van de esthetische waarde gaat.
- Een handleiding voor de klanten van Demakersvan ontwikkelen voor het positioneren van hun Solar Chandelier in de door hun beoogde ruimte.

E3. Doelstelling

Het technisch doorontwikkelen van het huidige conceptuele ontwerp van de Solar Chandelier, zoals aangeleverd door Demakersvan, zodat deze eind 2009 geproduceerd kan worden. In het huidige concept is de werking van de zonnecellen nog niet geoptimaliseerd. Hiervoor wordt met een softwaresimulatie de instraling en de energieopbrengst van de Solar Chandelier onderzocht. Ook zullen met softwaresimulaties de invloed van de omgeving en de invloed van de configuratie van de zonnecellen op de energieopbrengst onderzocht worden. Op basis van de resultaten uit de simulaties zal een advies ontwikkeld worden voor de configuratie van de zonnecellen, waarbij naast het optimaliseren van de werking van de Solar Chandelier de esthetische waarde van het advies ook een belangrijke factor is. In samenwerking met Erik Hop zal het advies verwerkt worden in een ontwerpvoorstel voor de Solar Chandelier. Ook zal er op basis van de verkregen informatie uit de softwaresimulaties een handleiding voor toekomstige eigenaren van de Solar Chandelier geschreven worden. Hierin wordt informatie gegeven over de omstandigheden die de Solar Chandelier vereist om goed te kunnen functioneren. Al de beschreven werkzaamheden zullen in 3 maanden uitgevoerd worden.

E4. Vraagstelling.

1. Hoe werken de zonnecellen in de Solar Chandelier?
    a. Welke zonnecellen worden in de Solar Chandelier toegepast?
    b. Hoe functioneren deze zonnecellen?
    c. Welke karakteristieken hebben deze zonnecellen?
    d. Wat beïnvloedt het functioneren van deze zonnecellen?

2. Welke factoren zijn van invloed bij het bepalen van de instraling?
    a. Welke invloed heeft de geografische locatie op de instraling?
    b. Welke invloed hebben weersomstandigheden op de instraling?
    c. Welke invloed hebben de seizoenen op de instraling?
    d. Welke invoed heeft de directe omgeving op de instraling?
        1. In welke omgevingen wordt de Solar Chandelier mogelijk gebruikt?
        2. Welke lichtomstandigheden brengen deze omgevingen met zich mee?

3. Hoe kan instraling met software gesimuleerd worden?
    a. Welke software kan hiervoor gebruikt worden?
    b. Welk type simulaties zijn met deze software mogelijk?
    c. Welke simulaties zijn voor deze opdracht nodig om de instraling te simuleren?

4. Hoe werkt de tool voor instralingssimulaties in 3D Studio Max?
    a. Wat zijn de werkingsprincipes van deze tool?
    b. Hoe kan deze tool ingezet worden bij het doen van simulaties in 3D Studio Max?

5. Wat is de energieopbrengst van de Solar Chandelier onder de verschillende instralingsomstandigheden?
    a. Hoe wordt de energieopbrengst van de Solar Chandelier bepaald uit de instraling?
    b. Wat is de invloed van de geografische locatie op de instraling?
    c. Welke energieopbrengst heeft de Solar Chandelier op deze geografische locatie?
    d. Wat is de invloed van weersomstandigheden op de instraling?
    e. Welke energieopbrengst heeft de Solar Chandelier onder deze weersomstandigheden?
    f. Wat is de seizoensinvloed op de instraling? Was 5d
    g. Welke energieopbrengst heeft de Solar Chandelier onder invloed van de seizoenen?
    h. Wat is de invloed van de omgevings lichtomstandigheden op de instraling?
    i. Welke energieopbrengst heeft de Solar Chandelier onder deze omgevings lichtomstandigheden?

6. Wat voor invloed heeft de configuratie van de zonnecellen op de energieopbrengst van de Solar Chandelier?
    a. Wat is de energieopbrengst van de Solar Chandelier in de originele configuratie?
    b. Welke mogelijke aanpassingen in de configuratie van de zonnecellen kunnen gedaan worden?
    c. Welke effect heeft elke aanpassing op de energieopbrengst van de Solar Chandelier?

