CHALMERS

Development of a

HYBRID LUMINAIRE for Parans Solar Lighting

Master of Science Thesis in the Master Degree Programme Industrial Design Engineering

REBECCA HALLQVIST
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Department of Product and Production Development

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Computer rendered image of the hybrid luminaire module

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Abstract

The aim of this Master's thesis was to develop a hybrid luminaire for Parans Solar Lighting (Parans). The company is based in Gothenburg and utilise an innovative technology to collect and conduct sunlight. Lenses and fiber optic cables transport sunlight to indoor environments where it is needed. The hybrid luminaire will incorporate both sunlight and LED light in the same luminaire.

During the project many aspects were studied: natural and artificial light, previous installations using the Parans system, technical solutions for LED systems and so on. It was concluded that the expression and perception of the light is crucial and that it needs to be packaged well. As it is fairly cold in its tone, especially compared to many electrical indoor lights, an interesting way of tinting the light was used. Hidden surfaces with coloured reflective materials create a warm glow.

Another important part of the project was to establish what kind of product Parans need in their product portfolio. There is no room for wasting resources, as the company is small. Parans need both something spectacular to open the eye of the public, and something useful - a product that fits many uses.

The result of this project was a modular luminaire that is combined with itself to create large cloudlike clusters. It integrates sunlight and LED in a clever way. The light sources are kept separate in the luminaire which takes care of the special qualities of the sunlight. Thereby the gain of investing in a Parans Solar Lighting system is emphasised.

The report is written in English.

Keywords: Luminaire, Fixture, Light, Hybrid, LED, Sunlight, Parans.

Preface

“Development of a Hybrid Luminaire for Parans Solar Lighting” is the master’s thesis of Rebecca Hallqvist and Magnus Renström, and is part of the M.Sc. programme Industrial Design Engineering at Chalmers University of Technology. The project was carried out in cooperation with Parans Solar Lighting, a Gothenburg based company. The project started in February 2011, ended in October 2011, and consisted of 30 ECTS.

First of all we would like to thank everybody at Parans for a good collaboration, throughout the project. You gave us time, answers and trust. A special thank you to Daniel Johansson, our supervisor, office neighbour and source of knowledge at Parans.

We would also like to thank Kajsa Sperling, lighting designer at White Arkitekter, for letting us interview you and for discussing ideas with us. You were a great source of inspiration.

Further, we want to thank Ulrike Rahe, our supervisor and examiner at Chalmers. You gave us much to reflect upon as well as firm advice in our design process. In other words, you have been an excellent supervisor.

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Thank you David Lamm for help with CAD related issues.

Finally we thank Fredrik Axelsson and David Gillblom for being our opponents.

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1

Introduction

1.1. Background

1.1.1. About Parans

Parans Solar Lighting (Parans) was founded in 2002 with the vision of bringing sunlight to indoor environments. The idea was to use lenses and fiber optics to transport light to those inner parts of buildings that windows cannot reach. The first generation of the Parans solar lighting system was commercialised in 2004 after research and development in co-operation with Chalmers University of Technology.

In the spring of 2011, sales started for the third generation solar lighting system, SP3. It represented a will to lower the price, facilitate installation and increase the light output from each receiver. These three aspects would make it available to more projects and more users. The luminaire developed during this project will be used with the SP3 system, and was designed accordingly.

1.1.2. About the project

This project was a master's thesis project within the Industrial Design Engineering Master of Science programme. The two participants were Magnus Renström and Rebecca Hallqvist.

1.2. Purpose

The purpose of this master's thesis project was to explore the Parans product portfolio and suggest a new addition to the range of luminaires. The idea and focus was to create a hybrid luminaire with two light sources: the Parans light and LED technology.

A parallel purpose was to conduct a thesis project within the Master of Science programme in Industrial Design Engineering. The approach to the project should be scientific – using methodology and tools gained during the education.

1.3. Aim

The aim of this master's thesis project, was to develop a production ready concept of a hybrid luminaire. It should fit the third generation solar lighting system SP3 and the current product portfolio.

1.4. Limitations

Since another hybrid luminaire was concurrently being developed by the Parans staff, one limitation was that the concept differ from that luminaire. It should not, then, be designed as a 60 x 60 cm luminaire for standard office ceilings.

The project, including documentation work, was limited to 20 business weeks, equalling one university semester. There was no fix project budget, but however limited.

The artifical light source, LEDs, had already been chosen by Parans. LEDs are known as the new energy saving alternative and can produce high quality light. They have a long life and are made mainly from silicon, which is an abundant material (Mangold, 2011a).

Another limitation was to choose production methods adapted for small series production, which was translated into trying to avoid expensive tooling.

2

Light Theory

In order to understand light, literature studies were made prior to the actual initiation of the product development project. These findings will be presented at this early stage in the report, as a way to prepare the reader. Light is complex in its nature; not so much in physical terms, but because of the way it is perceived by the human visual system.

2.1. What is light?

Light is defined as the part of the electromagnetic spectrum that is visible to the human eye. This is usually said to be the wavelengths from 380 nm to 780 nm. Light can be measured in the same units as other types of radiation, but as we are speaking of illumination, it is more useful to use the photometric units (Valberg, 2005), which are relative the human eye.

2.2. Photometric units

One could think that the eye is equally sensitive to light of all wavelengths, or that the strength of the visual signal would directly correspond to the energy content of each wavelength. This is not the case. In fact, the eye is more sensitive to the middle of the visible spectrum, and less sensitive to the outer parts of it. There is an overlap of the ranges of the photosensitive cells in the eye's retina, which gives a sensitivity peak in the yellow part of the spectrum, see figure 2.1.

Therefore the luminous units are defined as weighted sums of the radiometric spectral energy distribution, through the use of the Spectral Luminous Efficiency function, V(l). The varying sensitivity of the eye is thus taken into account. The function is not perfect, as some individual variation applies, but it works sufficiently well to measure light. The Spectral Luminous Efficiency function is defined over the visual spectrum (380-780 nm). It was established by the International Commission of Illumination, CIE, after empirical studies (Valberg, 2005).

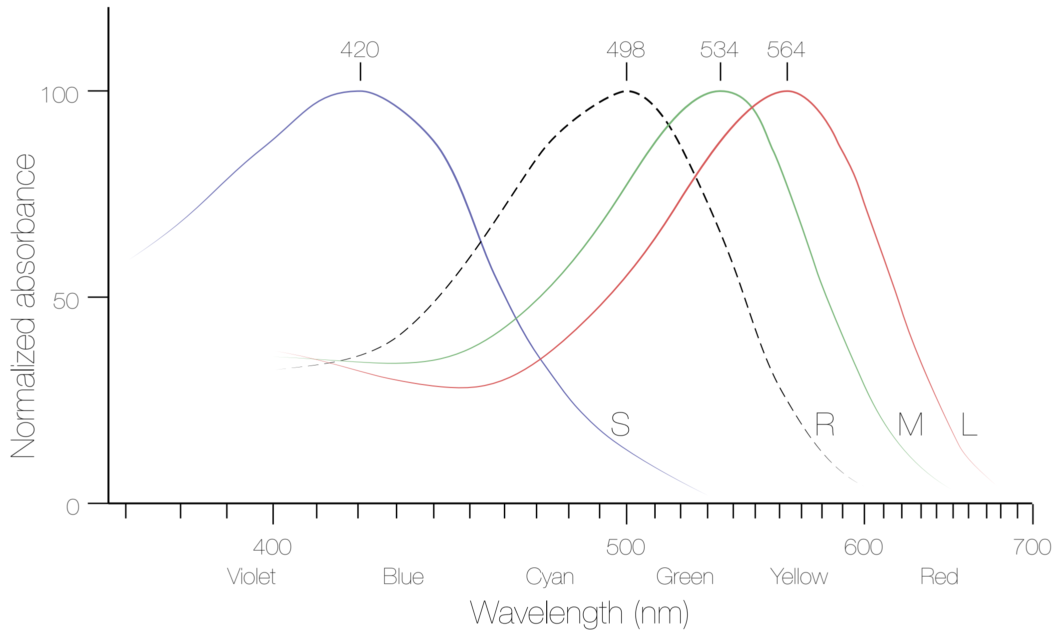

Fig. 2.1. The graph shows the respective sensitivities for the three colour seeing cone cells and the light sensitive rod cells (dotted line). Source: Wikimedia Commons.

2.2.1. Luminous flux

[lumen, lm]

Luminous flux, or light flux, is the total experienced light radiation from a light source (Renström, 2004). "Experienced light radiation" means that the varying sensitivity of the eye, mentioned above, has been taken into account. The luminous flux is measured in lumen (Valberg, 2005).

2.2.2. Illuminance

[lux, lx = lm/m^2]

When light is distributed over a surface, the illumination of that surface is measured in lux. One lux is defined as 1 lumen distributed over 1 m^2. Direct sunlight on a clear day measures about 100 000 lux (Renström, 2004). Other typical illuminance values can be found in Table 2.1. below.

2.2.3. Luminous efficacy

[lm/W]

Luminous efficacy measures how efficiently the energy is converted into the visual spectrum and how strongly it is perceived by a human eye. (Valberg, 2005) All artificial light sources also have losses through heat production.

2.3. Quality of light

There are several factors that influence quality of light. Amount and colour of light may be obvious factors, but a less known part is the Colour Rendering Index (CRI) and flicker (mentioned under 2.4. How light affects us).

2.3.1. White light

The colour of a white, broad-spectrum light is called the colour temperature. It refers to the colour of a theoretical black body, which is heated to a certain temperature, measured in Kelvin. The black body starts emitting radiation – first in the infrared spectrum, but with raising temperature it moves into the visible spectrum (Luckiesh, 1915). Around 1000 K colour temperature means a deep red light, moving on through different shades of orange, yellow and white, on into the blue part of the spectrum at temperatures over 10 000 K. Daylight has a colour temperature of about 5500-6500 K, depending on the time of the day (Kuehni, 2008). This light is relatively bluish, but is perceived as white, both thanks to its strength and to the adaptivity of our eyes. A tungsten filament lamp (a traditional light bulb) on the other hand, generates a light with yellow hue at a colour temperature of around 2800 K (Kuehni, 2008), which is also perceived as white light when seen alone. Annell Ljus + Form AB (2007) define 2700 K as warm, 3000 K as warm white, 4000 K as white and 6500 K as cold white.

2.3.2. CRI

In order to perceive colours correctly, the human visible system needs a balanced and full spectrum light. "Color Rendering Index" (CRI) or Ra is a common way of measuring the quality of a light source. The index is an average of the light's rendering quality of eight different, quite pale, colours (Annell Ljus + Form AB, 2007). The aim is to describe how complete and balanced the light spectrum is, compared to the full spectrum of the sun. However, it does not always describe the quality of light perfectly, since it only measures the rendering of the eight sample colours. The CRI is defined as 100 for full spectrum light, such as daylight. Also a tungsten filament lamp has a continuous spectrum and therefore has CRI 100. However, this light is for other reasons quite different from daylight, showing a much lower colour temperature, as described above. It is only possible to correctly compare two different light sources by their CRI, if they have the same colour temperature.

There is still no artificial light source that can perfectly simulate daylight. Hirschler (2011) quotes the CIE (CIE Publication on Colorimetry): "At present no artificial source is recommended to realise CIE standard illuminant D65 or any other illuminant D of different CCT. It is hope that new developments in light sources and filters will eventually offer sufficient basis for a CIE recommendation." A standard illuminant D65 is a theoretical standardised light source, which corresponds to sunlight at noon in southern and northern Europe (Wikipedia, 2011). What this means, is that no artificial light source of today holds the qualities of true sunlight.

2.4. How light affects us

2.4.1. The biological clock

Recently a new, third type of light sensitive cell in the eye was discovered (Berson et al., 2002). The newly discovered cells, called photosensitive retinal ganglion cells (pRGC), are in close contact with the suprachiamatic nucleus, SCN, referred to as our biological clock, and our pineal gland, which produces the sleep-hormone melatonin. The SCN regulates the amounts of melatonin and cortisol in the body, as a reaction to the light hitting the light sensitive cells in the eye. Cortisol prepares the body for wakefulness in the morning and the amount of blood sugar increases. Melatonin works opposite to cortisol, facilitating sleep (van Bommel & van den Beld, 2004). The melatonin level lowers in the morning, reducing sleepiness, and rises in the evening, making us ready to go to sleep. Van Bommel and van den Beld (2004) state that "... Bright light in the morning helps restoring the normal rhythm".

The newly discovered cells are more sensitive to light of shorter wavelength, i.e. bluer light, compared to the overall visual sensitivity, which is higher in the green-yellow span. It can be concluded that light is not only a means of visualising the world around us, but it also stands in close contact with the biological clock. Therefore we should be picky about the light that we are exposed to.

2.4.2. Flicker

A study by Küller and Laike (1998) investigated the difference between working in 50 Hz and 30 kHz lighting. It showed that stress levels were slightly higher with the low frequency 50 Hz system. The work speed was also slightly higher in the 50 Hz case, but was drawn back by a much larger amount of errors in the test. Van Bommel and van den Beld (2004) conclude: "it is wise, from both the well-being and productivity points of view, to use high-frequency fluorescent lighting instead of magnetic 50 Hz lighting to limit brain arousal or stress".

Persons with epilepsy are extra sensitive to flicker, including subliminal flicker (above 100 Hz), and it might lead to epileptic attacks (Mangold, 2011a). After being in touch with Svenska Epilepsiförbundet (a Swedish interest organisation for epilectics) however, they were unable to give a precise limit for a design specification, which would have been interesting in our work. This is further commented in 5.7.2. Implementation of LED technology.

2.4.3. SAD

Seasonal affective disorder (SAD) is a "seasonal depression often found among people living in northern latitudes" due to lack of daylight (Boubekri, 2008). Apart from the intensity of daylight you are exposed to, the length of the exposure and the spectral qualities of the light is important (Boubekri, 2008). It has also been shown that blue wavelengths are more favourable than red wavelengths (Glickman et al., 2006), possibly due to the sensibility of the photosensitive retinal ganglion cells, mentioned above.

2.4.4. Increased learning

A number of studies have concluded that access to natural light influences people in a multitude of ways. Studies on school children (Heschong, Wright and Okura, 2000) showed "a uniformly positive and statistically significant correlation between the presence of daylighting and better student test scores".

