Master Thesis

Development of a Sunlight Luminaire

Petra Kopp & Anja Sandberg

Division of Product Development • Department of Design Science
Faculty of Engineering LTH • Lund University • 2015

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Preface

This report is a part of a master thesis project executed in collaboration with Parans Solar Lighting AB, at the Division of Producr Development, Department of Design Science, Faculty of Engineering at Lund University.

Several people have assisted us during this project. Without any given order, thank you:

Olaf Diegel, head of department at the Division of Product Development and supervisor for this project, for providing us with guidance in combination with hands-on advice regarding both the design process and the mechanical construction.

Karl Richard Nilsson, Parans Solar Lighting AB, supervisor for this project, for input and guidance during the project. Especially thank you for encouraging us to have an open and creative design process.

Hillevi Hemphälä, Katarina Hennig, Thorbjörn Laike, Eva Nyquist and Lisa Morän for helping us getting a broad understanding of light and lighting.

All the people who took their time and volunteered for the test, the brainstorming session and the questionnaires.

Finally, we would like to thank the teachers at Division of Product Development that helped us with ideas, guidance, mechanical construction and building prototypes.

Lund, February 2015

Petra Kopp & Anja Sandberg

Abstract

People spend more and more of their awaken time indoors, resulting in no or little exposure to sunlight during the day. Natural daylight is superior to artificial light concerning our biological and psychological health, and it is one of the most important external signals to the circadian system, the “wake and sleep”-clock. The objective of this thesis was to develop a luminaire which spreads sunlight, collected and transferred indoors by Parans Solar Lighting’s system, SP4.

The aim of the project was to not only spread sunlight, but to also convey the feeling of sunlight. Hence, both the design of the light and the luminaire has to give the observer the instant perception of natural light and not artificial light.

Information regarding the behavior of sunlight, lighting design and how to manipulate light were collected in the first phase of the project, providing a broad understanding before starting the development process. Additionally, the target group and the user needs were defined to narrow down the focus of the project. The luminaire was supposed to be designed for an office environment, and this target area was specified even more by focusing on break rooms. Common coffee breaks are important since they encourage creativity and act as a valuable opportunity to exchange ideas amongst colleagues. A questionnaire were conducted to gather insights about break culture and preferences for light settings in break rooms.

The development process were divided into three parts. The first part was the development of the light design. When this design was set, the technique for manipulating the light from the optic fiber to the desired light shape had to be developed. The last step in the design process was to develop the actual luminaire.

In the end, a luminaire inspired by a skylight was created. The light from the luminaire will be projected onto a wall, in a shape similar to a pillar. The luminaire itself consists of two parts; one spotlight, transforming the light, and one shade, hiding the light source. The luminaire should be installed above the second ceiling, replicating a light shaft or a skylight.

The luminaire will be modular, which can either be installed together with the shade, in a dropped ceiling or independently on a beam. It should also be available in several different colors, and thereby suitable for a broad range of customers.

Keywords:

Sunlight, Fiber optics, Luminaire, Product development, Light design

Sammanfattning

Denna rapport beskriver arbetsprocessen för examensarbetet *Development of a sunlight luminaire.* Arbetet har en omfattning på 20 veckor och är en del i programmet Maskinteknik med Teknisk Design på Lunds Tekniska Högskola och har utförts i samarbete med Parans Solar Lighting AB. Parans utvecklar och säljer system där en solfångare samlar in solljus, som sedan leds in till inomhusmiljöer via optisk fiber. Dessa system möjliggör solljusinsläpp i lokaler som är belägna under markplan eller i mitten av djupa kontorsbyggnader.

I dagens samhälle spenderas mer och mer av vardagen inomhus, vilket resulterar i ingen eller liten exponering av solljus. Ny forskning har hittat en tredje receptor i ögat, som hjälper till att kontrollera vår dygnsrytm genom att påverka melatoninnivåerna i kroppen. Denna receptor reagerar framförallt på de kvalitéer som solljus har: intensitet och dynamik.

Innan projektet startades formulerades en brief som förtydligade målen för utvecklingsprojektet: En armatur skall tas fram för kontorsmiljöer. Då armaturen skall komplettera Parans existerande produktportfölj skall den projicera solljuset på en vertikal yta, en metod som ofta används då det får rummet att upplevas som ljusare. Förutom detta skall produkten förmedla Parans drivkraft och vision, nämligen att sprida känslan av solljus.

I första delen av designprocessen genomfördes litteraturstudier och intervjuer för att få en uppfattning om hur vi påverkas av och uppfattar solljus, hur ljusdesigners samt arkitekter arbetar när de planerar ljussättning av kontor samt karaktärsskillnaderna mellan artificiellt ljus och solljus. För att få en bredare förståelse för hur ljus beter sig gjordes även litteraturstudier gällande optikens grunder samt traditionella metoder för att transformera ljus.

För att få en uppfattning av vilka behov som armaturen skulle uppfylla specificerades det exakta användningsområdet till pausrum. Fikapauser är viktiga då de uppmuntrar till kreativitet och erbjuder en möjlighet att utbyta idéer mellan kollegor, vilket skulle kunna förhöjas genom extra energi och stimulans från solljus. En enkätundersökning utfördes för att validera valet av arbetsområde, denna visade att 40 % av de 53 svarande aldrig hade tagit en paus utomhus den gällande månaden, mestadels på grund av tidsbrist samt att 94 % tog minst två pauser per dag. Detta sågs som en indikation på att armaturen med fördel kunde designas för pausrum för att öka de anställdas exponering av solljus.

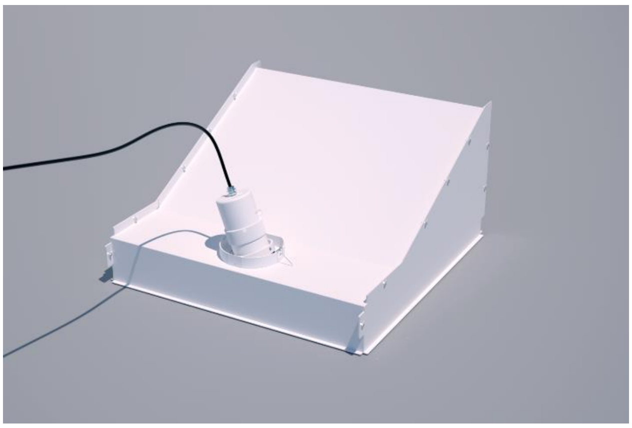
Det uppdagades relativt tidigt att utvecklingsprocessen behövde delas in i tre delar, först en för att designa ljusbilden, sedan en för att utveckla en optisk lösning för att manipulera ljuset och till sist en för att designa armaturen. Dessa tre delar kommer att förklaras kortfattat nedan.

Designen av ljusbilden togs fram genom att observera solljus samt att brainstorma idéer för hur solljus skulle kunna imiteras. Den valda ljusbilden ansågs intressant och hade en stark koppling till naturligt ljus, då den liknar de ljusbilder som skapas när solljus tränger in genom takfönster. Utöver denna ljusbild valdes det också att, som komplement, försöka skapa en jämnt upplyst vägg, en så kallad, wallwashing-effekt, vilket var Parans initiala önskan med projektet.

Efter att ljusbilden valts, behövdes en teknisk lösning för hur ljuset skulle manipuleras för att projicera den önskade bilden på väggen. Den tekniska lösningen togs fram genom inspiration från befintliga produkter där ljus används, såsom teaterspots och OH-apparater. Slutligen valdes en lösning som påminner om en teaterspot, med två linser och en schablon för att projicera en fokuserad och skarp bild. Utöver dessa komponenter adderades en prisma för att vinkla och förbättra ljusbilden, vilket även ledde till att armaturen kunde installeras närmare väggen.

När de optiska komponenterna av armaturen var fastställda kunde fokus läggas på utformning och design. Flera idéer genererades men då ljusbilden var inspirerad av ett takfönster, inföll det sig naturligt att även armaturen i sig skulle påminna om ett sådant. Lösningen blev en tvådelad armatur som består av en skärm och en spot-likande ljusmodul, se bild nedan. Skärmen kan placeras i innertaket och döljer därmed ljusmodulen. För att kunna leverera en modulär lösning till Parans, kommer det vara möjligt att installera ljusmodulen med sin skärm, infäst i ett innertak eller separat på en skena. Om delar av ljusmodulen monteras bort, kan även en wallwasher-effekt uppnås med denna produkt. Både ljusmodulen och skärmen kommer att tillverkas i ett flertal olika färger för att nå ut till en bredare marknad.

I det slutgiltiga stadiet av utvecklingsprocessen lades mycket fokus på att utforma armaturen så att den skulle vara enkel och intuitiv att montera ihop och installera.



Ljusmodulen infäst i skärmen.

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English – Swedish Glossary

Luminaire	Ljusarmatur
Circadian rhytm	Dygnsrytm
Retina	Näthinna
Skylight	Takfönster alt. diffust ljus från himlen
Second ceiling	Innertak
Dropped ceiling	En typ av innertak med plattor i grid
Structural ceiling	Bärande tak
Gobo	Ljusschablon
Light shape	Ljusbild
Protractor	Gradskiva
Pivot point	Rotationscentrum
Flutings	Räfflor
Plaster board	Gipsplatta
Plaster mold casting	Gipsgjutning
Abrasive blasting	Blästring

1 Introduction

This chapter presents the background of this thesis project and gives an introduction to the company Parans Solar Lighting. The brief of the project will be presented, followed by research questions and the scope and limitations.

1.1 Background

Light is defined as the visible spectrum of electromagnetic radiation, i.e. radiation with a wavelength between 400 nm and 700 nm. Besides affecting the visual performance, light is important for both our biological and psychological health. It is the most important environmental signal to the circadian system, the “wake and sleep”-clock. Light stimulates this system through, the recently found, third photoreceptor and enables a synchronization of our inner biological time to the external environment [1], [2]. Natural daylight is superior to artificial static light sources in terms of stimulating the circadian system due to its dynamic properties and the high illuminance, which is better matched to the systems spectral sensitivity [3] .

At the same time, people spend most of their time indoors, both in Europe and in the United States numbers show that 90 % of people’s lives are spent indoors [4], [5]. Spending a lot of time inside makes it difficult to perceive the natural light and the benefits that comes with it. Studies show that the occurrence of headaches, SAD (seasonal affective disorder) and eye strain decreases with the proper use of natural daylight [6].

In 2012 lighting consumed around 20 % of all energy consumption in the commercial sector in the United States [7]. In Europe the figures are similar, lighting in buildings consumed 20.78 % of the energy consumption in the tertiary sector[1] 2010 [8]. These numbers show that more energy efficient lighting will have a great impact on decreasing the total energy consumption.

It is obvious that lighting is important and that there is a need for new innovative lighting techniques which address these two concerns: improving health and decrease energy consumption.

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[1] The tertiary sector includes public sector, healthcare, services and commercial sector.

1.2 Parans Solar Lighting

Parans Solar Lighting, (Parans) was founded in 2002 in Gothenburg and currently has four employees. Together with Chalmers Technical University they have developed a patented technology to collect and transport sunlight through optics fibers, enabling sunlight into rooms and areas where it normally would not be possible to reach [9].

Parans' system has been installed in several areas such as education, retail, healthcare and offices. Parans has resellers worldwide with main markets in Asia and the United States [10].

The manufacturing, which still is quite small scale, is located near Gothenburg. Since Parans is developing and selling environmentally friendly products, the aim is to have a manufacturing that corresponds with this, e.g. by minimizing transportation impact [10].

The current system, SP3, consists of a receiver which is placed outside of the building, preferably on the roof, see Figure 1.1. The receiver which consists of 36 lenses follows the sun's movements during the day. The sunlight collected by the lenses in the receiver is then transported through optic fibers that are clustered into cables with six fibers per cable. The end of the cables are then attached to a luminaire or simply just attached to the ceiling. This gives the opportunity to have six luminaires for each receiver. The output from each cable is 430-730 lumen depending on the length of the cable [11].

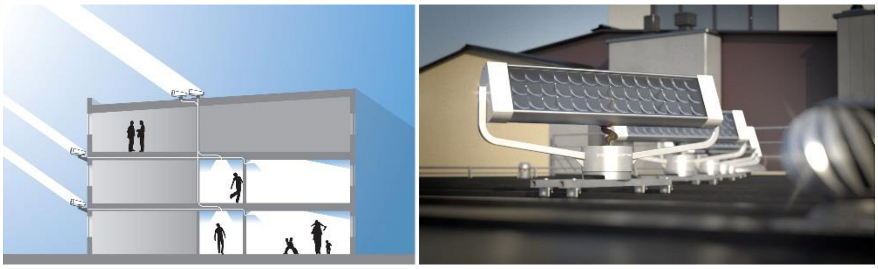

Figure 1.1 Parans' SP3 system.

Beside the receiver Parans has three different luminaires in their product portfolio, see Figure 1.2.

Figure 1.2 The three current luminaires in Parans' product portfolio.

Parans is developing a new system that will have glass fibers instead of plastic fibers, which will enable cable lengths up to 100 meters. The new system, called SP4, is planned to be launched in fall 2015 [12].

1.3 Brief

The objective of this thesis project is to develop a luminaire for Parans system, suited for office environment. The luminaire should illuminate a surface in a room with no or little sunlight intake, and thereby provide the room with indirect light. It should be suited for Parans' SP3 system, as well as for the new SP4 system. The luminaire will only use sunlight that the system provides, hence there will be no extra artificial light, and therefore the design has to be adjusted for both bright light during sunny days and no light during cloudy days.

Parans' vision for the company and their products is to bring focus to the sunlight and the natural feeling it provides. It is therefore important that the new luminaire enhances this feeling.

Since Parans' business concept is based on an environmental friendly method for lighting, they prefer the products to follow the same line in terms of material, manufacturing and transportation.

The new luminaire should be designed for customers who want to create a brighter feeling in the room and see value in having a playful, non-continuous sunlight instead of artificial light. The design, aesthetics and function, of the product should highlight these features, and thereby communicate Parans' vision to the customer. The luminaire should not be marketed as artificial luminaire but rather towards a new market segment, more similar to windows.

Since Parans is a small company with low investment possibilities, the final luminaire concept has to be adapted for small scale production.

1.4 Research questions

To facilitate the background research and the development process, a set of research questions were established.

Light Definition

- What is the definition of different types of light?
    - Sunlight
    - Direct sunlight
    - Natural light
    - Artificial light

Sunlight

- Is it possible to differentiate sunlight from artificial light?
    - How do humans identify sunlight?
    - How do humans perceive sunlight indoors?
- Which feelings are associated with sunlight? Evoked by sunlight?
    - How can the feeling of sunlight be conveyed to the user?
    - What is the big difference in how artificial light and sunlight are perceived?
    - How can sunlight be imitated?

Ergonomic and emotional studies of light

- What strategies are used when planning the lighting in office environments?
- How can lighting be placed to enhance the lighting experience?
- How does different kind of light and light settings affect humans?
    - How do sunlight and artificial light affect us?

Technical Aspects

- How is light measured?
- What techniques can be used to control and manipulate light flux?
- What techniques are used to introduce sunlight into buildings?

1.5 Scope and limitations

The project, with start in September 2014, was carried out during 20 weeks at Lund University. The product development was conducted in collaboration with Parans Solar Lighting.

During the product development, the light shape, the optical aspects and the aesthetics of the luminaire were considered and developed.

Focus during the project was on the perceived experience of light, consequently there was no thorough measuring of light levels in both the research and the evaluation tests. The ability to test the actual output of the light from the system was limited by the lack of sunlight during the time of the project, why other artificial light sources was used instead.

Parans' market is geographically broad but the participants in the questionnaires and tests carried out in this project was limited to Sweden. The interviewees were all based in Lund and Malmö.

The aim of this project was to deliver a working prototype. Manufacturing method and material was not specified and since exact detailed optimization for production is preferably carried out together with the chosen manufacturer this was left to further development.

2 Method

This chapter will describe the method used in this project and how it has been applied. The project plan is also included connecting the scope of the project to the method used.

2.1 Approach

The selected method for this project is the *double diamond design process*, developed by The Design Council, a British government based organization working with design and innovation projects. The model is based on a study of several successful brands and how their design departments work. The study shows striking similarities and shared approaches among the designers [13].

The model's strength is to visually display the divergent and convergent phases in the design process and to give concrete advices for tools and methods that can be used in these phases [13]. The phases in this design method are called *discover*, *define*, *develop* and *deliver,* see Figure 2.1. They are established to describe how the goal sometimes is to open up the project for new areas and a broad range of ideas while in other stages of the process, narrowing down the scope by focusing on distinct objectives [14].

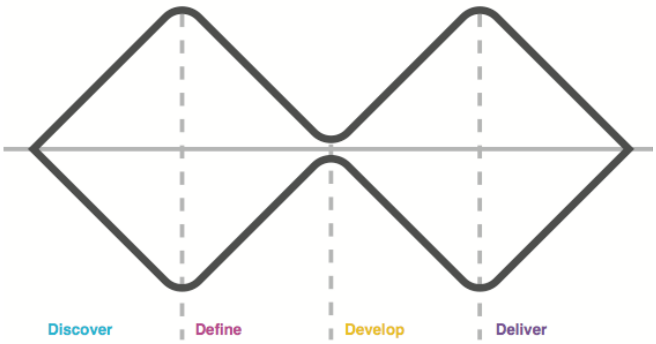

Figure 2.1 Double diamond design process [15]

In addition to this method, inspiration was taken from *Product Design and Development* by Karl T. Ulrich and Steven D. Eppinger [16]. Ulrich and Eppinger's methods were mainly used during the different selection procedures made within the project.

Here on it will be described how the *double diamond design process* has been used in this project. All the tasks in the different phases of the design process has been carried out parallel, enabling iterative and non-linearity work within the phases, see Figure 2.2. A deadline between every phase forced progression and gave structure to the project. At each deadline, the results were presented to both Parans and the supervisor of this thesis in order to get input and to ensure that the development of the luminaire was moving in a satisfying direction.

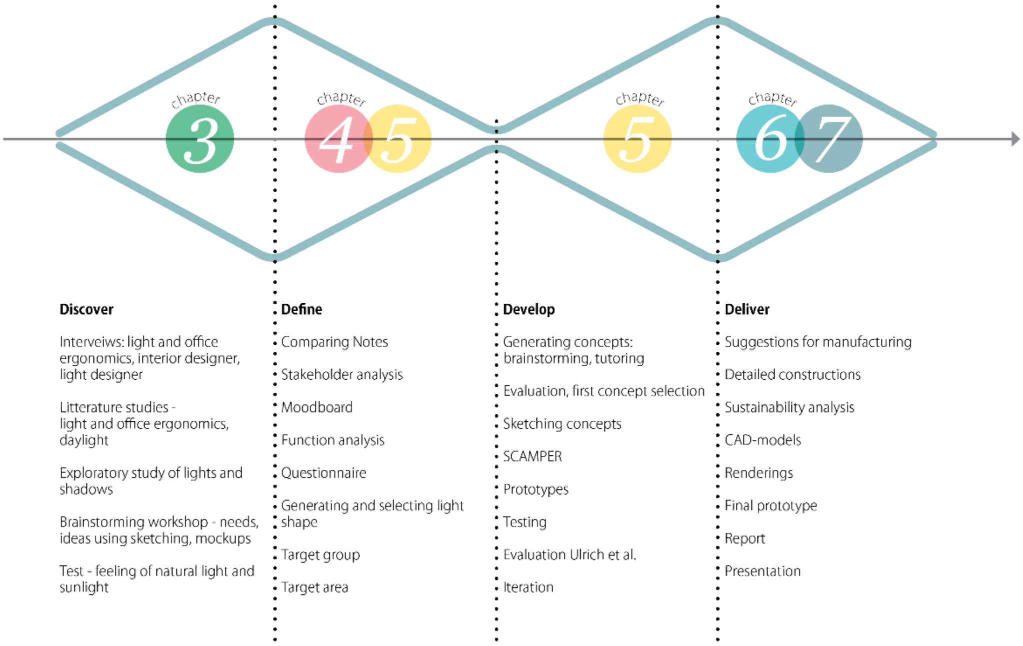

Figure 2.2 The double diamond method applied to the project.

Discover

In this first phase all the tasks involved gathering information regarding sunlight, lighting design and how to technically transform light. A first idea-based brainstorming session was also included in this phase, with the aim to gather a lot of ideas regarding how to create a new type of luminaire and how to use sunlight indoors.

Define

This phase purpose was to narrow down the broad focus from the *discover* phase. Parts included were: selecting target area, identifying user needs and establishing product requirements by tasks like creating a moodboard and a stakeholder analysis. With basis from these parts a list of requirements were set up with a method called function analysis.

In the beginning of the design process it became clear that the design of the luminaire had to be split into two steps, first the light shape had to be designed followed by the design of the luminaire. The design of the light shape was seen as a step towards narrowing down the scope of the project before the *develop* phase, hence it was a part of the *define* phase rather than the *develop* phase.

Develop
The goal in this phase was to develop a concept which fulfils the requirements collected in the *define* phase. Firstly an optical concept with the ability to transform the light into the required light shape was developed, the aesthetics of the product could then be selected to make the product fit the target group. The goal was to end up in one concept, including a technical solution, which could be developed further on a more detailed level in the last phase of the design process.

Deliver
Since this phase was the last part of the project, the goal here was to end up with a working prototype of the luminaire in combination with detailed concepts for assembly and installation. Suggestions for material and manufacturing methods were also concluded in this phase. The final concept of the product will not only be illustrated with the prototype but also with renderings of the CAD-models.

2.2 Project plan

A project plan was created prior to the project, based on the selected method. The actual outcome differed slightly from the plan, and some changes had to be made during the progress of the project.

See Appendix A for the original plan and the actual outcome.

3 Background research

This chapter is based on the define phase of the project, where the goal was to open up the mindset and gather information regarding the basic optics of light, lights effect on humans and lighting techniques.

3.1 Method

To gather the background information needed before starting the development process, interviews and literature studies were used as the main sources.

The interviews were unstructured with open questions, in order to get exploratory sessions [17]. The questions were designed to be neutral and easy to understand. To ensure this, pilot interviews followed by adjustments were performed before the actual interviews. Although the interview questions were similar for all the sessions they were adapted for each interviewee to fit their specific field of topic. In total four interviews were made with a duration of 40 minutes to two hours.

The interviewees were chosen to give a broad spectra of knowledge and to ensure covering all the research questions.

Hillevi Hemphälä
PhD at Design Sciences, Ergonomics, Faculty of Engineering, Lund University.
Hemphälä is a researcher working with visual ergonomics and focuses on how lighting affects the visual performance [1].

Katarina Hennig
Senior Lighting Designer and Section Manager at WSP group in Malmö.
Hennig is an experienced lighting designer working with both indoor and outdoor projects [18].

Thorbjörn Laike
Associate Professor of Environmental Psychology, Faculty of Engineering, Lund University.
Laike's research is focused on how humans are affected by the indoor environment and the impacts, both visual and non-visual, light and colors have on us [19].

Eva Nyquist and Lisa Morän
Owners of the architect bureau Nyquist & Morän in Malmö.
Nyquist and Morän mainly works with interior design for offices and have an expertise in planning work spaces [20].

3.2 Results

3.2.1 Light

Light consist of electromagnetic radiation of different wavelengths, but it is just a part of the broad electromagnetic spectrum, which includes everything from long radio wavelengths to extremely short x-rays wavelengths. Light has no essential physical meaning but is rather defined by the scope of wavelength, 400-700 nm, that are visual to the human eye [21].

3.2.1.1 Basic optics

Reflection

When light hits a surface it can either be reflected off or be refracted into the surface. Depending on the properties of the material, different types of reflection will occur. The three general types of reflection are: specular, diffuse and spread, see Figure 3.1.

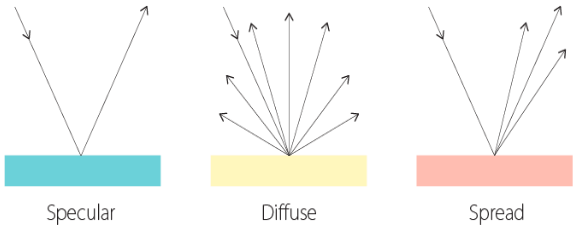

Figure 3.1 Different types of reflections.

In mirrors there will be a specular reflection since the incoming and reflected light has the same angle. If the reflective surface is matte, as a regular paper, the incoming light will be reflected into many different angles and create a diffuse reflection, also called scattered reflection. When the light hits an uneven and rough surface the light will be reflected in more than one direction, but with similar angles. This is called a spread reflection and occurs on glossy surfaces [22].

The law of reflection is normally demonstrated by a singled-ray specular reflection. The definition states that the angle between the incidence ray and the normal, θ, is the same as the angle between the reflecting ray and the normal, θ', given that the incident ray, the normal and the reflecting ray all lie in one plane [22], see Figure 3.2.

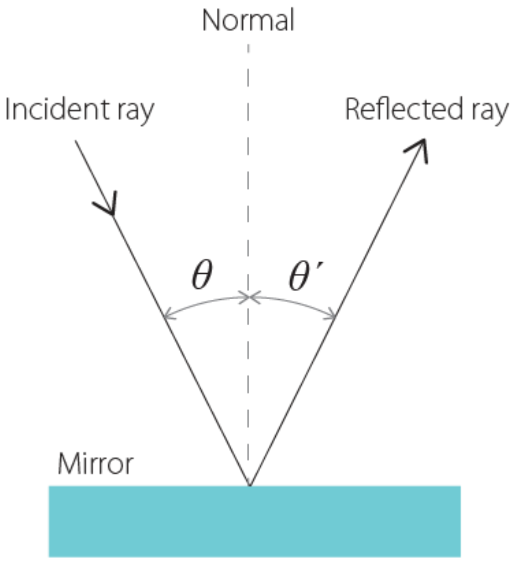

Figure 3.2 Single ray reflection.

Refraction

If light travels from one material to another, like sunlight hitting a window, a part of it will be reflected back and some will refract, bend at the boundary and change velocity and continue through the material. Assumed that the incident ray, the normal, the reflected ray and the refracted ray are in the same plane, the refraction angle, θ_2, depends on the incident ray, θ_1, and the reflective index of the materials, n_1 and n_2, see Figure 3.3. The relationship is given by Snell´s law of refraction:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

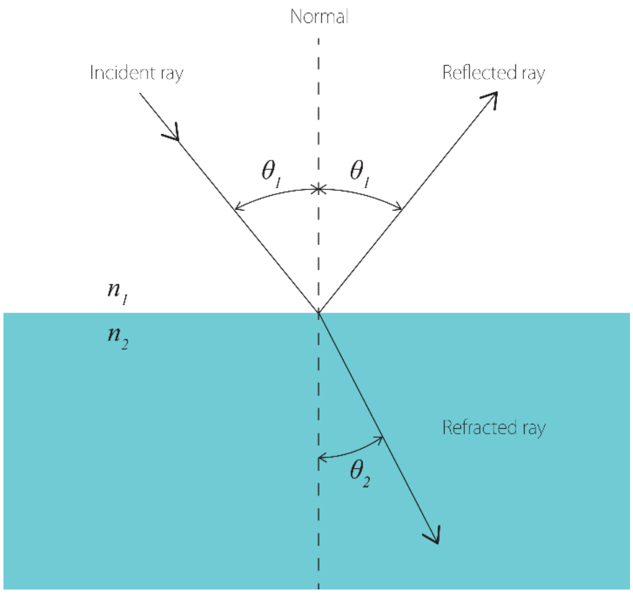

Figure 3.3 Snell’s law.

The reflective index, *n*, of a material is the ratio between the speed of light in a vacuum, *c*, to the speed of light in the material, *v*:

$$n = \frac{c}{v}$$

According to Snell´s law the light that travels from a material with a low refractive index to one with a higher refractive index ($n_1 < n_2$), will bend towards the normal and vice versa. The law also shows that if the incident angle is 0°, (sin0°=0), the ray will not bend at all and pass the boundary straight through [22].

A transparent material transmits almost all light. Though a small part is reflected, called the reflected loss, r_λ. The reflected loss when light with a normal incident angle ($\theta_1 = 0$) passes a boundary between two materials can be determined by Fresnel's law of reflection:

$$r_\lambda = \frac{(n_2 - n_1)^2}{(n_2 + n_1)^2}$$

When light travels from air to glass at a normal incident angle, there is a loss at 4% at each boundary. The reflected amount of light increases when the incident angle increases [22].

Total internal reflection

Snell’s law states that the refraction angle is higher than the incident angle when light travels from a material with a higher reflective index to one with a lower refractive index. When the incident angle increases away from the normal, the refraction angle will increase as well until the light is refracted along the boundary. This angle is called the critical angle, θ_c, see Figure 3.4 When the incident angle is higher than the critical angle, there will be *no* refraction and only reflection. By using thin fibers with a reflective index higher than air, it is possible to transport light with very little or no loss except for absorption. This method, which Parans uses to transport sunlight, is called fiber optics [22], [10].

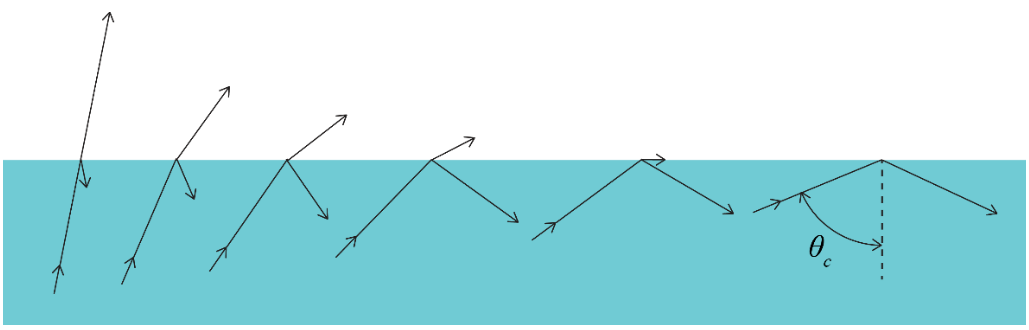

Figure 3.4 Total internal reflection and the critical angle.

Dispersion

The wavelength of the incident light hitting the surface of a material affects the reflective index. For example the index usually is higher for blue wavelengths, hence they bend more than red light, and this is called dispersion. This phenomenon is used in prisms to separate the different colors of white light [22].

Dispersion also affects light traveling through optic fibers, therefore there will be a loss of some wavelengths, which affect the color spectrum of the light output, if cables are too long [10].

Diffuse (scattering)

In the same way as for reflection, the light can be transmitted in different ways depending on the finish of the material's properties. One example of this is diffusion or scattering. The grade of diffusion depends on both the reflective index, the size and shape of the particles in the material and the wavelength of the light.

The sky is one example of this, where the molecules are the exact right size to scatter the short, blue, wavelengths. Hence, the sky is blue [22].

3.2.1.2 Basic photometry and physical units of light

Luminous flux

Radiometry is the study of optical radiation's power in space, as opposed to photometry which is characterized by human's visual response to light. Where radiometry is measuring the total energy content, photometry analyzes only the radiation humans can see. Radiant flux, expressed in watts, *W*, is the rate of the total amount of energy flowing out of a source. Luminous flux, ϕ_v, is the measure of the flow rate of energy in visual light, expressed in lumens, *lm* [22].

Luminous flux is weighted so it is more sensitive to yellow-green wavelengths to match the eyes color reception. To be able to measure light it is necessary to use instruments that respond to the radiation the same way as the human eye, called photometers [21] [22] [23].

Illuminance

Illuminance, E_v, photometric flux per unit area, is the total amount of visible light illuminating a point on a surface from all directions above the surface. It is measured in lux, *lm/m*^{2} [22] [23].

Solid Angle

To describe the following units, the concept of solid angle needs to be introduced. In 2D, see Figure 3.5, an angle, ω, can be described as the circular arc length, l, divided by the radius of the circle, r. E.g. a half-circle has arc-length πr and spans an angle of π radians.

$$\omega = \frac{l}{r}$$

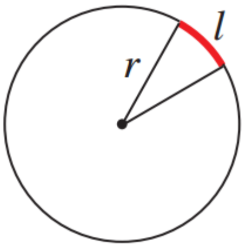

Figure 3.5 The circular arc length, l, and the radius of the circle, r.

The unit for solid angle is the steradian, *sr*. Analogous to the relations in 2D, the solid angle, ω, is described as the area, a, divided by the squared radius, r, of the sphere, see Figure 3.6. E.g. a hemisphere has a solid angle of 2π *sr* and a sphere corresponds to 4π *sr*.

$$\omega = \frac{a}{r^2}$$

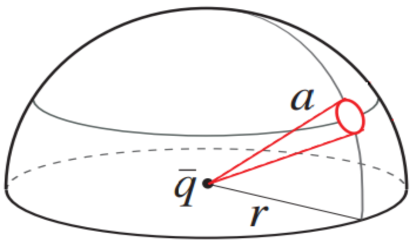

Figure 3.6 The area, a, and the radius of the sphere, r.

Luminous intensity

Luminous intensity, I_v, describes the amount of visible power emitted from a point source per unit solid angle and it is measured in candelas, *cd* or *lm/sr*, see Figure 3.7. In other words, it describes how much light goes in a specific direction. Candela is the SI base unit from which all other photometric units are derived [22] [23].

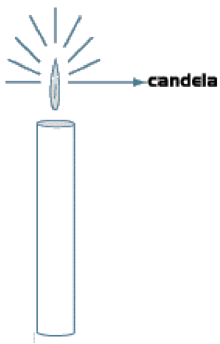

Figure 3.7 Luminous intensity.

Luminance

Luminance, L_v, is the luminous intensity emitted per unit area and is measured in candelas per square meter, cd/m^2. It is the unit that mostly describes a person's perception of brightness since it is only the rays hitting the eye that are perceived. Though luminance is the objective value, whereas the subjective brightness will change depending on adaption and contrast in the visual field [22] [23].

Figure 3.8 describes the relationship between the units and Table 3.1 gives a summary.