7. Wat is de beste configuratie voor de zonnecellen, rekening houdend met de energieopbrengst en vormgeving?
    a. Welke randvoorwaarden stelt de energieopbrengst aan de mogelijke configuraties van de zonnecellen?
    b. Welke randvoorwaarden stelt de vormgeving aan de mogelijke configuraties van de zonnecellen?
    c. Wat is de beste configuratie uitgaande van de optimale vormgeving?
    d. Welke configuratie voldoet zowel aan de gestelde randvoorwaarden qua energieopbrengst en vormgeving?

8. Onder welke omstandigheden de Solar Chandelier bij een klant goed functioneren?
    a. Aan welke eisen moet een ruimte voldoen als men daarin de Solar Chandelier wil gebruiken?

E6. Onderzoeksstrategie en materiaal.

Vraag	Strategie	Bron	Soort	Ontsluiting
1 a-d	Empirisch onderzoek Bureauonderzoek	Personen Literatuur	Erik Hop Artikelen	F-t-T Interview Inhoudsanalyse
2 a-b-c	Bureauonderzoek	Literatuur	Artikelen	Inhoudsanalyse
2 d1	Bureauonderzoek Empirisch onderzoek	Media Personen	Internet Demakersvan	Inhoudsanalyse F-t-F interview
2 d2	Bureauonderzoek Bureauonderzoek Bureauonderzoek	Literatuur Documenten Documenten	Artikelen Specs ruimtes Metingen Rik	Inhoudsanalyse Inhoudsanalyse Inhoudsanalyse
3 a	Empirisch onderzoek	Personen	Erik Hop	F-t-F interview
3 bc	Bureauonderzoek Empirisch onderzoek	Documenten Werkelijkheid	Documentatie software Berekening	Inhoudsanalyse Meetinstrumenten
4 a-b	Empirisch onderzoek Bureauonderzoek Empirisch onderzoek	Personen Literatuur Werkelijkheid	Erik Hop Artikelen Uitproberen tool	Ondervraging Inhoudsanalyse Observatie
5 a	Bureauonderzoek	Literatuur	Artikelen	Inhoudsanalyse
5 b	Bureauonderzoek Empirisch onderzoek	Documenten Werkelijkheid	Conclusies 2a Simulatie	Inhoudsanalyse Meetinstrumenten
5 c	Bureauonderzoek Empirisch onderzoek	Documenten Werkelijkheid	Antwoord 5a+b Berekening	Inhoudsanalyse Meetinstrumenten
5 d	Bureauonderzoek Empirisch onderzoek	Documenten Werkelijkheid	Conclusies 2b Simulatie	Inhoudsanalyse Meetinstrumenten
5 e	Bureauonderzoek	Documenten	Antwoord 5a+d	Inhoudsanalyse
5 f	Bureauonderzoek Empirisch onderzoek	Documenten Werkelijkheid	Conclusies 2c Simulatie	Inhoudsanalyse Meetinstrumenten
5 g	Bureauonderzoek Empirisch onderzoek	Documenten Werkelijkheid	Antwoord 5a+f Berekening	Inhoudsanalyse Meetinstrumenten
5 h	Bureauonderzoek Empirisch onderzoek	Documenten Werkelijkheid	Conclusies 2d1+2 Simulatie	Inhoudsanalyse Meetinstrumenten
5 i	Bureauonderzoek Empirisch onderzoek	Documenten Werkelijkheid	Antwoord 5a+h Berekening	Inhoudsanalyse Meetinstrumenten
6 a	Bureauonderzoek	Documenten	Conclusies 5c+e+g+i	Inhoudsanalyse
6 b	Empirisch onderzoek	Werkelijkheid	Uitproberen	Observatie
6 c	Empirisch onderzoek	Werkelijkheid	Simulatie (PC)	Meetinstrumenten
7 a	Bureauonderzoek	Documenten	Antwoord 6b+c	Inhoudsanalyse
7 b	Empirisch onderzoek	Personen	Demakersvan	F-t-F interview
7 c	Empirisch onderzoek Empirisch onderzoek	Werkelijkheid Werkelijkheid	Conceptueel ontwerp Uitproberen	Inhoudsanalyse Observatie
7 d	Bureauonderzoek Empirisch onderzoek	Documenten Werkelijkheid	Conclusies deelvragen Uitproberen	Inhoudsanalyse Observatie

8 a	Bureauonderzoek	Documenten	Concl. 3,4&6	Inhoudsanalyse