2.4.5. Increased productivity

Also when it comes to adults at work, light plays a crucial role in productivity and general well-being at the workplace. Edwards and Torcellini (2002) conclude, after reviewing a number of studies, that correct lighting and access to daylight will give an array of benefits to both employees and employer. General well-being, lower absenteeism, better health as well as downright productivity increase and lowered costs are reported. Making people enjoy their workplace will also lower employee turnover and requested salaries.

2.4.6. Increased sales

In retail environments, lighting is known to be important to display the products, and natural light has a number of benefits which indirectly lead to increased sales (Edwards & Torcellini, 2002). A study by Heschong Mahone Group, mentioned in the Edwards and Torcellini literature review (2002), states that store performance would increase as much as 31–49% by adding skylights to a store. They had studied 108 comparable stores of the same retail chain, where two-thirds of the stores were daylit. Daylight gives a number of benefits, including a perceived cleanliness, better colour rendering of products, pleasant environments making customers stay longer time and so on.

2.5. The adaptivity of the eye

2.5.1. Adaptation to light levels

While comparing the illumination levels in Table 2.1., it is clear that the lux levels in different illumination situations vary immensely – yet our visual system manages to adapt. The human eye is able to see in lighting conditions from 120 000 lux down to levels below one lux. Further, our eye has a much larger dynamic range than most cameras. That means that we are able to see more of both dark and bright areas at the same time. To handle different light levels, the iris adapts, but the physical adaptation only stands for about a tenth of the adaptability. The rest is done through neuro mechanisms in the retina (Valberg, 2005).

Clear summer day, direct sunlight		80 000[1] - 120 000[2] lux	[1]Passivent, 2011 [2] Lingfors, 2012
Bright cloudy day, direct sunlight		30 000[1] - 50 000[1] lux	
Overcast day, no direct sunlight		10 000[1] - 20 000[1] lux	
Twilight		1[1] lux	
Clear full moonlit night		0.1[1] lux	
Starlit night		0.001[1] lux	
Side roads at night		5[1] lux	
Main roads at night		15[1] lux	
40 W filament light-bulb	330 lumen[3]		[3]Kamesh, 2006
60 W filament light-bulb (pearlescent)	584 lumen[3]	50 lux*[1]	*measured 1.5 m from light source
100 W filament lightbulb	1160 lumen[3]	60 lux*[1]	
150 W filament lightbulb (pearlescent)		160 lux*[1]	

Table 2.1. Examples of light levels in natural lighting scenes and from artificial light sources.

2.5.2. Chromatic adaptation

Besides the visual system's capacity to adapt to varying light levels, our brain is skilled at neutralising variations in colour. The illumination of a surface may vary a lot over the day and in the light of different light sources - from cold to warm tones. Despite that, we in most cases interpret the surface as having the same colour. Or as Valberg (2005) writes, "The visual system works towards neutralizing (in an unknown way) the effect of the colour of the illumination." This is why photos taken in artificial light turn out surprisingly discoloured when the white balance is not set right, whereas the eye is able to distinguish colours. However, this is partly perception – if lighting conditions are poor, we actually guess the colour. This is why good lighting is important in commercial environments. In some cases, high CRI light is used to show the true colours of the object for sale. In some cases, light is used to trick the customer into believing the product is better – such as exposing fruit and meat in pinkish light, which makes the red colours pop.

3

Current Products

Parans as a company was founded in 2002, with the first solar lighting system launched in 2004. In 2011, the third generation sun collecting receiver SP3 was launched. The SP3 represents a major technological leap, having focused much attention on simplifying the system. The SP3 is more robust, easier to install and maintain, and has both larger light intake and a lower price. The receiver concentrates light into optical fibers, which transport the light indoors where it is distributed by luminaires.

The system does not bridge heat or cold, as it only makes a small penetration to the roof. Heating and cooling are two major expenditures in energy use of buildings (International Energy Agency, 2007, p. 87.).

Fig. 3.1. Computer generated image of the SP3 system receiver, installed on a roof. Source: Parans.

3.1. SP3 Receiver

The receiver consists of a tubular hollow body from extruded aluminium, which holds 36 fibers in separate metal holders. The holders function as heat sinks that remove heat and protect the plastic fibers. One side of the tube is covered by a glass plate with a matrix of Fresnel lenses. These are moulded onto the glass using silicon on glass technology. The lenses focus the incoming light onto each of the 36 fiber ends.

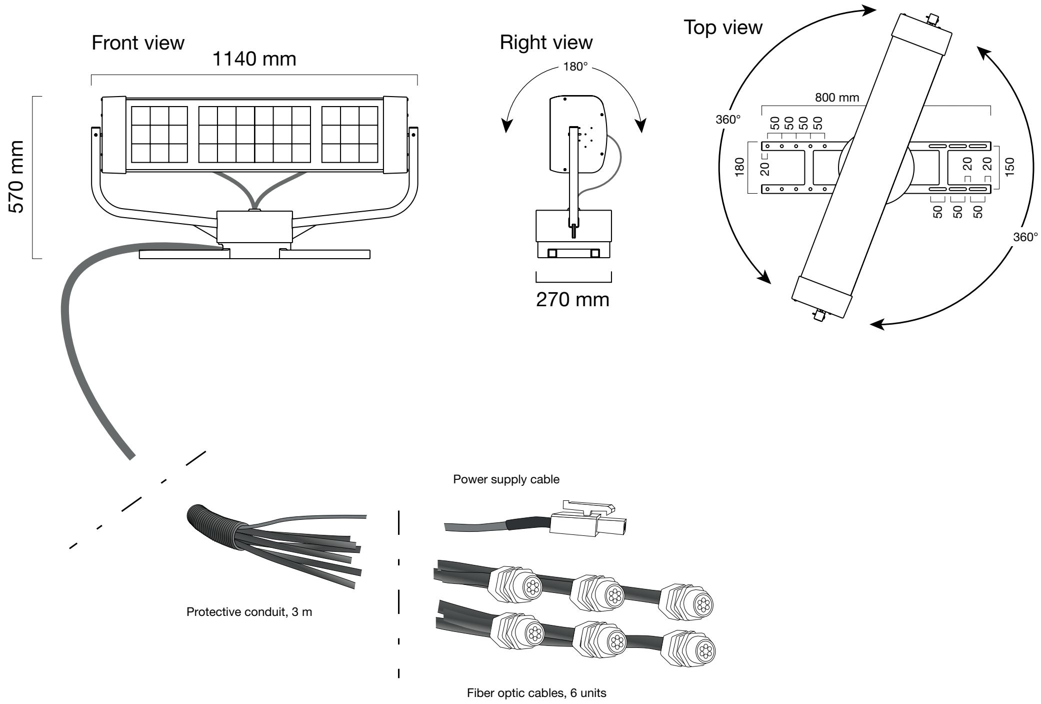

Fig. 3.2. Technical drawings of the SP3 system. Source: Parans.

3.2. Sun tracking

The whole receiver tracks the sun and turns to align itself perpendicularly to the parallel rays of sunlight, which are used by the system. With ability to freely rotate around two axes, the receiver can track the sun during all hours of the day. The movement is dictated by an integrated circuit board which is programmed to a sun path, specifically adjusted for each installation location. When installed on location, the path is also corrected by a directional light sensor. The two systems co-operate to follow the sun correctly, in order to collect as much light as possible. The total energy consumption of the receiver is 7 W approximately.

3.3. Fiber cabling

The fibers used are 1.5 mm PMMA fibers, also known as POF or plastic optical fibers. These are preferred due to their elasticity, which is useful for tight installations with small bend radii. They also have a much lower price than comparable glass fibers currently available on the market. The downside is higher light absorption, attenuation, at about 4.5 % per meter. That mean-that about 40 % of the collected light remains after 20 meters. Currently, Parans do not deliver longer cabling than 20 meters, because of the loss of light. The PMMA material does not have a uniform attenuation curve over the visible spectrum, but there is an attenuation peak in the red spectrum (Büttner, 2009). This will be treated more in depth under 3.4. The delivered light.

The SP3 system has been measured to collect 6 000 lm at an outdoor illumination of 100 000 lx, which is not a rare value on a clear sunny day. In fact, it is possible to find light levels up to about 120 000 lx (Johansson, 2011). The value is given at the start of the fiber, and then each meter of fiber cable means a loss of light, due to the attenuation previously mentioned. The output light depends on the fiber length, according to the following:

Parans System	SP3 5	SP3 10	SP3 15	SP3 20
Length	5 m	10 m	15 m	20 m
Light transmission	95,5 %/m	95,5 %/m	95,5 %/m	95,5 %/m
Light output	4200 lm	3300 lm	2580 lm	2100 lm
Light output for each cable	700 lm	550 lm	430 lm	350 lm

Fig. 3.3. Data from Parans SP3 Technical Specifications. Source: Parans, 2012

The 36 fibers from the receiver are gathered into six cables with six fibers in each. They can each be used for one luminaire and the light flux from one cable (in 100 000 lx outdoor illumination) is 350-700 lm, depending on the cable length. As a comparison, a normal incandescent 40 W light bulb has a luminous flux of around 500 lm, a 60 W light bulb around 800 lm. This means that one fiber cable quite well matches other light sources in terms of strength, which can be important when it comes to planning a complete lighting system with artificial and natural light.

3.4. The delivered light

The resulting light from the fiber end has a spread in the shape of a 60° cone. Just like direct sunlight, the light is very directional and casting sharp shadows. Infrared (IR) light and ultraviolet (UV) light are not transported through the system. These wavelengths are filtered out in the receiver, before entering the plastic optical fiber. The light transmitted is thus only the visible spectrum.

The output light is full spectrum and follows the characteristics of sunlight, that is its variations in intensity and colour. However the fiber has a higher attenuation in the red spectrum, with peaks in two specific wavelengths: 627 nm and 736 nm (Büttner, 2009), which are both in the red spectrum. The attenuation is due to harmonic vibrations in the molecules building up the PMMA material. This means that the output light has a slightly colder tint, which is more visible at low light levels. At the longest provided cable length and during low light conditions, for example during winter when the sun is lower, the light can get a faint aquatic green tone. It should be added that the effect was observed at installations using the SP2, and may not occur with the new product generation SP3.

Since lenses are used to concentrate light, the technology can only function for parallel rays of light, such as direct sunlight. When the sky is overcast or the air is foggy so that the sun cannot be seen, the light cannot be focused into the fiber end. Hardly any light is then transmitted, although it is not dark outside. The same thing happens when clouds pass overhead – the direct sunlight is blocked and the Parans light goes out. This dynamic of the light is inevitable for this technical solution, and is one of the reasons why the hybrid luminaires and lighting control systems are useful. The effect of the fading dynamic light can be beautiful, but it forms a design issue to be treated for the functionality of the lighting.

3.5. Luminaires

Today, three luminaires are available: the L1 ceiling surface luminaire in small and medium size, and the L3 Spotlight.

Fig. 3.4. The L1 Small luminaire. Source: Parans.

3.5.1. L1 Small

The L1 Small luminaire features a satinised transparent PMMA board with a cut prism, which diffuses part of the light. In the middle of the cut prism a square opening lets the light pass and project a square light beam of about 25 degrees. This results in a luminous square directly below the luminaire. The rest of the light is spread and diffused in the PMMA plate and projects on walls and ceiling (Parans, 2011). The L1 Small uses one optical fiber cable, so for each SP3 system, six L1 luminaires can be used.

Fig. 3.5. The L1 Medium luminaire. Source: Parans.

3.5.2. L1 Medium

The L1 Medium is similar to the L1 Small, but is double in size and uses two fiber cables. For each SP3 system, three L1 Medium can be used.

Fig. 3.6. The L3 Spotlight luminaire. Source: Parans.

3.5.3. L3 Spotlight

The L3 spotlight is a recessed aluminium spotlight with turnable lens, which connects to the end of the fiber cable. The lens concentrates the light into a 30 degree circular light beam.

3.5.4. Current development of new luminaires

Parans are currently developing a new hybrid luminaire, as a parallel project to this master's thesis project. It will combine Parans light with artificial light from LEDs. This new luminaire measures 60x60 cm and can either be recessed into or mounted on the ceiling surface. The size makes it fit into standard suspended ceilings, which are common in offices, schools and similar. The concept also features a wooden frame, which gives a warmer touch and brings to mind the Nordic roots of the Parans system.

Fig. 3.7. The L2 Hybrid luminaire. Source: Parans.

4

Methods and Execution

The product development process of this project can be schematically divided into six phases:

Analysis

Synthesis

Evaluation

Selection

Form development

&

Technical development

The project process was iterative and had one major iteration after the first selection of concepts, as a better definition of product meaning was made and the new information was used to spur new ideas. In this report, the process will be described as linear, for easier reading.

The methods utilised will be presented throughout Chapter 5, in connection to the results they generated. This should make for a clear relation between the method and the results that were found.

5

Results

As mentioned above, the design process featured several iterations. The design process followed the development of two different aspects that needed to work together: the design of the product and its expression, and the design and use of light from two different light sources. As many changes to the physical form would effect the spread of light and vice versa, there were many twists and turns to the process. However, we will be presenting the process as one linear development for easier reading.

5.1. Analysis

The project was initiated with thorough background studies, largely focused on literature, which are treated in the earlier parts of this report. As we move into the product design project, we have chosen to mention our analysis as the first part. Here we keep in mind previously learned facts, while studying and analysing the specifics for the product being developed.

5.1.1. Observations of current installations

There are about 150 installations of the Parans system in different parts of the world. Most of them use the second product generation SP2, and a few use the first generation SP1. We were interested in observing the light we would be designing for. Since no SP3 systems had yet been installed, we visited the two installations that are closest to Gothenburg; both of which use the SP2. One can be found at the Handels School of Business, Economy and Law in Gothenburg, the other at the healthcare clinic Husläkarna Carema in Kungsbacka.

The outer case of the SP2 receiver is fix, and even though the lenses move, they cannot track the sun as many hours of the day as the SP3. The new system also has a larger light output and the light may be slightly different, but we made the assumption that the existing installations offer good approximations of the light.

Fig. 5.1. Two SP2 systems used with L1 large luminaires in lunch room at ground floor.