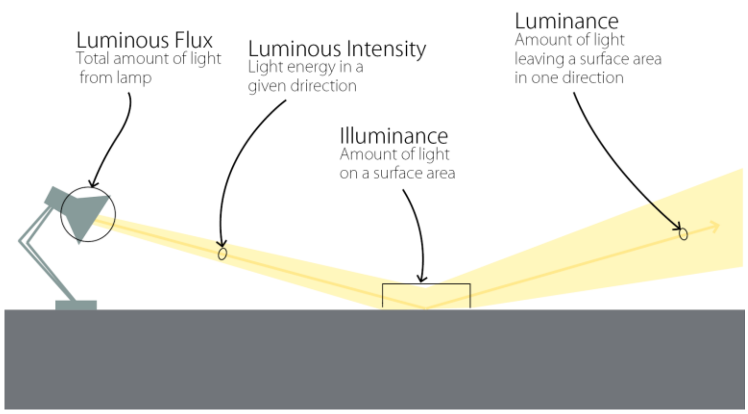

Figure 3.8 Relationship between luminous flux, luminous intensity, illuminance and luminance.

Table 3.1 Summary of the units

Quantity	Symbol	Units
Luminous flux	ϕ_v	lumens (lm)
Illuminance	E_v	lux (lx; lm/m^2)
Luminous intensity	I_v	candela (cd; lm/sr)
Luminance	L_v	candela per square meter (cd/m^2)

Lambert's cosine law

Lambert's cosine law states that the illuminance falling on a surface is proportional to the cosine of the angle of the incident light, see Figure 3.9. The angle, θ, of incident is measured from a line perpendicular to the surface.

$$E_{\theta V} = E_V cos\theta$$

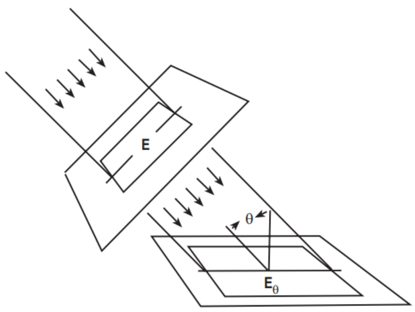

Figure 3.9 Lambert's cosine law.

This can be illustrated by imaging a surface being lit directly from a source. If the source then moves so the beam falls obliquely, the lit area will grow, but the amount of light falling per unit area will decrease [22] [23].

Inverse square law

For lights sources that can be approximated as point sources the relation between the luminous intensity, I_v, of the source, illuminance, E_v, of a surface and the distance, d, between the two can be described with the inverse square law, see Figure 3.10.

$$E_V = \frac{I_V}{d^2}$$

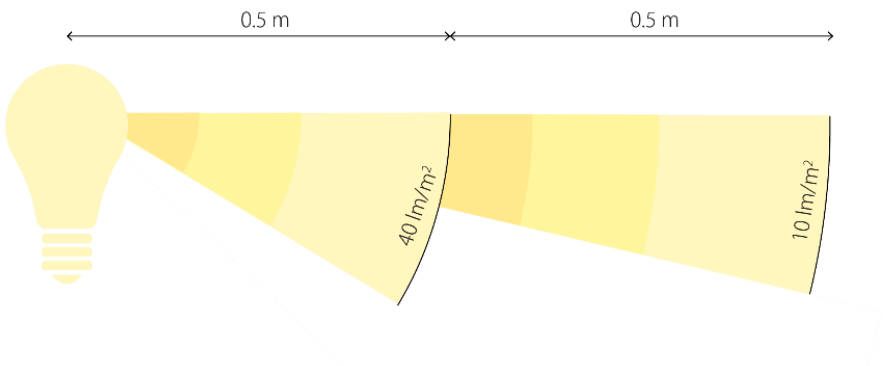

Figure 3.10 The inverse square law.

3.2.2 Daylight definition

In this report, the only natural light considered is the light coming from the sun, called daylight.

Daylight can be divided into three subdivisions: direct sunlight, diffused sunlight and skylight. *Direct sunlight* consists of the nearly parallel rays directly from the sun, therefore it casts sharp shadows. *Skylight* is the product of sunlight diffusing and scattering through the states of the atmosphere giving soft and weak shadows. *Diffused sunlight* is generated when the sunlight has interacted with a diffusing material such as the ground [23]. For the different kinds of light and how they relate to each other, see Figure 3.11.

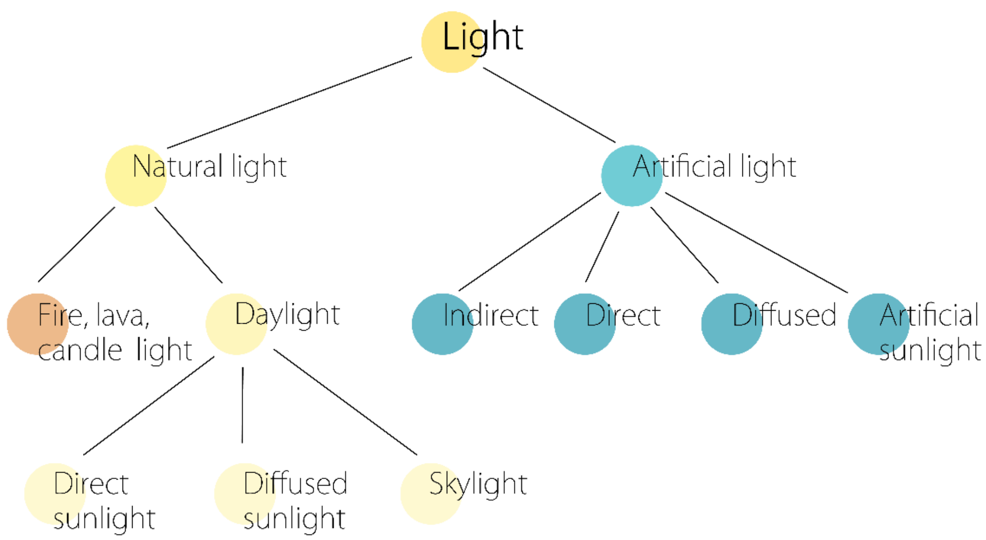

Figure 3.11 Daylight definition.

3.2.3 Light effects on humans

There is a fundamental distinction between the objective description of light and what people perceive. Light can, as mentioned earlier, be described physically in several ways, but subjectively people do not usually perceive the light itself, instead they see all the things that the light enclose. [23]

There are three aspects on how light affects people: visually, biologically and psychologically. [3] [19]

3.2.3.1 Visual effects

The effect light has on our vision is the most obvious one: humans need light to be able to see. Five parameters can describe the stimulus on the visual system: visual size, luminance contrast, color difference, retinal image quality and retinal illumination. By enhancing these, the visual performance will be faster and more precise [3]. However, Hillevi Hemphälä, emphasized that to high intensity will cause glare and too large of a contrast will be strenuous to the eye, why these levels should not be overstrained [1].

3.2.3.2 Biological effects

Light is the most important environmental signal to our circadian system. The circadian system can be described as our “wake and sleep”-clock. Light stimulates this system by, the recently found, third photoreceptor and enables a synchronization of our inner biological time to the external environment [1], [2]. When exposed to bright light the melatonin, which causes drowsiness and lowers the body temperature, levels are blocked and the more intense light, the faster the process will be. Wavelengths at 460-480 Nm, which is a blue light, are most effective for this restrain on melatonin levels [2], [19].

The circadian system affects our mood and this is well illustrated by seasonal affective disorder, SAD. SAD is a depression which occurs mainly during fall and winter at northern latitudes due to disturbances in the internal clock, leading to a delay of the circadian rhythm [2].

Light also has an effect on our mood through mechanisms that are independent from the circadian system. Light can control mood directly via effects on alertness and sleep, where increasing alertness has been an effective approach to improve mood [2].

3.2.3.3 Psychological effects

Lighting conditions affect emotions by the dynamics in the environment, the color temperature and how the light is modulated, i.e., the relation between light on vertical and horizontal surfaces [18]. However, what is considered as the best light is subjective and depends on individual, social and cultural factors, e.g. in northern countries, a warmer light temperature is preferred, when in countries with warmer climate a cold light temperature is generally favored [1]. Another aspect is the expectations about the lighting conditions. Purcell and Nasar proposes that changes in mood can be explained by the difference between expectations and reality [3].

Laike explained that environments, where lighting is one factor amongst other stimuli such as sound, with a low complex level will increase sleepiness while an overly high complex environment can evoke stress [19].

3.2.3.4 Daylight and artificial light

Daylight differs compared to other light sources in a sense that it is dynamic and changes all the time. The wavelengths present in daylight depends on the time of the day, weather conditions, latitude and season. The continuous spectrum also separates sunlight from other artificial light sources. The dynamic in daylight makes it superior to artificial static light sources in terms of stimulating the circadian system and the high illuminance is better matched to the systems spectral sensitivity [3]. Besides the effects on the circadian system, the dynamics in daylight also carries information, about the time, weather, location, which is at least as important as the energy of radiation [23].

Concerning the visual system, daylight, as such, is not inherently better than other light sources, it depends on how it is designed. Though, the color reproduction, given that it is adequate weather conditions, is superior in daylight due to the continuous spectrum [3].

There is a correlation between light and sick building syndrome, SBS, the lack of daylight is the second largest reason for SBS, after air condition. The typical syndromes for SBS, headaches, fatigue, numbness and irritation of eyes, increases in proportion to the use of artificial lighting [24].

On an emotional level, daylight is considered more attractive and comfortable than artificial light [24]. People prefer daylight over electric lighting as a primary source of illumination, however this can also be explained by a negative view on, and the belief that electrical lighting is detrimental to health [3]. This can be linked to people’s preference in naturalness. Humans have a tendency to prefer natural substances over their synthetic counterparts which have been explained due to two reasons. Firstly natural is seen to be functionally superior: healthier, more effective and less damaging to the environment. The other explanation is that natural products is seen to be morally superior. Additionally Rozin stated that what people consider to be natural is dependent on the source and the extent of transformation of the natural substance [25]. A study by Haans shows that the natural preference is present in the context of light and that the term natural is consistent when applied to light. Sunlight is perceived as most natural though if it passes through a medium, this medium considerably affects the perceived naturalness. When entering a room through clear glass, or more so for blinded or translucent glass it is considered to be less natural than entering through an open window [26].

Even though there are differences, it can be difficult to perceive the difference between artificial light and daylight by just observing at the light itself. The identification is often connected to the view [1]. In a familiar situation it is subconsciously sensed what to expect: artificial light comes from lamps and daylight from the sun [23]. This also links to the concept of constancy, which is the perception of assuming that one physical characteristic is changing rather than another, e.g. a daylit wall varies greatly in luminance but this is perceived as variation in illuminance since that is what is assumed to be possible, i.e. the perception is not that the wall itself is glowing but that light is lighting up the wall. However, if the light source is hidden, it is possible to break down the constancy and create illusions [23].

3.2.4 Lighting techniques

The intention with this sub-chapter was to obtain knowledge that could inspire the design of the luminaire. Information regarding techniques for designing with both daylight and artificial lighting were gathered, since the luminaire designed in this project was seen as a mixture between these two.

3.2.4.1 Daylight

Daylight through windows and slots behave in a way which differentiates it from both daylight outside and artificial lighting inside. The main reason is that daylight inside buildings goes through a subtractive process, since only a fragment of the light from the sun enters a room. Artificial lighting on the other hand is an additive process since the light is "created" as it spreads from the source [24].

The visual function of windows is to let daylight into the building and since the light bounces off the landscape outside, we perceive a view [23]. According to Laike, the view is a very important visual function of a window which affect us emotionally [19].

In domestic and rectangular rooms, normal rooms, there are usually windows on one or two adjacent walls and roof openings are uncommon. Associated with normal rooms are normal light shapes. These characteristic patterns of daylight are asymmetrical with bright surfaces close to the window which fades with the distance from the window. The brightness of the vertical and horizontal surfaces does also change with the distance from the window, where a greater amount of light hits the vertical surfaces [23]. Light luminance reflected on the walls reduces the sense of gloom and is generally preferred [3]. A disadvantage with side lighting is the limited radiation in the room, generally the effect of the daylight is lost after a distance of 2.5 times the height of the window [23].

The regular formation of the light shapes created from windows are bright trapezoid with a diffuse edges, see Figure 3.12 [1]. These patterns of light varies in brightness, size and shape during the day [23].

Figure 3.12 Typical light shape created from a window.

In official buildings on the other hand, toplighting is a common way to introduce daylight. These concepts of lighting behave as direct artificial light since they radiate light downward. The most common way to use top lighting, see Figure 3.13, is with skylight, no. 1, single clerestory, no. 2, sawtooth clerestory, no. 3 and monitor or double clerestory, no 4. The regular skylight only provides direct light, while the single clerestory and the sawtooth provides the room with both daylight and the double clerestory only provides the room with indirect light [27].

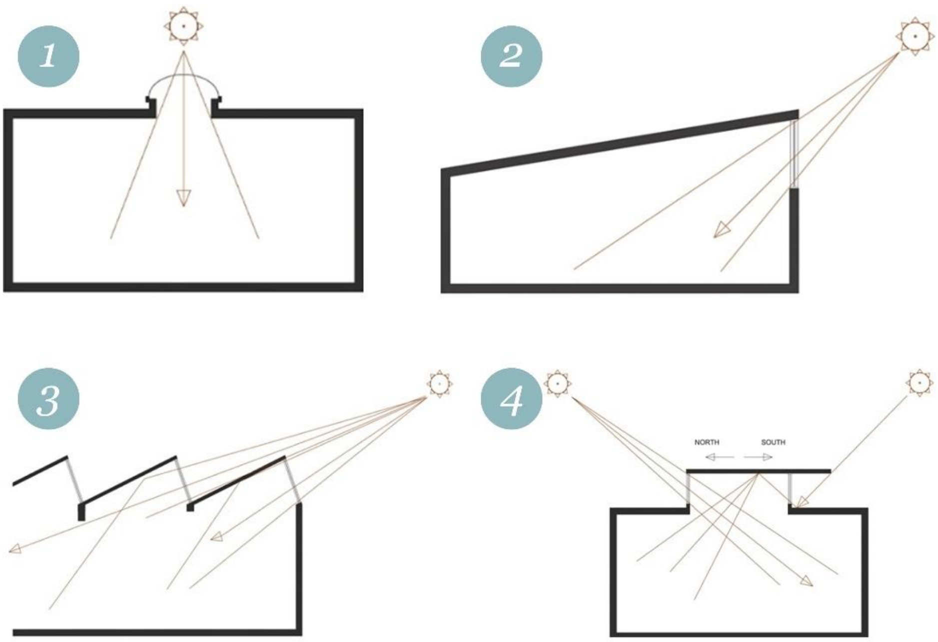

Figure 3.13 Examples of toplighting.

3.2.4.2 Artificial light

There are several techniques for designing the artificial lighting indoors, but a common way is to fulfil the illumination-needs by working with lighting layers or elements. Two methods are described below.

According to Hennig there are three elements of light that has to be covered when planning the lighting indoors. These elements are diffuse light, accent light and sparkles/playful light. If a room is lit up with too much or only diffuse light it will be hard to comprehend the size of the room and it is important to give the users a psychological frame of the space. Hence, the accent light should be used to light the walls, and thereby framing the room. The sparkles or the playful light is the element that makes the room interesting [18].

Karlen and Benya describes the same way of working, except they call it the four lighting layers: the ambient layer, the task layer, the focal layer and the decorative layer. The ambient layer provides an overall lighting to the room. It affects the mood of the room and gives the amount of light needed for basic visual recognition. If the amount of ambient light is low in comparison to the other light levels, the room will appear as dramatic. But if the brightness of the ambient layer almost is as bright as the other layers, the room will appear brighter, cheerer and more relaxing. The task level of lighting is needed to create a sufficient working environment in the room. Examples of task luminaires are desk lamps and shelf lights. The focal level of light is used to illuminate architectural features and artwork. The idea with the focal layer that the focus should not be on the luminaire and the lights but on what it displays. The last layer, the decorative layer, has the purpose to catch the eye and is important in interior design since it gives the room a theme [27].

It is common for light designers to fulfil two layers with one luminaire. Since it minimizes the costs and still maintaining the same effects. E.g. by using a decorative lighting as an ambient lighting. There is also an approach called general lighting where only one type on luminaire fulfills the lighting needs. This simple one-layered method is often used in basic offices, stores and classrooms [27].

Lighting for offices

According to Nyquist and Morän, the light effects on the mood have to be considered when planning the lightning for an office. A yellow light can give a cozy and private environment, which may not be desirable in an office environment [20]. It is the same way with the light levels of a room. Dark rooms is perceived as intimate and personal while bright rooms feels more sterile, public and active [28].

The light shapes, also affects the feeling of the room. Diffuse light sources create light with undefined borders and are used to minimize the shadows and give a long term visual comfort. Directional light sources, on the other hand, produce distinct shapes with clear boundaries. This results in harsh shadows, high contrast which increases the visual interest and stimulation [28].

The beam produced by directional light sources often creates pools of light on the wall. This is a way to add detail and interest to certain areas but they also come across as noisy and artificial. To avoid this, linear direct sources which follows lines in the architecture can be used. The beam from these sources will create an even glow. By using slots and washes this linear light can reminiscent natural daylight [28].

When planning the artificial lighting, calculation for the daylight distribution in the room has to be done, in this way it is possible to place the artificial lighting where it is needed. Lighting designers need to think about what type of light to use and which luminaire would spread the light in a desired way and at the same time minimize the loss of lumen [18].

To enhance the lighting experience in a room, a great amount of light has to reach the retina. When lighting up a surface, the chance to do so increases and it also minimizes the risk of glare. The surface that reflect the light is important since its properties, like color and reflectiveness, will influence the light [19].

The type of luminaire used will affect the light impact on a room, for instance, if you use a diffuse light source, almost half of the lumen will be lost [18]. But at the same time, you will get a big lighting area [1].

4 Target area and user needs

This chapter will describe the first part of the define phase, which narrows down the scope of the project by focusing on understanding the target market and collecting user needs. The process has been split into three parts for the report - selecting target area, identifying user needs and establishing product and light requirements. The actual chronological work process was iterative even if it is described as linear in this report.

4.1 Selecting target area and lighting layer

4.1.1 Selecting Target Area

The brief stated that the luminaire should be designed for an office environment, however to get an explicit picture of the requirements for the luminaire and the customer needs it had to fulfil, a more specific target area was selected. Even though the target area was narrowed down significantly, in the end, the new luminaire will be applicable to almost any area in commercial buildings.

4.1.1.1 Method

In the process of selecting a target area, plans of offices in different sizes were printed and reviewed, see Figure 4.1. The different kind of areas were color coded and their presumed characteristics discussed by using a pros and cons technique.

Figure 4.1 Plans of different offices.

When selecting which area to design for, the focus was on how the luminaire could give the highest experience for the observer, how it could reach as many employees as possible during the day, how frequent and long the interactions between user and product would be and how high the possibilities of implementing the luminaire in other areas were.

4.1.1.2 Result

The pros and cons for the alternative areas will be described, and at the end of this section the selected area will be presented. It should be noted that all the prospect areas below have no or little sunlight and are located far into the office building. It should also be clarified that the pros and cons were mainly based on discussions between the authors

Possible areas of an office

Deep office landscape

+ Reach out to a lot of people since almost everyone with a desk there will see the luminaire.
+ Give the employees extra energy where it is really needed.
- Hard to fulfill the lighting requirements for working areas since the light from the luminaire will not be static.
- There is usually sunlight in these areas due to workplace regulations, stating that daylight and a meaningful view should be provided to all workplaces [29].
- The variation in the light might be disturbing.

Conference room

+ Will reach a lot of employees if installed in this area.
+ The room has no windows which gives big vertical surfaces to illuminate.
+ The luminaire could be an object that increases the interest towards an otherwise unstimulating area.
+ The uniqueness of the light might be a good ice-breaker and a topic of conversation in the beginning of meetings.
- Maybe not seen as frequent as it would in the other areas of the office.
- Too much variation might distract important conversations.
- It is possible that the light has to be turned off during presentations.

Break room

+ Break rooms can be located deep in the office buildings since the light level requirements are usually not as high as for working areas [30].
+ The luminaire will reach all the employees and they will be there on their own initiative and almost whenever they feel like it.
+ The luminaire could increase the pause culture at the office, by inspire the staff to take a collective paus when the sun is shining.
+ Could work as a conversation starter and lead to creative conversation topics.

- Employers may not spend that much time per day in this area.
- A risk that the company cannot see the benefits in investing in this area since it might lead to people taking too long breaks.
- Employers might not go outside on the break.
- The environment in the break room feels good anyway since you have coffee and free time there.

Reception/lobby

+ First impression of the company and every employee passes it on their way to and from work.
+ It is a location where, the interior is often decorative and have items that describes the identity of the company.
- Only the receptionist stays in this area for a longer time.
- It could give the impressions to the employees that the resources of the company is used to impress guests instead of providing a better work environment at the office.

Corridors

+ Reach all the employees.
+ A lot of vertical surface to spread the light on, which would give a good perception over the room and set a mood [18].
- Time spent in this area is very short, and the sunlight might go to waste.

Selected Area

The part of the office selected to be the target area is the break room since it is one main meeting point at an office. The authors saw a great value in developing a luminaire that will benefit the employees by creating an energized and bright oasis in the middle of the office building.

4.1.2 Defining lighting layer

Working with lighting layers is an approach which many light designers use to get a good overview of the different lighting requirements in a room. By defining the lighting layer for the luminaire, the requirements of the light will become clearer.

4.1.2.1 Method

There are several, but similar, methods for the lighting layer technique, and the authors chose to work with the definition that Katarina Hennig described [18], see chapter 3.2.4.2.

4.1.2.2 Result

As stated in the brief, the developed luminaire in this project was only supposed to use sunlight as a light source, leading to a binary dynamic light which only provides light during clear sky. These product characteristics made the diffuse (ambient) layer unfitting, since the light might be unlit for quite long periods. The accent layer on the other hand, worked very well with the product brief. The purpose of this lighting layer is to light up vertical surfaces, normally walls, in a room. This leads to a brighter feeling for the observer due to the high amount of light that hits the retina. It also gives the sense of spatiality since it is easy for the observer to see where the room starts and ends [18].

The third layer in this method, the sparkling element, is used to set the mood and the theme of a room, making it interesting. Since the product was supposed to emphasize the feeling of sunlight and a sunlit room it was also decided to cover some parts of the sparkling element.

To summarize it, the luminaire developed in this project was chosen to mainly cover the accent element and light vertical surfaces, but also work as the sparkling element, to make the room more interesting.

4.2 Identifying user needs

This part includes steps utilized to get a better insight about the users in the target area. The goal here was to collect information about behaviors, wishes and needs connected to both light and the target area.

4.2.1 Exploratory light test

Even though the final concept in this project would not use artificial light it will still be similar to artificial luminaires in several ways, for example it would spread light from one single point without any visual connection to the outside and the sun. Since the goal was to develop a luminaire which communicate the feeling of sunlight to the observer, ideas regarding how to make artificial light look like sunlight were generated based on the background research.

To be able to estimate if these ideas on how to “fake” sunlight actually would work and which feelings and emotions could be connected to sunlight, a short test was performed.

4.2.1.1 Method

The test consisted of two parts, a pre-questionnaire and a short test session. The questionnaire took about five minutes to fill out, and contained questions regarding sunlight and emotions connected to sunlight. Finally there was a possibility to describe an artificial light source that the test person would say is most similar to sunlight.

The second part, the test session, lasted for approximately ten minutes and focused on the light shapes produces by artificial light. The test person was asked to describe the feelings connected to different light shapes, compare them to each other and describe which they felt looked most similar to sunlight.

The first step in this part was showing two identical lights A and B, first one where the test person could see the light source (A) and then one where it was hidden (B), see Figure 4.2. Then lighting both (A and B) and asking which alternative the test person thought was more similar to sunlight.

Figure 4.2 Light shape A, to the left, and B, to the right.

In the next step, two different light shapes from two identical hidden light sources, C and D, were shown to the participants, see Figure 4.3. First one at a time and afterwards both at the same time. The only difference between the alternatives was a silhouette creating a round shape (C) and a square shape (D).

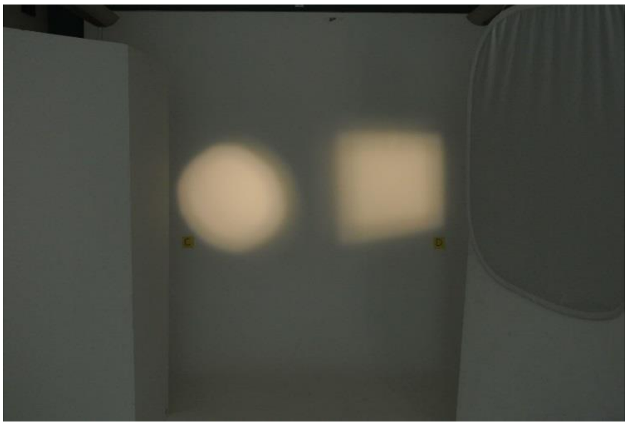

Figure 4.3 Light shape C, to the left, and D, to the right.

4.2.1.2 Result

Eight students from the program Mechanical Engineering with Industrial Design at Lund University volunteered to participate in the light test, all were between 24 and 27 years old and seven of them were men.

When asked which words they would describe sunlight with, six out of the eight participants said warm or heat and three of the participants said dazzling. Figure 4.4 illustrates the other words and how frequent they were mentioned.

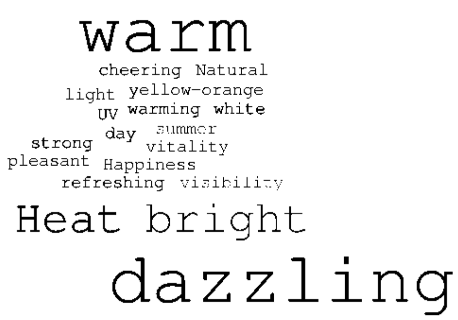

Figure 4.4 The words that the participants described sunlight with, the bigger word the more frequently mentioned.

When showing light A and B to the participants it resulted in different motivations, with no clear patterns between the answers. It was interesting that some participants claimed to associate sunlight with warm yellow light while some associated it with cooler white light. Figure 4.5 shows the set-up for light shapes A and B.

Figure 4.5 One participant describes light shapes A and B.

In the next part, showing light source C and D, a pattern between the answers could be seen. Three out of eight participants thought of the evening, dusk or moonlight when describing the emotions related to the round shape and five participants thought the square shape resembled light through a window. When asked which alternative they associated with sunlight three participants answered the round shape (C) since it is uniform with the sun. The remaining five participants claimed the square shape (D) felt more like sunlight since the shape resembled a window.

When showing all the lights (A, B, C and D) at the same time for the participants and asking which one, out of all of them, they thought resembled sunlight the most, four out of eight answered alternative B, where the lamp was hidden, with the motivation that the intensity and the color of the light were more similar to sunlight.

To summarize the results, they may give an indication that a square shaped light shapes resembles light passing through a window and a round light shape may be associated with the uniform sun. Also, the most important factor for faking sunlight might be to have the right intensity and color of the light.

4.2.1.3 Discussion

Several questions in the test and the pre-questionnaire did not lead to any conclusions, since there were no clear pattern between the participants' answers. Therefore only a few of the questions are presented in the result section above. For all the answers and questions see Appendix B

The results that are presented are still not applicable in a broader perspective since the test group consisted of a small number of participants and was extremely homogenous. Though, since the goal with the test was to see if some of the ideas regarding light shapes had any abutment, they gave a first indication that they might work when manipulating the light.

The test environment was not ideal, due to the lack of resources in this project, which may have affected the results. For example the light sources for alternative A and B were different from the ones used in C and D. If all the lights would have been identical, the result might have been different. But on the other hand, it indicated that the intensity and the color of the light makes a big difference for the observers' perception.

The order of the questions was the same for all of the participants, which led to the fact that light B always was seen in reference to light A, and D was always compared to C. If the order would have been reversed or altered for some participants, the results may have been different.

The fact that some participants associated yellow warm light with sunlight, even though sunlight usually is white, may be due to the fact that most of them described sunlight as warm and heat, and not due to the actual color of sunlight.

4.2.2 Questionnaires

According to Viveka Adelswärd, Professor Emeritus in Communication at Linköping University the common coffee breaks are important to a workplace. They encourage creativity and act as an opportunity to gain inspiration and exchange ideas with other colleagues [31].

Due to the decision that the luminaire should be primarily designed for break rooms in office environments, it was valuable to gain more information about break structure and culture in relation to the physical environment in break rooms from the specific target group. The goal was also to gather knowledge about preferences in light setting in break rooms. Another intention with the questionnaires was to get responses on two of the most promising ideas for the light shapes, generated early in the project. With questionnaires it is possible to gain answers to specific questions from a large amount of people, why this was the chosen method [17].

4.2.2.1 Method

Two questionnaires were designed and distributed, one to office workers at eleven different workplaces through e-mail with a short explanation about the project attached and the other through Facebook with no information regarding the project.

The first questionnaire was divided into three sections: background questions about work and work hours, more specific questions about breaks and preferences in break room layout and lastly the participants were asked to compare two different rendered pictures of light settings in a break room, see Figure 4.7.

The second questionnaire was divided in two sections: short demographic questions about age and work, and a question where the participants were asked to compare two rendered images with different light settings.

The second questionnaire was concluded to get a higher amount of participants to obtain a more valuable result. It also intended to compensate for the rendered images in the first questionnaire, as they were seen as too different to each other considering the total amount of light used.

Since no one is monitoring or assisting the respondent, the wording of the questionnaires is highly important, why the questionnaires went through a few pilot tests before launching.

The two questionnaires as a whole can be seen in Appendix C.

4.2.2.2 Results

The first questionnaire

Background information
This questionnaire got 53 responses (28 female, 25 male) and the majority (60 %) were between 35 and 54 years old. 37 respondents worked in private sector, whereof 22 were technical consultants or engineers. 96 % worked five days a week and 84 % reported to work eight to nine hours a day.

32 % worked in individual rooms, 38 % in an open landscape and 28% in a combination of the two. One of the participants worked in an activity based office environment. 43 of the respondents (82 %) spend 61 % or more of their working hours at the office.

Break culture and break room preferences
The layout of the break rooms in the offices varied. Out of the eleven offices six had regular windows in their break rooms, one had a skylight, one a glass door and three offices had break rooms with no windows.

Almost all of the respondents (94 %) took at least two breaks during one day and the majority (70 %) took three breaks. The breaks were spread out during the day and the average respondent took the first break around 9.00 am, which lasted 5-20 minutes. The second break, presumably lunch break, started around 11.00-12.00 am and lasted 20-60 minutes. Lastly the third break around 3.00 pm lasted for about 5-30 min.

43 % had scheduled work breaks, but one third replied that these times were not followed at their office. Out of the respondents who did not have scheduled breaks (57 %), one half replied to have mutual breaks nonetheless. All in all, 58% replied that there were mutual breaks at their office.

The most common reasons to take a break were: pause from work (85 %), social company (74 %) and a need for coffee (68 %). A change of environment (58 %) and discussing work related issues (53 %) were also common reasons for break.

The respondents were asked how many times they had spent a break outside during the month September 2014. 40 % replied that they had not spent any break outside, mostly due to lack of time. Out of the respondent that did go out, fresh air and sunlight were the most common answers.

The respondents were asked to describe a perfect break room to provide renewed energy. 38 of the respondents mentioned that light in some way to be important and 22 out of them especially mentioned daylight, windows or a view to be desired. Aside from light, moderate sound levels, comfortable furniture and that the break room should enhance social interactions were subjects raised amongst the respondents. Access to good coffee was also something some of the respondents mentioned. See Figure 4.6 for the words used, the bigger font, the more common word.

Figure 4.6 The words used to describe a perfect break room to provide new energy.

Light setting
When asked which of the two rooms, see Figure 4.7, the respondents would say were lit by daylight, 92 % chose option A. The reasons were the shape of the light, that it looked like light were coming through windows, that it was brighter and that a bigger surface were lit.

Option A was also most preferred to have as a break room (81 %). The most common argument was that it was perceived as lighter and the room felt more lit. It was also mentioned to feel more natural and lively. The respondents preferring B, perceived it to be more cozy, soft and harmonic.

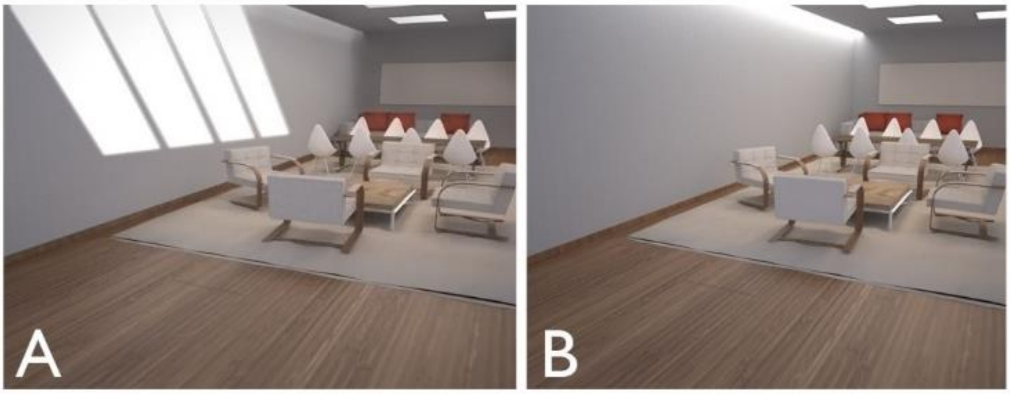

Figure 4.7 Renderings of two alternative light shapes, A and B.

The second questionnaire

The questionnaire got 84 responses (50 female, 33 male). 21 of the participants were under 25 years old and the majority (65 %) were between 25 and 34 years old. The majority (59 %) were working in the private sector. 17 % of the participants were students.

Between the two rooms, Figure 4.8, C and D, 61 %, chose room C when asked which room that most resembled a room lit by sunlight.