HANDELS SCHOOL OF BUSINESS, ECONOMY AND LAW

In order to bring more light into a dark lunchroom, two Parans systems were installed. In this particular installation the cable length was more than maxed out, at 23 meters. This allowed us to study the effect of the attenuation in the PMMA fiber, which will be discussed later. We visited this installation three times, in order to see the difference due to atmospheric conditions and time of the year. The luminaires used at Handels are the L1 Large (L1 is no longer available in this size, but instead in two smaller versions). In the pictures, the light spread can be seen with a rectangular light beam beneath the luminaire.

Fig. 5.2. Parans light installed into a light shaft feature.

INSTALLATION AT HUSLÄKARNA CAREMA, KUNGSBACKA

In the waiting room at Husläkarna Carema in Kungsbacka a series of L3 Spotlights were installed recessed into an opening in the ceiling. The light is projected onto a bent continuation of the wall, in order to create the illusion of a light shaft. The room has no direct intake of natural light and would otherwise be lit only using fluorescent lights.

Apart from the Parans light, the room is also fully lit using artificial light sources, which unfortunately flatten out the effect of the Parans light. We did however discover that one of the two solar receivers was not functioning, meaning that only half of the intended light was brought into the room. This contributed to that the Parans light seemed too weak to stand out in the ceiling, filled with artificial light. The proximity to the artificial lights made the colour difference observable.

A staff member commented: "What good does it do over there where no one notices it?" She pointed out that the staff would have preferred to have it installed in the office or reception, where they work.

COLOUR TEMPERATURE

Natural light has a cooler tone than most artificial lights. It was observed that the Parans light attains a faint aquatic green hue, which was more apparent at our visit during late winter. This effect comes from attenuation in the PMMA fiber, which has a peak at 627 and 736 nm (see 3.4. The delivered light)

Since the PMMA material absorbs these red light wavelengths, the resulting light has a vague green tint and the effect increases with cable length. As mentioned in 2.5.2. Chromatic adaptation, the eye has an extraordinary capacity to adapt to the colour of the light. Therefore the light is not perceived as very colour biased. The colour effect is much more apparent in photographs. For measuring the difference at our three visits, we used a camera with the same settings for exposure and white-balance. On the third occasion a different camera was used, and the images are not used in the comparison.

The fact that the light colour seemed to vary over the year may be due to the different strength of the light. Another possible reason is the height of the sun, which differs both over the day and also over the year, in our part of the world. The variation of height gives a varying angle of the incoming light. With the glass pane fix at one angle in the SP2, this is a possible reason for the variable attenuation. The light travels a longer distance through glass when the sun is low on the sky. If this is true, the SP3 will show less of this effect, as the whole body of the solar receiver turns to constantly stay perpendicular to the rays of sunlight.

Fig. 5.3. Comparison of light colour through same-setting comparison of photographs. Top image was taken February 18th 2011 at 11:00, bottom image was taken May 13th 2011 at 13:00. Note that light is perceived as whiter, as our visual system works to balance very effectively.

IN CONTRAST TO ARTIFICIAL LIGHT

When the Parans light is used alongside most artificial light-sources (such as incandescent bulbs or standard office flourescent tubes), it is possible to observe that the Parans light is cooler in colour temperature.

The idea of creating a light shaft or architectonical feature for the Parans light is good. According to Heschong (2011), that type of installation more clearly communicates the difference between the artificial light and the natural light. It will be more accepted to have a dynamic light, which is naturally varying in strength, in an architectonical feature or a form that is clearly distinguishable from conventional luminaires.

COMMENTS FROM USERS

At Handels we talked to a few staff members. The comments were mainly regarding cost of the installation. They did not seem to perceive the value of the light as high as the economic value paid. With the SP3 model selling at roughly half the price compared to the SP2, this should become less of a problem with the new product.

At Husläkarna Carema, we got more positive comments, but we also got the comment that the installation was placed too far away from the people working there. They would have preferred to have it installed in such a way that they could benefit more from it, in other words somewhere where the staff would be exposed to the light.

CONCLUSIONS AFTER OBSERVATIONS

The faint green tint of the light is an important issue – both for future technical development, but also for the design of the luminaires. The luminaire could complement and harmonise with the light in order to raise the perceived quality of the light. The light has to be packaged well in order to be perceived as valuable, beautiful and good. We also see it as an important task to make the light noticeable and understandable to the users. Good communication is needed to create a perceived and experienced value in the product and its light.

4.1. Observations

Observation in product development is a way of gathering information about needs and demands related to the use of a product. There are several types of observation methods, for example direct observation and self-observation. Observations can be structured or unstructured, open or covert, performed by a human or measured with an instrument.

Observations have many advantages compared to an interview, for example behaviour that the user herself/himself is unaware of can be observed. (Karlsson, 2007)

5.1.2. Context studies

To gain general knowledge of how light is typically used and presented, several visits to shops and furniture showrooms were made. In that type of environment, light is extremely important to present and describe objects for sale. Much attention is paid to the design of these installations and there are often professional light designers involved.

VISITS TO COMMERCIAL ENVIRONMENTS

As part of the project, several visits were made to shops in order to observe how light is used and presented. Above all, these exhibitions had connection to “home environments” and home products, although the actual use of light was quite far from the home situation. The result of these visits is not directly quantifiable but it gave us both inspiration and a understanding for light and how light is used. It made us see and understand differences between different kinds of light.

VISITS TO OFFICES

Alongside the visits to stores, we performed two simple observation studies at two different offices in Gothenburg. We looked at lighting situations and conducted unstructured interviews with the staff (Staff at Office One, 2011 and Staff at Office Two, 2011) (method to the right). Office One had recently been redecorated by professional interior and lighting designers. There were also large windows in all rooms, which were shaded with blinds and thin curtains. Since the office was on the top floor of the building and above other nearby buildings, they had extensive access to natural light. We were told that the rooms would become quite hot during summer afternoons, so that the blinds had to be kept closed.

The staff told us that they never really think about lighting. They usually turn on the lights in the morning, and turn them off as they go home, but never adjust them. During our visit, one of the persons we interviewed even discovered that he had dimmable luminaires in his office.

Another comment we received was that light serves as a signal for the co-workers that you are present in the office. Similarly, shops use light to explain to potential customers that they are free to enter – that the store is open (Heshong, 2011). This makes it hard to move toward entirely daylit stores.

Office two was quite different, having been planned long ago and for different needs than the current. Since activities at this office were highly focused to computers, the computer screens needed to be shaded from direct sunlight and other lights that might reflect in the screen. Some of the staff had closed the curtains and covered their windows in order to see better. All southward-facing windows had tinted films on the glass panes to delimit the light.

This office also featured an entirely closed conference room, which had once been lit using 100 W incandescent lights. This was reported not only to waste energy, but also to heat up the room very much – especially when many people were gathered inside. As a consequence, these light bulbs had been exchanged for energy-saving fluorescent light bulbs, that gave much less light. Some of the light bulbs had been exchanged at a later stage, so not only was the room quite dark, but the light colour of the different brand light bulbs varied notably.

4.2. Unstructured Interview

An interview is a basic technique for the gathering of user data where a number of questions are presented orally to an interviewee, and the answers are recorded.

A structured interview means that the interviewer asks pre-formulated questions. An unstructured interview is quite the opposite; the interviewer and the interviewee discuss freely. Sometimes an interview guide of some sort is used to remember what topics to discuss. The result of an unstructured interview is often qualitative data. During an interview it is important to try to reach to the depth of an answer. This can be done using probes, questions like “why?” and similar. (Karlsson, 2007)

NATURAL ENVIRONMENTS

During the project, there was a continuous exploration of light and we studied natural lighting mostly through spontaneous observations. In natural environments, dynamic light is inevitable and omnipresent. According to lighting designer Kajsa Sperling (2009), when people are asked to describe powerful light experiences they have had, most people describe natural light. Naturally lit environments offer relaxation for the eye and lighting companies are starting to understand the power of natural light – both by simulating the dynamic natural light and through new technical solutions for using the natural light.

Fig. 5.4. Examples of interesting lighting scenes.

STAKEHOLDER ANALYSIS

A stakeholder analysis was perfomed, aiming to map out which parties should be considered. There were obvious stakeholders, such as the end user. There were also some less obvious stakeholders such as the workers at the production site, who have to be able to mount the product in a safe way. All stakeholders were noted in a mind map.

5.1.3. Definition of product meaning

Early ideas were presented to the Parans staff to stir up a discussion, with the aim to define what type of luminaire was needed. The following guidelines were set up:

- The final product should be practical and useful; i.e., not too conceptual.
- The product should express the values of Parans and show off the technology. The product should be an eye catcher and have a wow-factor.
- The final product should make use of the unique qualities of the Parans light.
- The luminaire should be adapted to short series production to be economically viable. Expensive tooling cannot be afforded.
- The luminaire does not have to provide work light of ergonomic standards.
- The luminaire should fit a multitude of lighting situations.

To narrow down and concretise the "multitude of lighting situations", four scenarios were created. They are; a cafeteria, a bedroom, a conference room and a lobby. All scenarios have aspirational qualities. We called this method of working Roomsonas and it will be described under 4.10. Roomsonas.

5.2. Synthesis

5.2.1. Requirements

After the first analytic part of the project, a list of requirements was put together. Below, some of the more interesting and important parts of it are presented. The requirements list in its entirety can be found in Appendix A.

The different kinds of light should be distinguishable and presented in different ways.

The luminaire should express that it is something different than a common luminaire. It should possess something of a wow-factor.

The particularities of the Parans light should be used – colour, spread, directionality.

Light is precious and should be preserved, but may also need a little bit of help with the colour.

The product needs to be something noticeable, a strong form to package the light. This was emphasised both by Ulrike Rahe (2011a), our supervisor, and by Parans.

Solutions should still be simplistic, both for the sake of mounting, for economic reasons and as part of the expression Pure.

The LED-light should be of high quality, CRI. This is very important for a high-end and unique product.

The LED-light should be of about 4000 K. This slightly cooler light, compared to most tungsten filament bulbs, fits better together with the Parans light, the Parans light is perceived as warmer than together with a light source of 2700-3000 K. Further, the same colour temperature will be used in another new hybrid luminaire from Parans.

The luminaire should fit a multitude of lighting situations. It should hold some amount of versatility.

The luminaire should complement the product portfolio of Parans.

4.3. Stakeholder analysis

A stakeholder analysis is a graphical representation of all stakeholders with a relation to a product. This might be customers, the customer of a customer, the ones using the product, the distribution network, others that might have a demand on the product, and so on.

The stakeholders are usually derived through brainstorming (see 4.5. Brainstorming). All stakeholders are written down, relations are established and the result is documented. (Karlsson, 2007)

5.2.2. Expression

BRINGING THE SUN INSIDE

When speaking of sunlight, the heat is often mentioned, whether it is in a positive or negative sense. The sun is usually depicted as warm yellow or orange, and its light as warm or at least neutral, which is perhaps not all that strange. It is when the sun descends toward the horizon that its light is mild enough to look at, and at the same time its light turns the skies reddish. However, direct sunlight in the middle of the day does not have a warm colour temperature. Another reason for the mix up might be the physical warmth created by the sun. It is known that "physical warmth promotes interpersonal warmth" (Williams and Bargh, 2008). Considering Williams and Bargs (2008) research the connection between physical warmth and colour temperature seems more than possible.

A common light bulb usually has a colour temperature of 2700-3000 K. The colder fluorescent lights are about 4500-5000 K. In comparison to these values, sunlight has a rather cold colour temperature of around 5000 K, while daylight from the blue skies is even colder at 6500 K. This could potentially create a bit of a clash for the customers, as the Parans light obviously is connected to the idea of the sun, but naturally has a cold colour temperature.

4.4. Moodboard

A moodboard "is a collage of pictures displaying attributes and environments that represent moods and values of a target group" (translated from Österlin, 2003, p. 48).

MOODBOARD

Through interviews with Parans and our own discussions, a desirable expression was established. It is based around the following four defining terms; Vivid, Pure, Smart and Attention to details.

We had not been presented the company brand manual until after our presentation of the moodboard and our own formulated desired expression. However, we had very similar ideas about the expression. We saw this as a confirmation of the validity of both our and Parans' idea.

Vivid

The word was chosen to express the liveliness and dynamics of the light. The sun is in constant motion and the clouds that interfere with the direct sunlight create a dynamic light also through the Parans system. We wanted the product to reflect this.

Smart

To capture the innovation that the system embodies and the intelligent way of using the sunlight, the word “smart” was chosen. The product challenges the ideas of what is possible – such as transporting natural light through walls and roof in thin cables. Understanding the complexity of the system may add value and appreciation for the product.

Pure

This word stands for the concept of clean, natural light. The actual sunlight is brought to the inside of the building, instead of transforming the energy into electricity and back to light with large losses in energy and light quality. This is an important idea to communicate.

Attention to details

In the search for perfection and care about the beauty of a well-made product, attention to details is crucial.

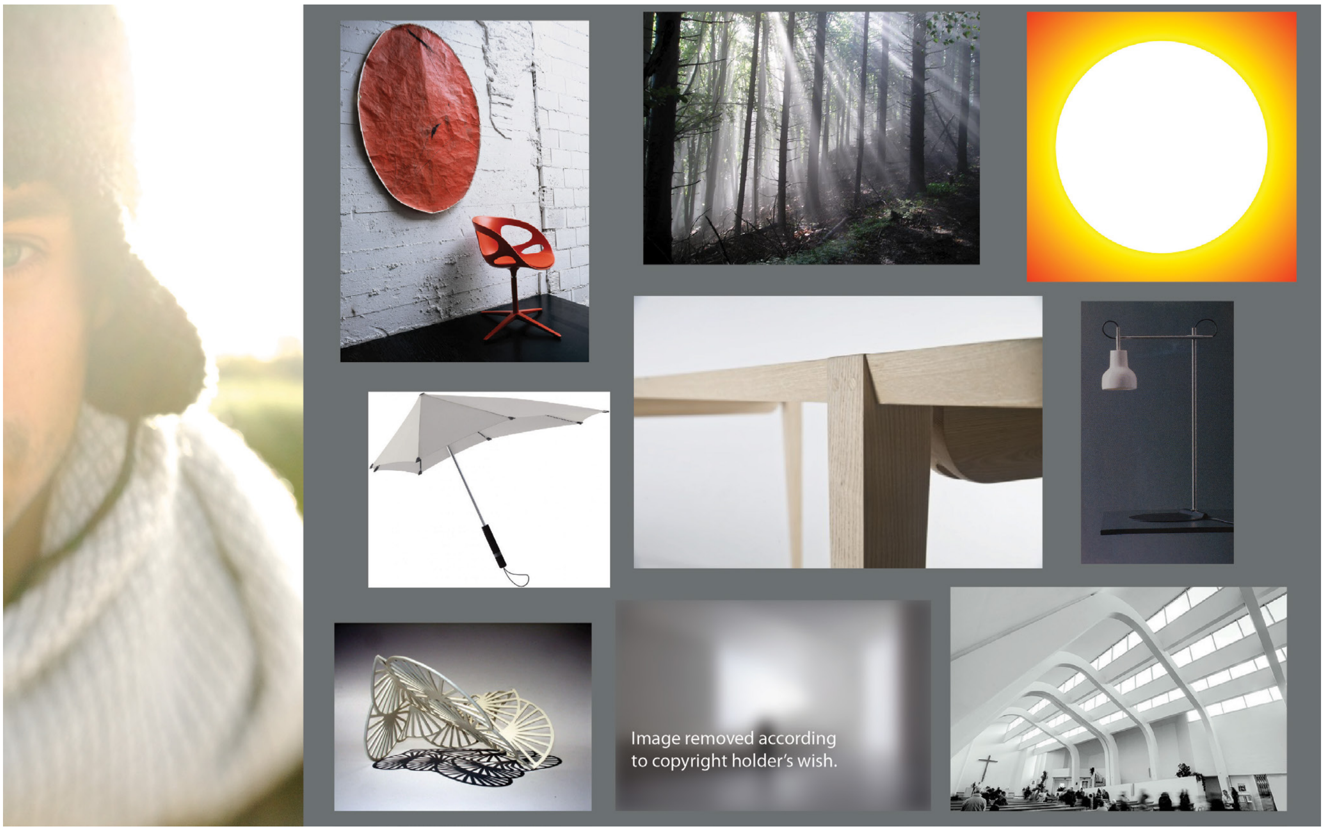

Fig. 5.5. From the desired expression a moodboard (4.5. Moodboard) was created.

METAPHORS

We early realised that Parans' technology and the delivered light represent a product that is unknown by the vast majority of people, and which is thus hard to relate to. Therefore we tried to find good metaphors for the product. During the early interviews, observations and literature studies a number of ideas came up, some of which could be used during idea generation.

Cloudy skies

One of the ideas we held on to was the cloudy skies with the sun peaking through. This is a metaphor that well explains the functional principle of the system – it will illuminate when the sun can be seen on the sky. The underlying technical principle is harder to relate to, as it takes some insight in lens design and optics.

Sunny rain

The intriguing situation when rain falls although the sun is shining, is somehow as strange as having sunlight shine out of fibers in the inner parts of a building. The combination with water seemed an interesting fusion.

Window

In a room without windows, natural light is a welcome addition. The window works as a metaphor for the Parans light. Perhaps it is possibile to create an abstract window-like luminaire, which would represent, but not imitate, a window.

5.2.3. Idea generation

BRAINSTORMING

We worked with simple brainstorming (see 4.5. Brainstorming) techniques using probing questions such as:

"How can light be spread?"

"How can light be directed?"

"How can the origin of the light be expressed?" and so on.

The initial idea generation aimed at investigating how the Parans light can be used.

The ideas were noted quickly in words and pen sketches (see 4.8. Sketching) and we tried to keep an open mind towards

4.5. Brainstorming

Brainstorming is an idea generating method for groups. Brainstorming sessions are often about an hour long. Ideas are noted on a big paper or similar. During brainstorming all kinds of criticism is forbidden, a huge number of ideas that could be well out of the ordinary is strived for. Combining ideas is encouraged. (Österlin, 2003, p. 45) radical ideas. However it became evident that in many cases the actual light is hard to imagine and sketch, and that much experimentation would be needed to understand the correctness in the ideas.

We repeated the brainstorm session with two fellow students to try and catch more ideas. Since at this time the scope of the project was still very open, the ideas were of varying nature - from outright art installations to standardised modular systems.

BRAINSTORMING WITH MEDIATING OBJECT

A series of type rooms were set together as a reference and mediating object during idea generation (see 4.7. Mediating object). We called these rooms roomsonas and they gave a context to the product and lighting, and presented four possible use situations for the Parans system. The Scamper method (see 4.8. Scamper) was also used to stir imagination during idea generation.

SKETCHING

All ideas were documented in words and quick pen sketches (see 4.9. Sketching). One of the new ideas was a modular system with a threedimensional combination. Quick paper sketch models were used to understand its three-dimensionality.

4.6. Mediating object

A mediating object can be a three-dimensional thing, an image or a story read to all participants of a discussion. The use of a mediating object during discussion within a group of people, serves as a platform that all participants can relate to, as it is in front of them. It can give some input to the discussion, for example knowledge about an object or situation, but it can also stir up discussion about different points of view or previous experiences. The object will also tend to keep the discussion focused, as it becomes more obvious what the topic is. (Palus & Drath, 2001)

4.7. Scamper

The basic idea of the Scamper method is that "everything new is a modification of something that already exists", and therefore you need ways of modifying what you already have. The ways of modification provided (or suggested) by SCAMPER is; substitute, combine, adapt, modify, put to other uses, eliminate (or minify), rearrange (or reverse). For all categories SCAMPER provide "helper questions" and "trigger words" that can be used in the modification process. (Passuello, 2007-2012)

4.8. Sketching

Sketching is a fast way of visualising and developing ideas by creating pictures. Sketching could be a tool for the designer her/himself and it can be a way of displaying ideas to others. (Österlin, 2003, p. 59)

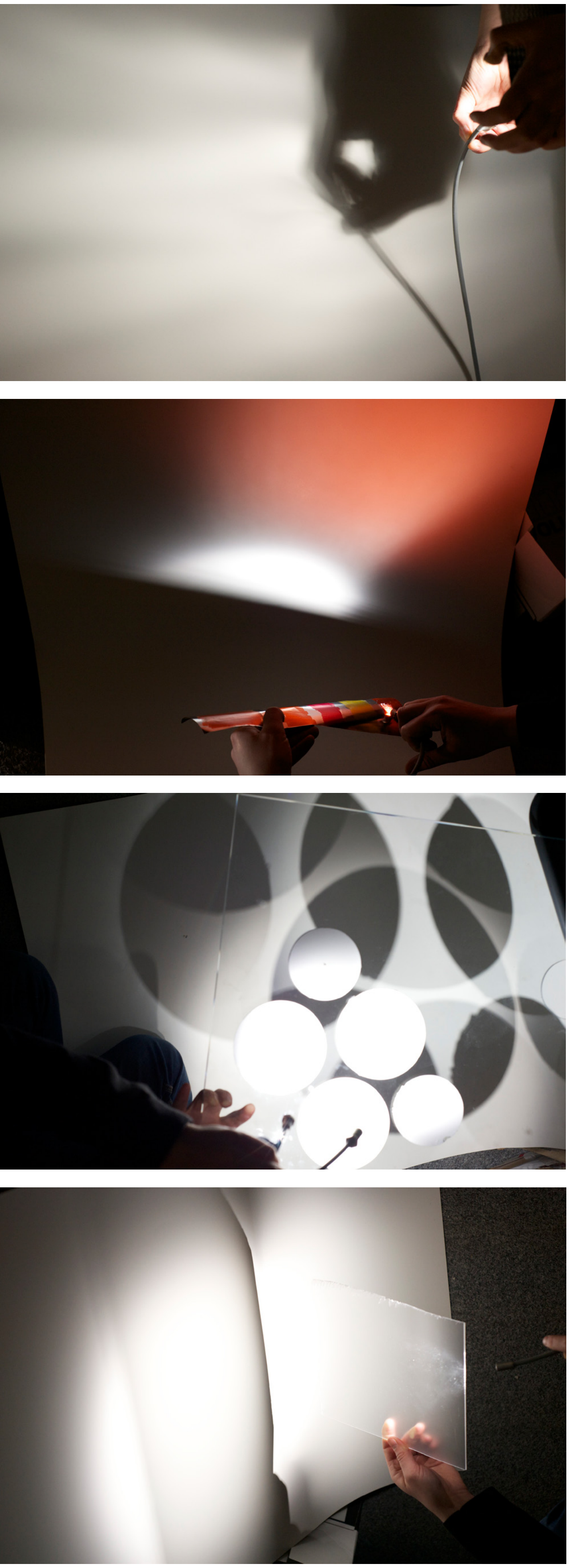

Fig. 5.6. Explorations of spreading light.

5.2.4. Light experiments

Experiments and simple models were made for evaluation of the chosen concepts. Although the experiments were each based on a specific concept, their results were general knowledge and formed a base for the understanding of light in luminaires. These are our findings:

REFLECTION

Reflection is commonly divided into diffusive and specular reflection. Diffusive reflection (defined by Lambert's Cosine Law) is omidirectional and scatters light in all directions, while specular reflection mirrors the light and can reproduce the same image. In virtually all real world applications, there will be a combination of the two types of reflection.

REFLECTION IN DENTED MATERIAL

The reflection in a dented metal surface gives wavy lines where light is concentrated. One dimension is missing, compared to the reflected light on the ocean. The constant movement in a reflection on water is naturally missing. The light is however still interesting.

REFLECTION IN COLOURED SURFACE

An alternative way of colouring light instead of using filters is to reflect it in a coloured surface. Using the right reflective surface, light could be colour corrected or given a colour effect. This effect could be subtle or strong, depending on the surface used. We made a series of colour samples using a fluorescent orange paint, a copper orange paint and some different markers and reflective materials. It was found that this process has to be remade for the exact surfaces and print colours used for actual production, since the resulting light did not seem to exactly follow the colour on the samples. The light was simply not easily predictable from examining the surface. It also needs to be made relative the Parans light, which was not available for testing.

PATTERNS

Different patterns and combinations of patterns were lit using a fiber cable connected to a projector, in order to understand the spread and behaviour of the light. We realised that the sharp shadows had high contrast and may need to be softened by using a fill-in light, but that the effect was exciting. The size of the pattern also showed to be very important; both for the right amount of light to be let through, and for the light to create a relaxing spread rather than to seem dotty.

DIFFUSION

We laborated with different materials to study the diffusion through plastics, glass, paper and so on. It seemed hard to effectively diffuse the Parans light without using a reflective material, as it is very directional. When light is diffused, it is spread to a larger area and obviously some light is lost as well as the illumination level per area unit.

5.2.5. Light studies using simple computer models

Some of the early concepts were computer modelled in order to understand light spread and shapes of the luminaire. This provided a general idea of the result, but we could not determine whether light spread was realistic. It was decided that CAD (see 4.10. CAD) should be used after selection of one concept, in order to use the project hours in the most rational way.

5.2.6. Review of earlier concepts

Before the thesis project started, Parans had used the services of a design consultant firm. The result of that work was a number of interesting design concepts. Except from one concept, none of them had been taken longer than to a sketch stage. Together with Parans, we decided to include the old concepts and treat them as equal to the new ones. The old concepts were presented briefly at the start-up of the project, but were not reviewed thoroughly until after our own idea generation stage, in order not to influence or hinder new ideas.

5.2.7. Concept formation

The more promising of the initial concepts were given some extra time. We tried to understand and define some important features such as how light is spread, proportions and placement due to the spread of light, what types of materials and surfaces could be used and how to simplify the idea for a rational production. We also tried to explore some different variations of the idea and choose one direction rather than to leave too many options.

However, we understood that the field was still too wide for us to be able to prioritise rationally. We decided to do a first presentation for Parans in order to understand their thoughts about the project, or at least to stir up some discussion about what direction to go with the next hybrid luminaire.

4.9. CAD

By using CAD programs it is possible to create digital 3D-models. CAD programs use one of several methods to define objects in three dimensions. CAD programs can be used to create a basis for production and to “render” a picture where among other light bounces and refractions can be calculated in the process of creating a picture of the 3D-object. (Österlin, 2003, pp. 65-67)

5.2.8. Discussion and selection with Parans

The aim of the first presentation was to show our findings and to decide what direction to take. In order to trigger comments and ideas, a wide range of different ideas were presented.

First of all it was concluded that the colour of the delivered light has been seen as an issue also by Parans (see also 5.1.1. under Colour temperature). The light should be perceived as white or cold white in order to correspond to the expectation of a customer and how the light is marketed. It might therefore be interesting to modify the tonality towards a slightly warmer and less acquatic tone, if this can be done without losing much luminous flux.

The concepts and possible directions were discussed. In order to reach best results, a holistic view on the ideas should be taken. The luminaires should be considered in a context. It was previously concluded that the light is not suitable as task lighting in an office environment. We should rather try to develop something eye catching and special and a decorative ambient light.

5.3. Concepts

A total of eight concepts were selected for further development and evaluation.

CIRCLE OF SUN

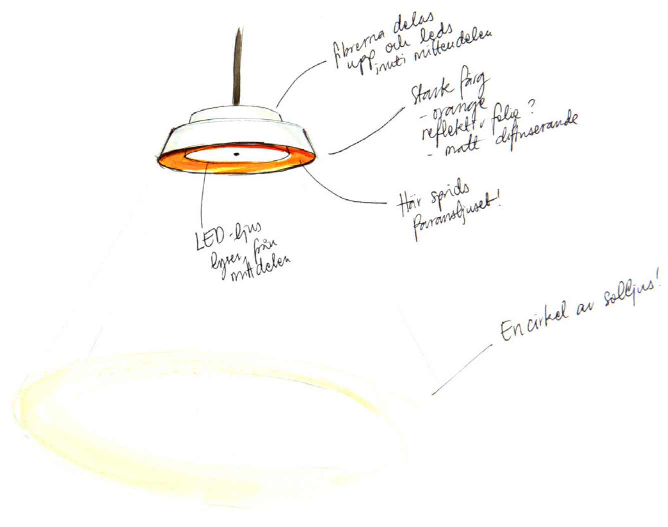

Fig. 5.7.

The Parans light is shaped to a circle, which falls around a table or on the floor. Part of the Parans light is reflected in the orange inner surfaces of the luminaire, which colour the light warm. LED light is spread through a central circular piece. The product form resembles a conventional pendant lamp.