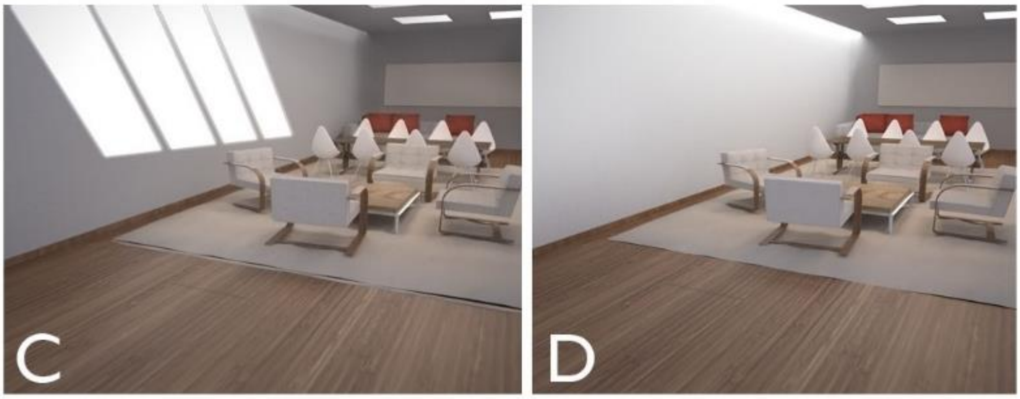

Figure 4.8 Renderings of two alternative light shapes, C and D.

4.2.2.3 Discussion

The first questionnaire

The age and gender distribution amongst the respondents was satisfying. The amount of participants was expected and sufficient: 68 persons clicked on the link and 53 fulfilled the questionnaire. Though, since the distribution was by direct channels, there was no possibility to know the exact number of received mails about the questionnaire.

The respondents worked at eleven different offices why no statistical conclusion could be drawn from the description of the offices, they rather gave a few examples, and an indication, for how different break rooms can look like. Out of the concerned offices, almost half, had break rooms which were windowless or had a limited amount of daylight.

Breaks are important, so the layout of the break room should be of high priority, but the study showed that there is a great difference in how much concern that has been taken in designing the break rooms [31].

The majority responded that they take breaks together, either scheduled or by habit. Social company was the most common reason, after pause, for breaks, and in the open commentary field about the dream break room, many of the respondents brought up the importance of furniture and layout to enhance social interactions.

Even though September 2014 was warmer and sunnier than usual with a mean temperature between 10 - 15°C at the offices locations, 40 % responded that they did not go outside for a break at all. The most common reason being a lack of time. Though the majority took breaks, the time to go outside of the office was not there [32].

Light was mentioned amongst 38 respondents when asked to describe their dream break room. This indicated that light and daylight are seen to be important, though the knowledge about the subject of the questionnaire, being lighting in break rooms, might have affected the result towards this direction.

The hypothesis before the questionnaire was that option A would be considered to feel the most like sunlight, which it significantly did. Though the participants were asked to only choose one option with no grading or semantic scales. Therefore the result can only determine that option A looked more like sunlight than option B, but not that it actually looked like sunlight.

Though, one indication that goes in the same direction as previous literature studies and interviews, were that lighting walls would increase the perceived amount of light. The respondents thought that option A gave a brighter feeling in the room, even though, the light actually spread out more in option B.

The second questionnaire

The design of the renderings in the first questionnaire aimed to use the same amount of light in both settings. However, it was not possible to quantify this, why this could be a plausible source of error in the results. The second questionnaire aimed to adjust the renderings so that they would correspond to equal amount of light. This gave a more even distribution of the results, however the left picture, were also in this case believed to look more like sunlight.

4.3 Establishing product and light requirements

This part will describe how the gathered information from the background chapter as well as the information about the target area and the users were processed using tools that aimed to help in the latter development process.

4.3.1 Officonas

Officonas, personas for an office, are fictional offices which are created to represent the different segments of the target market. The officonas consist of an image board and a short description about the imaginary company. The purpose is to quickly communicate the different types of styles, work conditions and employees that these offices have. The officonas were intended to help in the next coming steps in the design process by providing some insights about the target market needs.

4.3.1.1 Method

In this project three different officonas were created, and they describe three quite different types of offices. The offices for the officonas were chosen due to Parans' thoughts regarding their market segment. To get some brief knowledge and inspiration before creating these offices, some research was carried out, mostly by monitoring different companies' websites and statistics.

To get a common picture of the company values, photos were collected, discussed and finally a few made it to the image board. As for personas, a short describing text was written to get a clear character of the fictional offices.

4.3.1.2 Result

One big consulting firm, one small media bureau and one private dental clinic were chosen to represent Parans' target market.

The order in which the project focused on the different officonas was:

1. The big consulting firm
2. The dental clinic
3. The media bureau

The big consulting firm were chosen due to most potential and resemblance with Parans' target market.

The big consulting firm

WBCF is a well-known technology consulting firm focusing on building engineering, construction services and architecture. Since they have a stable economy, WBCF has the opportunity to invest in their employees' wellbeing by having a stimulating and creative work environment. Nevertheless, they still believe that it is important that the employees do not feel too comfortable, since they always should be alert and perform well while at work.

The office is located in a corporate headquarter outside Los Angeles, close to existing and potential clients. Consequently, the office environment is designed to impress on the big amount of guests that visits every day. The downside to have the office outside the city is the distance to lunch restaurants which results in the staff spending their entire day at the office building, with little or no environmental variation.

WBCF has about 300 employees at the Los Angeles office. Almost all of them have a Master of Science degree, which influences the distribution between male (70%) and female (30%) employees.

See Figure 4.9 for the image board to the officona.

Figure 4.9 Officona for the big consulting firm.

For the other two officonas, see Appendix D.

4.3.2 Moodboard

A moodboard is a type of image board illustrating the *values* and *the first sight emotions* of the product based on the target segment. A moodboard is a great tool to get the design team to agree on and communicate the aesthetic direction of the product [33].

4.3.2.1 Method

The method used for creating the moodboard in this project was inspired by Anders Ljungmarks lecture in Graphic Design and Typography at Malmö Högskola. The method forced a collective decision by the creation of a mind map together. The words in the mind map was generated by the word *consultant firm* and the consultant firm officona was used as inspiration. Out of all of the words, three were selected to best represent the officona. Then, pictures were individually collected based on the three words, resulting in about 100 pictures in total. The last step was to, by taking turns, remove one picture at the time, until there were only a few left. Now the moodboard was done and the decisions were actively made together [34].

4.3.2.2 Result

The words selected from the mind map, and which became the base for the moodboard were:

- Clean
- Color blocking
- Strict curves

105 pictures were generated and narrowed down to 22 pictures which described the mood wanted for the developed concept, see Figure 4.10.

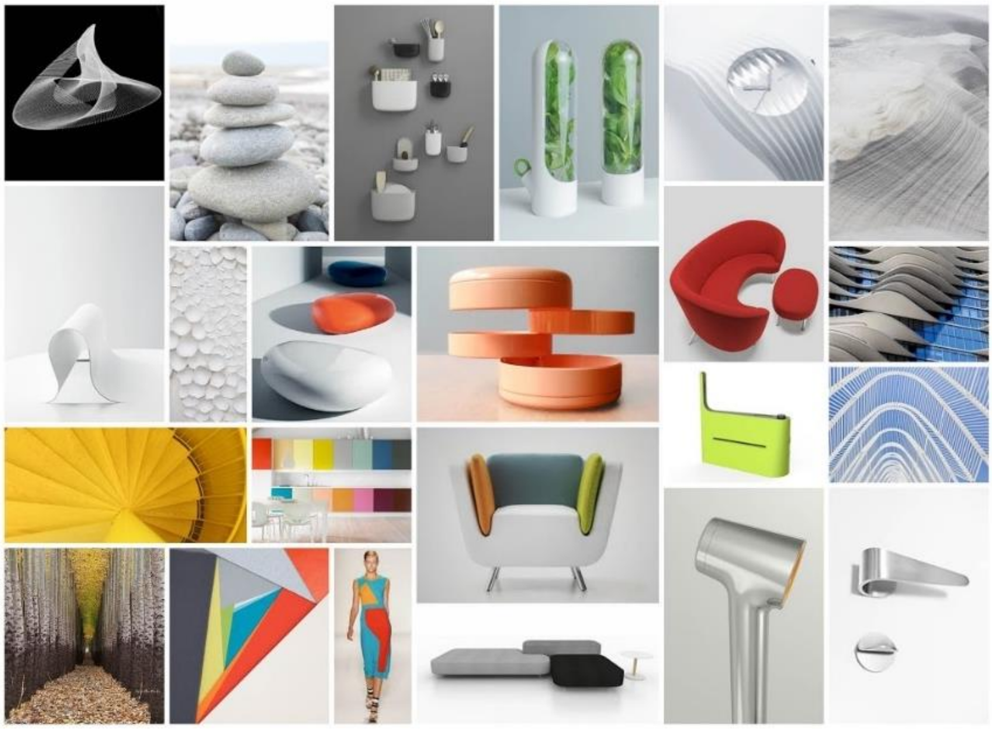

Figure 4.10 Moodboard.

4.3.3 Stakeholder Analysis

A rough stakeholder journey will lead to a greater understanding over the lifecycle of a product, which stakeholders that have the highest interest and power and what requirements there will be on the product in each stage, from decision making to recycling. A stakeholder analysis and journey will lead to greater insights when choosing between design concepts [33].

4.3.3.1 Method

The process towards creating a stakeholder analysis started with brainstorming to find out all stakeholders the product will have contact with. The list of stakeholders was then reduced to seven, based on how big their estimated interest would be regarding the luminaire. Afterwards the stakeholders were ranked and weighted considering their power and influence on the future product. To be able to develop a product with passion, the authors also ranked and weighted the stakeholders based on a user centered design perspective. After this step, a stakeholder journey started by brainstorming all the interactions that the seven selected stakeholders might have with the product and which needs they would lead to.

The stakeholder analysis were discussed and reviewed together with the supervisor and Parans since they have more insights about the stakeholders and could therefore increase the reliability of the analysis.

4.3.3.2 Result

All the stakeholders that were brainstormed and their connection to each other can be seen in Appendix E.

The seven stakeholders chosen to be used in the stakeholder analysis and the stakeholder journey were *manufacturer*, *landlord*, *architect*, *light designer*, *assembler*, *office workers*, and *installation/maintenance*. These stakeholders were all seen to have a high interest in the design of the luminaire but their demands are very different, which led to a broad range of requirements. Figure 4.11 shows the score and weighted score for each stakeholder. The given score considering the amount of power and influence represent 70 % of the total score while the user centered design perspective represent 30 % of the total score. The total score shows that the *light designer* became the most important stakeholder, followed by the *architect* and the *property owner*.

	Power & influence 70%		UCD 30%		Total score
	Score	Weight	Score	Weight	
Property Owner	5	3,5	2	0,6	4,1
Architect	5	3,5	3	0,9	4,4
Light designer	4	2,8	4	1,2	4,9
Manufacturing	3	2,1	5	1,5	3,6
Assembly	2	1,4	4	1,2	2,6
Installation/Maintenance	2	1,4	4	1,2	2,6
Office Workers	2	1,4	5	1,5	2,9

Figure 4.11 Result from scoring the importance of the stakeholders.

The stakeholder journey aimed to illustrate all the interactions between the product and the stakeholders. When brainstorming these interactions, and to ensure to cover all, three different scenarios for buying and installing the new luminaire, were considered.

- A new building, designed to use Parans’ system.
- Existing building, installing Parans’ system.
- Building with Parans’ systems installed, needing a new luminaire.

These scenarios only affected some stakeholders, such as the *light designer*, the *architect*, the *property owner*, the *installer* and the *office workers*. For the others, the interactions were seen to be independent from the scenarios.

4.4 Function analysis

A function analysis is a tool used for collecting product requirements and needs and thereafter list them as functions. It provides an easy way to apprehend an overview of all the needs and to ensure that all aspects are considered, and thereafter use them to choose between different concepts. A function is described by one verb and one noun, e.g., *minimize cost*. The value in having to describe every need with only two words is that it forces team members to truly understand and agree on what the need is [35].

4.4.1 Method

The method for concluding the function analysis was rather simple, yet time consuming. After gathering all the needs, they were listed as functions and when the list of functions was made, the functions importance to the product was ranked. One function was selected as the main function, some ranked as necessary functions and the rest as desirable functions.

4.4.2 Result

The chosen main function for this product was *distribute sunlight*. Some of the other functions will be described below, sorted by which part of the process they originates from. The functions mentioned are all ranked as necessary if nothing else is stated. For the entire function analysis and all the functions see Appendix E.

Brief

The functions from the brief are all the basic requirements of what the product has to fulfill. Some examples are that it has to *convey sunlight*, *fit office* and *provide indirect light*.

Background

The background research provided new knowledge which was transformed into functions. Lights effect on humans transcribes to *stimulate circadian system* and *avoid glare.* The theories of how to increase the lighting experience in a room were reformulated to functions like *illuminate vertical surfaces*. The information regarding optics led to the understanding of how to *minimize light loss* and how to *facilitate light modulation*. The last function refers to making it easy to modify and reform the light into desired spread and shape. The part with perhaps most importance to the design was the information concerning how sunlight behaves indoors and what we, as humans, perceive as natural light. This led to ideas on how to fulfil functions like *communicate sunlight* and *communicate naturalness*.

Selecting target area and lighting layer

Specifying the target area in the office did transform to desirable functions like *encourage pause*. This part of the process made it possible to select lighting layer for the luminaire, giving *fulfil accent layer* as a necessary function and *fulfill sparkling layer* as a desirable function.

Identifying user needs

The test and the questions gave insights regarding the users and provided functions like *maximize light intensity, increase sunlight intake* and *own room independence*.

Establishing product and light requirements

The officonas made it possible to describe the nature of the target market which refined to the functions *communicate drive* and *increase brand value.* The moodboard made some properties of the target market even clearer when addressing the aesthetics; *convey clean, convey color blocking* and *convey strict curves.*

The last part, the stakeholder analysis, was the source of functions concerning the property owner, the architect, the light designer, the manufacturer, the assembler, the installation, the maintenance and the office workers. Some functions originating from these stakeholders were *maximize lifespan, reduce hazards, allow standard tools* and *own beauty.*

5 Concept generation and selection

This chapter is mainly a product of the project's develop phase. Once again the aim was to open up the perspective in order to generate o broad range of ideas before choosing one. The process was divided into three sections: light shape design, optical design and aesthetic design. Although, the light shape design was considered as a part of the previous phase, the define phase, since it narrows down the scope of the project before focusing on the actual luminaire. In the end of this chapter all these three parts were then adjusted and finalized to one complete concept.

5.1 Method

The methods described below have been utilized in this, and the next chapter, in order to drive the design process forward.

Brainstorming
Brainstorming is a technique developed to generate a great number of ideas quickly, together within a team. There are some rules of brainstorming which should be applied in order to get a high and broad level of ideas. [36], [13].

The rules of brainstorming:

- Defer judgment
- Do not criticize
- One conversation at the time
- Go for quantity
- Have wild ideas
- Stay focused
- Be visual

Comparing notes
To get an overall picture of a large amount of information, a method called comparing notes can be used. The method is a technique for sorting and comparing information in order to facilitate a decision. The information treated by comparing notes can be everything from facts to ideas [13].

Sketching
Sketching, or fast visualization, is a way of illustrating ideas. The sketches are helpful when understanding, communicating and will stimulate new ideas [13]**.**

Prototyping
Prototyping is a way of communicating ideas and getting them out of your head by building physical objects. They can be created with everything from paper to molded plastic. Prototypes can be used for testing, exploring or just to get a deeper understanding of functions and shapes [36].

Testing
Tests can be performed in every stage of the design process, mainly to evaluate a concept or to getting to know your users [36].

Concept scoring
Concept scoring is an evaluation process which takes the customer needs and product requirements into consideration. When using this method the different concepts are evaluated against a handful criteria and then compared to each other. The criteria are weighted according to relevance for the product. A matrix is used to compare the concepts' scores for each criterion and to sum the total score. In the end it is easy to see how well the different concepts performed and for the team to discuss the results and agree upon which concept to select for further development [16].

5.2 Light shape design

A light shape, the shape of the light projected onto a surface, is essential for the expression of the room and is a necessary part in the interior to make a space interesting [28]. By selecting the light shape, before designing the luminaire, the process became more comprehensible and the continuing part of the project could focus on the actual luminaire and how to create the desired light shape.

5.2.1 Generating ideas

To generate ideas, brainstorming sessions were conducted. These sessions were conducted early on in the process when the division between the different parts of the concept was not set, why ideas on both light shapes, luminaires and overall concepts were generated.

To receive input and inspiration a brainstorming workshop was carried out. Three students, in excess of the authors, from different faculties at Lund University were invited and participated.

As mentioned above, focus shifted from more general ideas to more specific ideas regarding light shapes. Besides sketching, this process consisted of collecting images and light experiments with different patterns and objects that manipulated the light.

5.2.2 Selecting light shape

Nine groups of light shapes were collected from the generated ideas, see Figure 5.1

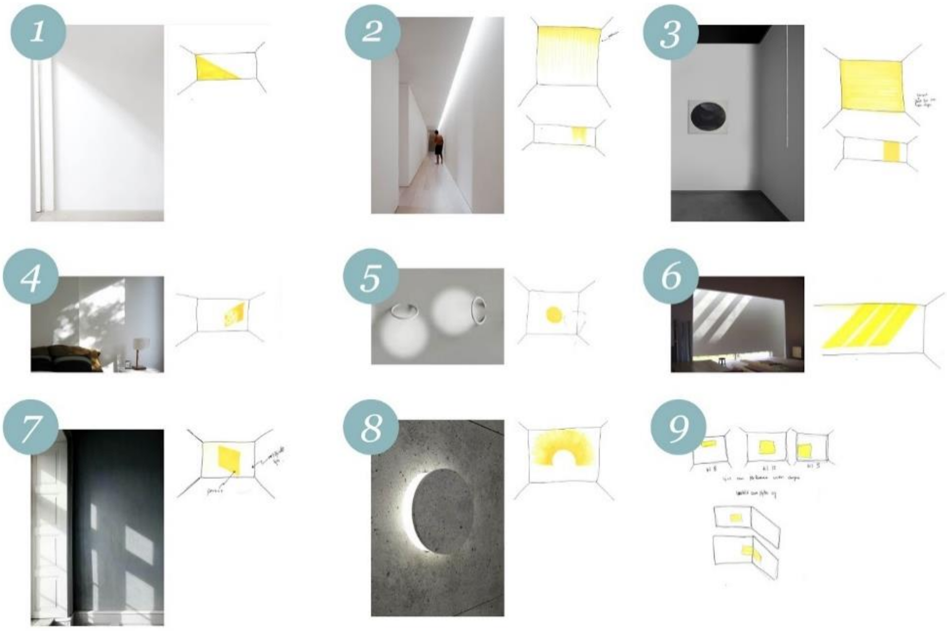

Figure 5.1 The nine different groups of light shapes.

1. Triangular light shapes
2. Gradient light shapes
3. Homogenous planes of light
4. Window shaped light with noise
5. Circular shaped light
6. Skylight shaped light
7. Window shaped light
8. Gradient light from a circle shaped source
9. Dynamic light shape

The function analysis was used to be able to consider the different needs from Parans, the possible clients, the user segment and the stakeholders. Out of all of the necessary functions in the function analysis, 18 were seen as applicable to the light shape design, and the alternative light shapes were scored based on how many of these functions they fulfilled.

Only the *skylight shaped light*, alternative no. 6, fulfilled all of these functions, and were therefore selected as the primary design for the project.It received high scores since it resembles sunlight and could work well as an energy providing stimuli in break rooms. Both the *window shaped light*, no. 7, and the *homogenous planes of light*, no. 3, fulfilled 14 of the 18 functions and got ranked as the second best alternatives. Developing a solution for the *window shaped light* was seen to be superfluous since if a solution was found for *skylight shaped light*, this would work for both. Hence, the continuous work was focusing on the *skylight shaped light*, though a solution which also is able to create the *homogenous planes of light* was strived for as well, see Figure 5.2 and Figure 5.3. This decision was also based on the results from the questionnaires conducted previously.

Figure 5.2 The primary light shape chosen for continuous development.

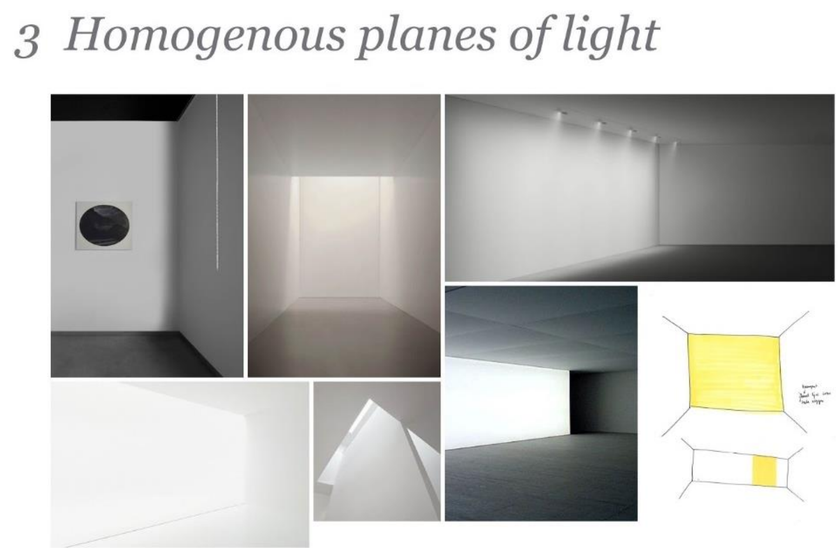

Figure 5.3 The secondary light shape chosen for continuous development.

5.3 Optical design concept

After the desired light shapes were selected, technical solutions on how to create the light shapes, had to be developed. This part includes the optics that transform the light from the fiber to the desired light shape on the wall.

5.3.1 Second research

5.3.1.1 Lenses

Lenses are a light controlling element frequently used in optical devises. A lens is a piece of transparent material where the surfaces are spherically shaped. The incident light ray refracts at the first boundary, continues through the lens and refracts once again, when passing through the second boundary, on its way out of the material [37].

The lenses used in this project were convergent, also called positive lenses. These type of lenses cause parallel rays passing through to converge towards one point, called the focal point, *F*, see Figure 5.4 [37].

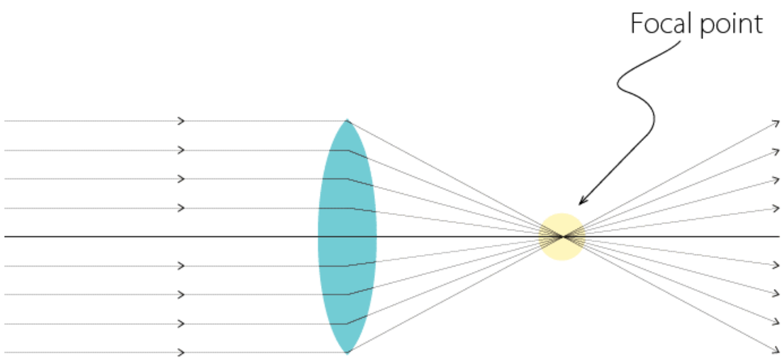

Figure 5.4 Illustration of a convergent lens.

The image produced by a convergent lens can be determined if the height of the object, *h*, the focal length, *f*, and the distance between the object and the lens, *p*, are set, see Figure 5.5. The equations

$$\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$$

and

$$\frac{h'}{h}=-\frac{q}{p}$$

are useful for calculating the distance to, q, and the height, h', of the image produced by a thin convergent lens [37].

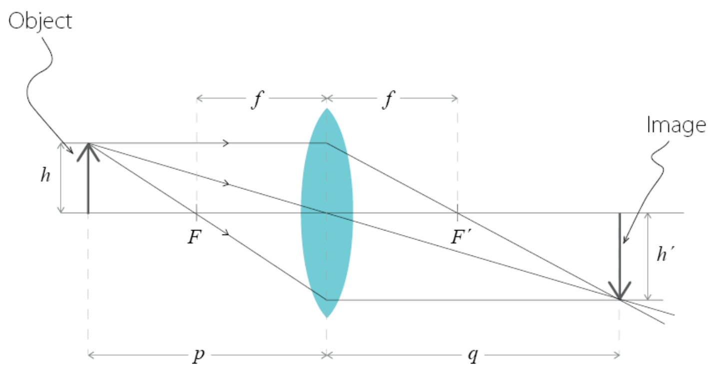

Figure 5.5 Defining quantities for image formation with a thin, convergent lens.

5.3.1.2 Light guide

Light guides are optical elements used to transport light from a source with minimal losses, due to internal reflection, see chapter 3.2.1.1. Material often used for light guides are polycarbonate, epoxies, acrylic resin and glass [38]. See Figure 5.6 for an example on how light rays can travel through a light guide.

Light guides are for instance used in LCD screens, where the light source is attached to the edges of the screen and spread to an even image by the light guide [38].

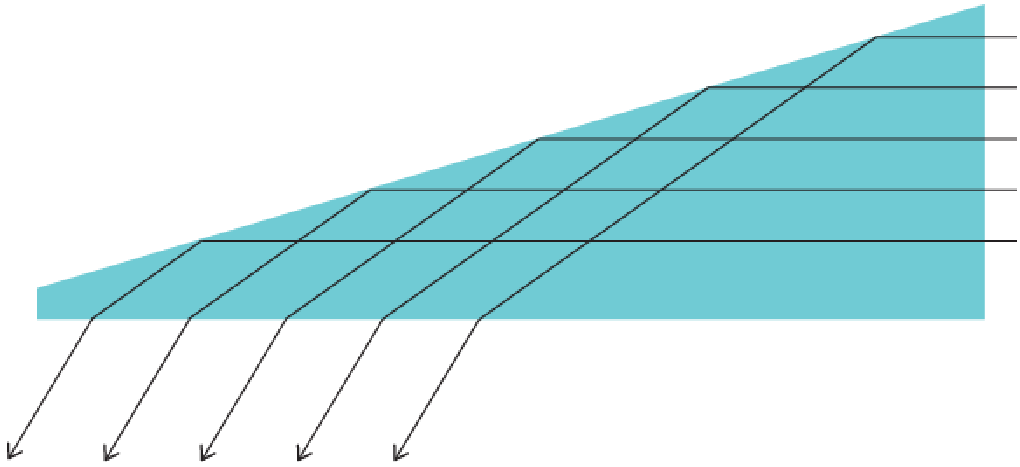

Figure 5.6 Light guide.

5.3.1.3 Prisms

Another optical element is the prism, often used to redirect the light. The refraction in a prism can be understood by Snell's law, see chapter 3.2.1.1. The ray of light enters the prism at one angle, and either refracts or reflects at the boundaries, and the exiting ray has then deviated from the original direction, see Figure 5.7. How the light behaves when hitting the boundaries depends on the angle of the incident ray and the material of the mediums [37].

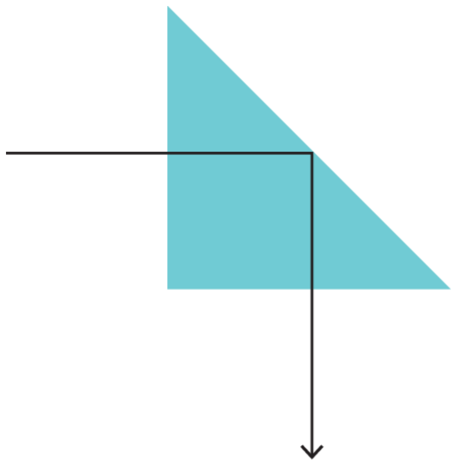

Figure 5.7 Prism.

5.3.2 Generating optical design concepts

To get inspiration for the optical concept products using optical elements were studied. The idea was that some of the techniques found could be applied and used in this project.

As described above, see chapter 5.3.1.2, light guides are used in LCD-screens to spread the light from a thin slot to the wider screen. Since the aim of this project was to spread light from a point source to a linear source, this technique was found interesting.

Theatre lighting is often used to create dramatic effects but also simulating natural sunlight, which are two qualities of similar character as for the chosen light shape design. Theatre lighting uses lenses, see chapter 5.3.1.1, to change focus and scale of the light shape. Patterns can also be used to change the shape of the light.

In both cameras and overhead projectors, mirrors are used to angle the light. This can be beneficial when there is limited space, such as the space above the inner ceiling where the luminaire is presumably to be placed.

With inspiration from above described techniques concepts were generated through sketching and prototyping. Ray Optics Simulation, was used to quickly be able to see how light was influenced by mirrors, lenses and refracting materials [39]. Since light spreads in a three-dimensional space it was difficult to visualize on paper or in the two-dimensional ray tracing program, why the concept generating mostly took part by prototyping so that the output could be seen and tested right away.

The concepts were generated focusing on the skylight light shape. Due to the input from Parans, ideas that also would be able to create homogeneous planes of light were considered.

Out of the many concepts that were generated, five were chosen to be most promising and therefore selected to be tested more thoroughly. The five concepts are described below:

Light guide

The light guide consists of a sheet of PMMA cut so that the light reflects internally and then down on the wall, see Figure 5.8 for a sketch and Figure 5.9 for the prototype.

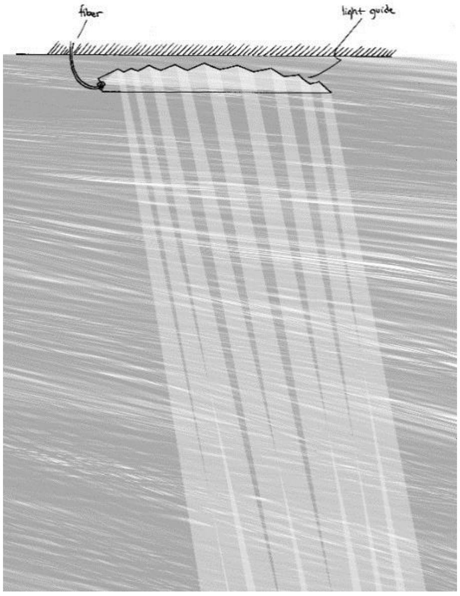

Figure 5.8 *Lightguide* concept.

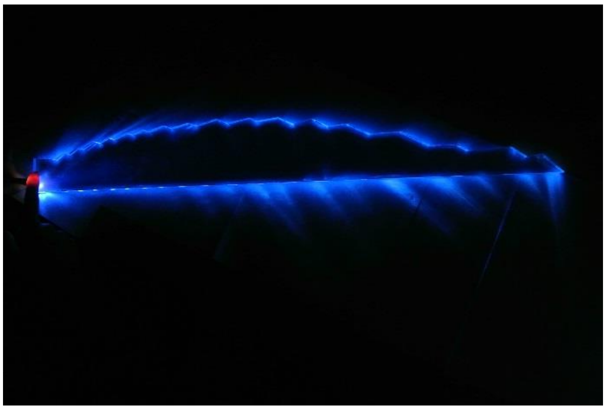

Figure 5.9 *Lightguide* concept prototype.

Theatre

This concept uses two lenses to enlarge and focus the light shape on the wall. After the first lens, a pattern can be attached to create the desired shape. The construction is directed towards the wall, with a slight angle to assure that the light goes as far down as possible, still having the top of the light shape at the edge between the ceiling and the wall, see Figure 5.10 for a sketch and Figure 5.11 for the prototype.

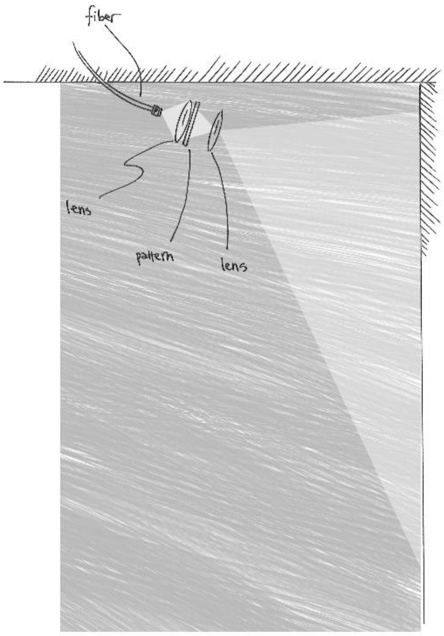

Figure 5.10 *Theatre* concept.

Figure 5.11 *Theatre* concept prototype.

Overhead projector
Since the developed product preferably should be able to be installed near the wall, this concept uses a mirror to lengthen the distance the light travels between the light source and the wall. The light source is facing outwards the wall and the light passes through two lenses and an angled mirror which directs the light towards the wall. As in the previous concept, a pattern can be attached after the first lens, see Figure 5.12 for a sketch and Figure 5.13 for the prototype.

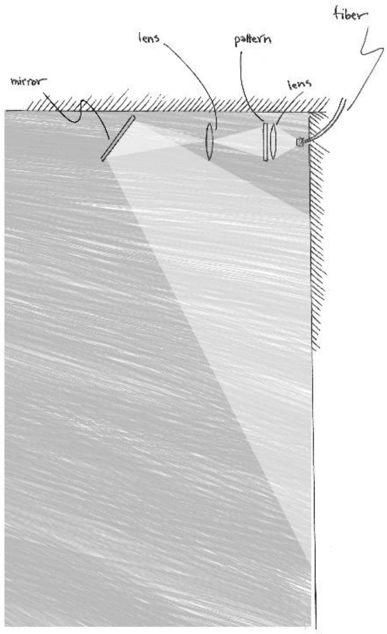

Figure 5.12 *Overhead projector* concept.

Figure 5.13 *Overhead projector* concept prototype.

Adding a prism sheet
Two more concepts were created by attaching a prism sheet, see Figure 5.14 and Figure 5.15, after the second lens in the concepts *Theatre* and *Overhead projector*. The prism angles the light further and also has the benefit of spreading it more in one direction, so that a square shape would be transformed to a rectangular shape, see Figure 5.16. This has the benefit that less light needs to be cut away by the pattern since the desirable light shape is of a more rectangular character.

Figure 5.14 Prism sheet close-up [40].