THE CONE

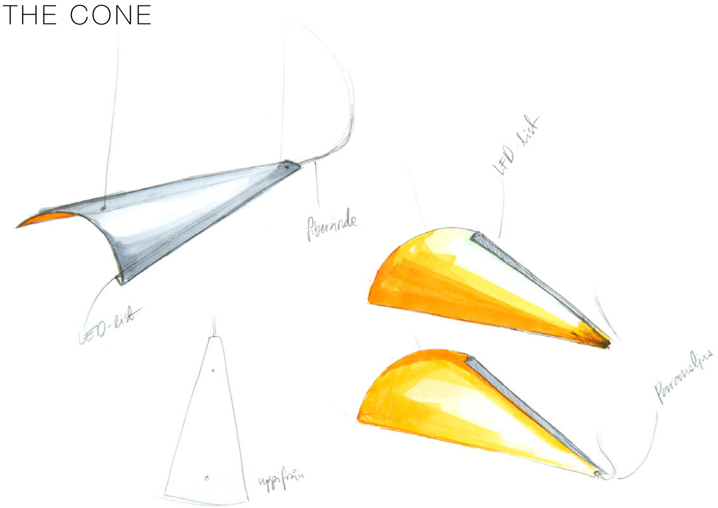

Fig. 5.8.

The fiber cable is mounted at the thin end of a half cone. All or most of the Parans light is reflected in the orange inner surface in order to diffuse and balance the light colour. LEDs are attached linearly to one of the sides of the luminaire. The two light sources are thus distinguished by form and light spread.

SUN THROUGH THE CLOUDS

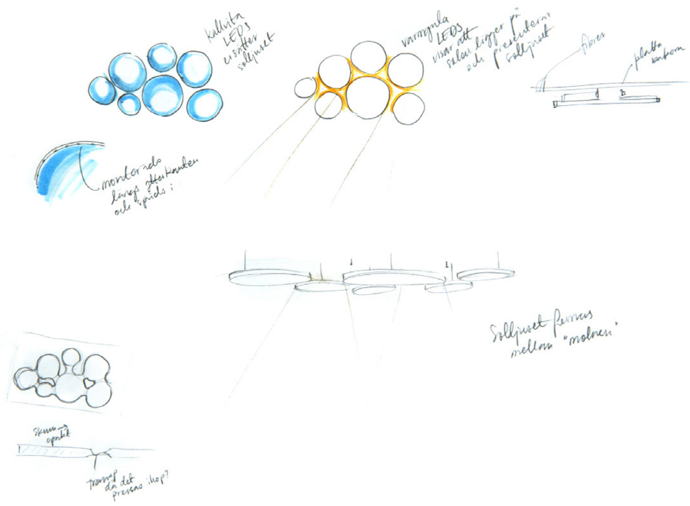

Fig. 5.9.

A series of circular forms are clustered to resemble a simplified cloud. They illuminate using LEDs. The Parans light is released above the circular forms, seeping through the cloud like the sun's beams on a partly cloudy sky. They cast a pattern of light and the luminaire features automatic dimming of the LEDs when Parans light is transmitted.

CEILING OCEAN

Fig. 5.10.

This concept had already been explored by a design consultant firm. The Parans light is reflected on a dented metallic surface in order to create a light pattern on the ceiling, resembling the reflection of sunrays on water. The dented surfaces are attached in a type of frame and can be rotated to reflect or let more light pass. LED lights are integrated in the frame.

WINDOW

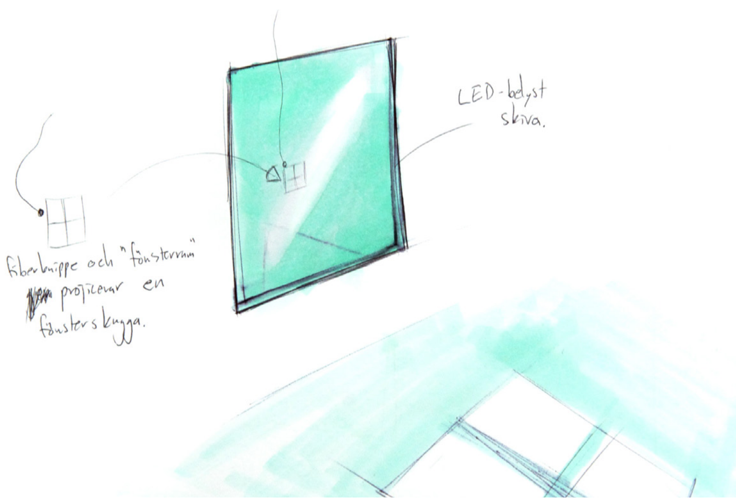

Fig. 5.11.

Early explorations of materials had revealed the possibility to use edge-illuminated boards. The Window concept distributes LED light over a surface using these materials. The Parans light is released through a mask, a gobo, in order to cast a light beam the shape of a window. When the sun is not out, the Window gives a diffuse glow. When there is direct sunlight in the system, it casts a light beam on the floor.

SCULPTURE

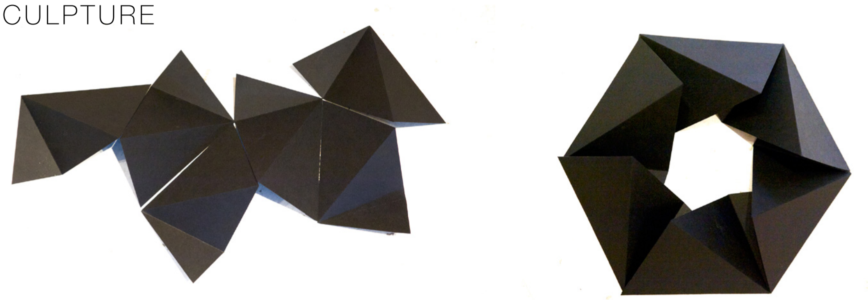

Fig. 5.12.

Inspired from an image on the imageboard, the concept Sculpture plays with the directionality of the Parans light. It features a light mask, which projects a shadow pattern while part of the light is reflected. The luminaires are angular modules that can be built together in three-dimensional clouds.

RAIN OF SUN

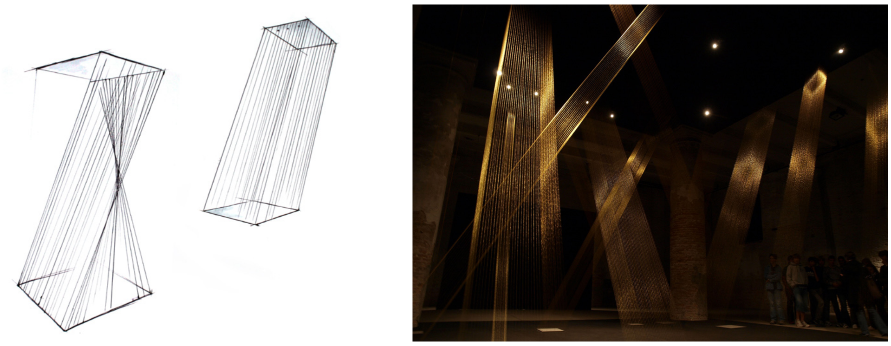

Fig. 5.13.

An art installation called Ttéia by Brazilian artist Lygia Pape at Venice Art Biennale of 2009 came up during the brainstorming sessions. It featured metal wires strung between ceiling and floor, which looked like rays of light when illuminated. Rain of Sun was a concept using the idea of diagonal strings illuminated with the Parans light.

THE BEND

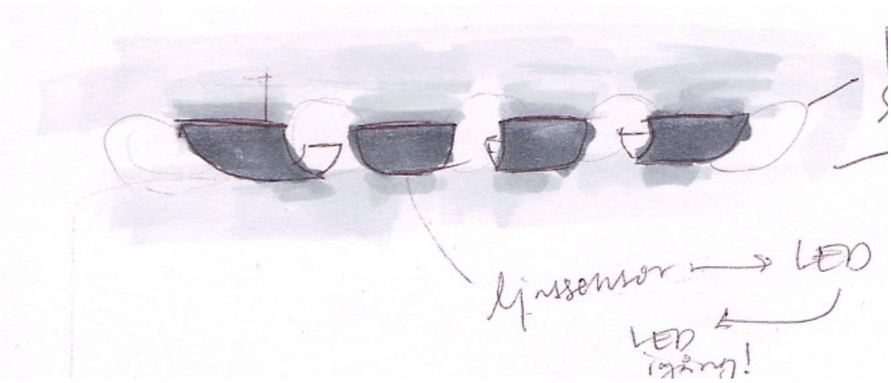

Fig. 5.14.

This concept would hide the light source and reflect the light back into the ceiling, seeming to be smooth openings in the ceiling. When placed next to each other they look like broad bars or gills of a fish, letting the light seep out in between.

5.4. Evaluation

We used two methods to evaluate the total of eight concepts, in order to select one concept for further development. Roomsonas is a method invented during this project, whereas the PUGH-matrix is a product design classic.

5.4.1. Roomsonas

Each concept was tested for feasibility in each type room or Roomsona (see 4.10 Roomsonas). We evaluated what different places in the room the luminaire could be hung, how many would be used and in what constellation or combination with other Parans luminaires or other light sources. Although we could collect numerical data from the evaluation, what makes more sense is the qualitative knowledge from making these small case studies for each combination of luminaire and room. The Roomsonas created can be found in Appendix B.

5.4.2. Pugh concept selection matrix

The Pugh concept selection matrix (see 4.11 Pugh matrix) was used to evaluate the eight selected concepts against the requirements mentioned earlier. It was found that the concepts Cone, Ceiling Ocean, Sun Through the Clouds and Sculpture received the highest scores.

5.4.3. Tutoring session

After performing the two evaluation methods, our findings were discussed during a tutoring session and one final concept was selected as our favourite.

5.5. Selection

The concept we decided to further develop was Sculpture. The choice depended on a combination of factors. Its modularity gives the possibility to construct large clusters, while the units could also be used separately. The form was rationalised to become a low asymmetric pyramid, which could form interesting cloud-like clusters together. The light mask pattern would make use of the directionality of the light and the two light sources could be separated both spatially, in terms of light spread and pattern. The special qualities of the Parans light is thereby better appreciated.

4.10. Roomsonas

Some context was needed and we then decided to create a number of reference rooms. We wanted to give the rooms some aspirational qualities, which would transfer into the product design. The concept could be compared to the room in order to evaluate how strong the idea was in the context and also for the practical aspects of using the concept in that specific room. As this method has some similarities with the method Personas, we called this new method Roomsonas. We chose to give the rooms aspirational qualities, as we wished to create an aspirational product.

4.11. Pugh Matrix

A Pugh matrix is a concept selection tool. When using the method, all concepts are tested against a list of requirements. One concept serves as a reference against the others and during the evaluation one asks the question for each requirement; “Is this concept better (+), worse (-) or equal (0) to the reference concept?”. The requirements can be weighted according to importance and a plus or minus is then multiplied with the weight. The final result is an indication of what concept or concepts seem to fulfill the requirements in the best way. (Karlsson, 2007).

Another reason was that the general form suited the desired style and expression well.

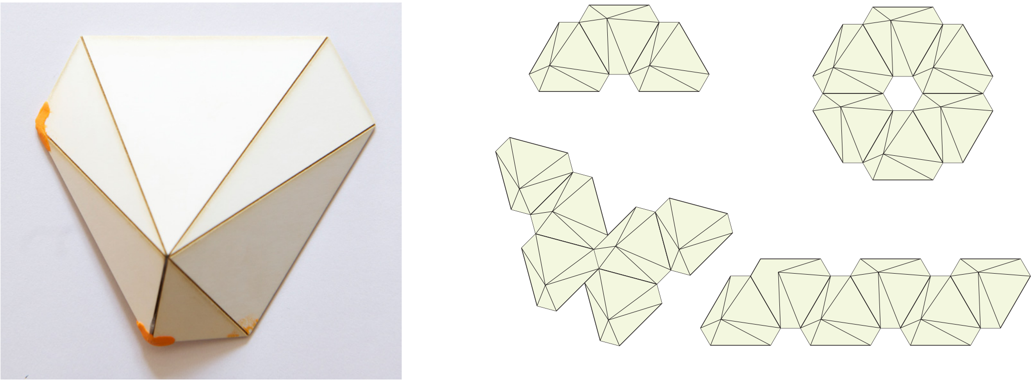

Fig. 5.15.

5.6. Form Development

From the selection of Sculpture as the concept for further development, the focus was on development of form and technical solutions. These processes were treated concurrently and integratedly. The technical development will be presented after the form development for easier reading.

5.6.1. Redefinition of light placement

The original idea of light placement was revised, as can be seen in figure 5.16. The Parans light was originally planned to be released from above the shell of the Sculpture, on the "outside" of the luminaire, in order for light to partly reflect on the upper

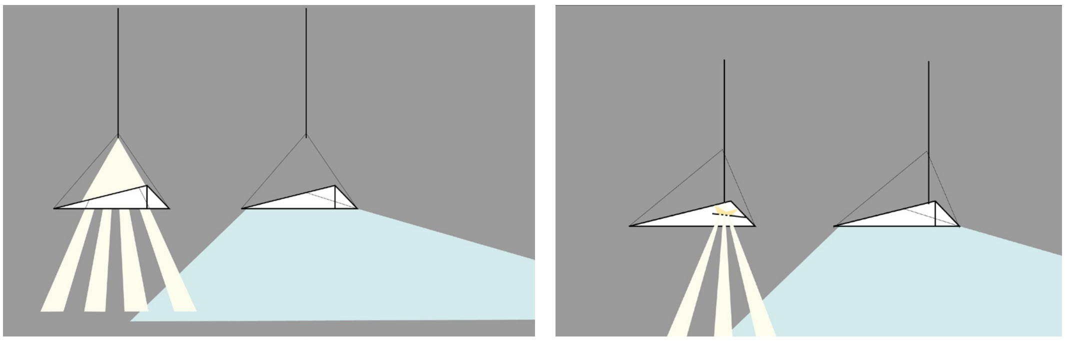

Fig. 5.16.

surface to the ceiling and partly fall through the pattern. The LED light would be produced inside the shell and the two lights would thus be strictly separated. When taking into consideration the placement of the luminaire relative the user, we realised that the contrast would be large when seen from below. If only Parans light is on, this would make the luminaire seem very dark from below.