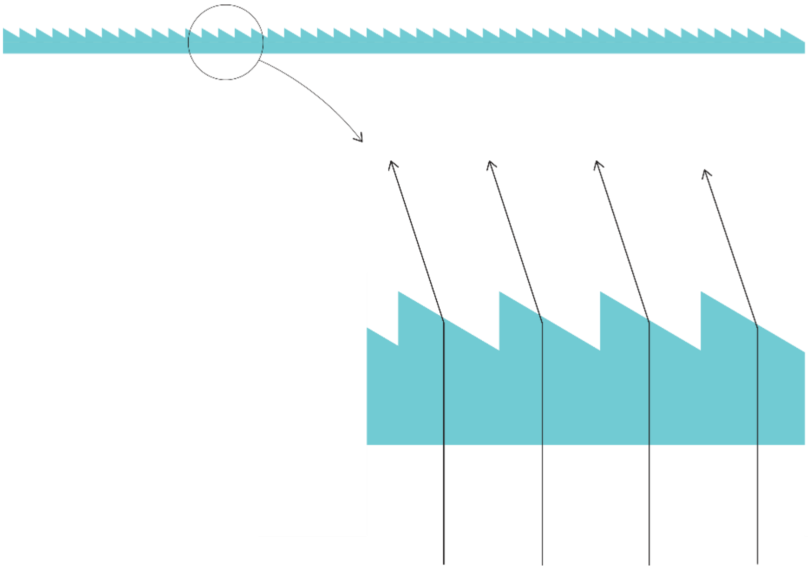

Figure 5.15 The prism sheet consists of many small prisms

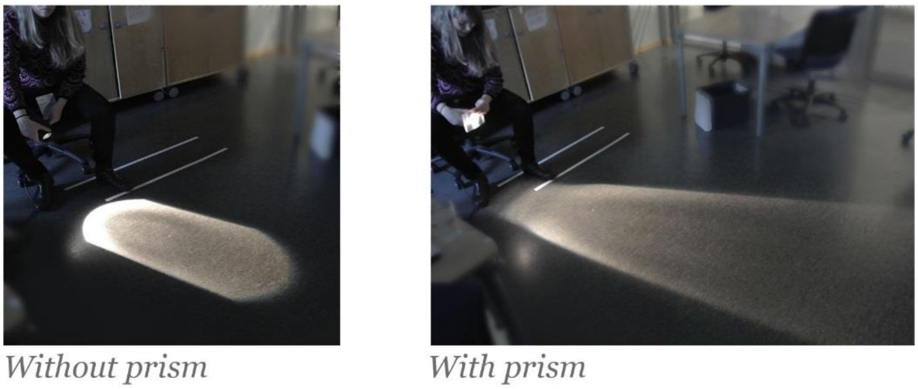

Figure 5.16 Comparison of light shade without and with the prism sheet.

This led to two additional concepts:
Theatre with prism, see Figure 5.17, and *overhead projector with prism,* see Figure 5.18.

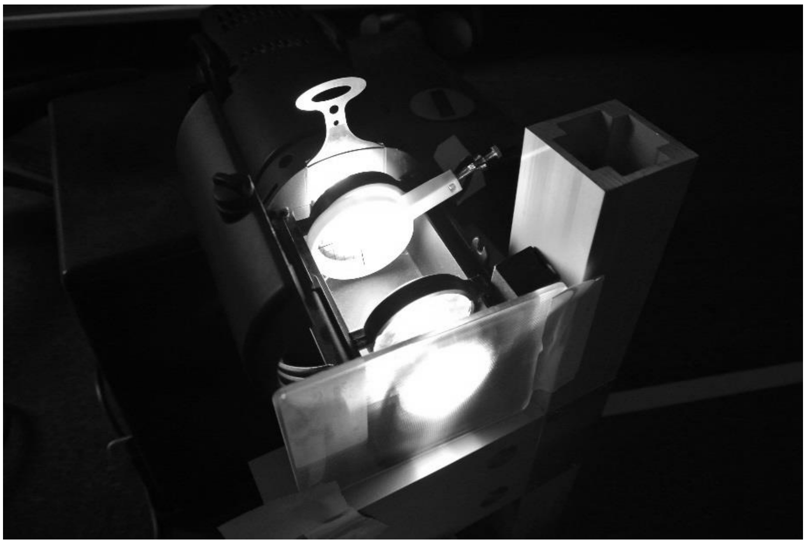

Figure 5.17 Prototype of *theatre with prism* concept.

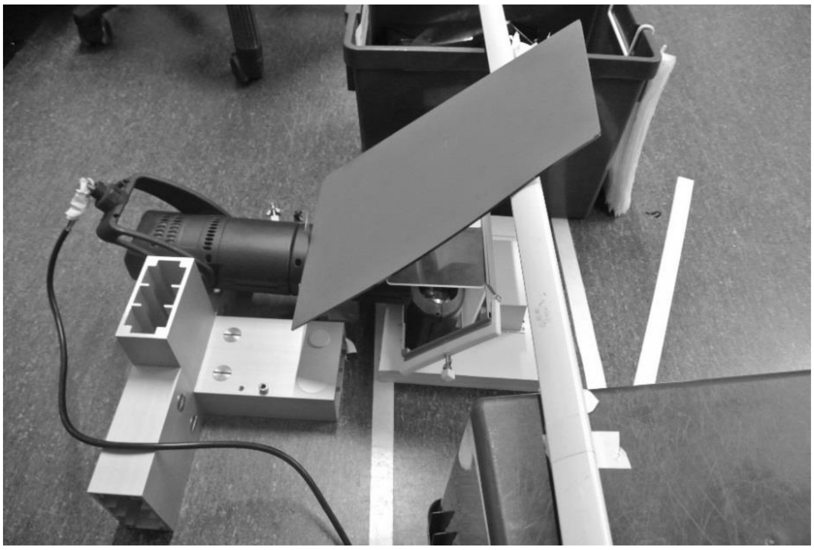

Figure 5.18 *Overhead with prism* prototype.

5.3.3 Selecting optical design concept

Concept scoring was the applied method for evaluating the optical concepts. The criteria chosen for the concept scoring matrix are listed and their relevance for the different stakeholders, see chapter 4.3.3, is described below.

Size is relevant for nearly every stakeholder.

Height affects the distance from the roof to the bottom of the luminaire and will have an impact on how the luminaire will appear in the visual space. This criteria is especially important if the customer uses dropped ceilings, since it leads to stricter space limitations.

Complexity (standard components, adjustments needed, amount of components) also affects almost all stakeholders. But more importantly it affects the efficiency of the luminaire, since every time light travels from air to glass or vice versa there is a light loss of approximately 4% [22].

Light performance (intensity, light shape, homogeneity, risk of glare) is the most important criteria hence the light has to be controlled and manipulated in to the selected light shape. The intensity and homogeneity of the light is important as well since these factors are highly important for the perception of the light shape.

Development progress refers to the further workload needed when continuing to develop the product.

To be able to rank the concepts against each other some tests and calculations had to be done. The aim with the tests was to distinguish the different concepts' light performance. This was done by lighting a surface in a dark room. By using a photometer, data for lux-levels for different spots on the lit surface were collected, see Figure 5.19. Additional to the measurements, photos were taken to see how big and even the lit surface were. This test gave a hint of how the light spread and how the intensity differed over the surface.

Figure 5.19 Testing the lux-levels with a photometer.

Besides light measurements, approximate values on how much space each concept would need and the height it would require were estimated.

When translating the values from the tests and the calculations to scores in the concept scoring matrix, see Appendix G, the concept *Theatre with prism,* see Figure 5.20, proved to be the best since it had high scores in almost every criteria. The concept was considered straight forward and gave a promising light shape to develop further.

Besides the described concepts, an additional concept was developed by exploration with the prism sheet. The idea was that with the use of only the prism, the light shape *homogenous planes of light* could be created. Though, some further testing had to be done to ensure the functionality of the concept. The hope was that the concept could be developed parallel or be combined with *Theatre with prism*, why it was decided to continue also with this concept in the following stages of the development.

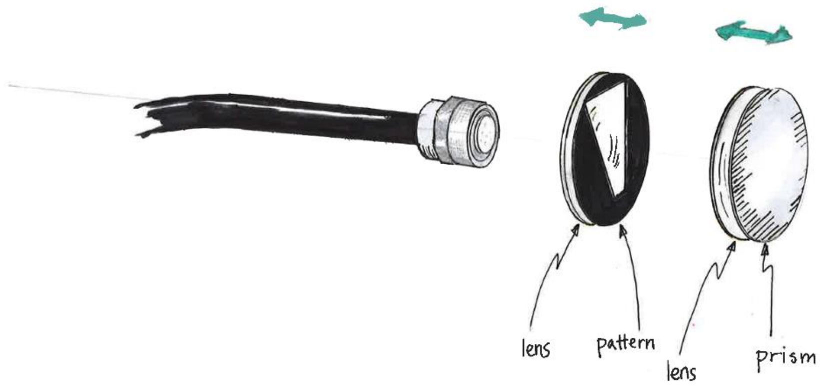

Figure 5.20 Chosen optical design concept.

5.4 Aesthetic design concept

When the optical design concept was chosen, focus shifted to the aesthetic design concept which includes the visual parts of the design and the attachment to the ceiling.

5.4.1 Generating aesthetic design concepts

Some ideas for the aesthetical design of the luminaire had already been developed spontaneously during the project. To gain a broader range of ideas a brainstorming session was performed, with the goal to generate at least fifty new ideas. The inspiration for this session were the moodboard, the officonas and the requirements from the function analysis.

The fifty new ideas and ideas from previous idea generation sessions were sorted and organized in eight different groups based on their basic shape and function, see Appendix H.

To ensure that as many ideas as possible were thought of, additional brainstorming around the different groups was carried out. The ideas were then ranked within the groups and seven concepts were chosen for further evaluation.

5.4.2 Selecting aesthetic design concept

Rapid prototypes, using clay, cardboard and paper, of the seven concepts were prepared to facilitate the evaluation, see Figure 5.21.

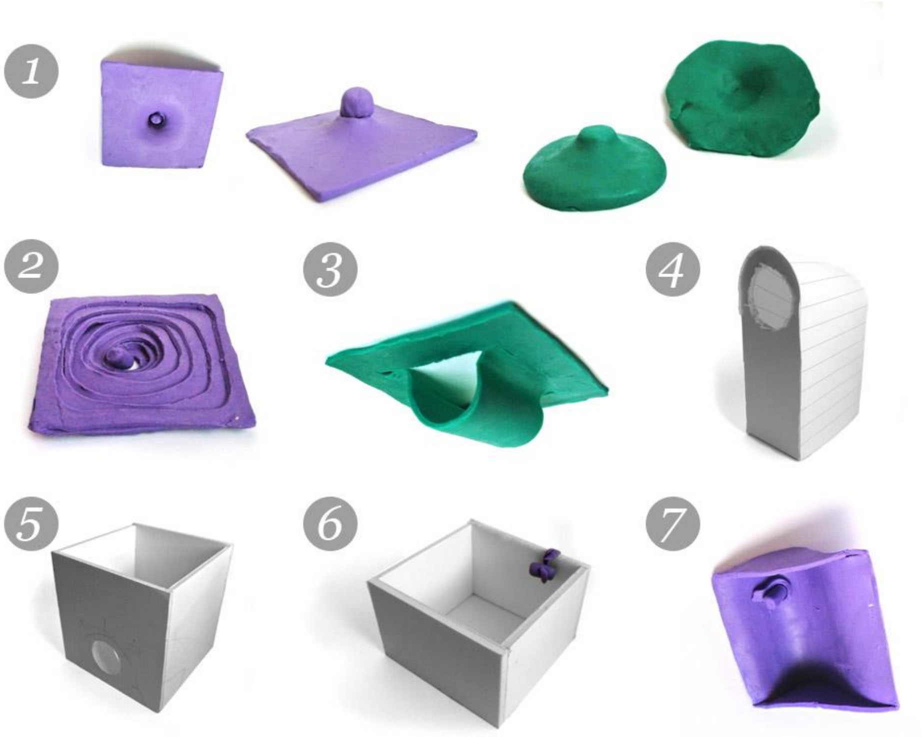

Figure 5.21 Rapid prototypes over the aesthetic concepts

1. Architectural spot
2. Inversed mountain
3. Bended slice of sheet
4. Small geometric slope
5. Small cube
6. Window imitation
7. Mounded sheet

The prototyping showed that two of the concepts, *Small geometric slope* and *Bended slice of sheet*, did not work. The other five concepts were evaluated by concept scoring. By analyzing and discussing the concept scoring matrix, see Appendix I, two of the concepts, *Mounded sheet* and *Window imitation* were seen so similar that they were merged into one with the name *Window imitation*. *Inversed Mountain* were seen too complicated in its expression to further develop. The three concepts, *Small cube*, *Architectural spot* and *Window imitation* were chosen to further discuss with Parans, see Figure 5.22, Figure 5.23 and Figure 5.24

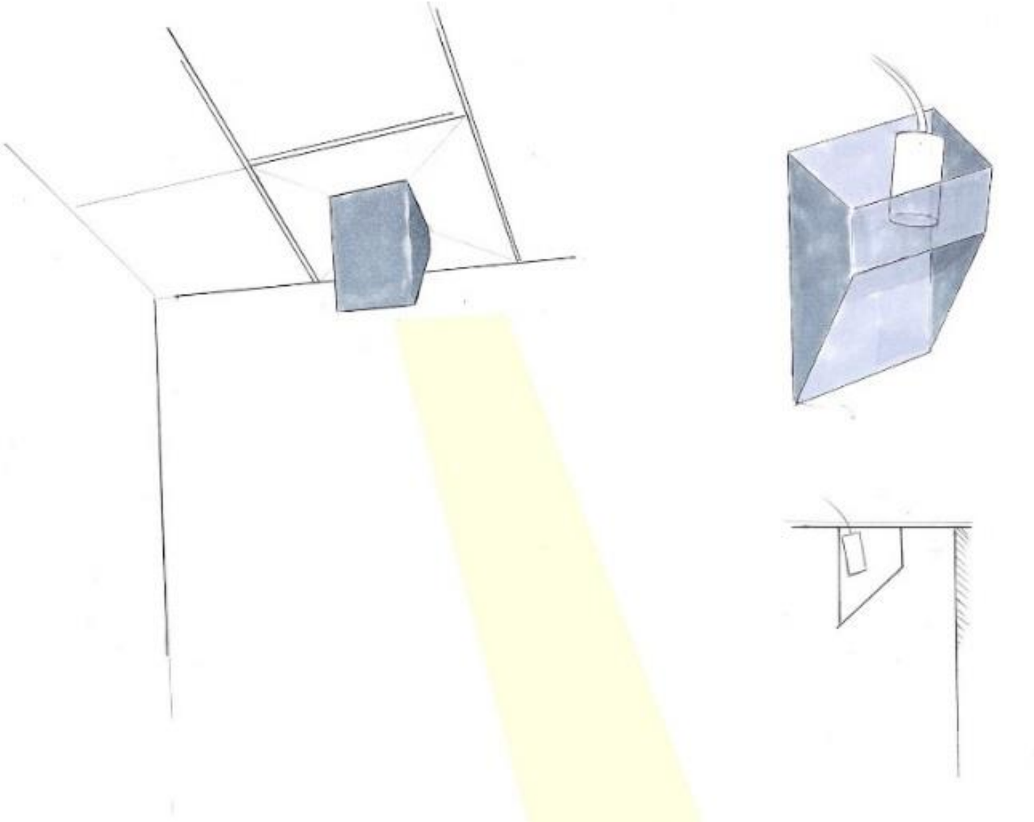

Figure 5.22 Small cube concept, adjusted to hide the light source.

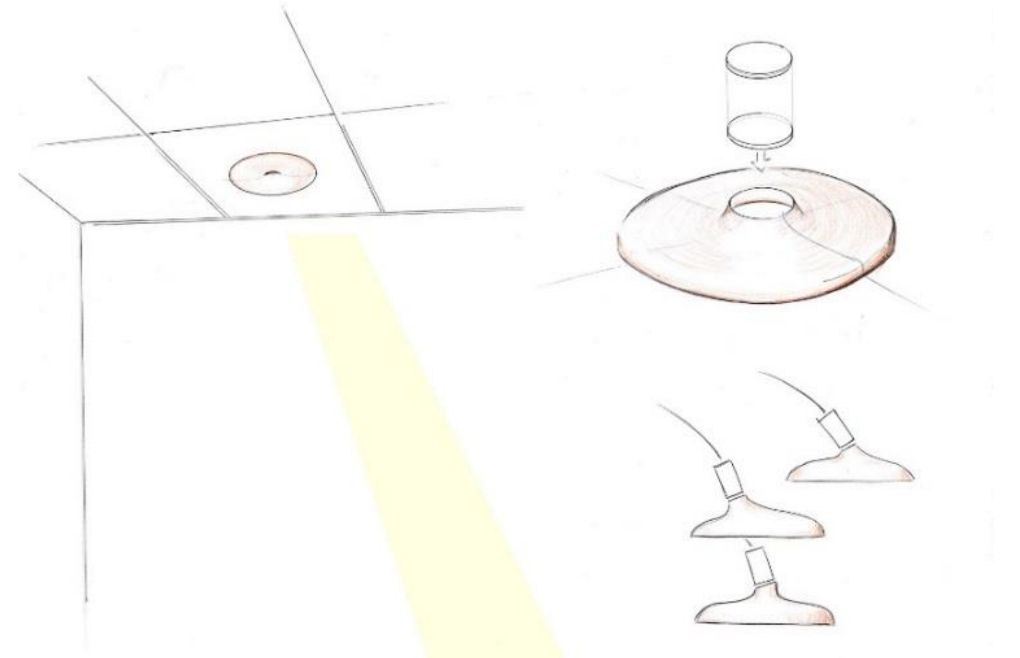

Figure 5.23 Architectural spot concept.

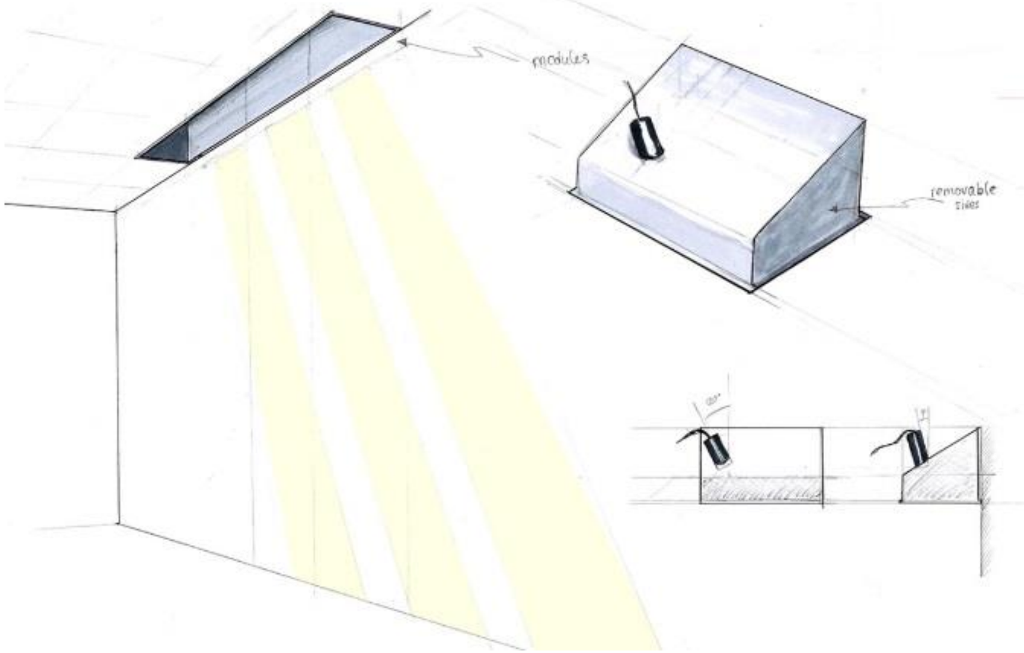

Figure 5.24 Window imitation concept.

From the discussions it was decided to further develop the *Window imitation* concept since it was the one that best corresponded to the chosen light shape. Besides the shade, a light module that could fit the shade, work well alone or be mounted directly on the dropped ceiling was chosen to be developed. This left the opportunity to develop the disregarded or other shades to fit with the light module in the future.

5.5 Result – selected concept

The overall chosen concept, see Figure 5.24, is described below:

The output is a skylight light shape to resemble the light through windows. The light is created by an optic construction made of two lenses, one sheet prism, and a pattern to be able to get the desired shape. The lenses and the pattern is removable to be able to create a homogenous plane of light if desired, by only using the prism.

The optics are contained within a small light module which can be attached on different shades or simply be attached in a hole in a dropped ceiling tile. In cases where there are no inner ceiling the light module could simply be attached to a beam or similar. This project will focus on the *Window imitation* shade since it corresponds best to the function analysis. This shade will hide the light module by having it fixated at a distance higher than the dropped ceiling. The aim is that the top part of the shade will not be visible when looking at the shade from a distance in the room, creating an illusion that there is an opening in the ceiling where sunlight is shining through. Also, since the light only will be “on” when the sun is shining, this discrete solution will almost be invisible when there is no light. Through inspiration from discarded concepts it was decided that the shade should be modular, making it possible to connect a few of them to create a wider shade, mimicking a long light shaft.

6 Concept development

This chapter is the first part of the projects deliver phase, with the goal to finalize the project. This chapter describes the detailed development of the luminaire, starting with a description of all the new requirements for the design, regarding the selected optical concept. The requirements will be followed by the development of the light module and of the shade.

6.1 Specifying requirements

In addition to previously established requirements, see chapter 4.4.2, some additional technical requirements were defined regarding the selected concept from the previous chapter. Furthermore some of the requirements from the function analysis, see chapter 4.4.2, were highlighted as critical criteria for selecting between the ideas for the detailed construction.

6.1.1 Technical requirements

The restrictions for the design of the light module were based on the need of projecting the selected light shape on to a wall, see chapter 5.2.2. The technical requirements of the light module were generated through a test with a prototype of the light module, see Figure 6.1, and calculations.

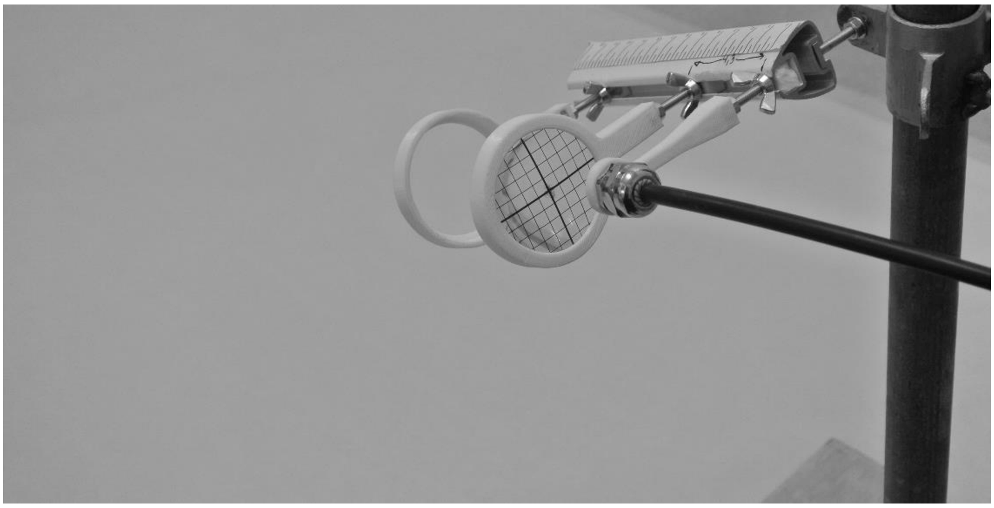

Figure 6.1 Prototype of the light module.

6.1.1.1 Standard requirements

By reviewing images of skylight shaped light created by real skylights, it was decided that the light shape produced by the luminaire should be 500 mm broad at the top and reach from the top to the bottom on a wall with a height of 2700 mm, projected at an angle of 25°. The test showed that the distance between the luminaire and the wall should be 500 mm. The prism used for this luminaire is angling the light in 20° towards the wall and requires the light module to be constantly parallel to the wall, ergo it cannot rotate around its own axis. See Figure 6.2 for illustrations over these requirements.

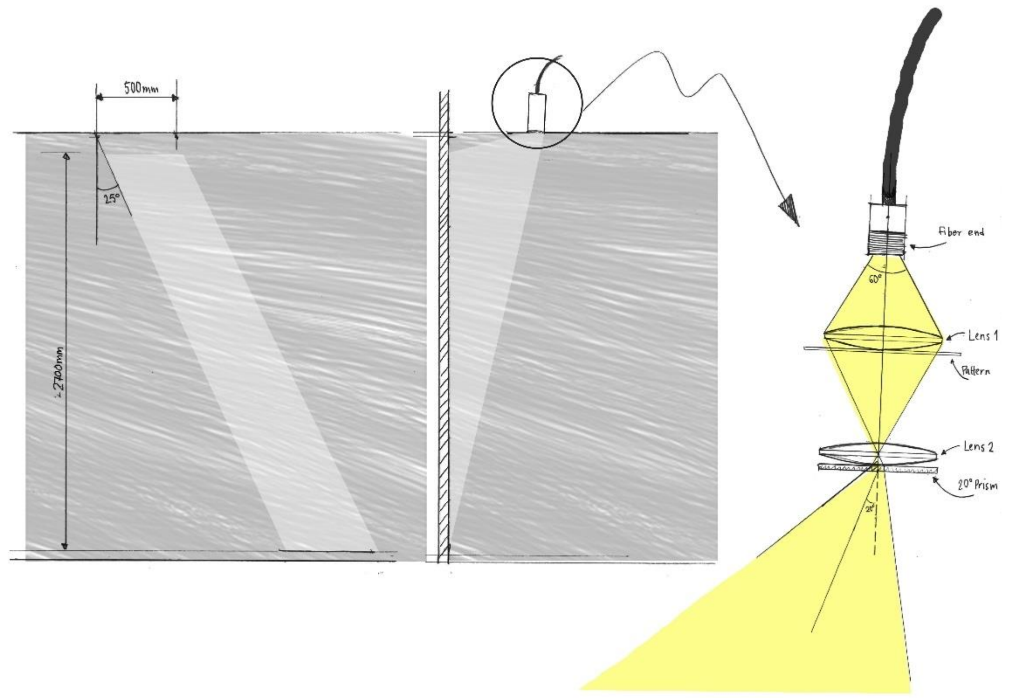

Figure 6.2 Desired light shape and up-scaled light module.

These settings leave three parameters to vary in order to get the desired light shape; the focus length of the lenses, the distance between the two lenses and the angle normal to the wall.

The focus length of the first lens only affects the distance between the light source, the end of the optic fiber, and the first lens, while the second lens affects how the light spreads and therefore also the focus point and the size of the enlightened area on the wall. This made it possible to use lenses with the same focus length, where the selection was based on the light spread. See Figure 6.3 for how the light is affected by the optical components.

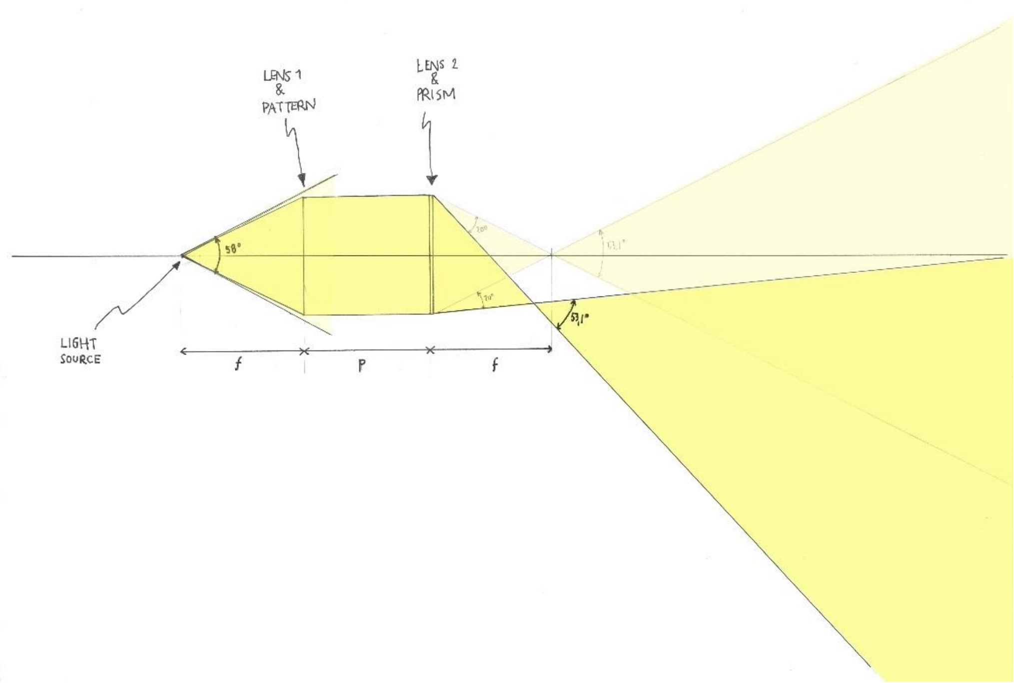

Figure 6.3 Optic illustrations of the light module.

Simple calculations with the desired size of the light shape as a base showed that the focus length of the lenses should be approximately 50 mm, which was confirmed while testing different lenses with the prototype. Lenses with higher focus length gave a spread which was too narrow and the opposite for the lenses with lower focus length. By choosing a lens with the focus length of 50 mm the distance between the light source and the first lens could be determined to 50 mm and the distance between the lenses, *p*, to 51.4 mm. These distances were confirmed with the test. When selecting the diameter of the lenses, the aim was to use a standard lens in order to minimize the costs. This aim led to the selection of a lens with a diameter of 50 mm, the downside is that this leads to a minor loss of light since only a 53° light beam can be collected by the first lens, instead of the entire 58° beam from the light source. It was concluded that this loss was negligible, both since the beam from the fiber optics is more concentrated in the middle and that the loss is minimal in comparison with the loss when shaping the light with the pattern.

When testing the prototype with these settings for the lenses and distances, the approximate angle of the light module in direction normal to the wall was only 2°, ergo almost vertical.

To create the light shape it was decided to include a pattern in the light module, often called a Gobo when used in theatre lighting. To facilitate for the customer to change this pattern a standard Gobo, metal size M, will be used. The M sized Gobo has an outer diameter of 66 mm, an image diameter of 49.5 mm and the thickness of maximum one millimeter [41]. The established requirements stated that the Gobo should be changeable and rotational, since precision adjustments, after the light module is installed, might be needed to receive the desired light shape.

The goal was to develop a luminaire which both can project a sharp light shape, for the *skylight shaped light* as well as a wall washing effect, the *homogenous planes of light*, see chapter 5.2.2. The test showed that this can be accomplished, with satisfying result, if the prism is installed directly after the light source, see Figure 6.4. Therefore it was desirable to construct the light module in a way that makes it possible to remove the two lenses and the gobo-pattern and only use the prism. The distance between the light source and the prism should be no longer than 37 mm in order to maximize the spread without losing any light.

Figure 6.4 Testing the wall washing effect when using only the prism.

As mentioned in the brief, see chapter 1.3, the light module needs to fit both Parans' systems, SP3 and SP4, hence the light module need to fit the fiber attachment desiged by Parans, see Figure 6.5. These systems will have the same design for the ends of the optic fiber cables, The only difference between the systems that affects the luminaire will therefore be the amount of light provided by each cable.

Figure 6.5 Parans’ cables with optic fiber, and the design of the end attachment.

It was decided to not change the color of the light output from Parans’ system even though the exploratory test, see chapter 4.2.1, showed that some of the participants associated sunlight with warm and yellow light. By not changing the color all the natural qualities of the full spectrum sunlight will be preserved.

6.1.1.2 Enabling variations in room layouts

The previously established settings of the luminaire are static but the aim was to design a luminaire that fits different ceiling heights and rooms with or without a second ceiling. The standards for office ceiling heights in Europe are 2.8 m [42] and the American standards are 2.7 m for offices bigger than 14 m^2 and 2.3 m for office spaces smaller than 14 m^2 [43]. There are also standards for dropped ceilings. In Europe the standard size of the grid is 600×600 mm or 600×1200 mm while the grid standard size in the United States is 2×2 ft (609.6×609.6 mm) or 2×4 ft (609.6×1,219.2 mm) [10]. The standard thicknesses of the dropped ceiling tiles, in both United States and Europe, are 15 mm and 20 mm, even though there are tiles with thicknesses of 2 mm, 35 mm, 40 mm and 55 mm [44] [45]. The average distance between the dropped and the structural ceiling is often around 300 mm and seldom less than that [10].

Although the high possibility of variation in ceiling heights for different rooms, it was decided to let the light shape be constant. This decision was based on observations of sunlight entering from skylights with the conclusion that the light shape could have the same size and be projected at the same distance from the ceiling independently from the ceiling height. This leaves a static requirement for the luminaire to be able to project a 2.7 meter high light shape, see Figure 6.6.

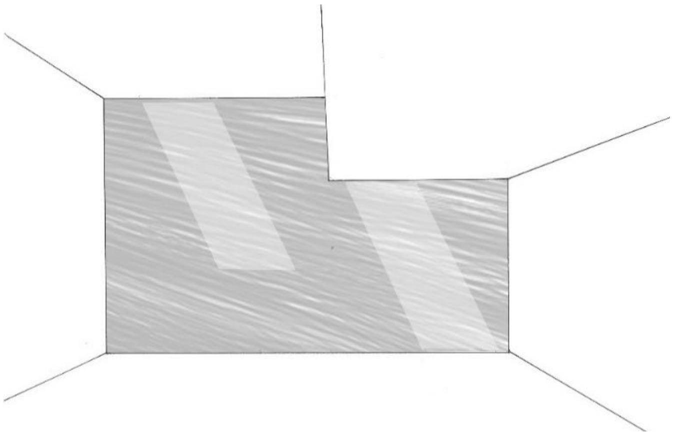

Figure 6.6 Static light shape though variation in ceiling height.

The differences in ceiling solutions in different rooms can result in different needs regarding how close to the wall the luminaire can be installed. This resulted in a need of an angle adjustment of the light module, in the direction normal to the wall, see Figure 6.7. When testing, the angle differed between 2° and 12° as the distance from the wall increased from 100 mm to 600 mm. To get some extra tolerance if there is a need to increase the distance even further, the light module should be able to angle up to 20°.

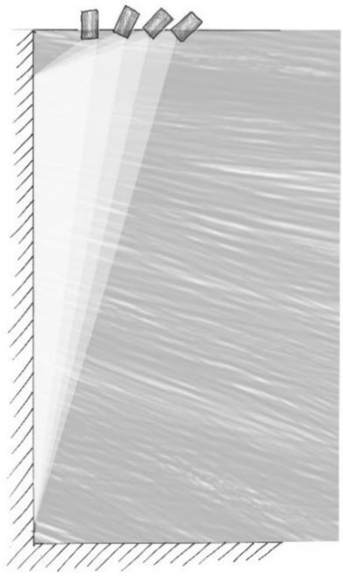

Figure 6.7 Angle variation normal to wall.