In order to illuminate the inside of the shell, the Parans light needed to be reflected back into it, if only partly. Contrary to a light bulb or other artificial light source, the fiber light is very directional and does not spread back into the luminaire unless bounced on a surface.

The light from the fiber is either released above the luminaire (left image, Fig. 5.16.) or inside of it (right image).

Fig. 5.17. By reflecting light in a coloured surface a warm glow is acheived, although the coloured surface itself can be hidden.

We realised the possibility to include an idea from other concepts - the fiber light could be partly reflected in a coloured surface inside the shell. This coloured surface could even be hidden, which would make the Parans light change the appearance of the product by bringing a warm glow when shining. The warm glow inside of the luminaire gives the illusion of a warmer light.

The product meaning is also enhanced through connecting the fiber into the shell of the product. The hybridity of the luminaire depends on the double light sources held in the product. Otherwise, the Parans light might as well be projected onto the outside of any standard electric luminaire.

5.6.2. Model making

In order to verify ideas on form and proportion, cluster formation and suspension, models were built in many versions during the process. Most were cut from paper, cardboard or foam board. In addition, plastic sheets, string, electric wires and hot glue were used.

A great tool for accurately, and relatively quickly, verifying form was the use of a laser cutter. Since patterns needed to be examined and the resulting light depended largely on the accuracy in the model, it was not possible to use hand tools.

MOCK-UP AND SCALE MODELS

Natural size modules were used to verify form and size, while scale models were combined to study clusters and their shapes. A mock-up (see 4.12. Mock-up) cluster was built using four natural size modules, which were then hung from the ceiling. These were lit using fiber cables connected to a light projector. Although the amount of light was not comparable to the output of the SP3-system, we were able to study the light spread. The interaction between the light from the different modules was studied so that patterns could be adjusted accordingly. Since the light was projected asymmetrically respective the module, different combinations were tested.

4.12. Mock-up

A mock-up, a (often) rough full-scale model, is an inexpensive way of testing shape, functions and structure. (Österlin, 2003, pp. 67-68)

CAD

Computer aided modelling was used at three points during the development of Sculpture. Early on, it was used to visualise clusters and light spread relative a room. As the focus moved to manufacturing and specifying all of the details, CAD models were needed for technical drawings. These models were also used to produce renderings of the final result for the presentation and documentation of the design.

5.6.3. Projection patterns

A series of patterns were cut and tested with fiber light in order to study light spread. The important parameters such as size and spacing of openings were noted. This work also aimed at finding a beautiful pattern that harmonised with the general form and expression of the product. The pattern cut part was a corner of the same sheet, which was folded into the shape in order to create this functional feature. After a tutoring session it was decided that the part should be mounted separately.

5.6.4. Redefinition of product form

During the last tutoring (Rahe, 2011b) session two important decisions were made in regards to the product form. The asymmetry had proven troublesome for the suspension of clusters, as they varied depending on the rotation of each module. Also a cluster of asymmetrical modules took away some of the simplicity in the shape.

The pattern piece placed inside of the luminaire did not make sense with the overall aesthetics. One idea was to double the form in order to close the lower side of it. The lower side would need to be transparent. Another idea was that of closing the form using a flat surface. This surface could be a light guide and the LEDs could be placed along the edge of it.

Quick computer modelling and pen sketches were used to explore the validity of the three proposed changes, we decided to make the following changes:

SYMMETRY

The module should be symmetric, as the general impression was not altered much, were the modules asymmetric or not. The important aspect was the cluster shape, and this had been changed to the better.

This decision meant that the modules became easier to group into clusters. It would also be easier to manufacture, since fewer different angles were needed – each requiring a tool. The general aesthetic was largely unchanged, yet some complexity to the form had been taken away.

LIGHT GUIDE

The use of a light guide meant that LEDs could be placed along the edge and did not have to be placed horizontally on the loose part.

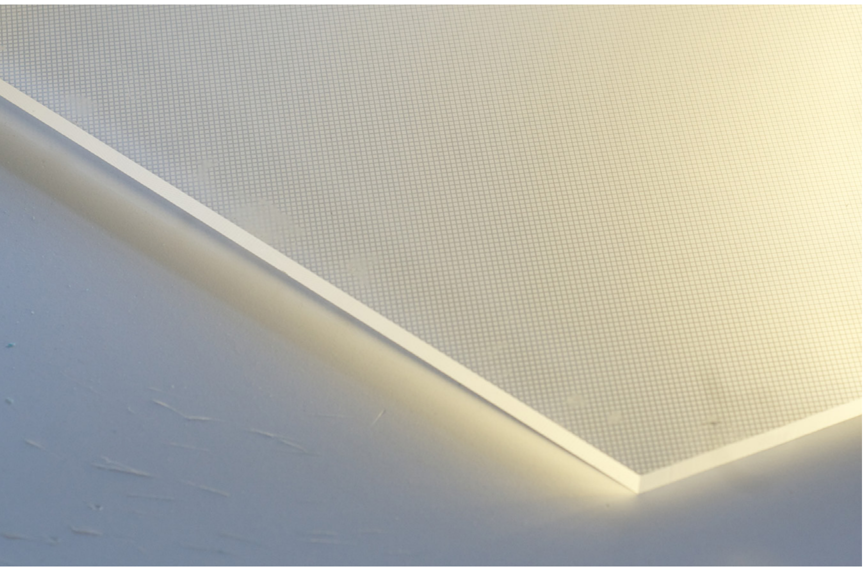

Fig. 5.18. Plastic light guides from recycled TV and computer screens can be used to spread the light.

This was beneficial in terms of assembly time. The LED light would change appearance, but this was foreseen to be more beautiful. Instead of the pattern cut metal part, a reflective and double-sided, pattern cut foil could be placed on top of the light guide. This would give the wanted double reflection and also add a beautiful depth as you would see the foil from behind the light guide.

MAGNETS OR CLIPS

It was also decided that the modules should not be fixed in sub-groups, but attached upon installation using little clips, or if possible, strong magnets integrated into the shell.

5.6.5. Suspension

One important feature had not yet been explored enough: the suspension of the luminaires, the technical system to group them together and the facilitation of its installation. In short, we lacked a defined way of suspending the luminaires together.

FIBER SENSITIVITY

The fiber cable is one of the key components in the Parans solar lighting system and must be respected. It can be bent with a minimum bend radius of 50 mm and loaded with maximum 12 kg. The luminaire could possibly be held by the fiber cable alone, not considering possible threats to the cable. If usage is taken into account, including unlikely events and violence to the luminaire, some sort of security system is needed. It was found that a separate suspension component or system was preferable.

STABILITY

The modules must remain stable and horizontal, since the formation of clusters depends on the horizontal edges touching. With such a flat form as the low pyramid modules, the luminaire may easily flip or hang askew.

VISUAL ELEMENT

The concept of a cloud makes it unfavourable to turn the cables and suspension system into a strong visual element. As the cables cannot be avoided, these components should differ from the actual luminaires in colour or material. They should not be seen as one unit growing from the ceiling, but the cloud-like cluster should be visually floating in the air. An advantage may be that the fiber cables will always be black (defined outside of this project) and clearly distinguished from the white modules.

IDEA GENERATION

Different ways of treating the cable were explored through simple pen sketches and inspiration was taken from similar products.

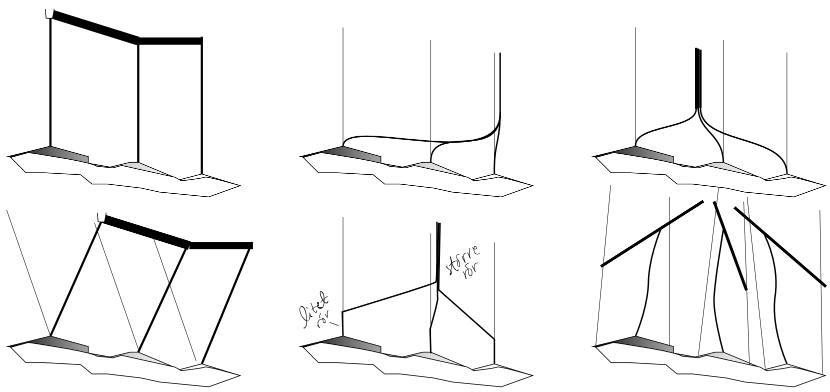

Fig. 5.19. Different ideas on how to handle the luminaire cables

FINAL SELECTION

After exploring the alternatives, a simple solution seemed the most favourable:

- Suspension wires with a trisect connector toward the module, with matching holes in the module.
- Cables run vertically from the ceiling creating straight lines toward the cluster.
- An optional ceiling mounted piece collects the cables for three units and facilitates suspension. As one Solar Lighting System SP3 will always come with 6 cables, three is a good sub-group.

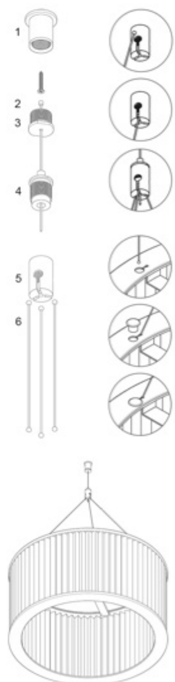

Fig. 5.20. The choosen suspension components (here presented on another product). Source: ALEM teknik.

5.7. Technical development

As mentioned before, technical development of Sculpture was done concurrently and integrated with the form development.

5.7.1. Preliminary selection of manufacturing method

As the design became more specified, a tutoring session about materials and production methods was requested. Having explored the possibilities of laser cutting, we needed to confirm the cost efficiency of using such a method also for production.

The answer we received was that laser cutting had used to be an expensive method, but that it is becoming common and rationally preferable to stamping even for larger production series (Rosenberg, 2011). The blank would then be bent, using a press brake, into the final volume. A simple thin steel sheet of 0.5 mm should give the requested strength, yet be light enough. For good surfaces, durability and the wanted colour, it could be powder coated.

We also decided to try to use the fiber cable for suspension, in order to keep it straight for visual purposes. This idea was later abandoned due to the sensitivity of the fibers.

5.7.2. Meeting with manufacturer

The production methods discussed in 6.3. Manufacturing were also discussed with the production partner INM Mekaniska, to discuss what they could help us with and to find out what kind of tooling was needed. We were told that one simple tool would in fact be needed in order to bend the blanks, since the form is closed. (Fjelldal, 2011).

5.7.3. Implementation of LED technology

Following the redefinition of the form mentioned in 5.7.4., we met with Stephan Mangold (2011b) to discuss the implementation of LED technology. Firstly, we were told that heat might be a problem, as there was no heat sink large enough in the construction. For that reason we were advised to design for the outer shell for the use of aluminium sheets, which is an excellent heat conductor.

This requirement was allowed to affect the product form, as we gave the shell a vertical frame for attaching the LEDs. It also happened to work well for attaching modules to each other.

The colour temperature was chosen to be 4000 K to match the parallel project at Parans (see 3.5.4. Current development of new luminaires), the other hybrid that Parans are developing. It also matches the natural light better than conventional lights, which are often yellow or warm white.

The number of LEDs was decided after a simple calculation of the light needed to match that of the fiber light. It was realised that the LEDs could be mounted in series, which would make the components fewer and slimmer (Voss, 2011b).

As we wished the LED light to be dimmable, this possibility was explored. There are two techniques for dimming LEDs: by lowering the electric current or by pulse width modulation. The second alternative substantially means that light flickers with high frequencies to give a lower luminous flux. Being the simplest technically, the downsides had to be studied. As mentioned in 2.4.2. Flicker, flicker is a factor in a stressful environment, but we were interested in finding out whether there was a standard or limit to respect. As we were unable to obtain an answer even from the interest organisation for Epileptics in Sweden (Svenska Epilepsiförbundet, 2011), we had to rely on advice from the electronics consultant. They would use frequencies above 20 kHz in order not to make audible noise to the human ear (Voss, 2011a), a frequency that was assumed to be high enough in terms of visual flicker as well.

5.7.4. Visit to manufacturing partner

Also the manufacturing partner was consulted regarding the use of aluminium. We received the answer that it was possible, but that welding would be a little more difficult (Fjelldal, 2011). The thickness of the sheet was changed to 1.5 mm accordingly.

5.7.5. LED prototyping

The starting point was a normal circuit board with LEDs mounted. A couple of alternatives were explored as well. LED tape seemed to be a simple and good choice, but showed not to provide enough light per meter to be utilised. Another problem would be the varying quality in the LED chips used. The only LEDs of decent quality are the so called power LEDs (which are not available as LED tape) (Voss, 2011a). Martin Voss recommended LEDs with CRI of around 90 or above.

Also stacked LEDs of the brand Citizen were tested. These had longer illuminated surfaces that would not give a dotted light distribution, which is otherwise typical for LED luminaires. Although giving promising results as to light distribution, the idea was discarded since the connectors were placed in an unfortunate way. It did not fit with the thin space where the LED circuit board would be mounted.

After the second meeting with Martin Voss (2011b) it was decided that the edge height was too low to be able to fit LED cards, even though they were custom made. The cards need at least another 1.5 mm height. To be on the safe side the edge was extended by 2 mm to a total of 14 mm.

6

Final Result

All previous work eventually boiled down to the final design proposal, which will be treated in this chapter. It contains a final specification of the concept, but may be adjusted or changed to suit production methods available with the production partner of choice.

6.1. Design specification

The final design of the luminaire essentially holds two different parts: the design of the luminaire and the design of the light. The two aspects are, as mentioned before, closely intertwined – the shapes and composition of the luminaire change how the light is spread, and the light changes the appearance of the luminaire.

Fig. 6.1. The final concept.

6.1.1. Product design and expression

THE MODULE

Firstly, the design of the luminaire will be treated. On its own, the luminaire has a simple shape, responding to the chosen expression “Pure”. The outer shell, made up of triangles and a surrounding edge, has simplistic lines, yet an unusual shape. It is however in the clustered configuration that the product gets a more distinct shape. This will be discussed below.

Inside the luminaire, the simplicity is broken up with an interesting detail. The pattern seen from below harmonises with the shape of the shell, yet gives more personality and edge to the luminaire. Apart from an element of style, the net serves as a double reflector. It creates a warm glow when the sunlight comes in through the system, and reflects the LED light downward, closing the shape when the electrical light is on.