The light module should also be adjustable in the angle parallel to the wall, but in difference to the angle normal the wall, this angle only affects the aesthetic of the light shape, and thereby how the user experience the light, see Figure 6.8. E.g., a high angle of the light module will result in a light shape that resembles the sunlight late in the afternoon or early in the morning.

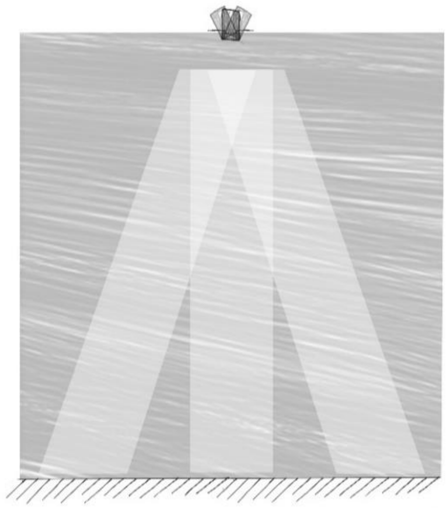

Figure 6.8 Angle variation parallel to wall.

Moreover, the variation of the distance from the wall also requires an adjustment in the distance between the two lenses in the light module. This adjustment is necessary to get sharp edges on the light shape, since it adjusts the focal point. But this will also affect the size of the light shape, which means that if the light module is installed further away from the wall the light shape will become bigger. Based on the test of the prototype, the required variation in the distance between the lenses is only five millimeters as the distance from the wall to the light module increases from 100 to 600 mm. Though, in order to get a good error tolerance from the test the variation was set to 20 mm. The distance between the two lenses will therefore be variable from 45 mm to 65 mm.

6.1.1.3 Installation requirements

As mentioned previous in this report, the light module has to fit different types of shades but also be able to be installed independently. Therefore both the shades and the light module need to be designed for this.

To create a product that is user friendly, it was critical to design the luminaire with the installation process in mind. The possibility of installing several luminaires next to each other is fairly high, since these types of lights often are used to light up broad walls. It will therefore be critical that all the light shapes on the wall are identical. Hence, a goal in the development of the luminaire was to facilitate repetition of the settings for one luminaire to the other ones. It was also necessary to make it possible for the installer to do all the adjustments of the light module after installation, while looking at the light shape projected on to the wall.

For the entire list of the technical requirements for the light module, see Appendix J.

6.1.2 Requirements from function analysis

In addition to the technical requirements collected above, some of the functions from the function analysis, see chapter 4.4.2, were extra significant when developing the detailed construction of the luminaire. These functions were categorized into three groups; aesthetic functions, manufacturing and assembly functions and usability functions. A list of these functions can be found below.

Aesthetics

- Own simplicity
- Own discreetness
- Express quality
- Fit moodboard
- Fit officona

Manufacturing & Assembly

- Reduce parts
- Own Simplicity
- Optimize wallwashing
- Minimize tolerance sensitivity
- Reduce errors
- Minimize volume
- Minimize costs

Usability

- Facilitate installation
- Own intuitiveness
- Facilitate repetition
- Reduce errors
- Enable one-hand handling

6.2 Light module

This sub-chapter will illustrate the further evolution of the light module. To facilitate for the reader, the process has been split into sub-chapters for each part of the module. These development processes are described separately and linear, one for each part, but in reality they were developed parallel in an iterative process.

In order to get a chance to review the design of the light module within the scope of the project, it was decided to send the first of the CAD-model to a company, called Shapeways, for 3D-printing in nylon [46]. In the end, a second version of the CAD-model was printed for the final prototype.

6.2.1 Main body with lens adjustment

To generate design concepts that fulfilled all the technical requirements regarding the lenses, the prism and the gobo-pattern was not a simple task, mainly since some parts had to be static, like the prism, while some had to be adjustable, like the distance between the lenses, see Figure 6.9.

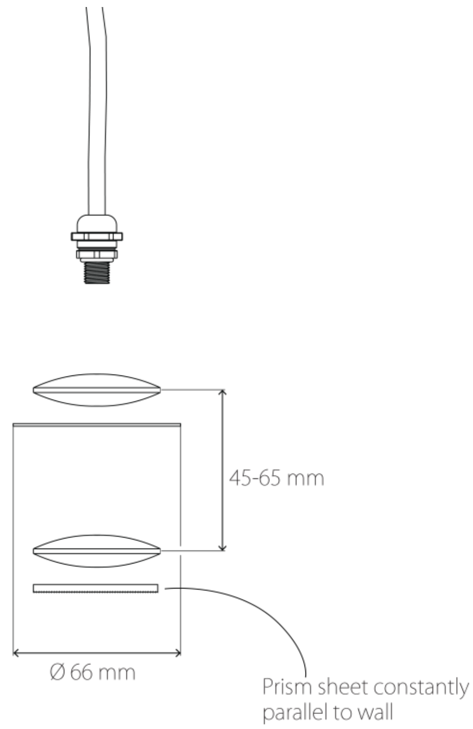

Figure 6.9 Some of the technical requirements for the lens adjustment.

Three concepts were generated and developed from sketches to CAD-models before a selection between them was made. The reason for developing these concepts as far as to CAD-models before eliminating any of them, was due to the difficulty in determining if they were going to work or not, and motion simulations with CAD-models was a way to get the missing input. The three concepts and how they developed are described briefly in the following sub-chapters.

6.2.1.1 Lens adjustment 1: Rotation

This concept was developed from the principle that the distance between the lenses could be adjusted in the same way as in a camera objective. A rotating motion can be redirected to a sliding motion with a pin in one part, and an angled groove in the connected part.

The next step was to set the dimensions in order to fit the technical requirements. The concept ended up having four parts: a front part containing one lens and the prism, a rotating part with one angled groove and one straight grove, a middle part fixating the second lens and holding the gobo and a back part fixed to the optic fiber, see Figure 6.10. The desired wallwashing effect could also be achieved with this solution, by screwing the back part directly on to the front part.

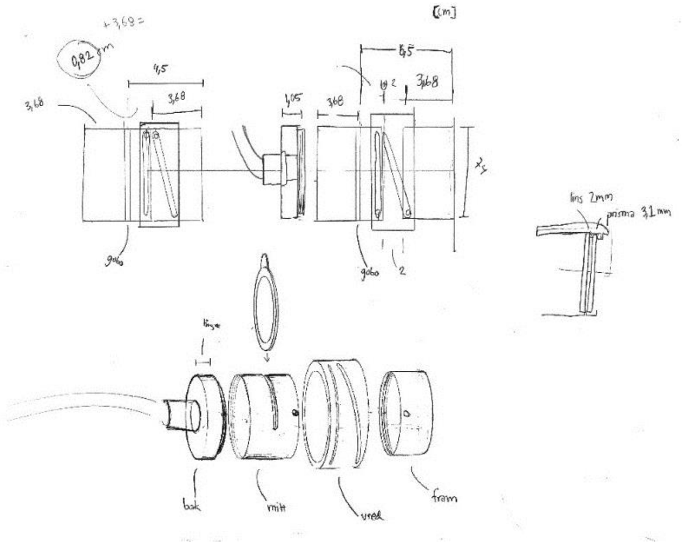

Figure 6.10 Further development of the rotation concept.

Finally the concept was modeled in CAD and some features were added in order to get the right motion without the light module falling apart, see Figure 6.11.

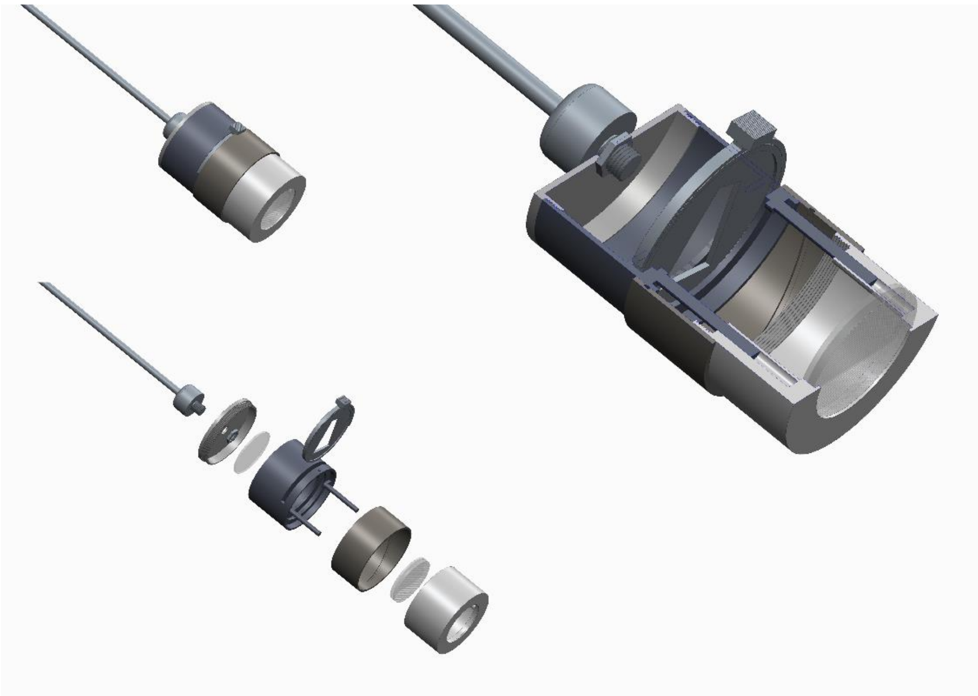

Figure 6.11 CAD-model of the rotation concept.

6.2.1.2 Lens adjustment 2: Push

The focus for this concept was to make the construction as simple as possible. This was done by letting both the distance between the two lenses and the gobo-rotation be adjusted by only one pushing or twisting motion from the end of the light module.

When developing this concept it ended up having three parts; a front cylinder fixating one lens and the prism, another cylinder which extends the first cylinder and a slide-able part which includes the second lens and the gobo, see Figure 6.12.

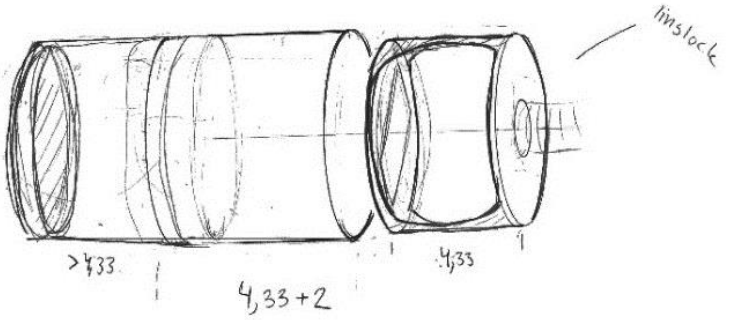

Figure 6.12 Sketch with basic dimensions.

The sliding part was complemented with a locking mechanism in the end, with two buttons, which needs to be pressed in when pushing the part through the cylinder. By using a two part cylinder instead of one long, this concept would be able to reassemble into a wallwasher by simply removing the back part of the cylinder, the two lenses and the gobo. See Figure 6.13 for the CAD-model of the push concept.

Figure 6.13 CAD-model of the push concept.

6.2.1.3 Lens adjustment 3: Gear

For the third concept a gear was used to transform a rotating motion to a sliding motion.

This concept contained three parts as well. A front part holding the prism and one lens, a middle part for the other lens, the gobo and the rotating wheel and a back part which could be screwed on to either the front or the middle part, depending on which light to project. By rotating a small wheel, the front part slides into the middle part and thereby decreasing the distance between the lenses. The idea was also that the same thread could be used both for the sliding motion and for screwing the back part onto the front part, for the wallwashing effect. See Figure 6.14 for sketches and Figure 6.15 for the CAD-model.

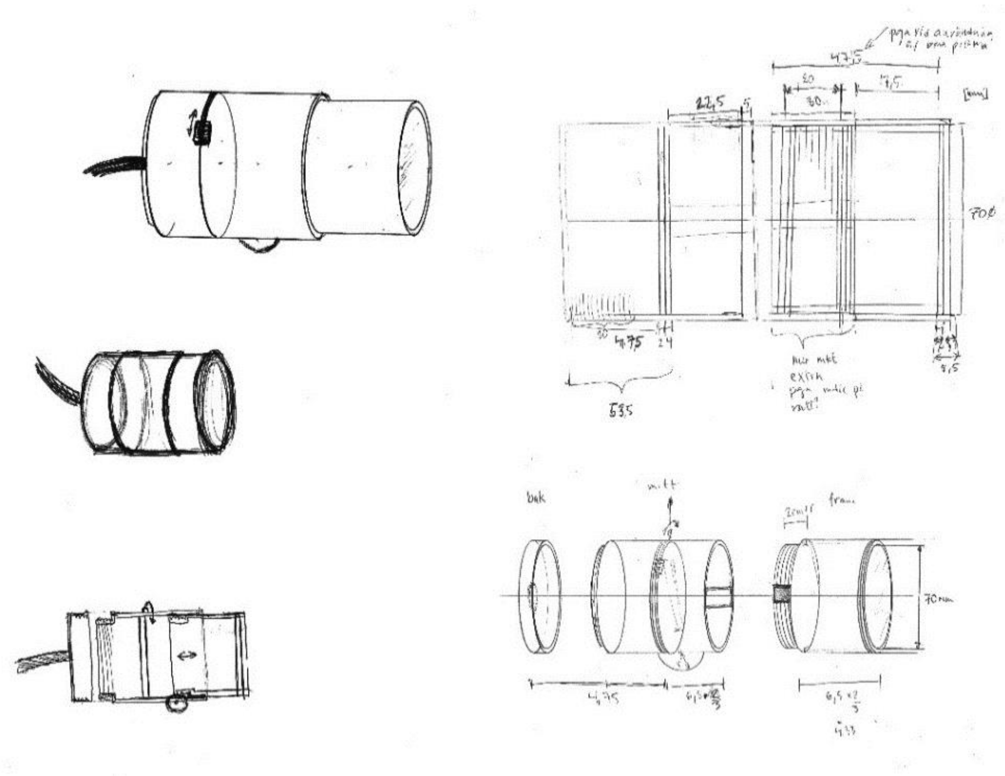

Figure 6.14 Further development of the gear concept.

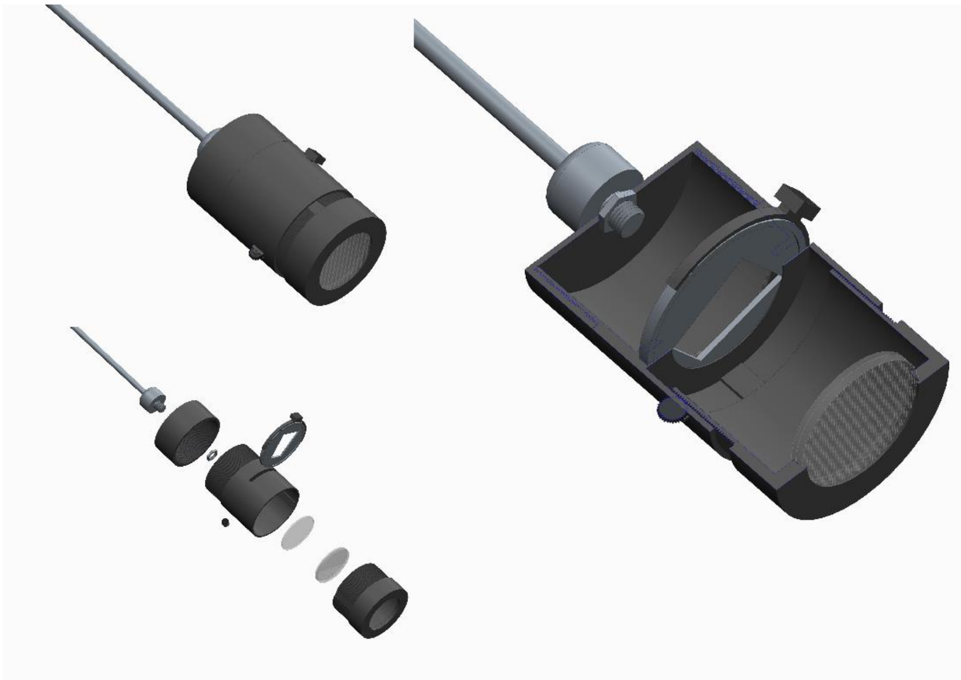

Figure 6.15 CAD-model of gear concept.

6.2.1.4 Selecting lens adjustment and developing it further

The selection between the lens adjustment concepts was based on the function analysis, mainly with focus on the requirements from the manufacturing, assembly and installation point of view. In consultation with the supervisor, aspects of complexity, accuracy and usability were discussed. This discussion lead to the selection of the rotation concept, see Figure 6.16, since the other concepts had too many flaws while this concept provided the user with consistency by working in the same way as a camera objective [47]. Examples of the flaws in the other concepts were that the gear concept needed low tolerances and was therefore too complex while the push concept made it difficult to adjust the lenses with the high precision that would be necessary in order to get a sharp light shape on the wall.

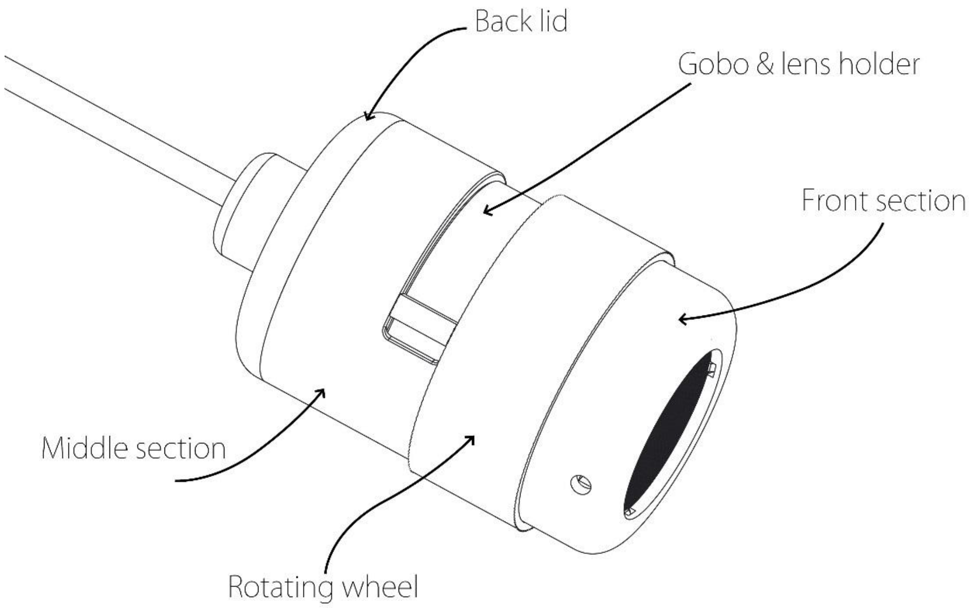

Figure 6.16 The new design after the first adjustment, displaying the different parts of the main body. These names will be used onwards in the report.

When consulting with the supervisor it became clear that many adjustments had to be made in order to develop the concept into a working product. The primary points of development were:

- Ensuring a working rotation and slide mechanism by adding extra groves in the rotating wheel, making it symmetrical, see no. 1 in Figure 6.17.
- Simplifying the part which holds the gobo and adding the lens to this part instead of the middle section, see no. 2 in Figure 6.17.

- Adding a simple lock mechanism, groove and pin, to fix the gobo and lens holder to the middle section, see no. 2 in Figure 6.17.
- Changing the thread used to fasten the back lid on to the middle section or the front section to a simple twist and lock mechanism, see no. 3 in Figure 6.17.
- Reducing unnecessary material.
- Setting a minimum material thickness to 2 mm and the tolerance between parts to 0.125 mm.
- Designing the angle adjustment for the light module, described in sub-chapter 6.2.2.

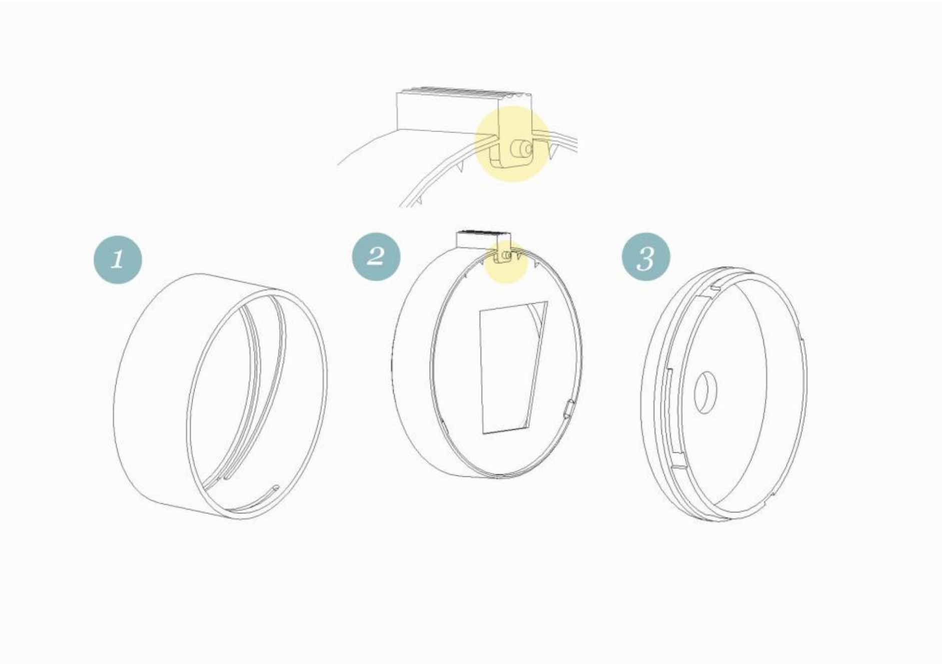

Figure 6.17 New features for the main body.

When these adjustments were made, flutings were added to the rotating wheel as well as to the handle of the gobo and lens holder, see Figure 6.18, to increase the affordance of rotation [47]. Rounds were also added to make it fit the moodboard a bit more, even though the aesthetic development of the light module were planned to be postponed until all the technical requirements were fulfilled. The CAD-file were now sent for printing in nylon, see Figure 6.19, Figure 6.20and Figure 6.21.

Figure 6.18 Main body after the first adjustments.

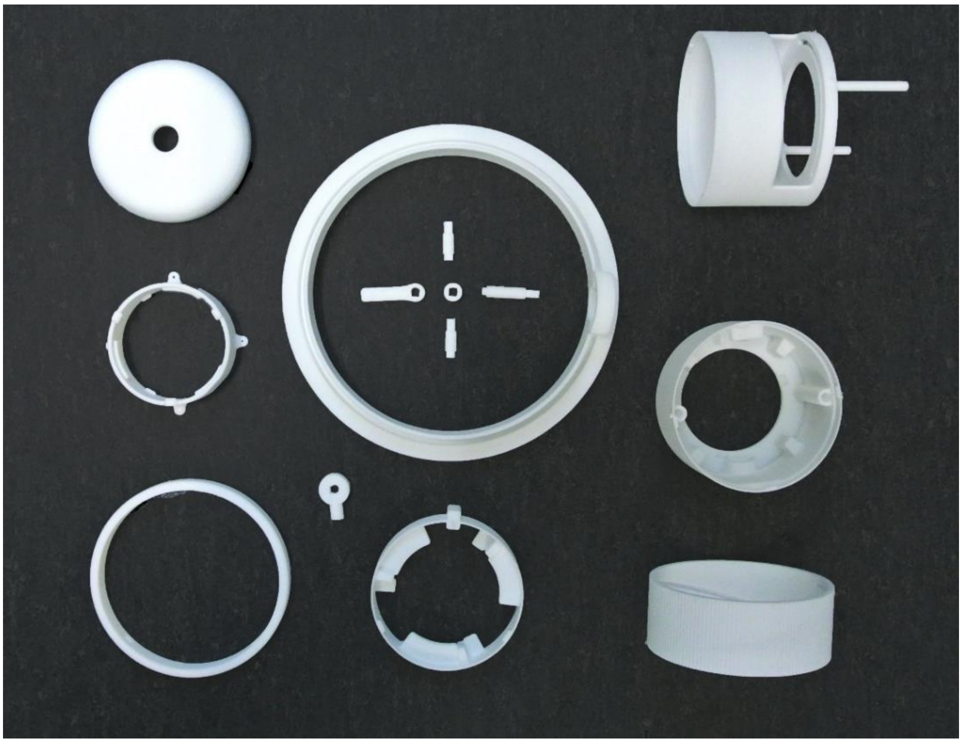

Figure 6.19 All the parts for the 3D-printed prototype of the light module.

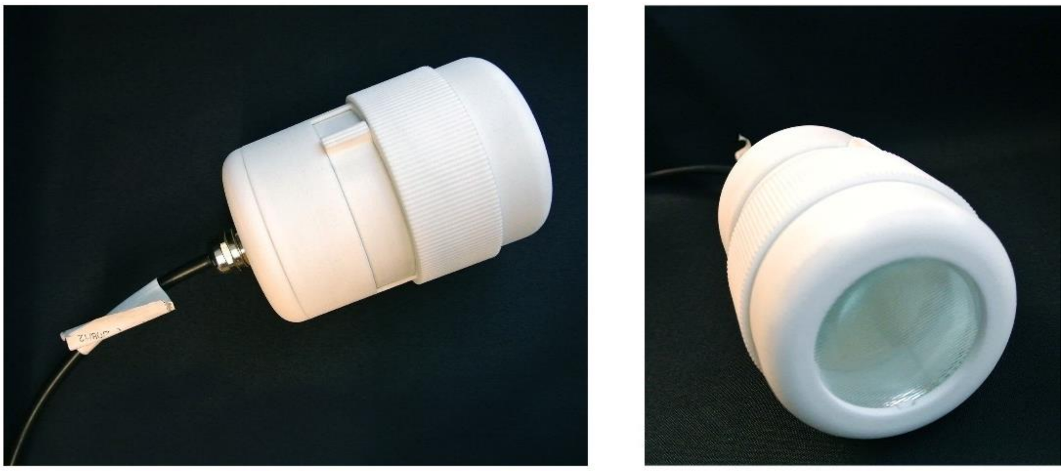

Figure 6.20 Photos of the 3D-printed prototype.

Figure 6.21 The back lid connected directly to the front section.

When the first prototype arrived, assembled and tested, there were a lot of obvious defects and every part had to be re-designed. Furthermore, when walking through the planned assembling steps, even more adjustments had to be done to make the assembly process easy and intuitive. The major re-designs are listed below.

Adjustments in the construction

1. Broadening the hole for the gobo and lens-holder, allowing it to be removed and rotated smoothly.
2. Adjusting the stop pin for gobo and lens-holder and changing the side for the groove, making it easier to remove the gobo and lens-holder
3. Adding a lock-notch for the back lid, securing it from accidently falling off.

4. Making the pins that connects the front and the middle sections longer, to facilitate the assembly process.
5. Adding constrains, making it impossible to assemble the middle section upside-down.
6. Adding constrains, making it impossible to assembly the prism wrong.

6.2.2 Angle adjustment

This subchapter will describe the process of developing a solution for how to angle the light module both normal and parallel to the wall. Since the goal was to have a hidden light source that would fit a shade, see chapter 5.5, it was decided early that the pivot point of the light module should be located in the front. This resulted in having the lateral movement in the end of the light module while the front will remain in the same location unaffected by the angel.

A brainstorming session was performed with inspiration from other spotlights and classical joint solutions. At this session, five possible solutions were selected, see Figure 6.22.

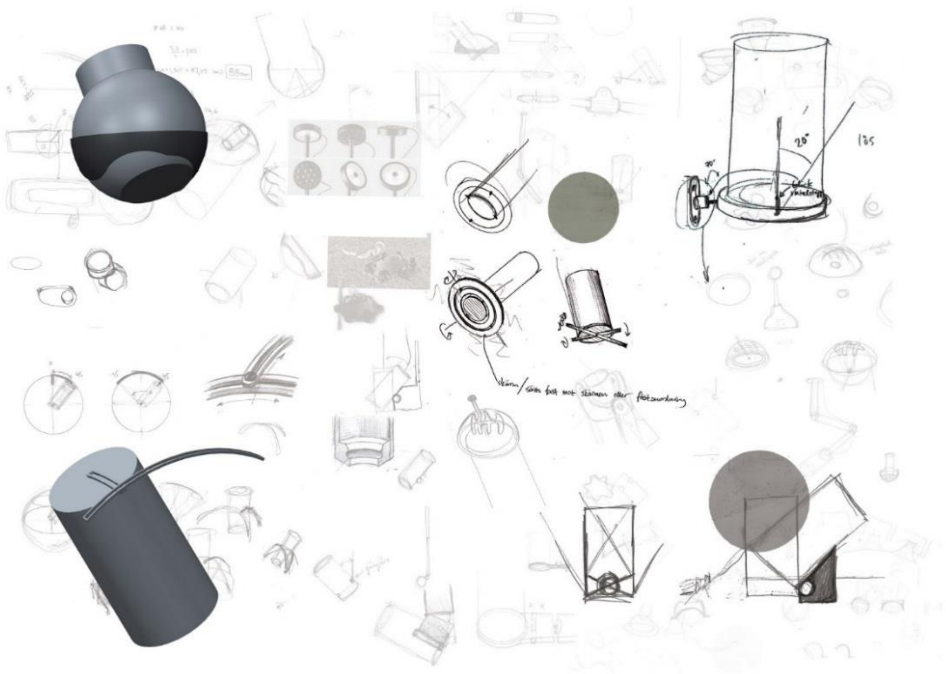

Figure 6.22 Sketches of the five solutions generated at the first brainstorming session.

When evaluating the five solutions by discussing how well they would work regarding the technical requirements, a two axis rotation solution was chosen as the concept for this project. The light module will be attached to a surrounding ring, by one or two shafts. The ring will be attached to the mounting surface in the same way, with one or two shafts. This solution fulfills the requirements of just angling in two directions, it is simple and gives a minimal movement in the front of the light module.

6.2.2.1 Further development of the angle adjustment concept

As mentioned, see chapter 6.1.1.3, one requirement was to make it possible for users to copy settings from one light module to another when installing several luminaires next to each other. During a brainstorming session, possible solutions for this requirement were generated. A visual and a tactile feedback solution were the two most promising ideas.

The idea with the visual feedback was that a scale would be printed on the luminaire, like a protractor, showing how much it was tilted. The downside with this idea was that the scale would be difficult to see when orienting the light module from beneath the ceiling.

The other solution, with tactile feedback, would work by making the angle adjustments in notch-steps instead of a continuous motion, e.g., one notch would be representing an adjustment of one degree. This solution would make it possible to look at the wall and the light shape when tilting the light module, just counting the steps when setting the angles. This idea for feedback was found to be the most promising, and therefore selected for further development.

When benchmarking for solutions similar to this one, a component called spring plunger was found, see Figure 6.23.

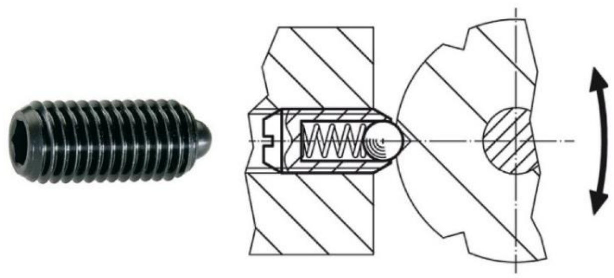

Figure 6.23 Spring plungers [48].

Since it was difficult to know if these spring plungers would work to give the tactile feedback required, different sizes and designs were ordered with the attempt to test them on the first prototype. Below, see Figure 6.24, illustrations show how the luminaire was designed using spring plungers to give feedback on the angles both normal and parallel to the wall.

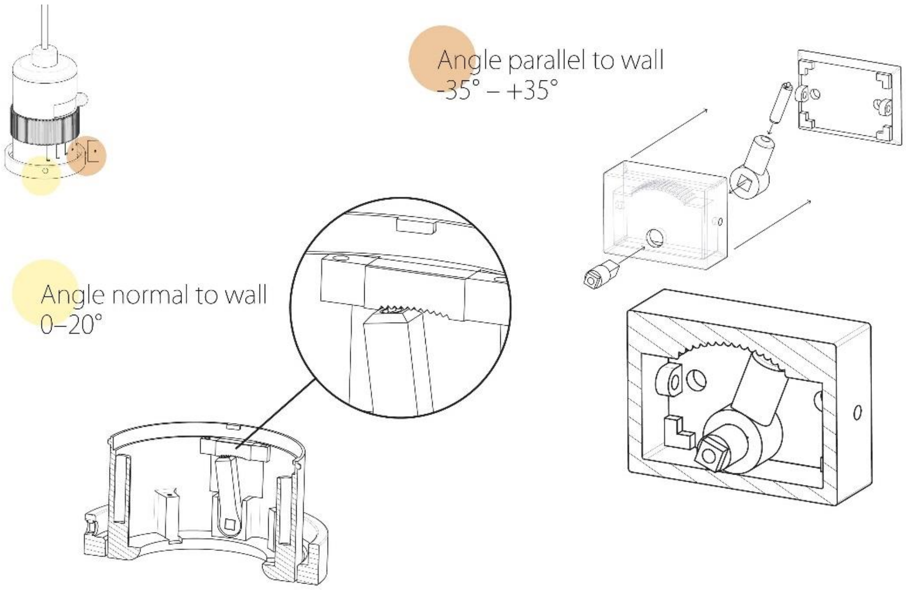

Figure 6.24 Angle adjustment with tactile feedback for the first prototype.

When getting the first prototype and trying the spring plungers, see Figure 6.25, it became clear that the solution might work, though this first design did not provide the strength to hold up the light module and the tilting was not as smooth as required. Due to time limitations, it was decided that it was not feasible to develop this solution further in this project.

Figure 6.25 Spring plunger in the prototype.

In consultation with the supervisor it was instead decided that the handling of the angle settings would be done by measuring and aligning the light shapes projected on the wall, similar to the procedure performed when hanging paintings. This solution might be superior to the two other solutions, since small errors in tolerances may have made the visual or the tactile feedback incorrect. It will only be the friction in the end of the shafts that locks the light module in the desired angle, making the solution a lot simpler than the previous one.

Moreover, the shafts holding up the light module were too weak in the 3D-printed prototype, see Figure 6.26. This was a product of only working in CAD, losing the perspective of how small the components would be in real life.

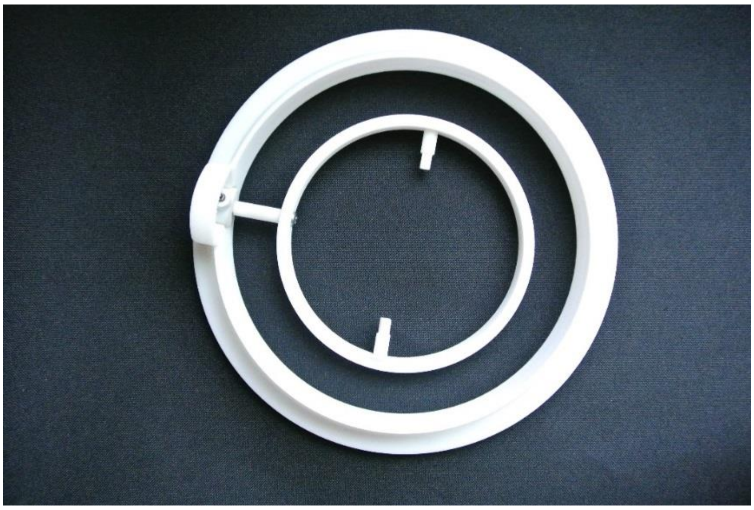

Figure 6.26 Photo of the shafts in the 3D-printed prototype.

So for the final concept, the shafts were not only made dramatically thicker but also shorter to ensure a sturdy construction. To minimize the amount of parts, the two inner shafts were connected to the front section of the light module and the outer shaft incorporated into the angling ring, see Figure 6.27.

Figure 6.27 Light module with thicker shafts.

6.2.3 Attachment of light module

A solution for how the light module would be attached to a second ceiling, a shade or independently to a structural ceiling had to be developed. See Figure 6.28 for the first idea sketches for the attachment.

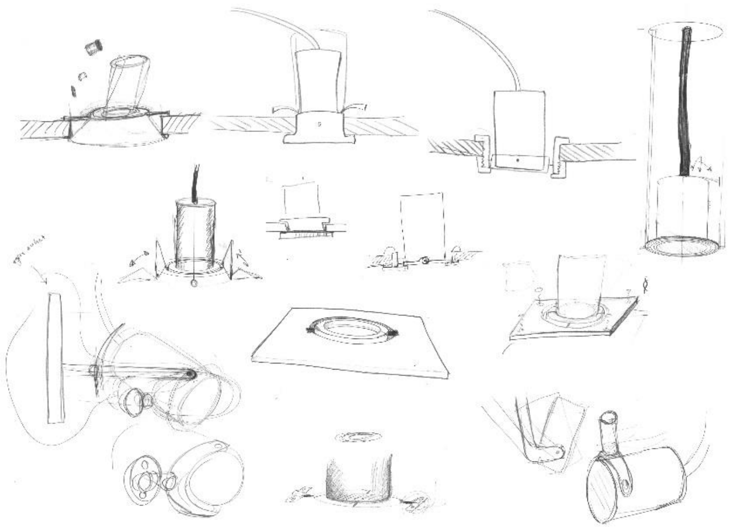

Figure 6.28 The first sketches for the attachment of the light module.

When generating ideas, three optional solutions were found, see Figure 6.29. no. 1, a ring that could be fixed onto the ceiling by screwing one part into the other, no. 2, a ring that could be attached with springs and no. 3, a solution that would independently be screwed onto the mounting surface with screws.

Figure 6.29 Pictures of the three module attachments.

The attachment concept with the springs were selected to be developed further in this project. The basis for this selection was that springs are often used in these types of luminaires, making it a solution that would be recognizable for the installer but mainly it will lower the costs of the luminaire due to the usage of inexpensive standard components. These features were not included in the first prototype and were therefore not tested before the final prototype arrived, which also made it preferable to select a safe and tested concept.

It should be noted that Parans easily will be able to provide their customers with solution no. 3 as well, since it easily can be implement by using a small disk with holes, making it possible to screw the light module onto the disk and then the disk onto a wall or a beam.

The further development of this component will be described in the next sub-chapter since it mainly regards the aesthetic perception of the product.

6.2.4 Aesthetic development

Since there were a great number of technical requirements for the light module, the aesthetical design were postponed to the last stage of the development process. The emphasis here was to make the product fit the moodboard, see 4.3.2.2, but at the same time be discrete, letting the light be the focus of attention rather than the luminaire.

The approach used were discussions mixed with sketching ideas, while evaluating the existing design. When ideas for the design were generated they were tested by adding them to the CAD-model which were followed by a comparison between the designs.

Since many of the parts were designed separately, one of the goals with this phase was to make the light module look like one coherent product. The biggest issue here was the connection between the *main body*, *angle adjustment* and *module attachment*, see Figure 6.30. These were redesigned and a smooth transition was made by having the same curve flow through all three parts.

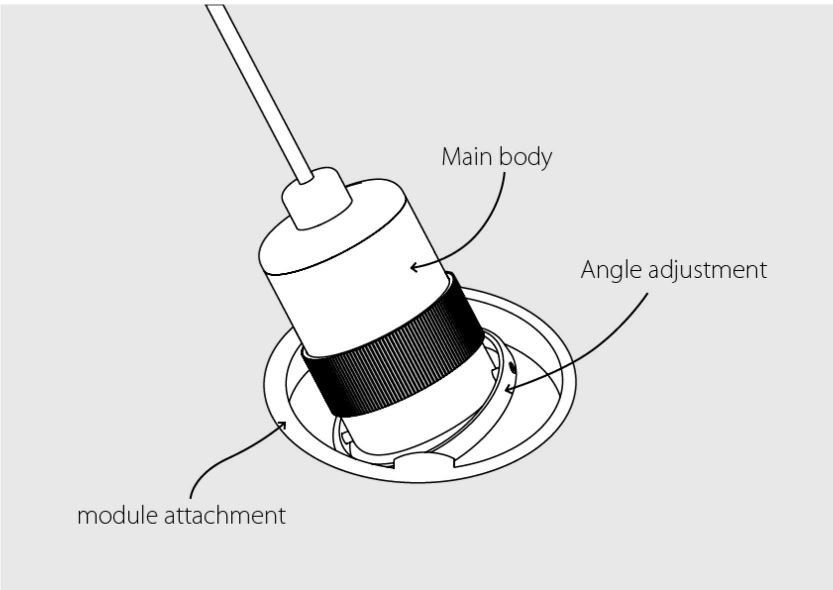

Figure 6.30 The main body of the light module together with the angle adjustment part and the module adjustment part.

The part that would be fixed to the ceiling or to the shade, the module attachment, was also redesigned. The aim was to add some features of resemblance to a window, even when the light module would be installed without its shade. This was achieved by re-shaping this part to a square, making the luminaire look less like a spot. When the first prototype arrived, one of the instant responses were that the gaps between the main body, the angle adjustment ring and the module attachment were too big, allowing the observer to see the space behind the dropped ceiling. Hence, the angle adjustment ring and the module attachment square were re-designed to minimize the gap without restricting the tilting of the light module's main body, see Figure 6.31.

Figure 6.31 Quick renderings showing the redesign of the *main body*, *angle adjustment* and *module attachment*.

It will be critical to install the luminaire with the correct side towards the wall, otherwise the prism will direct the light away from the wall. Hence, a constraint was added, which makes it easier to know in which direction to install the light module. The top of the module attachment was designed as a circle with a flat side, this flat side should be parallel and towards to the wall, see Figure 6.32.

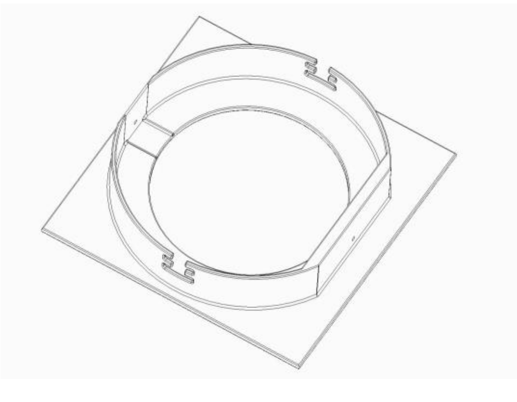

Figure 6.32 Ceiling attachment from above.

Another aesthetic issue was the handle of the gobo and lens-holder. In the design of the first prototype, it was too small and therefore difficult to get at good grip of. Moreover, the shape was poorly designed and did not fit the moodboard.

Many different shapes were designed and tested for the handle, with inspiration from all types of products used for this type of pinch grip. Finally a new design was agreed upon, making the handle more visible and still coherent with the style of the product.

To facilitate the installation of the luminaire, it was determined that a scale should be added to the main body indicating the distance between the lenses. This can be useful when installing several luminaires in a row, to make sure that all light shapes have more or less the same size. The scale was added to the front section in a combination with an arrow on the rotating wheel of the main body. To get the right design, sketches were made of the flutings, the arrow and the scale.

Finally all the rounds on the light module were changed, so that just a small number of different radius sizes were used, giving the light module a uniform design, see Figure 6.33.

Figure 6.33 Quick rendering showing the new design of the light module

6.2.5 Colors and surface finish

The user's impression of the light module will be strongly affected by the color and surface finish.

As mentioned before, the idea with the developed concept was to be discrete, letting the light be the focus of attention. Hence, the primary color selected for the light module will be white. However, black ceilings are quite common, especially in rooms without second ceilings. This requires black as an optional color for the light module, preventing undesired attention when installed on a dark background.

By looking at the moodboard, see Figure 4.10, and the officona, see Figure 4.9, the decision that some accenting colors should be offered as well, was made. This will make the luminaire reach out to a broader range of customers. Three accent colors for the light module were picked from the moodboard, where color blocking were one of the words used. These colors would fit both if installed together or separately, see Figure 6.34.

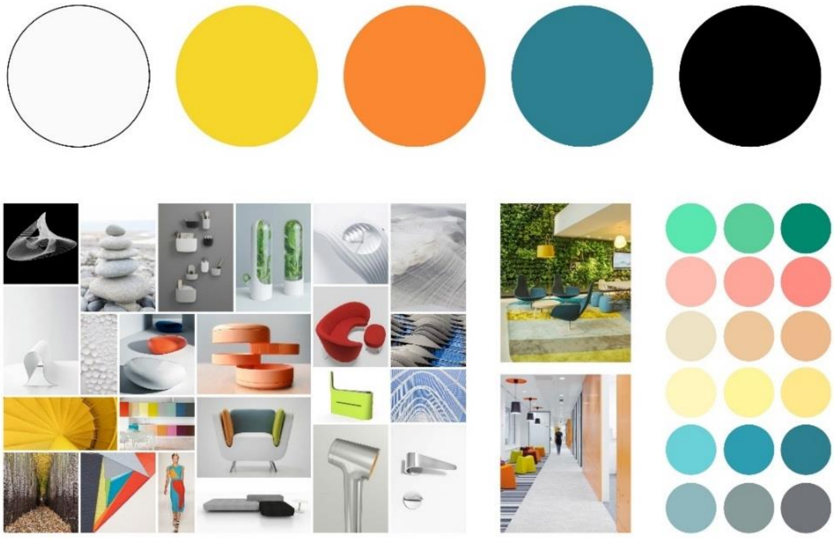

Figure 6.34 At the top: the five colors selected for the light module, below: colors were determined with inspiration from the moodboard and the officonas.

It should be noted that the selected colors have to be reviewed with material samples before production. The downside with providing several colors are increased warehouse costs for Parans, although the sales might increase as well.

The outer finish selected for the light module was a matte, slightly structured surface, see Figure 6.35. The exact value for the surface finish will not be set in the scope of this project, material samples will be needed in order to make these specifications as well.

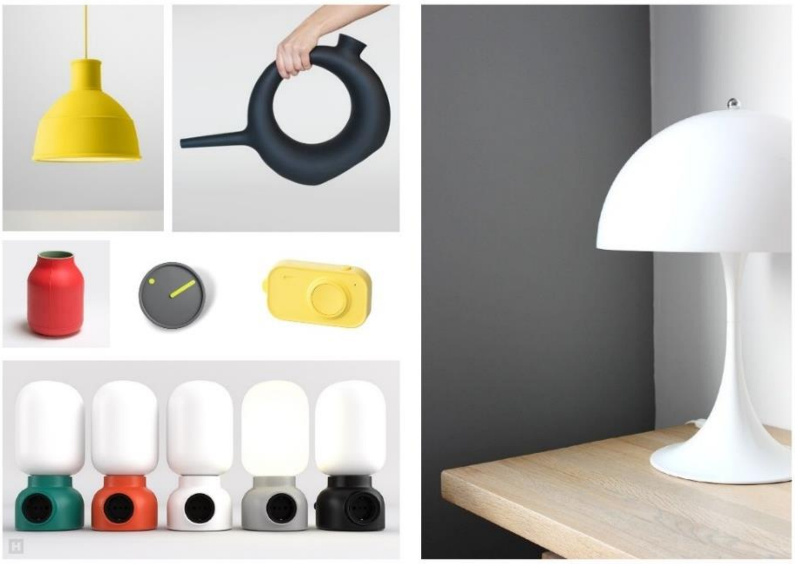

Figure 6.35 Products with the surface finished desired for the light module.

On the other hand, the finish of the light modules inner surfaces should be reflecting as much light as possible. This will minimize the light loss as well as preventing the luminaire to glow due to light leakage.

6.2.6 Suggestions for material and manufacturing methods

Different materials have been reviewed for the light module. Since the luminaire should be installed in a dropped ceiling there is a weight restriction of 2 kg [45], otherwise extra load-bearing material will be required.

Besides the weight restriction, the selected colors and the surface finish add up requirements for the material and the manufacturing method, resulting in two possible materials for the light: plastic and aluminum. Due to the time limit of this project, only suggestions were made and further investigations should be done before a final selection.

If plastic would be selected, there will not be any problems in offering several colors, providing the desired surface finish and get a low weight construction. Since there will be heat transfer from the gobo to the gobo and lens holder, ABS or reinforced nylon would be suitable [49]. Nylon can be continuously exposed to 120°C while ABS has a lower maximum temperature of 80°C [50], [51]. The major cost if using injection molded plastic would be the tooling cost, this might be reduced if redesigning some of the light modules cylindrical parts, as the front section and the middle section, e.g., by splitting them lengthwise.

Aluminum would suit as material for the light module as well, since it has low density and, can be colored by anodizing. The desired surface finish can easily be accomplished by abrasive blasting. Also, the heat transfer will not be any problem in an aluminum construction. For aluminum, the material would be more expensive, in comparison to plastic, but the tooling cost can be minimized by using plaster mold casting. This method is used for series of 1-1000 pieces per year [52].

Another option could be to 3D-print all the parts for the light module, this could be done in either plastic or metal. In contrary to the two alternatives mentioned above, there will be no tooling cost here although the price for each unit will be remarkable higher, for prices see Appendix K. This might be a good option to start with and to get responses from the first costumers before deciding on which material and manufacturing method to use. By 3D-printing the product, Parans' highest environmental impact, the CO_2 emissions from transportation, could be reduced since the light module can be produced near the location for installation. By postponing the manufacturing until a product is order, Parans' warehouse costs will be reduce as well.

As mentioned in the previous chapter, the inner surface of the light module needs to reflect as much light as possible. This requirement can be fulfilled both through the selection and the polish of the material but also by adding a layer of reflective paint. [49], [10].

6.3 Shade

When developing the shade it was decided to focus on making it compatible with the European standard dropped ceilings, see chapter 6.1.1.2, and the 600×600 mm grid that comes with it. When other inner ceilings, such as plasterboards are used, it was seen to be more probable to use special adjusted solutions, why these particular situations were neglected for the development of the shade.

6.3.1 The grid system

There are several suppliers of dropped ceiling grid system, and after exploring some of them the conclusion was that the systems construction and dimensions were alike with only negligible differences [44], [45], [53], [54].

The grid system consists of profiles, see Figure 6.36, of different lengths. The profiles are divided into main runners that are attached to the structural ceiling, and cross tees that are attached between the main runners. To ensure the grid's suspension in the structural ceiling, the main runners has to be installed maximum 1200 mm apart from each other or from the wall, see Figure 6.37 [44], [45], [53], [54].

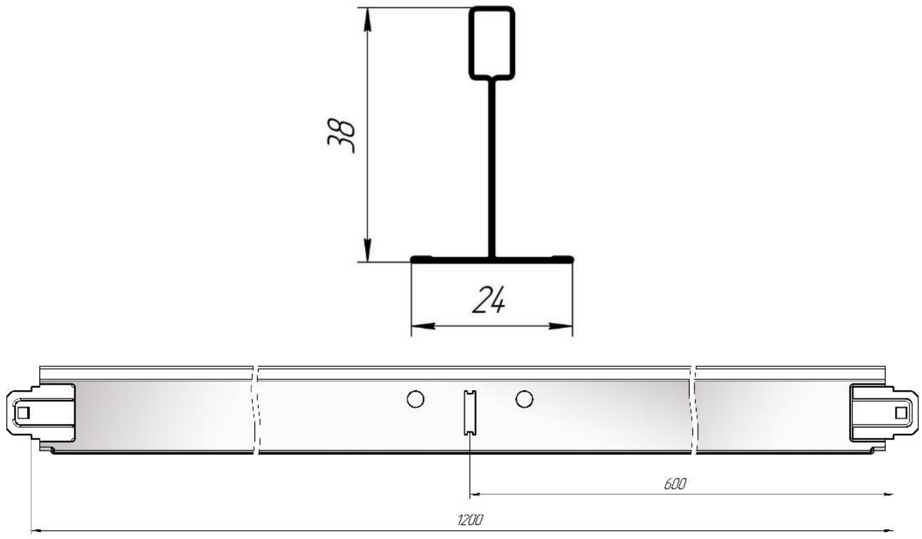

Figure 6.36 Section and side view of grid profile [54].

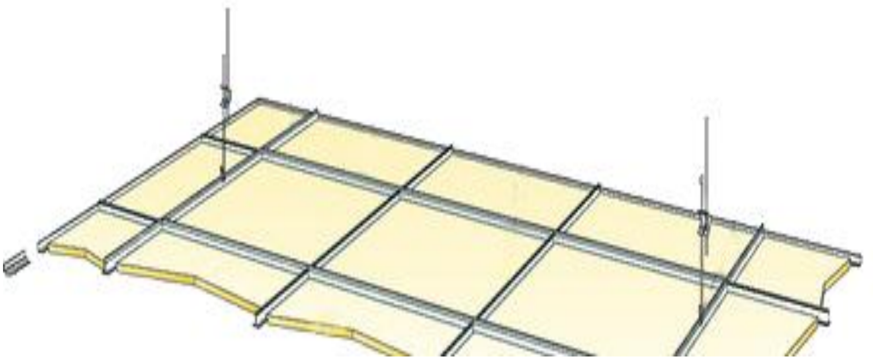

Figure 6.37 Overview of the grid system [45].

The tiles between the main runners and cross tees could easily be taken down and the initial idea was to replace one tile with the shade. The width of the shade was therefore set to 600 mm so it will be able to rest on the profiles. The depth on the other hand, was firstly intended to be around 400 mm to minimize the risk of someone seeing the light source. With this solution a tile had to be cut to fill the gap. After reconsideration, and more thoroughly examination of the technical requirements, see chapter 6.1, where it was stated that the optimum distance between the light source and the wall was 500 mm, it was decided that the also the depth of the shade was going to be 600 mm. This gave a more robust construction since the shade will rest on the grid on all four sides.

The total height of the shade was decided to be 300 mm, corresponding to the average distance between the structural and the dropped ceiling [10]. Since the light module will be attached in an angle almost parallel to the wall the attachment part of the shade was set to be horizontal. The length of the light module together with the minimum bend radius of the cable reached almost 200 mm giving the maximum distance between the height of the dropped ceiling and the bottom of the light module to be 100 mm.

6.3.2 Development of the shade

With these parameters set, a few options for the design of the shade were developed, see Figure 6.38.

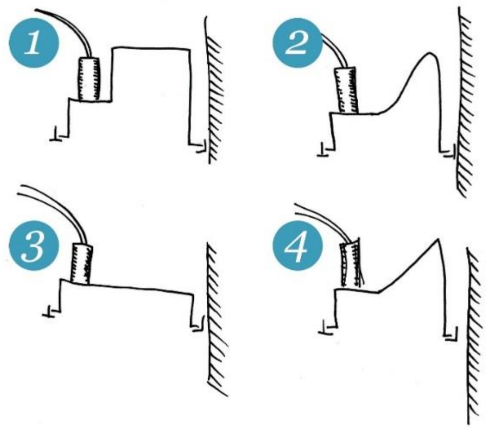

Figure 6.38 Section view of the four general shade concepts.

Draft prototypes were created for the concepts in order to evaluate how well they fulfilled the aesthetic and visual requirements. The prototypes also enabled testing of how easy the installation would be. In concept no. 3, the top part of the shade was visible even at a quite long distance. This ruined the impression of a light shaft why this concept was put aside. The other concepts fulfilled this requirement, yet it was decided to further develop no. 4 since no. 1 was difficult to install and material consuming no. 2 was seen to be difficult to prototype and test thoroughly why it was chosen not to develop further within the scope of this project.

Before making the final prototype, a prototype in foam board was made to assure that the dimensions were right and that installation went smoothly, see Figure 6.39. When installing the prototype, it became apparent that the cross sections of the dropped ceiling was detachable which facilitated the process considerably.

Figure 6.39 The foam board prototype mounted in the dropped ceiling.

The prototype made it possible to test the concept with light and the visual impression of a light shaft could also be ensured, see Figure 6.40 and Figure 6.41.

Figure 6.40 Installing the prototype of the light module to the foam board shade.

Figure 6.41 The light output from the first prototype.

To enable the modularity of the concept, the construction was divided into three parts: one main part and two side sheets, see Figure 6.42. The main parts could thereby be connected with each other, creating a wider shade, see Figure 6.43. Flanges were attached to the parts to enable the connection between them.

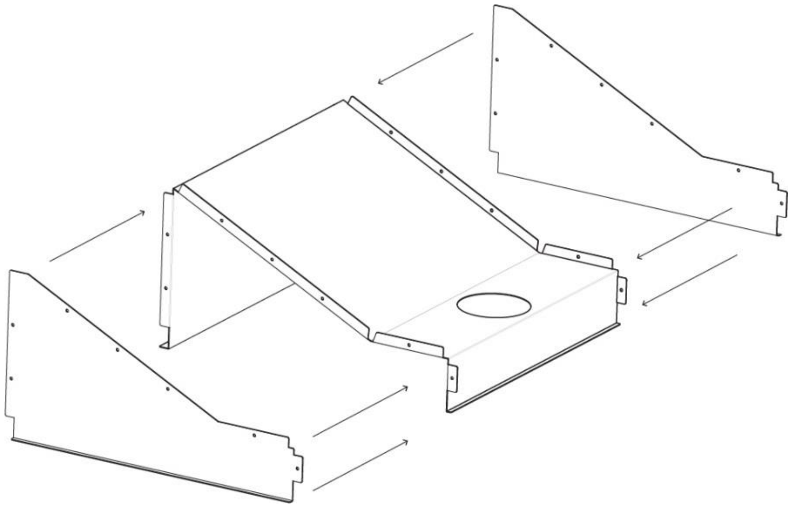

Figure 6.42 The three parts of the shade.

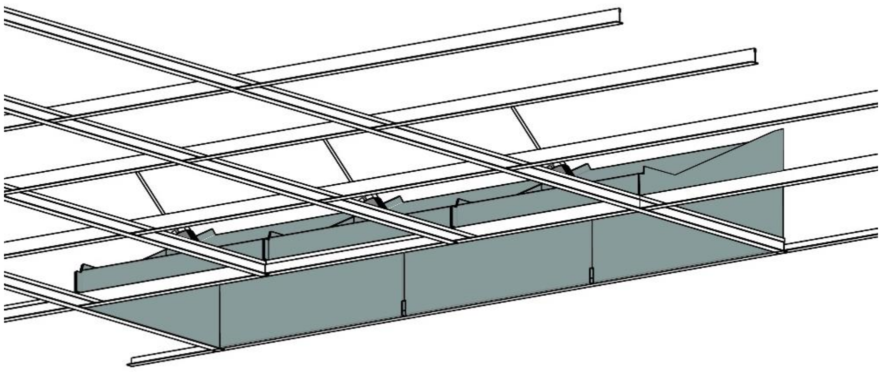

Figure 6.43 Three shades put together as one unit.

To evaluate this, and for the final prototype, CAD-models were made. In the CAD-model, it became evident that there would become a gap between the side of the shade and the grid when merging the modules to a wider shade. This is due to the construction of the grid, the tiles are 600×600 mm but since a profile lies between them, they are about 1-2 mm apart. This space is not possible to have between the main parts of the shade since they will be attached directly to each other and the cross tees will be removed, e.g., it will result in a gap of 2-4 mm if the module consists of three main parts. To overcome this, the side sheets were redesigned so that the main part could be 602 mm wide, see Figure 6.44.

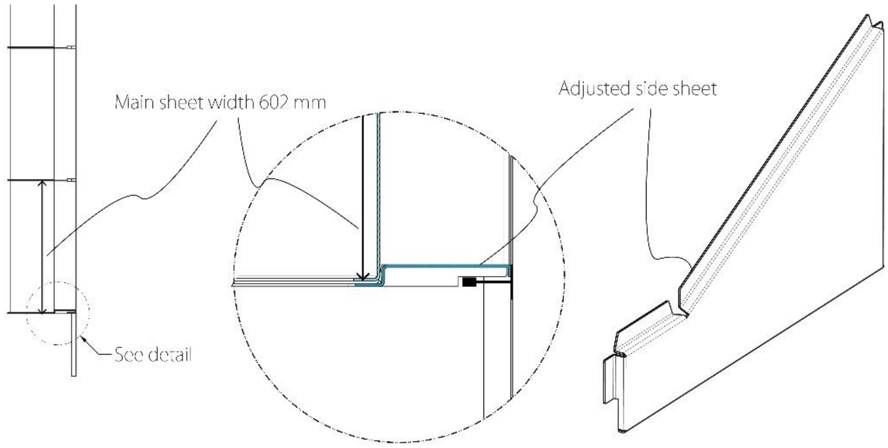

Figure 6.44 The adjusted side sheet and width of the main sheet.

However, in discussions with the supervisor of this project and Parans the idea of having different solutions for different widths instead of the modularity came up. Or simply just having one solution with 1200 mm width. To be able to select solution, more information about what Parans clients requests was needed, why it was decided to further develop the first solution that replaces one tile in the grid. If Parans later on realize that their clients would like a wider shade, they could simply adjust the width of the main part. Hence, the side sheets will be, flat except for the flange at the bottom.

6.3.3 Suggestions for material and manufacturing methods

Due to the construction of the shade the most obvious manufacturing method was bending sheets of metal. This method was also possible to use when making the final prototype, see Figure 6.45.

The two materials considered was aluminum and steel. Together with the personnel at the workshop at the faculty, the thickness of the sheets was decided to be 1.5 mm. When calculating the weight it showed that the weight of the construction, was 9.75 kg for steel and 3.35 kg for aluminum. To facilitate installation aluminum was chosen as material for the shade.

When making the final prototype, the method to cut the shape of the sheet to be bended was water-cutting. Other methods such as punching and laser-cutting could be used as well depending on the amount of shades produced. For a lower number, laser-cutting would be the most profitable alternative [49].

To match the interior, the prototype was spray painted, however for the final product powder coating in white was seen to be the best alternative. A white color would blend in well with most interiors. Still, the shade should be able to match with the color of light shade, why a suggestion is to offer these colors for the shade as well.

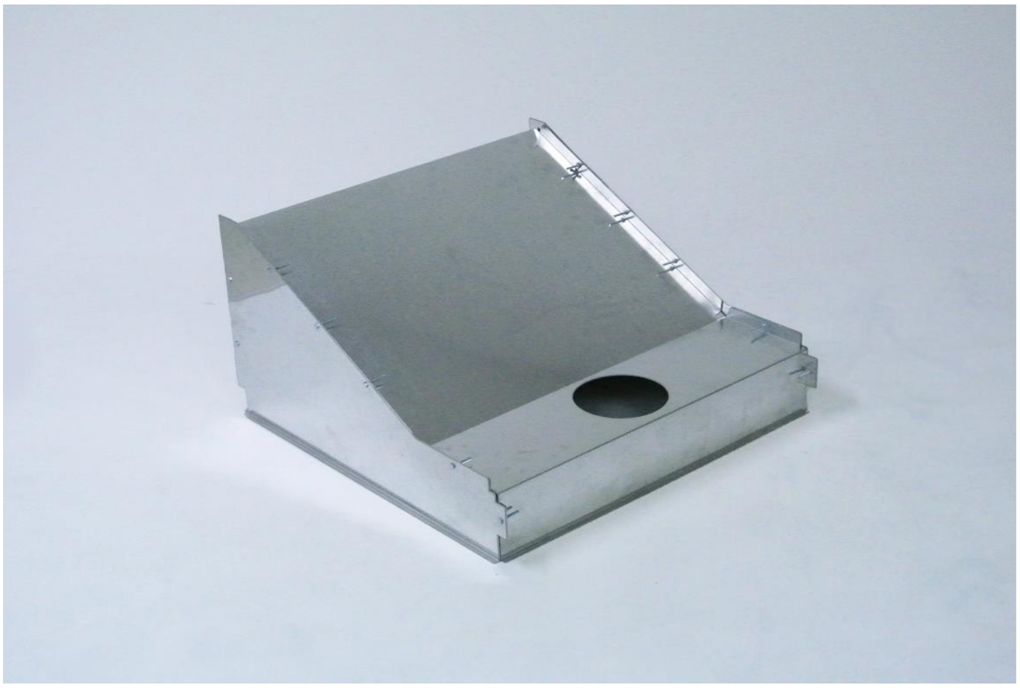

Figure 6.45 Final prototype of the shade

7 Final concept

This chapter is the final part of the deliver phase, and it illustrates how the final concept fulfills the brief and requirements set in the beginning and along the project. The concept is described as a whole and in detail.

The solution consists of a light module which is discrete, intuitive and adaptable. In addition to the light module, a shade, which blends in perfectly to the interior is available, see Figure 7.1.

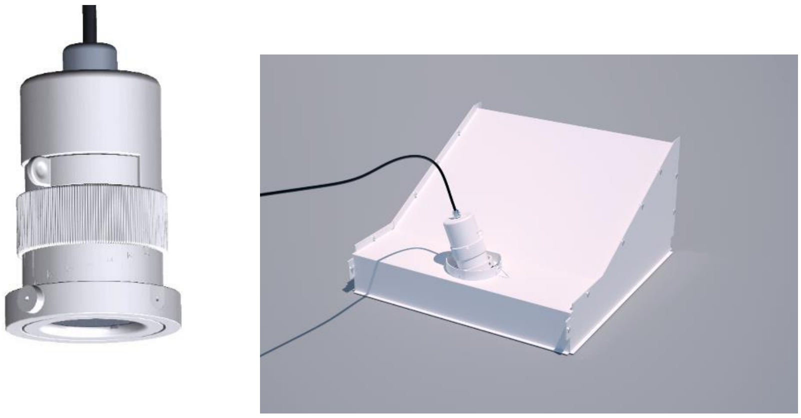

Figure 7.1 Rendering of the light module and shade.

The light module is based on a method used in theatre lighting where two lenses and a pattern manipulates the light from the source to create different light shapes. The pattern can be changed depending on the clients' request. However, the standard pattern provided with the product will create light shapes similar to those that evolve when sunlight is coming through a skylight or a light shaft. The light shapes have the same characteristic geometric appearance as light indoors has due to architectural formations, see Figure 7.2. The light is suited for the accent lighting layer as well as providing a sparkling element, making the room interesting.

Figure 7.2 The light shapes created with the light module

To fit different installation requirements and aesthetic preferences the angle of the light module is adjustable in the front. By adjusting the angle parallel to the wall, different angles of the light shapes can be set, giving the possibility to choose between light shapes similar to those in the morning, noon or afternoon, see Figure 7.3. The angle normal to the wall is adjustable to enable installation at different distances from the wall, see Figure 7.4.

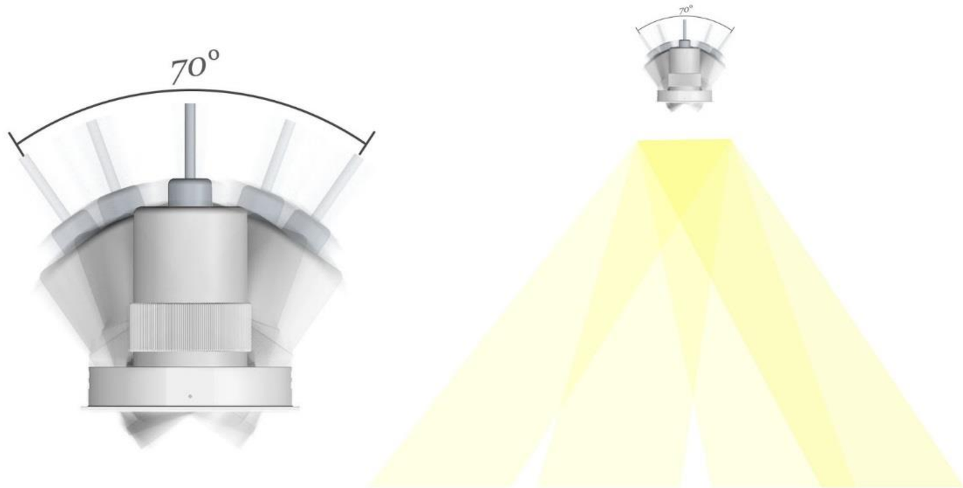

Figure 7.3 Adjustable angle parallel to wall.