CLUSTERS

The most important feature of the luminaire is the ability to combine several units into one big light sculpture. The cluster forms a stylised cloud, which was one of the initial metaphors

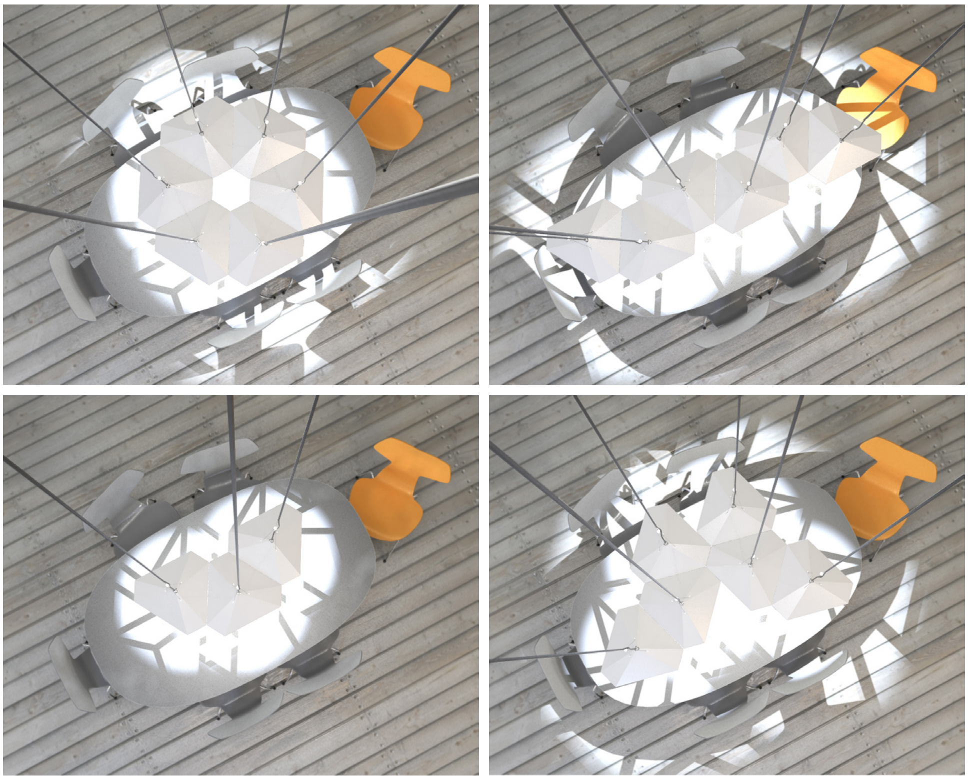

Fig. 6.2. Cluster formation

that we worked with. The possible assymmetry of the clustres expresses “vivid”. It also gives a simple way of creating a sculptural feature and an impressive luminaire. Some of the possible combinations are shown in figure 6.2.

6.1.2. The parts

FIBER CABLE

Each module is put together of a number of parts. Light is transported through fiber optic cables, which have a cable gland attached to the end. The cable gland is a threaded connector of M12 size and enables fastening into the different luminaires. This detail is not negotiable. It should not be twisted to fasten the luminaire, as the movement damages the fibers. Instead the luminaire or a part of the luminaire has to be twisted. The Parans light leaves the cable in a 60° cone.

LIGHT GUIDE

Below the cable ending there is a prismatic plate, a light guide, made from PMMA. In the middle of the light guide, a pattern is cut, which precisely fits the pattern of the double reflector. Holes are cut only where the light cone hits the light guide, which is a circle with a diameter of around 70 mm.

Fig. 6.3. Pattern in light guide

DOUBLE REFLECTOR FOIL

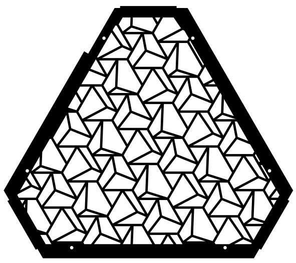

Fig. 6.4. Pattern of reflector foil.

On top of the light guide, there is a pattern cut reflective foil. Its pattern matches the one cut out of the light guide. The foil has a copper-orange top side and a white bottom side and is made out of an entirely opaque material. Light should be reflected and not pass through the material.

When the Parans light reaches the light guide and the foil, most of it just passes through the pattern through the cut holes. The light that hit the foil changes colour due to the colour of the foil and is bounced back up into the shell of the luminaire.

SHELL

Fig. 6.5. Exploded view.

Covering the light guide and the film is the aluminium shell. The light that bounces back from the foil is bounced again in the shell. The result is a warmly lit luminaire, and a perception that the emitted light is warmer than it actually is. Tricking the eye in this way, instead of filtering the light, saves valuable light that would have been lost through attenuation in the filter.

FRAME

To cover the uneven light close to the LEDs, at the edges of the light guide, a frame is placed below it. This part also serves as a fastening component. It is divided into three parts for rational material use during manufacturing.

LED COMPONENTS

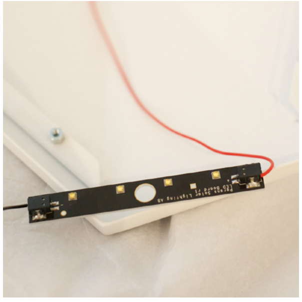

Fig. 6.6. An LED card.

Placed on the short edges of the light guide are three LED circuit boards, with four diodes on each board. The light from the LEDs is guided through the light guide and distributed mainly downwards and partially upwards.

The decision to place the diodes on the short edges was an aesthetic one, as we wanted to avoid the typical dotted line of light that occurs in LED luminaires. Fewer, but powerful LEDs are used, which means that assembly and material costs are lower. It is also a choice of high quality LEDs, which last longer and have good colour rendering capabilities, a CRI of around 90.

The diodes are placed in height with the vertical centre of the light guide so that all light goes in to it. Some tolerance to difference in height of the light guide is planned. This may be an important detail as the light guides may be recycled and will vary in size.

The hole in the circuit board (see fibure 6.6.) makes room for a small magnet, which holds the module together with another module. The modules will automatically find each other and connect to facilitate the formation of large clusters. The seemingly magical connection of the modules conveys the message of a well thought through product, where attention to details has made it smarter.

JOINING COMPONENTS

The three outer frames, the light guide and the double reflector foil need to be attached to the rest of the body. The shell features joining frames, which are welded to the shell. Six screws and six distances are used to fasten the parts to each other. The screws are chosen to interfere as little as possible with the simplistic lines of the total form, but they do not try to hide.

In order to control the position of the fiber optic cable, keep it stable in place and immerse the cable gland into the shell, a mounting plate is placed on the inside of the shell. In the middle of the plate, there is a hole that holds the cable gland.

SUSPENSION

The suspension is a crucial part for this pendant luminaire, since it protects the fiber cable from external stress. The cable is actually strong enough to hold the luminaire, but this would mean putting the fibers at risk. If the users would pull the luminaire or in other way stress the cable, the fibers could be damaged. That would in turn affect the light conduction properties of the fiber. Since the cable is one of the more important parts of the system, and at the same time hard to replace, the decision was made to avoid this sort of situation. A simple solution is to fasten suspension wires to the top of the luminaire. The optical cable and electrical wiring are both attached to the suspension, for less visual clutter. This solution was chosen for its simplicity when it comes to manufacturing, and economical advantages at short series. Other solutions may be aesthetically preferable. The solu-

Fig. 6.7. Suspension in cluster.

tion may need to be reviewed before final production is set up.

6.1.3. The light from two light sources in symbiosis

The two light sources of the luminaire are clearly separated through the differences in light distribution and how the luminaire is lit internally. Light actually changes the appearance of the luminaire: opening or closing its shape and changing the colour of its inside.

LED LIGHT

The LEDs project their light into the light guide. The result is a more evenly lit luminaire and a very evenly lit surface below. This has been modelled for a forecast of the final look. The light is high quality, but nothing out of the ordinary.

Fig. 6.8. Light spread of LEDs (above) and Parans light (below).

PARANS LIGHT

The light from the fiber, on the other hand, is more particular. It is designed to show off the special qualities of the sunlight transported. Both the directionality and the dynamics of the light are present. The pattern of the light (see figure 6.8.) is a strong factor to show of the directionality, without creating too large contrasts. The early experiments and studies of light, served to find the right balance of pattern size and contrast.

INTERACTION BETWEEN THE LIGHT SOURCES

The interaction between the two lights is created to be similar to the light interaction of a daylit room. The two light sources are separated and are controlled separately. The Parans light can be turned off and on again (given that the sun is out, and provides light) and the LED light can be dimmed between off and maximal light flux.

When artificial light is used and the sun suddenly comes out of the clouds, the user will experience what is so special about the system. The illumination increases with the sunlight and gives a strong illumination. The dynamics of the Parans light are used to its full extent. There is a direct connection to the outdoor weather, even if you lack windows or other access to daylight in the room. The electrical light can then be turned down, or the user can enjoy high light levels.

AUTOMATED INTERACTION

An even more sophisticated interaction could be created through the use of light sensors and automated regulation. However it was found that the gain of such a solution did not correspond to the cost, at this stage.

INTERACTION BETWEEN THE USER AND THE LUMINAIRE

To create some sort of interaction between the user and the luminaire is essential, but was excluded from the project due to time constraints. Some thought and discussion were put into the question but no final solution is presented here.

6.2. Ideas not included in the design specification

As the project scope was rather ambitious, some parts were left on an idea stage. These will be mentioned here for later reference.

6.2.1. Ceiling mounting

A detailed description of how to fasten the luminaires to the ceiling has not yet been given. This is a part of the luminaires that has been excluded from the final design specification. However we would still want to present some of the ideas regarding this.

The luminaires need to be fastened in the ceiling, and the fiber cables have to be held or hidden for a clean look of the installation. The suspension wires should be hung at the right positions and the fiber cable would need to be attached somewhere close to this. The relative positions of the suspension wires are important for the luminaires to hang together. Fiber cables can then pass the ceiling in one opening, and be distributed to their right places. Furthermore, the electric wiring has to be connected to a LED driver that also has to be placed somewhere.

The simplest solution for Parans is to provide a drill template in the package. The downside is that it will expose holes, cables, wires and the driver. It would then be up to the customer to develop a solution for their installation.

A more complete solution is to create a cable channel out of plastic or metal, onto which wires, cables, and electric wiring are attached, as in figure 6.9. It would also hold the driver and cover the hole in the ceiling. An advantage of such a solution is that it is adapted to where the wires should be hung, there is no risk of

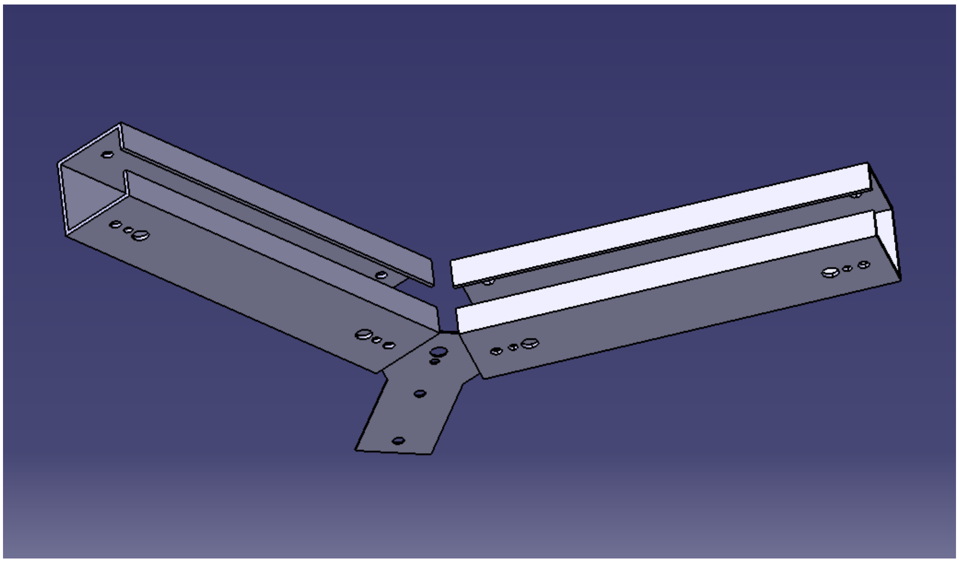

Fig. 6.9. Principle for a ceiling mounting device.

messing up while using a drill template. With this solution it is possible to create something more of the ceiling mounting, to hide cables in style instead of just covering up.

6.3. Manufacturing

Given the size of the company, the current sales of the system and current prioritising of investments, the production volumes of the luminaire may be rather limited in the initial phase. Although sales will probably rise rapidly through a recent repositioning with global market presence, a basic assumption in the project has been to utilise tool-free production methods as far as possible.

To upscale production, other methods could be used, with initial investments in tools and automation, but with lower unit costs. Alternative methods are mentioned after the description of selected method. Further investigation is needed to determine which methods will be most economic, but these must be preceded by strategic decisions and sales approximations.

As of today, all production is outsourced to local and international partners. Local production is preferred to lower freight costs and delivery times. The same logic proposes that production be later on moved closer to the large markets. Although all products are today shipped from Sweden, the main markets will possibly be on other continents. For the near future, the aim has however been to find local producers. Assembly may be performed by the current partner. A proposal for the manufacture of each part will follow.

6.3.1. Outer shell

The outer shell is produced from 1.5 mm sheets of aluminium. The blanks are laser cut directly from a computer file with very fine tolerances. The blanks are then press brake shaped with manual lay-up. This choice was made after consultation with Ralf Rosenberg (2011) Meeting edges are joined through welding, in order to close the shape. Laser cutting is an economically rational choice for production of up to about 5000 units, according to Joakim Fjelldal (2011), employee at one of Parans' suppliers, INM.

For larger series this part could be shaped using superforming. There would then be no need to weld meeting edges, but machining through roll cutting (Thompson, 2007) or 3D laser cutting would be needed to cut off scrap borders after the forming operation. Centrifugal casting may also be used, integrating the joining frames into this single part. If available, all aluminium components should be recycled aluminium.

6.3.2. Joining frames

To join together the different parts, joining frames need to be attached to the shell. These are cut from 2 mm sheets of aluminium. To attach the joining frames permanently, they are welded in place according to little marks already engraved when laser cutting the blank for the outer shell. These frames feature screw holes for joining the parts together.