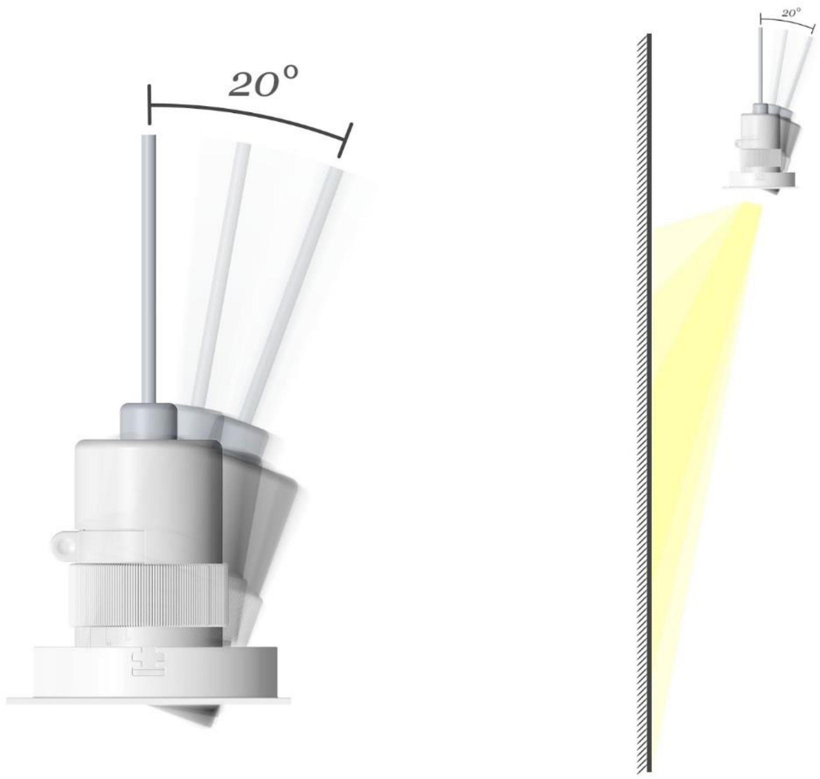

Figure 7.4 Adjustable angle normal to wall.

To provide a sharp and clear light shape at different distance from the wall, the distance between the lenses is adjustable. This is done simply by turning the rotating wheel on the light module, an intuitive motion, which is recognized from, and commonly used on, cameras and binoculars, see Figure 7.5. The scale on the front part indicates the distance between the lenses and creates an easy process when repeating the focus adjustment on additional light modules.

Figure 7.5 Rotating the rotation wheel will adjust the focus of the light shape.

If a more discreet lighting is preferred, the product could be delivered without the middle section. The back lid is then mounted directly on to the front section. With only the prism, a smooth and refined wallwashing effect can be achieved, see Figure 7.6.

Figure 7.6 The light module creates a homogenous plane of light with the prism only.

The additional shade is developed to blend in with the interior and appear as a part of the surrounding architecture. By mimicking the shape of light shafts, and since the top is hidden, the impression of natural light, created by the light shape, is enhanced even more, see Figure 7.7.

Figure 7.7 Photo of the luminaire and light shape.

The shade is modular and it is possible to connect several shades into one unit giving an even more effective visual experience, see Figure 7.8.

Figure 7.8 Three shades connected as one unity

Even though emphasis is on the light shape, the light module has a discrete but appealing look. Mostly it will be seen from below, why great effort has been given to create a smooth transition between the front section, the tilting ring and the module attachment, see Figure 7.9.

Figure 7.9 The light module from below, even though three parts are visible, they appear as one coherent unity.

7.1 Assembly and installation

Since there are many kind of ceilings used in different office environments, the attachment is adaptable to suit the majority of situations. The shade fits perfectly in the 600×600 mm grid of dropped ceilings used in many offices. Simply replace one tile with the shade and the installation is done, see Figure 7.10. The shade consists of aluminum, making it lightweight which facilitates the installation and durability further.

Figure 7.10 Shade installed in dropped ceiling

The shade has a hole where the light module is fastened with springs, the same attachment can be used when the light module is placed directly in a 600×600-tile or other type of ceiling by simply drilling a hole, see Figure 7.11.

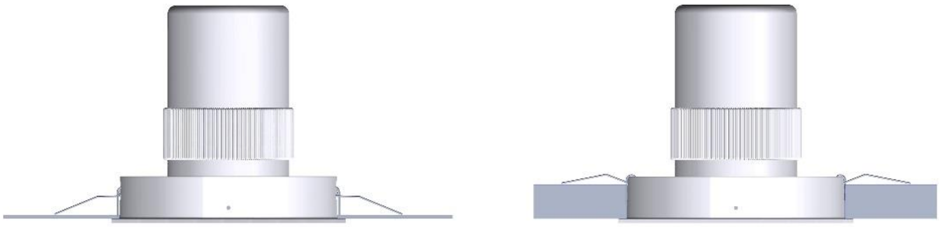

Figure 7.11 The easy attachment onto a shade and onto a tile.

The light module can also be attached directly to a beam, see Figure 7.12, wall or such if there are no inner ceiling. For those cases there is no need for the ceiling attachment, the light module can be mounted on a brick which enables fastening on vertical surfaces.

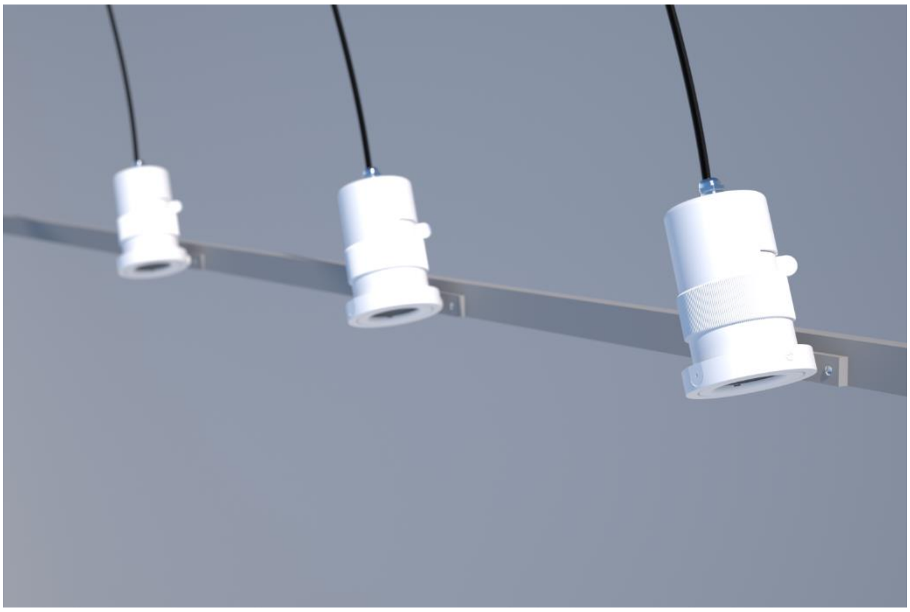

Figure 7.12 Several light modules attached to a beam.

The luminaire will be both intuitive and easy to assemble due to constraints and guidelines. The constraints make it impossible to assembly the non-symmetrical parts incorrect and they facilitate the installation of the prism and the middle section into the main body of the light module, see Figure 7.13. The guidelines are arrows, which should be pointed towards each other. These facilitates the assembly of the rotation wheel on to the main body, the assembly of the main body to the angling adjustment ring and to the module attachment part.

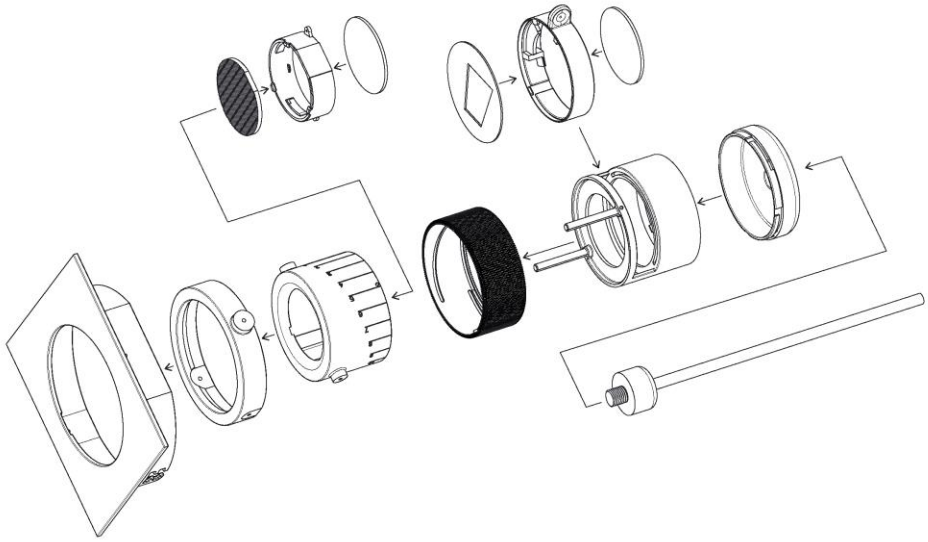

Figure 7.13 How to assembly the light module.

It is critical to install the light module correctly in reference to the wall, otherwise the prism might angle the light away from the wall instead of towards it. By ensuring that the flat side of the module attachment is towards and parallel to the wall, it is easy to know when the installation is correctly performed.

To get the most out of the luminaire, the surface of the wall should be white and matte to reflect the full spectrum sunlight without reducing its qualities and to minimize the risk of glare. If the wallwashing-setting is used, a painting could be lit evenly to get the high quality color perception which can only be provided with sunlight.

The aim of this project was to create a luminaire which enhances the feeling of sunlight and fits the layout and interior in different office buildings. By fulfilling both the accent layer and giving a sparkling element it provides spatiality and creates an interesting environment. By making the product adaptable, both in light output and installation opportunity, it can fit many different and specific requirements.

8 Discussion

In this chapter the method applied, the process and results of this project are discussed. Suggestions for the continuous development of the product are also included.

8.1 Process

The method used in this project, with strict deadlines between the different phases worked well and made it possible to keep the work structured and allowed for iterations within the phases. The initial plan was nearly followed, and the deadlines met, though some tasks had to be neglected since they were seen to be superfluous or better postponed to further development due to time limitations. The method with clear divergent and convergent phases were well suited for the development of the concept.

In the early *discover* phase, a lot of research regarding light and lighting was conducted. In the end, parts of this research were not used and could therefore be considered unnecessary for the project. However, several techniques and a solid base in the understandings of optics were seen to be needed to allow a broad idea generation in the following phases. Both since neither the light shape nor the technique for modifying light were determined at this early stage.

The interviews gave a profound understanding about how light affects humans and different lighting techniques, which were complemented and further confirmed by the literature studies. Without this understanding of light and lighting, the project might have ended up neglecting the design of the light shape, only focusing on the design of the luminaire, which would have been unfortunate.

In the end of the *define* phase the light shape were selected, setting the groundwork for the development of the luminaire. Both here and later in the process, several ideas were discarded, not due to performance but to the time restrictions. For example a dynamic light, where the light shape would transform during the day, would have been the ultimate way to communicate the feeling of sunlight. But this concept was too complicated to develop in the project.

The purpose of choosing the light shape in the end of the *define* phase, was to make the further process more focused and effective. Although, due to the lack of experience and knowledge in the area of optics, the *develop* phase ended being both time and energy consuming. The research had given a theoretical understanding, which was more difficult than expected to apply into practical solutions. As a result, the idea generation became quite limited to well established techniques.

The restricted knowledge about light and optics also led to limitations in the conducted light tests. They were quite exploratory and conclusions were drawn only from what was perceived without any thorough light measurements. The concepts were evolved by trial and error, which in combination with the lack of the right light source, left the result in the final concept quite open for flaws. To summarize the develop phase, it was something outside of the comfort zone, but even though no highly innovative solutions were generated, the authors ended up satisfied, since several working optical concepts were produced.

The final part of the project, the *deliver* phase, contained mechanical construction with focus on aesthetic and user friendly design. In contrary to the *develop* phase, this phase felt comfortable and a high amount of solutions were developed somewhat quickly.

The possibility to 3D-print two prototypes of the light module facilitated the process of testing and evaluating the concepts, which was of high value due to the amount of movable parts. This also led to the realization that the perception of size and scale easily get lost when using CAD. When the first prototype was delivered and assembled the authors became aware of another advantage, the possibility to discuss the construction and the design with people unfamiliar to the project, and new input and ideas were collected.

An initial goal was to deliver a production ready concept, which had to be neglected due to the complexity of the light module. When developing the light module, a greater focus was on creating an intuitive and user-friendly product rather than design for low cost and easy manufacturing. The decision was to deliver a strong concept rather than a production ready product which would be unpleasant and difficult to use.

This project included various methods for selection as a part of narrowing down the scope and moving forward in the design process. In the *define* and the *develop* phases the decisions were quite thorough, and different types of scoring techniques were used. A downside with these are that the exact score numbers can easily be seen as the truth even though they are based on presumptions and estimations. It is therefore important to regard them as indications and as a helping tool in the developing process rather than absolute facts.

The decisions in the *deliver* phase were rather straight forward, mainly considering whether the solutions were feasible. This was the product of underestimating the time consumption of all the planned tasks in this phase. Though, the authors feel that it was the early decisions which needed to be more carefully performed since they were the foundation for the entire concept.

8.2 The final concept and suggestions for further development

The original plan was to create an innovation, far different from usual luminaires and lamp shades. However, the final product became quite similar to a spotlight and in hindsight, it might have been better to gather more information and benchmark other luminaires early in the process. Also, the region Skåne, where the project was carried out, is the location of many luminaire producers. A visit to any of them might have given valuable information and inspirations for the technical design.

The chosen light shapes was well validated, both with basis from the background research and the research done within the project. The aim was to focus on the light, which was certainly fulfilled by creating such a dramatic and unusual light shape. Although, it might be seen as cutting away too much light. Something discussed in the project, but since focus was on the perceived light, the effect was considered to compensate for the missing light radiation. Further development of the optics, regarding the losses in the lenses, the prism and the gobo, would be of great value to optimize the light output.

The aesthetics of the light module became a secondary focus after the mechanical concerns were solved, which led to difficulties to make all the different parts coherent. However, with help from the moodboard, established earlier in the process, the final design evolved into something clean and smooth. Though, before producing the luminaire, beneficial insight might be received if showing the concept for both architects and light designers, getting their professional opinion on the design.

The shape of the shade came quite early in the process and was derived from the idea of creating something of architectural nature. It also came natural in combination with the light shape. The decision to make it fit dropped ceilings felt legitimate due to the frequent use of those kind of ceilings.

The main area for further development should be the selection of material and manufacturing method. However, information regarding the size of the production scale will be needed in order to minimize the costs. When this selection has been made, the light module may need to be redesigned in order to optimize and facilitate the manufacturing process.

In conclusion, a luminaire concept that could be a good complement to Parans existing product portfolio has been developed, with the focus to make the sunlight transported indoors actually look like sunlight.

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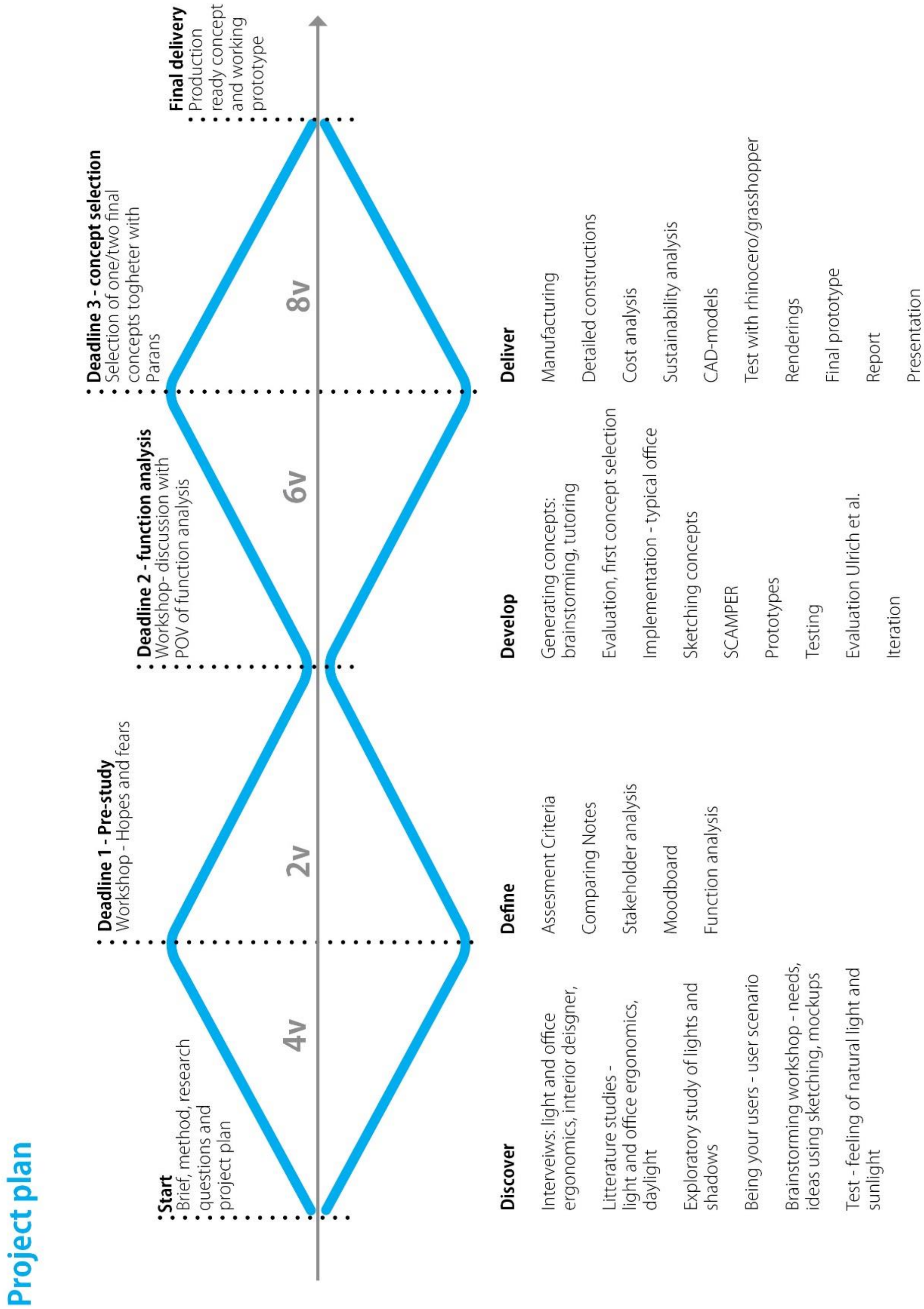
Appendix A: Project plan

A.1 Project plan


Project plan
Start
Brief, method, research questions and project plan
Deadline 1 - Pre-study
Workshop - Hopes and fears
Deadline 2 - function analysis
Workshop- discussion with POV of function analysis
Deadline 3 - concept selection
Selection of one/two final concepts togheter with Parans
Final delivery
Production ready concept and working prototype
4v
2v
6v
8v
Discover
Interveiws: light and office ergonomics, interior deisgner,
Litterature studies - light and office ergonomics, daylight
Exploratory study of lights and shadows
Being your users - user scenario
Brainstorming workshop - needs, ideas using sketching, mockups
Test - feeling of natural light and sunlight
Define
Assesment Criteria
Comparing Notes
Stakeholder analysis
Moodboard
Function analysis
Develop
Generating concepts: brainstorming, tutoring
Evaluation, first concept selection
Implementation - typical office
Sketching concepts
SCAMPER
Prototypes
Testing
Evaluation Ulrich et al.
Iteration
Deliver
Manufacturing
Detailed constructions
Cost analysis
Sustainability analysis
CAD-models
Test with rhinocero/grasshopper
Renderings
Final prototype
Report
Presentation

A.2 Actual outcome

Appendix B: Answers from exploratory light test

Appendix B: Answers from exploratory light test

	1	2	3	4	5	6	7	8
Kön	Kvinna	Man	Man	Man	Man	Man	Man	Man
Ålder	26	24	28	24	25		26	27
Beskriv solljus med tre ord	Varmt, gulorange, skarpt ljus	vitalt, bländande, värmande	Värme, UV, sommar	glädjande, uppiggande, behagligt	varmt, synliggörande, bländande	vitt, bländande, starkt	varmt, skarpt, dag	Värme, Lycka, Naturligt
Hur känns det i kroppen om du fått för lite solljus?	Seg	Tycker att jag blir tröttare än vanligt	Deppigt	deprimerande	Ser dåligt. Inte så pigg	Jag blir trött	Trött och orkeslös	Något dämpad, nästan undermedvetet. (upptäcker det oftast när jag märker skillnaden när jag får lite sol)
Hur kännsd et i kroppen om du fått för mycket solljus?	Trött, seg, utmattad	Det bränner och jag är varm länge	Matt	slött	Varm och seg. Bländad. Huvudvärk	Får nog huvudvärk	utmattad, värsta fall bränd	Snurrigt, trött, varm
Vilken typ av ljuskälla (lampa) tycker du känns mest som solljus?	Wake up light, som att vakna till gryningsljus	Stora strålkastare på typ fotbollsstadion	Stor frostad lampa med varmt vitt ljus	Jag tycker att glödlampor ger ett väldigt behagligt ljus men det är ändå långt ifrån att vara likvärdigt med solljus. Hade den varit möjligt att ha solljus inne hade jag valt det framför dagens lösningar.	Det ska vara ganska varmt och starkt. Traditionella glödlampor i rätt lampa	Glödlampa för dess "varma" ljussättning.	Taklampor, lysrör de som är lite vitare i ljuset. Dock är det kallare än solljus	Någon form av större ljuskälla. Kanke en ljusvägg typ. Inte för gult ljus. Mer åt vita hållet.
A: Beskriv känslan av det här ljuset?	Kallt i mitten, ganska varmt i kanterna	Päron, ljummen i temp. Skillnad i ljuset, kallare i mitten. Distinkt ljuskägla med skarpa kanter. Ganska härlig känsla, inte bländande.	Nattlampsbelysning, sänglampa, lässtämning	lite bländande fast ändå mörkt, ljustet kommer i ögonen men lyser inte upp rummet.	Matt och lite vek. Det känns inte så starkt. Men bra att läsa i (håller handen under). Lite dött. Vill inte säga kallt, men inte heller varmt.	Lagom. Den är mycket mer intensiv i mitten än i kanterna. Ingen honomgen ljussättning, vilket är jobbigt - beror säkert på att man måste ändra ögoninställning.	Varmt, lite rödgult. Inomhus. Inte så bra för detaljerat arbete	Mysig och privat. Det beror nog på formen. Den är härlig för den är rund som ett ägg. Kollar på vad ljuset kommer ifrån, och en nattlampa känns privat.
B: Beskriv känslan av det här ljuset?	Nästan likadan som den förra (A). Känns bättre när man kapat bort ljuskällan. Större ljuskälla trots samma lampa.	Irriterande att den går över kanten. Känns svagare än A. Vitt Ljus. Samma skifte i ljus som i A, olika färger i käglan. Begränsad i sitt omfång. Man måste kolla mot den för att uppleva ljuset.	Typ samma som A. Lite korridors, ledbelysning. Som såna i korridorer i rad. Känns mer riktad då ljuskällan inte syns.	Mindre blöndanden, kanske mer ljus är A. Mer behagligt pga slipper ljuspunkten, det blir skönare att kolla på. Ljuset är mer där det ska vara, där det ska lysa upp.	Känns påfallande likt förra. Men lite större.	Samma ljus känns det som. Ingen större skillnad mot A. Lite mer utspritt pga ytan. Den är kall i mitten.	Lite vitare, mer kliniskt. Suddigare mot kanterna (än A).	Mer offenligt även om ljust är likt A. Men eftersom man inte ser ljuskällan ser den större ut. Ljuset är bara där utan att man ser vad det kommer ifrån. Det ser ut som en brevlåda.
A&B: Vilket ljus känns mest som solljus?	B - känns inte så solljusigt med lampan. Det stämmer inte överrens med den mentala modellen av solljus.	B- som solljus i snö. Den ser ut som om det strålar ner. A känns gulare.	A - pga mer varierat. Känns som inne, som om det gått genom fönster. Solljus känns jämnt, men kan påverkas av glas och skuggor så att det blir varierat.	A - för den känns varmare, även om det kanske är samma lampa. Den är lite gular vilket också känns som solljus.	B- Som något som är belyst av solen. A är mer som att titta in i solen. Inget känns direkt som sol	A - för den känns varmare. B är mer som en molnig dag.	Inte något av dem. De ser konstgjorda ut pågrund av snabbt slut vid kanterna. Solljus hade fortsatt. Det är ganska mörkt trots att det är upplyst. Men kanske B. A ser gulat ut.	B - Vit känns mer som solen. A ser gulare ut, längst upp. Gult känns artificiellt.
C: Beskriv känslan av det här ljuset?	Sömnig, skymningsljus, trött, behaglig. Det är nyansen, att den är dov och utan skarpa kanter som gör en sömnig. Inte formen,	Sagolik känsla. Månsken nästan. Sjukt tydlig kant. Tre ljus i ett. Distinkt mitt och sen fade i kanterna. Oregelbundet, förvirrande men skönt att det inte är helt runt. Obekvämt om man kollat för länge.	Mörk lokal eller natt. Svårt att säga känsla utan kontext. Kvälls- eller månljus	Mystiskt, dallrar som om något slög omkring. Svårt att fokusera på, känns som om jag set debbelt. Som att ha kollat på en lampa och sedan kollar på en ljus vägg.	Svagt, varmt, diffus ljuskägla, inte helt vitt. Mysigt pga gulaktigt	Väldigt gulaktigt, en sepia ton. Den är jobbig att se på för att den stämmer inte och är osymterisk. Det är inte ett naturligt sätt för ljus att sprida sig på.	Julljus. Mysfärg pga dovt. De andra (A&B) var skarpare. Dåligt att arbeta i, ser inget. Man kan ta det lugnt för man kan inte använda ljuset till något.	Skymning, kväll - för att det är gult. Gatulampa - Det är nog för att den är gul och kanske pga formen också. En äldre variant av gatulampa.
D: Beskriv känslan av det här ljuset?	Inte lika sömnig som på C. Kanske har med formen att göras, den är lite som ett fönster.	Samma ljus som förra, fast det känns inte som det. Först kändes det som ljus genom fönster, men sen ser det mer ut som om det kommer från en fyrkantig ljuskälla. Känns som sagoljus. Ser ut som en skärm från sidan.	Ljus som letar sig in i mörk lokal, typ källarfönster. Pga formen. Känns styrt och manipulerat	Lättare att fokusera på pga still och att formen är kantig. Den har tydligare avgränsningar som också gör det lättare att fokusera. Den andra (C) är mer oskarp i kanterna och har därför inget tydligt slut. Mystisk och spöklik som ett spöke i filmer eller som en spök-tv.	Kantigt och därför inte så mysigt. Fin färg, ganska varm. Känns som bil på natten, strålkastarljuset. Placeringen gör att det skulle kunna vara ett fönster (i hus).	Känns som en biografduk pga formen och ljusstryrkan. Halvjobbigt att det är så stark ram.	Liknar det andra, känns också mys. Som en fönsterruta som lyser igenom eld. Känns som naturlig eld snarare än konstruerat.	Offentlig plats, typ köpcenter. Runda ljuskällor är vanligare i hemme, där man lyser upp något specifikt. Fyrkantiga ljuskällor lyser upp en hel yta. Den fyrkantiga gör en piggare, den känns mer som dag.
C&D: Vilket ljus känns mest som solljus?	D - pga fönsterkänsla. Det finns mer ljus där ute. Man är också mer van vis att se solljus i den här formen.	D- Pga formen. Kopplar till fönster, fast nä den är lurig. Man ser sällan formen (C), det är sällan som solen lyser in genom ett runt hål i en vägg. Borde inte bli så mycket spridning med solljus. Solljus borde ge skarpare kanter (om både C och D)	D- pga C känns mer som månljus. D känns instängd, som om ljuset passerat någonting, C känns goare.	C - Trots lika ljus så känns den mer som en sol pga formen. Båda känns solaktiga - som om det är disigt ute.	C- ljuskäglan påminner om sol. Den är klarare i mitten.	C - Mest lik en sol till formen, mer naturligt sätt att sprida sig på.	D- Ser ut som reflektion av solljus. Pga utformning, det tonar från mitten och utåt. Känns som solnedgångsljus. C känns konstruerat.	C - (spontant) mkt pga att den är starkare och lite vitare. Om C och D var lika starka hade jag valt D, känns det som. En rund form känns mer som en lampa än ett fönster.
Vilket ljus, av alla vi testat, gillade du bäst?	D - Den är spännande och det händer mer än på de andra.	B- tilltalade mig mest. Gillade formen och ljuset.	C - känns nyare. Men svårt att bestämma sig utan kontext	A - För den känns som en glödlampa, jag gillar det. Det känns behagligt och naturligt, kanske för att jag är uppväxt med det. Det känns som naturligt ljus inomhus. Plus att de är coola.	B - pga blir bländad av A. C och D associerar jag mer till färgen. B gör det ljus så att man ser bättre	A - Känns mest lagom i styrka.	Beror på vad jag ska ha det till. Pilljobb: A eller B. Om det är till vardagsrum passar de andra bättre pga varmare.	B - Gillar äggformen, den är en blandning mellan cirkel och fyrkant. Den är som ett scenljus, som en spotlight. Dillar inte att se ljuskällan.
Vilket ljus, av alla vi testat, kändes mest som solljus?	Alla på olika stadier men lite mer på C och D, solljust beters sig dovt sov de gör. Solljus brukar inte vara så koncentrerat som på A och B, solljus beter sig inte så.	B - Den har rätt intesitet. Samt färgen och formen.	D- Känns väldigt likt solljus som letat sig in.	A - som solljus mitt på dagen. C&D - som solljus om det är disigt och deras form är mer solig.	A och B uppfattar jag mer som solljus för att de är starkare. A påminner om sol, B något som blir belyst av sol.	B - Solljus är ljust och inte så varmt som man brukar framställa det som.	D- Det är närmare väggens ljussättning och flöt in i nyansen av väggen. (inte så hög kontrast)	B - Ljusast, mest vit, ser ej ljuskällan. Tänker ej på solen utan på ett ljus som bara existerar, har ej lika tydligt slut. På den fyrkantiga och den runda ljuskäglan vet man när den tar slut, för att det är så vanliga former. Formen från B är inte lika sj'lvklar, mer fri och inte lika kontrollerad.

Appendix C: Questionnaires

A.3 First questionnaire

Enkät om ljus

Hej!

Vi är två studenter från Lunds Tekniska Högskola och just nu skriver vi vårt examensarbete i teknisk design. Examensarbetet görs i samarbete med Parans Solar Lighting som har utformat en teknik för att leda in solljus med hjälp av optisk fiber.

Solljuset upptas av solfångarna på taket (1), leds in i byggnaden med optisk fiber (2), för att sedan spridas ut i rummet genom en armatur (3). Med denna teknik kan solljus ledas in i rum som inte har tillräckligt solljusinsläpp via fönster, t.ex. rum långt inne i djupa byggnader.

I projektet fokuserar vi på belysning av fikarum som har behov av extra solljus.

Vi vore väldigt glada om du skulle vilja hjälpa oss genom att besvara den här enkäten. Det tar max 5 min.

Tack på förhand!

Anja och Petra

1. Ålder

(Ange endast ett svar)

Yngre än 25 år	25-34 år	35-44 år	45-54 år	55-65 år	Äldre 65 år
❑	❑	❑	❑	❑	❑

2. Kön

(Ange endast ett svar)

Kvinna	Man	Annat
❑	❑	❑

3. Inom vilken sektor arbetar du?

(Ange endast ett svar)

Privat	Offentlig
❑	❑

4. Till vilket yrke vill du räkna ditt arbete? (exempelvis lärare)

_ _

5. Hur många dagar i veckan jobbar du?

(Ange endast ett svar)

1	2	3	4	5	6	7
❑	❑	❑	❑	❑	❑	❑

6. Hur många timmar är en normal arbetsdag för dig?

(Ange endast ett svar)

<4	4	5	6	7	8	9	10	11	12	>12
❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑

7. Vilken typ av kontorslokal arbetar du i?

(Ange endast ett svar)

Cellkontor - Individuella kontorsrum	Öppet kontorslandskap	Kombikontor - Kombination av cellkontor och öppet landskap	Flexkontor - Ingen fast arbetsplats	Aktivitetsbaserade kontor - Ingen fast arbetsplats, denna bestäms utifrån arbetet som ska utföras
❑	❑	❑	❑	❑

8. Hur många procent av din arbetstid spenderar du i arbetsplatsen lokaler?

(Ange endast ett svar)

<10 %	10-20%	21-30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%
❑	❑	❑	❑	❑	❑	❑	❑	❑	❑

Nu följer frågor om pauser och fikaraster.

I denna enkät syftar pauser på avbrott i arbetet där du lämnar din kontorsplats.

9. Hur ser fikarummet på din arbetsplats ut? Beskriv kort (antal platser, fönster, belysning)

_ _

_ _

_ _

10. Hur vill du ha det i ditt fikarum? Beskriv det ultimata fikarummet för att ge ny energi.

_ _

_ _

_ _

11. Hur ofta och länge tar du paus under en arbetsdag? Nedan kan du fylla...

(Sätt endast ett kryss per svar för följande : Ungefär när börjar pausen?, Hur lång är pausen?)

	Ungefär när börjar pausen?														Hur lång är pausen?								
	Innan 8	Kl 8	Kl 9	Kl 10	Kl 11	Kl 12	Kl 13	Kl 14	Kl 15	Kl 16	Kl 17	Kl 18	Kl 19	Efter kl 19	Kortare än 5 min	5-10 min	11-20 min	21-30 min	31-40 min	41-50 min	51-60 min	61-70 min	Längre än 70 min
Paus 1	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Paus 2	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Paus 3	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Paus 4	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Paus 5	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Paus 6	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑

12. Har ni bestämda tider för pauser (utöver lunchpaus) på din arbetsplats?

(Ange endast ett svar)

Ja, alla möts i fikarummet vid dessa tider	Ja, men nästan ingen följer dessa tider	Nej, men alla fikar samtidigt ändå	Nej, vi fikar inte tillsammans
❑	❑	❑	❑

13. Av vilken anledning tar du paus? Du kan välja fler alternativ

(Ange gärna flera svar)

❑ Sällskap

❑ Avbrott i arbetet

❑ Kaffebehov

❑ Miljöombyte

❑ Vara ifred

❑ Diskutera arbetsrelaterade frågor

❑ Träning

Annat, nämligen

_ _

_ _

_ _

14. Hur ofta spenderade du din paus utomhus förra månaden?

(Ange endast ett svar)

Flera gånger varje dag	En gång per dag	Några gånger per vecka	En gång per vecka	En gång	Aldrig
❑	❑	❑	❑	❑	❑

15. Av vilken anledning går du inte ut? Du kan välja fler alternativ

(Ange gärna flera svar)

❑ Tidsbrist

❑ Spenderar tillräckligt mycket tid utomhus på fritiden

❑ Ser inget behov

Annat, nämligen

_ _

_ _

_ _

16. Av vilken anledning går du ut? Du kan välja fler alternativ

(Ange gärna flera svar)

- ❑ Miljöombyte
- ❑ Ärenden
- ❑ Frisk luft
- ❑ Solljus
- ❑ Rökning
- ❑ Motion

Annat, nämligen

_ _

_ _

_ _

17. Vilket av de två rummen skulle du säga har solljusinsläpp?

(Ange endast ett svar)

Rum A	Rum B
❑	❑

18. Motivera varför alternativ A känns som solljus

19. Motivera varför alternativ B känns som solljus

20. Vilket rum skulle du föredra att ha som fikarum?

(Ange endast ett svar)

Rum A   Rum B

❑ ❑

21. Motivera varför du föredrar A

____

____

____

22. Motivera varför du föredrar B

____

____

____

Tack för att du har tagit dig tid för att hjälpa oss i vårt projekt!

Kontakta oss gärna på anja.sandberg.600@student.lu.se eller petra.kopp.806@student.lu.se om du har några frågor eller idéer kring projektet.

/Anja och Petra

Glöm inte att trycka på "skicka" för att avsluta enkäten och skicka in dina svar!

A.4 Second questionnaire

Enkät om ljus

Hej!

Vi är två studenter från Lunds Tekniska Högskola och just nu skriver vi vårt examensarbete i teknisk design. Examensarbetet görs i samarbete med Parans Solar Lighting som har utformat en teknik för att leda in solljus med hjälp av optisk fiber.

Vi vore väldigt glada om du skulle vilja hjälpa oss genom att besvara den här enkäten. Det tar max 1 min.

Tack på förhand!

Anja och Petra

1. Ålder

(Ange endast ett svar)

Yngre än 25 år	25-34 år	35-44 år	45-54 år	55-65 år	Äldre 65 år
❑	❑	❑	❑	❑	❑

2. Kön

(Ange endast ett svar)

Kvinna	Man	Annat
❑	❑	❑

3. Inom vilken sektor arbetar du?

(Ange endast ett svar)

Privat	Offentlig	Annan
❑	❑	❑

4. Till vilket yrke vill du räkna ditt arbete? (exempelvis lärare)

_ _

5. Vilket av de två rummen skulle du säga har solljusinsläpp?

(Ange endast ett svar)

Rum A	Rum B
❑	❑

Tack för att du har tagit dig tid för att hjälpa oss i vårt projekt!

/Anja och Petra

Glöm inte att trycka på "skicka" för att avsluta enkäten och skicka in dina svar!

Appendix D: Officonas

A.5 Smile Dental Clinic

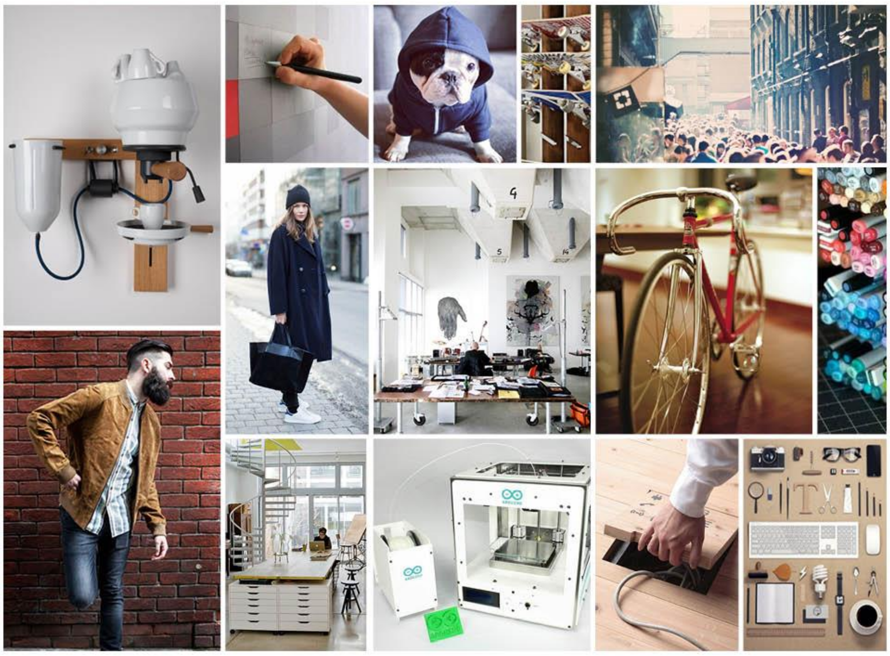
Smile Dental Clinic is a private dental practice located in the center of Copenhagen. The workforce consists of three dentists and nine dental nurses. At Smile Dental Clinic, the workload can sometimes be stressful for the nurses since some of the clients are very demanding and the nurses job is to make them feel taken care of in any situation. Because of the demanding clients, the employees sees much value in their break room. It is their own space where they can escape the rush and take a much needed coffee. Due to the small workforce, the atmosphere amongst the employees are warm and friendly.

The management want the atmosphere at the clinic to be calm and peaceful, both for the sake of the employees as well as for their clients. The clients should feel safe and the environment should convey health and cleanness; the goal is to be sterile but yet cozy. This goal has made them invest in a renovation and a completely new interior at the clinic.

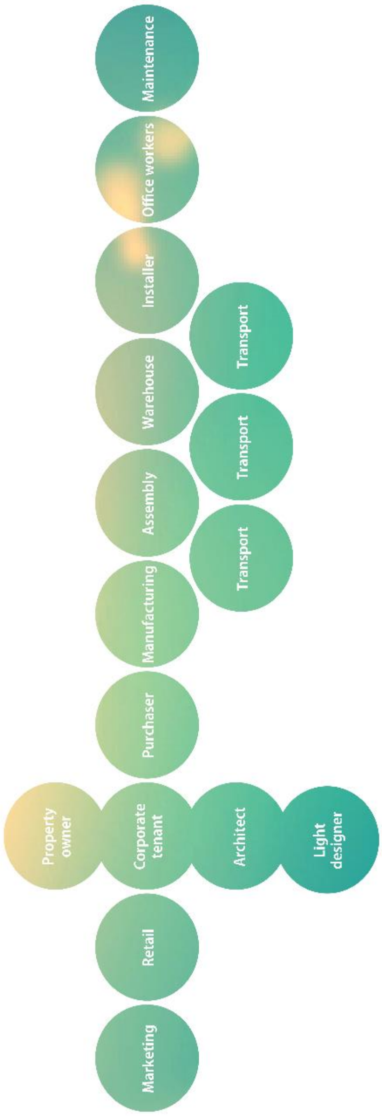
A.6 The young media bureau

The London based advertising agency Bulldog believes that they are different from any other agency. They offer services in branding, advertising, production and web development. The team of eight employees (the office loveable puppy included) consists of a young homogenous group that really likes spending time together, even outside the office. Every Friday they have an after work at the office, which often continues to a pub nearby.

Bulldog are famous for their innovative solutions and crazy campaigns. They want their office to convey this and that they are always up to date with the latest. The office interior consists of the latest designer furniture in combination with random stuff found on Brick Lane market.



Appendix E: Stakeholders



Appendix F: Function analysis

MF: main function, N: needed function, D: desired function

Category	Verb	Noun	Comment	Type
Brief	Distribute	Sunlight	only	MF
Architect/Lighting designer	Maximize	Usability		N
Architect/Lighting designer	Offer	Light calculations		N
Architect/Lighting designer	Offer	Understanding		N
Architect/Lighting designer	Possess	Versatileness		N
Assembly	Allow	manual assembly		N
Assembly	Allow	Standard tools		N
Assembly	Eliminate	Hazards		N
Assembly	Minimize	Injuries		N
Background	Alienate	artificial light		N
Background	Avoid	Glare		N
Background	Communicate	Naturalness		N
Background	Communicate	Sunlight		N
Background	Facilitate	Light modulation	vertical surface	N
Background	Fulfill	Accent layer		N
Background	Illuminate	Vertical surfaces		N
Background	Minimize	Light loss		N
Background	Provide	Light data		N
Background	Receive	60 light spread angle	60	N
Background	Stimulate	Circadian system		N
Brief	Allow	Small scale	assembly, production, storage, transportation	N
Brief	Communicate	Parans' vision		N
Brief	Convey	Brightness		N
Brief	Convey	Variation		N
Brief	Enhance	Sunlight		N

Category	**Verb**	**Noun**	**Comment**	**Type**
Brief	Fit	Office environment		N
Brief	Fit	SP3		N
Brief	Fit	SP4		N
Brief	Illuminate	Surface		N
Brief	Protect	Environment		N
Brief	Provide	Indirect light		N
Brief	Provide	Naturalness		N
Brief	Reduce	Overheads		N
Brief	Support	light variation		N
Brief	Target	new market segment		N
Installation/maintenance	Allow	Component replacement		N
Installation/maintenance	Enable	Standard tools		N
Installation/maintenance	Minimize	Hazards		N
Landlord	Actuate	Interest		N
Landlord	Allow	adjustment	angle	N
Landlord	Allow	Relocation	luminaire when installed	N
Landlord	Convey	Premiumness		N
Landlord	Convey	Value		N
Landlord	Enable	Combination	with other light sources	N
Landlord	Fit	Interior		N
Landlord	Fit	Building dimensions		N
Landlord	Insure	Functionality		N
Landlord	Maximize	Life span	luminaire	N
Manufacturing	Enable	Short-series		N
Manufacturing	Reduce	Hazards		N
Moodboard	Convey	Clean		N
Moodboard	Convey	Color blocking		N
Moodboard	Convey	Strict curves		N
Moodboard	Suit	Moodboard		N
Office employee	Convey	Light variation		N
Office employee	Convey	Naturalness		N
Office employee	Convey	Sunlight		N
Office employee	Maximize	Light experience		N
Office employee	Own	Beauty	on and off	N

Category	**Verb**	**Noun**	**Comment**	**Type**
Officonas	Communicate	Drive		N
Officonas	Increase	Brand value		N
Questionnaire	Increase	Sunlight intake		N
Questionnaire	Own	Room independence		N
Tests	Maximize	Light intensity		N
Architect/Lighting designer	Allow	Innovation		D
Architect/Lighting designer	Convey	Mindset of today	Environment...	D
Architect/Lighting designer	Convey	Uniqueness		D
Architect/Lighting designer	Illustrate	Trend consciousness		D
Architect/Lighting designer	Minimize	Installation limitations		D
Architect/Lighting designer	Offer	Changeability		D
Architect/Lighting designer	Offer	Color variation	on luminaire	D
Architect/Lighting designer	Offer	Creativity		D
Architect/Lighting designer	Offer	Energy calculations		D
Architect/Lighting designer	Offer	Visualization		D
Architect/Lighting designer	Optimize	Light distribution		D
Architect/Lighting designer	Personalize	Light beam		D
Architect/Lighting designer	Possess	Agelessness		D
Assembly	Allow	Bottom up assembly		D
Assembly	Allow	Inexperience		D
Assembly	Avoid	Obstruction		D
Assembly	Avoid	Tight tolerances		D
Assembly	Contain	Constrains		D
Assembly	Contain	Self-aligning		D
Assembly	Contain	Standard components		D

Category	**Verb**	**Noun**	**Comment**	**Type**
Assembly	Enable	One man assembly		D
Assembly	Facilitate	Error-handling		D
Assembly	Facilitate	Fixturing		D
Assembly	Maximize	Rate		D
Assembly	Maximize	Symmetry		D
Assembly	Minimize	Scratching sensibility		D
Assembly	Minimize	Assembly-levels		D
Assembly	Minimize	Damage		D
Assembly	Minimize	Force		D
Assembly	Minimize	Tolerance sensitivity		D
Assembly	Minimize	Reorientation		D
Assembly	Own	Simplicity		D
Assembly	Prevent	Disassembly		D
Assembly	Reduce	Errors		D
Assembly	Reduce	Parts		D
Assembly	Simplify	Handling		D
Assembly	Simplify	Packaging		D
Assembly	Utilize	Color codes		D
Assembly	Utilize	Gravity		D
Assembly	Utilize	Self-fastening		D
Background	Avoid	Sleepiness		D
Background	Avoid	Stress		D
Background	Avoid	Visual noise		D
Background	Carry	Information	time, weather, location	D
Background	Convey	Activeness		D
Background	Convey	Corporateness		D
Background	Create	Illusions		D
Background	Differentiate	from sunlight outside		D
Background	Enhance	Color difference		D
Background	Enhance	Dynamics		D
Background	Enhance	Retina illumination		D
Background	Enhance	Visual size		D
Background	Enhance	Image quality		D
Background	Focus	On light		D

Category	**Verb**	**Noun**	**Comment**	**Type**
Background	Fulfill	Sparkling layer		D
Background	Hide	Source		D
Background	Imitate	Architectural style		D
Background	Imitate	Skylight		D
Background	Imitate	Sunlight through slots		D
Background	Imitate	Sunlight through windows		D
Background	Improve	Mood		D
Background	Indicate	Anonymity		D
Background	Lit	Wall		D
Background	Mimic	Light patterns	normal in offices	D
Background	Mimic	Subtractive process		D
Background	Minimize	Modification	(stay natural..)	D
Background	Optimize	Contrast levels		D
Background	Optimize	Stimuli		D
Background	Outshine	artificial light		D
Background	Prevent	SAD		D
Background	Prevent	SBS		D
Background	Project	Direct light	on wall	D
Background	Provide	Color variation	on surface	D
Background	Provide	Interest		D
Background	Provide	Sunbeam variation		D
Background	Provide	Theme	for the room	D
Background	Provide	View		D
Background	Reduce	Gloom		D
Background	Save	Energy		D
Background	Spread	Full spectrum light		D
Background	Transmit	460-480 Nm Light		D
Brief	Allow	Local manufacturing		D
Brief	Allow	Local assembly		D
Brief	Convey	Playfulness		D
Installation/maintenance	Contain	Modules		D
Installation/maintenance	Enable	Adjustment	after installation	D
Installation/maintenance	Enable	One man installation		D
Installation/maintenance	Facilitate	Installation		D

Category	**Verb**	**Noun**	**Comment**	**Type**
Installation/maintenance	Facilitate	Reparations		D
Installation/maintenance	Facilitate	Troubleshooting		D
Installation/maintenance	Minimize	Adjustment	for different properties	D
Installation/maintenance	Minimize	Installation space		D
Installation/maintenance	Minimize	Installation steps		D
Installation/maintenance	Minimize	Modification needs		D
Installation/maintenance	Minimize	Tools		D
Installation/maintenance	Facilitate	Handling		D
Installation/maintenance	Own	Intuitiveness		D
Installation/maintenance	Reduce	Error		D
Installation/maintenance	Reduce	Fasteners		D
Installation/maintenance	Reduce	Labor		D
Installation/maintenance	Reduce	Product damage		D
Installation/maintenance	Simplify	Unpacking		D
Installation/maintenance	Utilize	Color coding		D
Installation/maintenance	Utilize	Self-fastening		D
Installation/maintenance	Utilize	Standard fasteners		D
Landlord	Actuate	Hype		D
Landlord	Convey	Goodwill		D
Landlord	Decrease	energy-consumption	property	D
Landlord	Eliminate	Irritation		D
Landlord	Emphasize	Quality		D
Landlord	Fit	Ecophon		D
Landlord	Illustrate	Style	moodboard	D
Landlord	Improve	Pause environment		D
Landlord	Increase	Property value		D
Landlord	Increase	Workspaces	number	D
Landlord	Joy	Employees		D
Landlord	Minimize	Costs		D
Landlord	Minimize	Maintenance		D
Landlord	Minimize	Packaging		D
Landlord	Possess	Mainstreamness		D
Landlord	Possess	Prestige		D
Landlord	Satisfy	Employees		D
Landlord	Simplify	Installation		D

Category	**Verb**	**Noun**	**Comment**	**Type**
Manufacturing	Allow	Eco-friendliness		D
Manufacturing	Allow	Low cost material		D
Manufacturing	Allow	Recycling		D
Manufacturing	Enable	Stockholding		D
Manufacturing	Encourage	Recycling		D
Manufacturing	Enhance	Communication	between Parans and manufacturer	D
Manufacturing	Facilitate	Disassembly		D
Manufacturing	Maximize	Rate		D
Manufacturing	Minimize	Costs		D
Manufacturing	Minimize	Energy consumption		D
Manufacturing	Minimize	Equipment		D
Manufacturing	Minimize	Material variations		D
Manufacturing	Minimize	Waste		D
Manufacturing	Minimize	Weight		D
Manufacturing	Optimize	Surface finish		D
Manufacturing	Reduce	Material		D
Manufacturing	Use	Local source		D
Office employee	Actuate	Pause		D
Office employee	Actuate	Sunlight interest		D
Office employee	Convey	Benefits		D
Office employee	Convey	Employee appreciation		D
Office employee	Convey	Oasisness		D
Office employee	Create	Surrounding awareness	direct surrounding outside office	D
Office employee	Decrease	Fatigue		D
Office employee	Encourage	Pause		D
Office employee	Enhance	Spontaneity		D
Office employee	Enlighten	Variation benefits		D
Office employee	Increase	Alertness		D
Office employee	Increase	Well-being		D
Office employee	Influence	Office environment		D
Office employee	Maximize	Pause experience		D
Office employee	Minimize	Irritation		D
Office employee	Offer	Conversation topic		D
Office employee	Offer	Stimulation		D

Category	**Verb**	**Noun**	**Comment**	**Type**
Office employee	Provide	Energy		D
Office employee	Provide	Variation		D
Office employee	Shape	Office environment		D
Officonas	Enhance	Uniqueness		D
Officonas	Improve	Style		D
Officonas	Increase	Performance		D
Questionnaire	Control	Sound level		D
Questionnaire	Encourage	Creativity		D
Questionnaire	Enhance	Social interaction		D
Questionnaire	Enlighten	break room importance		D
Questionnaire	Provide	Clear shapes		D
Questionnaire	Provide	High contrasts		D
Questionnaire	Provide	Inspiration		D
Tests	Fake	Sunlight		D
Tests	Project	square shape		D
Manufacturing		Raw material		
Manufacturing		Size		
Manufacturing		Thickness		

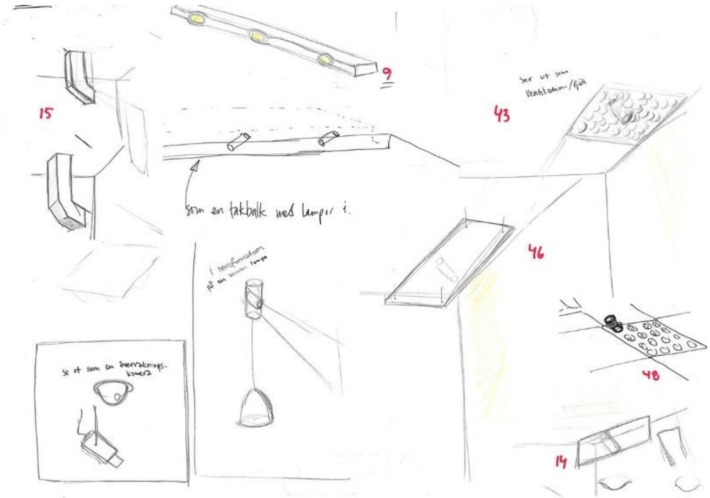
Appendix G: Concept scoring – Optical concept

		Theatre without prism		Theatre with prism		OH without prism		OH with prism		OH long mirror and prism		Light guide	
		rank	weighted rank	rank	weighted rank	rank	weighted rank	rank	weighted rank	rank	weighted rank	rank	weighted rank
Size	0,1	3	0,3	3	0,3	2	0,2	2	0,2	1	0,1	2	0,2
Height	0,2	2	0,4	2	0,4	2	0,4	2	0,4	2	0,4	3	0,6
Complexity	0,15	3	0,45	2	0,3	2	0,3	1	0,15	1	0,15	2	0,3
Standard components		yes		prism		mirror		mirror, prism		mirror, prism		lightguide	
Adjustments needed		angle in two planes, distance between lenses		angle in two planes, distance between lenses		lamp angle, mirror angle, distance between lenses, distance between lens and mirror		lamp angle, mirror angle, distance between lenses, distance between lens and mirror		lamp angle, mirror angle, distance between lenses, distance between lens and mirror		angle	
Amount of components		2 lenses, pattern		2 lenses, pattern, prism		2 lenses, mirror, pattern		2 lenses, mirror, pattern, prism		2 lenses, mirror, pattern, prism		lightguide	
Light performance	0,5	1	0,5	3	1,5	2	1	1	0,5	3	1,5	1	0,5
Intensity		--		+		++		-		+		0	
Shape		--		+		+		--		+			
Homogeniousity		--		+		--		--		+			
Risk of glare		non		non		non		non		risk		non	
Development progress	0,05	3	0,15	3	0,15	2	0,1	2	0,1	2	0,1	1	0,05
Sum	1		1,8		2,65		2		1,35		2,25		1,65
Rank			4		1		3		6		2		5

Appendix H: Aesthetical design concept groups

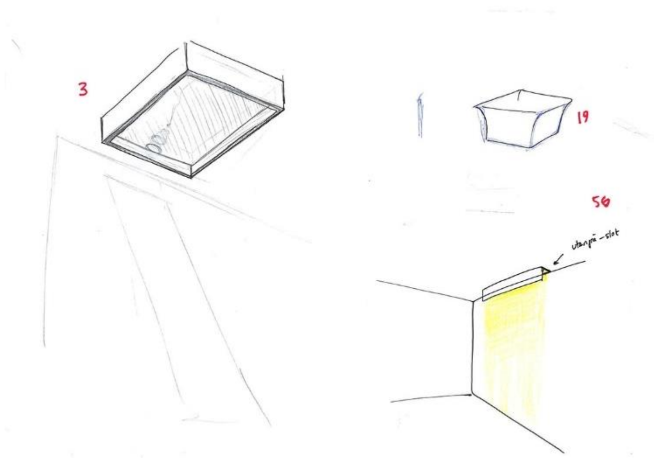
Camouflage

Invisible by their similarity to ordinary objects such as the ventilation, these concepts aim to fulfill the requirements *hide light source* and *alienate artificial light.*



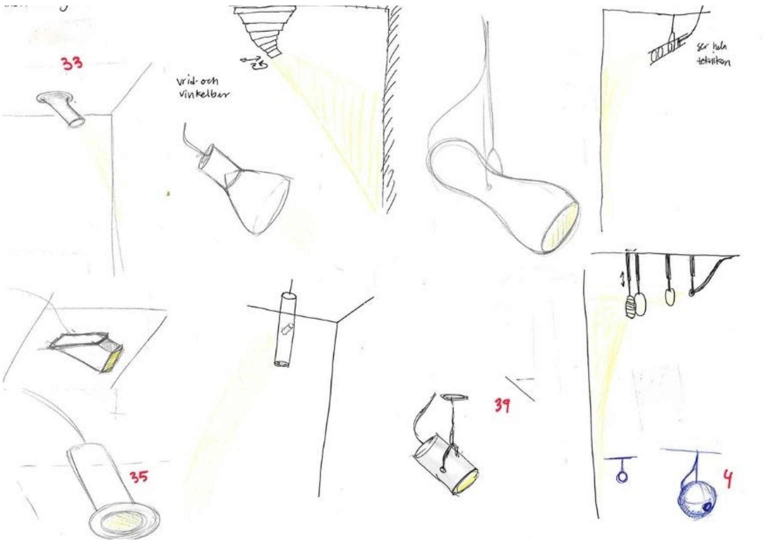
Window imitation

By the similarity to a skylight or a window these concepts are targeting a strong connection to sunlight.



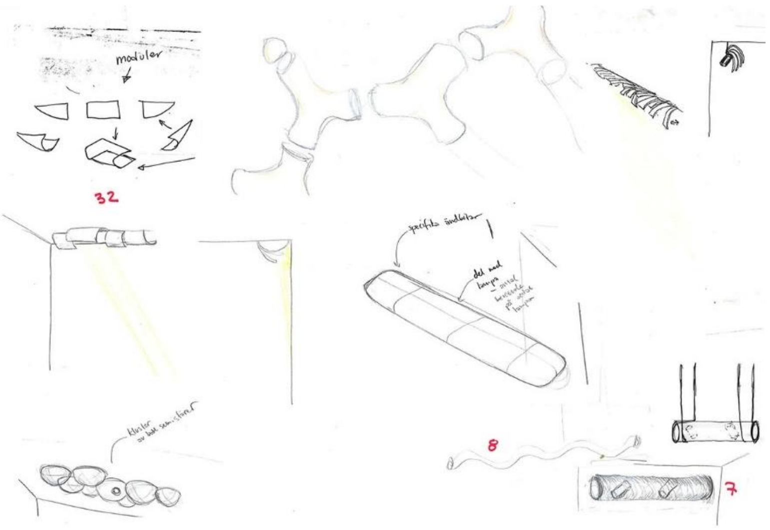
Simple revealing

These concepts clearly shows where the light is coming from, though the small size and the clean design create a discrete object which gives focus on the light shape instead.



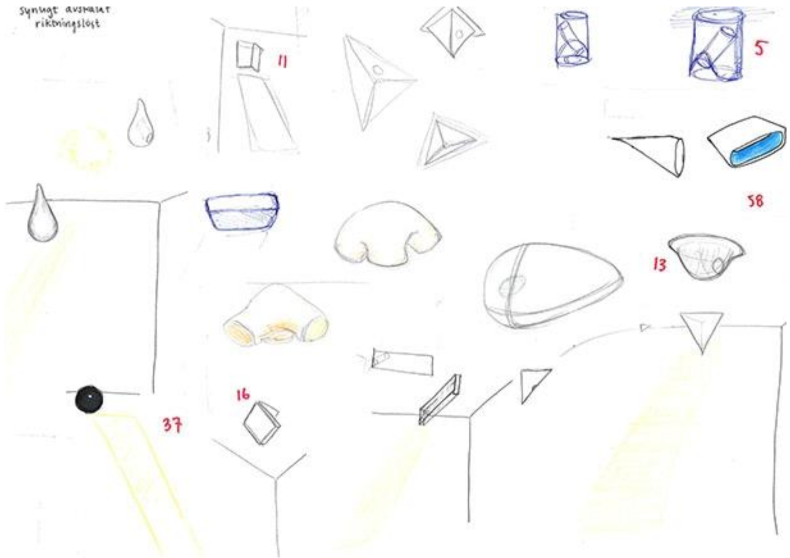
Obvious modules

By the modularity several light sources could be placed beside each other and create one unity.



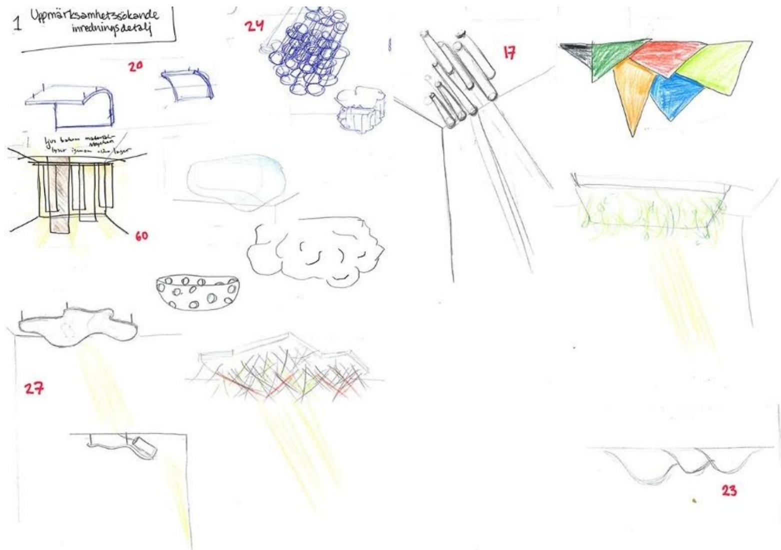
Visible clean directionless

By having no direction, these concepts separates the light shape from the source.

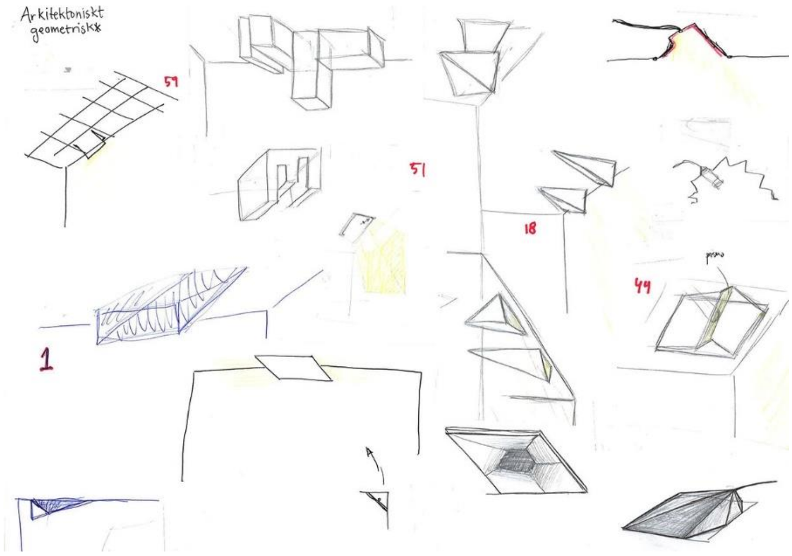


Attention seeking interior accessory

From the shapes in the moodboard, these concepts were created to draw attention, though without revealing the light source attached.



Architectural geometric
By merging the design with the room so that it resembles an architectural feature these concepts are giving the impression that the light is coming from an opening in the building, hence coming directly from the sun.



Architectural organic
These concepts are similar to the previous concepts but with more organic shapes and therefore they fit the moodboard in a distinct way.

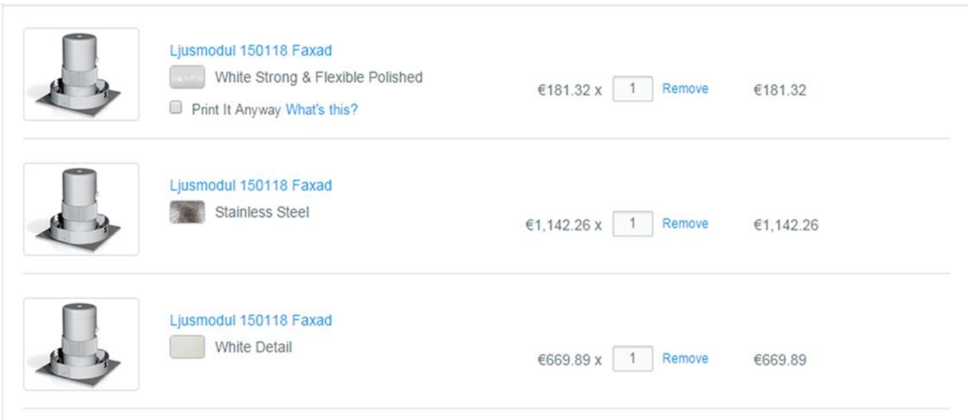
Appendix I: Concept scoring – Aesthetical design concept

		Window		Small cube		Mounded sheet		Architectural spot		Inversed mountain	
	weight	Rank	Weighted rank	Rank	Weighted rank	Rank	Weighted rank	Rank	Weighted rank	Rank	Weighted rank
Moodboard	0,08	1,00	0,08	2,00	0,15	3,00	0,23	3,00	0,23	3,00	0,23
Complexity	0,23	1,00	0,23	2,00	0,46	1,00	0,23	3,00	0,69	3,00	0,69
Installation	0,15	1,00	0,15	3,00	0,46	1,00	0,15	2,00	0,31	1,00	0,15
Adjustable to different types of ceilings	0,08	2,00	0,15	3,00	0,23	1,00	0,08	1,00	0,08	1,00	0,08
Modular	0,08	3,00	0,23	1,00	0,08	3,00	0,23	1,00	0,08	1,00	0,08
Conveying sunlight	0,15	3,00	0,46	1,00	0,15	2,00	0,31	1,00	0,15	1,00	0,15
Size	0,15	1,00	0,15	3,00	0,46	1,00	0,15	2,00	0,31	2,00	0,31
Hiding light source	0,15	3,00	0,46	1,00	0,15	3,00	0,46	1,00	0,15	1,00	0,15
Total Score			1,92		2,15		1,85		2,00		1,85

Appendix J: Technical requirements

- Project a 500 mm broad light shape.
- Spread light over a 2700 m high wall.
- Prism and therefore light module constantly parallel to wall.
- Lenses with f=50mm.
- Distance between light source and first lens is equal to the focus length (50mm).
- Lens diameter of 50 mm.
- Fit a size M gobo, with the outer diameter of 66 mm and a pattern diameter of 49.5 mm.
- Enable rotation and the possibility to change the gobo.
- Eliminate lenses and gobo for wall washing effect, distance between light source and prism should be maximum 3.7 mm.
- Fit rooms with our without dropped ceilings.
- Fit European standards for dropped ceilings, 600×600 mm or 600×1200mm.
- Fit standard thicknesses of dropped ceiling tiles, 15mm and 20mm.
- Maximum usage of vertical space 30 cm, including light module and shade.
- Angle adjustment in direction normal to the wall, minimum 0 - 20°.
- Angle adjustment in direction parallel to the wall, minimum -35° - 35°.
- Adjustable distance between the lenses, p, 45-55 mm.
- The light module needs to fit the different shades.

Appendix K: Prices for 3D-printing



Prices for 3D-printed light module from Shapeways [46]