6.3.3. Cable mounting plate

This small plate is cut from 1.5 mm sheet of aluminium, and serves to attach the cable end fitting to the shell.

6.3.4. Outer frames

The outer frame could be one single piece, but is broken up into three angled pieces in order to cut the material in a rational way, without large amounts of scraps. The outer frames are also laser cut from 1.5 mm sheets of aluminium. Each piece features screw holes for joining the pieces together.

6.3.5. Surfaces

All above mentioned metal parts are powder coated matte white. Apart from aesthetic factors, the surface reflects and diffuses light. The coating covers heat marks from welding and also gives rounded corners and edges without having to polish them after the laser cut.

6.3.6. Light guide

The light guide component is cut from recycled PMMA sheets with a light diffusing pattern. These have been retrieved from old computer screens and are made to distribute light very evenly over a surface. The light guide is laser cut into shape. It could also be cut using water jet or CNC machining with following edge polishing (Felix, 2011)

This component could also be made from new material - either of the light spreading type, or ordinary PMMA sheets with a satinised surface. These are more costly, but provide more liberty as of material sizes. There is also a stable supply and quality. However, the recycled parts are preferred both for cost and for goodwill factors.

6.3.7. Double reflector foil

The double reflector needs to be cut, but could be made out of many different materials and cutting techniques.

PHOTO-ETCHED METAL

For an effective reflection of light, this part could be photo-etched from a thin steel tin, which could be coloured on one side. This solution is our favourite option for the high quality material and beautiful finish. However it is also a more costly alternative and a photographic tool has to be made for our specific part.

	Source	LOW	HIGH	Volume
Outer shell	INM	679 SEK	700 SEK	100 units
Light guide, material	CIT	20 SEK	100 SEK	Uncertain value
Light guide, machining	-	100 SEK	200 SEK	Supplier not contacted
Reflector	Mikroponent	185 SEK	185 SEK	
LED components	Voss	900 SEK	2000 SEK	
Suspension	Alem teknik	80 SEK	140 SEK	Quotation for volume not requested
Screws	ELFA	20 SEK	50 SEK	
Heat conducting tape	ELFA	10 SEK	50 SEK	Not optimal solution
Mounting	-	Unknown	Unknown	-
Packaging	-	Unknown	Unknown	-
TOTAL		1994 SEK	3425 SEK	

Table 6.1 Cost estimation of the components.

PRINTED PAPER OR PLASTIC FILM

These kinds of materials could be cut using a laser cutter for tool free manufacturing. It could also be cut using a die, which would mean that a tool is made.

SCREEN PRINTING

It may be possible to screen print directly on the surface of the light guide. To obtain a double layered print, this method would need to be repeated.

FOIL BLOCKING

When using the foil blocking technique a thin film is attached to the surface of the light guide by stamping it on, which would be similar to the screen printing alternative. The film may have better covering properties in order to block and reflect light, and possibly also dry faster. Further investigation is needed.

6.3.8. LED Components

The three LED circuit boards can be connected in series as a loop, with four LED chips per circuit board. That would give a maximum light output of around

$$1\ W * 70\ lm/W * 12 = 840\ lm$$

The driver circuit board is connected first in the loop, feeding all LEDs with the right current (Voss, 2011b).

6.3.9. Magnets

The luminaire modules will be held together using small neodymium magnets integrated inside the shell.

6.3.10. Assembly

LED components are fastened directly to the shell using heat transfer tape. The same kind of tape is also used to attach the LED circuit boards. The magnets fit into pockets in the LED circuit boards and also attatch to the tape. The light guide and three frames are stacked and screwed in place using self tapping screws.

6.4. Economic calculation

As a hint as to what production costs may actually be, an estimate of the cost at a production volume of 1000 units was requested for all prototype parts. The rough estimates are listed below, with a high end and low end value.

As no manufacturer was contacted for the cutting of the light guide, that estimation may be wrong. However, we see that the cost of manufacturing one module would be roughly between 2000 and 3500 SEK. The cost seems a bit high, given that each system will require 6 units. Further investigation should be done for this question. If other production methods can be used for the outer shell, the production cost might go down radically. Those methods would most probably include more tooling, which means an initial investment, bur later on a lower unit price.

7

Discussion and Conclusion

The conclusion and discussion parts of this report will be treated together. It is divided into four subchapters; the product, the light, the process and sustainability.

7.1. The product

As a whole, we are very pleased with the result of the project. The modular design makes it versatile so that the luminaire can be used in a multitude of lighting situations. We aimed for it to be an eye-catcher that presents the light in an interesting way. It should also fit the product family and the brand. We think that the design lives up to all of these aims.

7.1.1. Manufacturing and costs

The manufacturing processes chosen utilise few specialised tools in order to create the parts. This choice was made for keeping costs down at small series production. At the same time it means that more manual labour will be required and that unit costs are higher than more automated manufacture. It may turn out to be the wrong decision, depending on future sales volumes. In that case a re-design to adapt the concept to different producton methods is an option.

The largest difference may be if the aluminium shell could be cast. If a casting method is chosen for the shell, the joining frames can be integrated into the shell and the outer frames may be produced as one piece. The shell would not need to be bent and welded into shape and assembly would be faster and simpler. However, the initial cost for tooling has not been investigated.

The rough cost calculation that has been made, tells us that the component cost of the product will be somewhere betweeen 2 000-3 500 SEK. Given that some profit will be needed, the price may be too high for the end customer. The right price has to be found, and it may not need to be very low, but at the same time it has to be acceptable to buy even a whole cluster of six units.

As we did not have a good definition of the market and the final customer, it was not possible to determine what will be an acceptable price. We did not analyse the market in these terms, nor do we have previous experience of outright market analysis.

FUTURE

What should be done before starting future production, is to investigate the market further and find out how much is an acceptable price for this hybrid luminaire, possibly comparing to different sales volumes at different price levels. Then the appropriate manufacturing methods can be chosen. With initial investments in tooling for other production methods, the unit costs may be radically different for larger scale production.

Perhaps the product is instead kept as a sort of showcase product to present the technology. If it is available only upon request, and at a higher price, it may be acceptable to keep the current production methods. The same goes for a hesitant start-up of sales.

7.1.2. Takes many forms

The luminaire was made to stand out and to be flexible enough for the small product portfolio. The modules can form large clusters, which can become impressive light sculptures adapted to the room they are in. The pattern of the projected light is also something rather unusual.

At the same time, the luminaire can also be used by itself or in small clusters, which broadens the use of the product and will therefore increase sales.

7.1.3. Pendant luminaire

The choice to go for a pendant luminaire may be questioned. It makes this luminaire different from the current product portfolio, but made development harder. As there has to be an optical fibre cable, visual clutter was an issue, especially in larger clusters. Although it would have been easier to design for a fix luminaire, where cables would not be exposed, we are happy about the choice and the final result.

Perhaps it would have been visually favourable to enclose the fibre cables, suspension system and electrical wiring in a tube of some sort. This option can be further explored later on. We are content to have reached the goal of proposing one way of solving suspension. That said, it may not be the optimal solution. The same goes for the ceiling mounting device, which has not reached a final form, although a principle concept exists.

FUTURE

The ceiling mounting device needs to be developed further if it should be provided.

7.1.4. The expression and aesthetics

The exterior shape of the luminaire is in our opinion both simple and beautiful. We believe it to be a relevant shape with present style trends and something that can stay relevant for a long time. It is also simple enough to be true to the style and expression of the brand.

The interior shape of the luminaire has more detail and an intricate pattern. This type of feature is something that did not exist in previous luminaires – neither in the current nor earlier product family. However it is a subtle detail in that it is hidden, placed behind the light guide and has a neutral colour.

The fibre cables are drawn vertically, but the line will be disturbed by the suspension system. For visual purposes, this may not be the optimal way to lead the cables to the luminaire. For practical reasons it is still the proposed design.

7.1.5 User interaction

User interaction was treated during the project, but no actual proposal has been presented in this report. Although an interaction device would have great possibilities to take the design to another level, it showed to be too complex an object to successfully develop it as parallel to this project. Rather than presenting a less thought through concept, we preferred to concentrate on the luminaire.

Fig. 7.1. The proposed concept.

FUTURE

An interaction device such as a special light switch or remote control could be a good complement to Parans' products; both to control the separate light sources and as a place to remind the user of the technology and the brand of Parans.

7.2. The process

7.2.1. Lighting design vs. product design

After a while we realised that designing a luminaire is in fact two parallel design processes: the product design and the lighting design. They are intimately connected and constantly affect each other, but still this double design work creates a greater complexity. We often found ideas and concepts that were not complete luminaires, but merely part solutions. Sometimes the ideas joined and created interesting combinations.

7.2.2. Perceived colour temperature

After some initial though and studies, it seemed obvious to us that most people perceive sunlight as either warm or neutral in colour temperature. We do not know the exact reason why, but one reason could be that sunlight creates physical warmth. Paradoxically, the mid-day sunlight that will be the main input light for the luminaire is relatively cold. Perhaps the perceived colour temperature is just a misunderstanding due to the physical warmth of sunlight.

Another possible reason might be that the few times we look directly at the sun, is during sunrise and sunset, when the light gets an orange tone. It should also be noted that our visual system is extremely good at adapting to current lighting conditions, perceiving the bluish daylight as neutral white.

Looking back, it would have been interesting to make some sort of study of this phenomenon, at least to confirm the supposition that sunlight is perceived as warm. This was not done due to lack of time. At each point in time, there were more important activities, which made it so that this small study was not performed.

7.2.3. Methodology

No systematic and extensive use studies were performed, due to unclear definition of markets and typical customers. As far as ergonomics goes, limits and guidelines could be found. For questions such as aesthetics, no thorough use studies were performed. The result could have been affected by studies like this, and we may have had a chance to make a better luminaire. On the other hand, when it comes to aesthetic discussions, use studies are hard to design. We were advised not to spend time on any deeper use studies, as the process needed to be rather quick. Instead we focused more on observations and interviews with experts.

In an attempt to use two methods previously learned – creating personas and finding lead users – we found that the functional demands with regards to the users was a hard task. We did not believe that we would achieve interesting results and decided to use our own invented method. We call it Roomsonas, using inspiration from the established method of creating personas. It is described under 4.10. Roomsonas.

The method provided a structured way of assessing the usefulness and style of different concepts. We were the experts making the analysis. A more thorough way of doing the same analysis could have been as a workshop with perhaps architects or light designers. However we found that the results achieved were helpful and that the method was efficient.

7.3. Sustainability

7.3.1. Economic

Economic sustainability has not been treated in this master thesis.

7.3.2. Social

The working environment is an important part of the employees' wellbeing and health. Lighting is a very important part of our working environment, and both the Parans light and the LED light are of high quality. The broad spectrum of the sunlight is so far impossible to imitate. The LEDs chosen for our hybrid luminaire have a high Colour Rendering Index, meaning that they give high quality light for an electric source.

The luminaire designed within this project fits an innovative technology that saves energy and betters our planet. It is important to lift and show good examples, especially if they do good both on a macroscale as well as for the person next to it.

7.3.3. Ecological

The Parans system provides an efficient way of bringing natural light inside buildings. Making only a small penetration of the roof, it does not bridge heat or cold – heating and cooling being two major expenditures in energy use for buildings. It also provides a passive light, meaning that energy is saved on electric lighting. There is, however, a need of energy for the motors to turn the panel toward the sun. The receiver uses 7 W, which means that some energy is consumed.

The combination with LED technology is a good match. Using LEDs is an energy saving alternative and can produce high quality light. As mentioned earlier, LEDs have a long life and are mainly made of silicon, an abundant material.

The luminaire features a recycled part, which is upcycled instead of becoming landfill, being incinerated or used as lower-grade plastic material. This fact also saves production energy. However, the actual outcome has not been assessed. We did not make a calculation of the energy used to handle, transport and transform this component. It is possible that the total energy use is larger due to such factors, or that the gain is less than imagined.

Also the aluminium parts could be made out of recycled material, if available.

7.4. All in all

This project set out to create a new addition to the Parans range of luminaires. It should hold two light sources and put emphasis on the special qualities of the Parans light.

The developed luminaire has an updated style and bold form, especially in that it uses a pattern and colour, although on a hidden surface. The pattern and change of light colour in the luminaire makes the user notice the Parans light as it varies over the day. The product still has the form simplicity needed to fit the current product portfolio and the pure expression.

This project aimed to present a production ready concept.

There are some aspects that can be explored further, in terms of finding the best and most economically viable production techniques, especially after reviewing how large the expected production volumes will be. However, the delivered result is a defined concept which have also been verified in the form of a physical prototype. If desired, the concept could be taken into production as is, after only some minor modifications.

The luminaire gives the user the possibility to create more striking light installations with the Parans light. The product makes the technology visible and should be used to promote the technology and Parans light also from an aesthetic perspective.

8

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LIST OF FIGURES

For images where the autors are not the copyright holders, the sources are as follows:

Appendix A

Version 1, before selecting concept		Version 2, after selecting concept	
Technical Function			
Allow hanging		Allow hanging	
	from ceiling or wall		from ceiling
Allow attachment of fibre cable		Allow attachment of fibre cable	
	1-6 cables		1 cable
Dissipate heat		Dissipate heat	
	from LEDs		from LEDs
Possess simplicity in solutions		Possess simplicity in solutions	
		Hold components	
			LED components
			Light guide
			Optic cable
		Hide LED components	
		Hide light hotspots from diods	
Delivery of sunlight			
Offer white light		Offer white light	
	as close to the sun spectrum curve as possible		as close to the sun spectrum curve as possible
Optimize use of sunlight		Optimize use of sunlight	
	no wasting of precious light		no wasting of precious light
Add value		Add value	
	through the use of sunlight		through the use of sunlight
LED-light			
Exceed flicker threshold		Exceed flicker threshold	
	frequency > 60 Hz		frequency > 60 Hz
Exceed auditive threshold		Exceed auditive threshold	
	frequency > 20 000 kHz		frequency > 20 000 kHz
Offer white light		Offer white light	
	of around 4000 K		of around 4000 K
Maximize CRI		Maximize CRI	
Offer high energy efficiency		Offer high energy efficiency	
	> 65 lm/W		> 65 lm/W

Appendix B